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STUDY OF CIVIL MARKETS FOR HEAVY—LIFT AIRSHIPS

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ABSTRACT

The civil markets for heavy-lift airships (HLAs) are defined by first identifying areas of most likely application. The operational suitability of HLAs for the applications identified are then assessed. The operating economics of HLAs are established and the market size for HLA services estimated by comparing HLA operating and economic characteristics with those of competing modes. The sensitivities of the market size to HLA characteristics are evaluated and the number and sizes of the vehicles required to service the more promising markets are defined. Important characteristics for future HLAs are discussed that are derived from the study of each application, including operational requirements, features enhancing profitability, military compatibility, improved design requirements, approach to entry into service, and institutional implications for design and operation.

FOREWORD

This final report presents the results of a study of civil markets for heavy-lift airships performed under NASA-Ames Contract No. NAS2-9826 by the Booz, Allen Applied Research and Transportation Consulting Divisions of Booz, Allen & Hamilton, Inc.

Dr. Mark Ardema of NASA-Ames was the technical monitor of the program. The Booz, Allen program manager was Mr. Robert Byrne. The principal investigator was Mr. Peter Mettam. Prime contributors were Mr. Dagfinn Hansen and Mr. Charles Chabot. Others who made important contributions were Mr. Michael Lowman, Ms. Laura Moore, and Ms. Beatrice Ross. Inquiries regarding this study may be directed to Mr. Fred M. Marks, Officer-in-Charge for the project.

Grateful acknowledgement is expressed to the Goodyear Aerospace Corporation and Canadair for supplying basic operational and cost data for candidate HLA systems.

Recognition and thanks are also expressed to all those individuals and firms listed in Appendix A and mentioned throughout the body of the report.

This report consists of two volumes:

Volume I - Study of Civil Markets for Heavy-Lift
Airships, Appendix A

Volume II - Appendix B

Volume II, Appendix B, contains proprietary information supplied by Goodyear Aerospace and Canadair and is not available, except to the NASA-Ames technical monitor.

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TABLE OF CONTENTS

LIST OF ACRONYMS

AAR	Association of American Railroads
ACR$_i$	Annual Capital Recovery Cost for Facilities or Support Item, i.
AFC	Annual Fixed Cost
AFCS	Automatic Flight Control System
ASEA	(Swedish Electrical Equipment Manufacturer)
BBL	Barrel
BURD	Direct Labor Burden Cost per Project
B&W	Babcock and Wilcox
CAB	Civil Aeronautics Board
CACI	Consolidated Analysis Center, Inc.
CE	Combustion Engineering
CER	Cost Estimating Relationship
CF	Cruise Fuel Oil Cost per Cruise Hour
CH	Cruise Hours
COTS	Container Offloading and Transfer System
CREW	Flight Crew Costs per Project
CRF	Capital Recovery Factor per Year
DCC	Annualized Development & Certification Cost
DEV	Annualized Development & Certification Costs per Aircraft
DLB	Direct Labor Burden per Vehicle per Flight Hour
DLBF	Direct Labor Burden Factor
DOC	Direct Operating Cost
EPA	Environmental Protection Agency
FAA	Federal Aviation Agency
FAO	Food and Agriculture Organization
FBW	Fly-by-wire
FC	Flight Crew Cost per Flight Hour
FCC$_i$	Facility or Support Capital Cost for Item, i.
FCML	Flight Crew & Maintenance Labor Cost per Flight Hour
FERIC	Forest Engineering Research Institute of Canada
FF	Cost of Ferry Fuel & Oil per Ferry Hours
FFV	Free Flight Vehicle
FH	Ferry Hours
FMC	Federal Maritime Commission
FOC$_i$	Facilities or Support Annual Operating Cost for Item, i.

FTL	Flight Transportation Laboratory
FUEL	Fuel Cost per Project
GE	General Electric
GNP	Gross National Product
H	Project Flight Hours
HF	Hover Fuel & Oil Cost per Hover Hour
HEL	Helium Replacement Costs per Year per Vehicle
HH	Hover Hours
HLA	Capital Cost Recovered per Year per Vehicle (in model)
HLA	Heavy Lift Airship
HLAC	Heavy Lift Airship Capital Costs per Vehicle
IC	Internal Combustion
ICC	Interstate Commerce Commission
IMU	Inertial Measuring Unit
INS	Annual Cost of Insurance per Vehicle
IP	Insurance Premium
ISA	International Standard Atmosphere
LASH	(Barge Carrying Vessel)
LCM LCU	Landing Craft types
LEAS	Annual Cost of Capital Recovery per Vehicle
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
LTA	Lighter-than-air
MAINT	Maintenance Labor and Material Costs per Project
MARAD	Maritime Administration
MBOE	Millions of Barrels of Oil Equivalent
ML	Maintenance Labor Cost per Flight Hour
MLM	Maintenance Labor and Material Cost per Flight Hour
MW	Mega Watt
N	Number of Vehicles
NASA	National Aeronautics and Space Administration
NTSB	National Traffic Safety Board
OECD	Organization of Economic Cooperation & Development
O/H	Overhaul
O&M	Operations and Maintenance
OPEC	Organization of Petroleum Exporting Countries
OSHA	Occupational Safety & Health Administration
PAFC	Prorated Annual Fixed Cost
PEI	Prince Edward Island
PHS	Precision Hover System
PL,P	Payload

POC	Project Operation Costs
POL	Petroleum, Oil and Logistics
RDT&E	Research, Development Test and Engineering
RICA	Rail Industrial Clearance Association
Ro/Ro	Roll-on/Roll-off
ROW	Right-of-Way
SAS	Stability Augmentation System
SEABEE	(Barge Carrying Vessel)
SEC	Securities and Exchange Commission
TCN	Total Fly Away Cost of N Aircraft and Spares
TFAC	Cost of HLA and Spares, per Vehicle
TOC	Total Operational Cost
TOT	Total Project Costs
U	Annual Utilization Hours
UAE	United Arab Emirates
UL,L	Useful Load
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
VTOL	Vertical Take off and Landing
WAES	Workshop on Alternative Energy Strategies

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 1

LIST OF TABLES

1. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1.1 Summary

A study of the civil markets for Heavy-Lift Airships (HLA) has been conducted, in which HLA are defined as combining buoyant and powered lift, and are designed to

- Carry oversize and overweight payloads (compared to conventional transport modes) from 25 to 500 tons (or more as required by the application)
- Travel over relatively short distances, up to about 200 miles (or more as required by the application)
- Hover with precision for significant periods.

Domestic and worldwide heavy lift market areas have been assessed for HLA applicability and the more promising areas have been identified. Studies of HLA operations were conducted to define the operational factors on which HLA design and costs depend. Detailed cost studies of specific heavy lift activities (case studies) have been performed in each of the promising areas to establish the costs of performing heavy lift services using current methods and to establish the methods by which the HLA could be used competitively. From these, an HLA "threshold cost" was determined (defined as the HLA job cost that makes performing the services with an HLA equal in cost to the conventional approach.) The extent of market penetration in each market area was assessed as a function of the extent by which the HLA threshold cost exceeded the HLA job cost estimate.

HLA job cost estimates used in these market penetration analyses were made by averaging the job cost estimate for two different HLA concepts, the Goodyear Quadrotor and the Canadair Aerocrane. The estimates for each individual concept were not used, since these were based on proprietary data from Goodyear and Canadair.

The number and size of HLAs required in each application were determined from the market assessment, the market penetration analyses, and the estimates of HLA costs. The study concluded with an assessment of the operational requirements of each application and other features that significantly influence HLA success.

Specific guidelines for the study encompassed the following:

- A broad analysis was needed, not encumbered by regulations or other institutional factors. Safety, environmental, regulatory, and insurance implications should be noted but not limiting
- Vehicle parametric analysis or design definition work was to be obtained from previous studies of the Goodyear Quadrotor HLA concept
- Consider vehicle operations in the 1980-1990 time frame
- Consider payloads from 25 tons to 500 tons, with particular emphasis on the 50-100 ton payload range
- Consider adverse weather impacts on the effectiveness of HLAs in each application
- Consider HLA operation in rough terrain and/or remote areas
- HLAs with 75 to 100 tons payload must meet the Navy's short haul, heavy lift air system requirements whenever feasible
- The study was to be as concept-independent as possible
- Foreign markets were also to be considered
- A maximum range of 200 miles was to be considered
- Assume that base operations provide only open mooring
- Consider both Government and private financing alternatives.

Study results show a strong case for HLAs around the 75 tons payload range, with major applications in logging, and other opportunities in unloading containers, placing electric power transmission towers, support of remote drill rig construction, and high rise construction.

In addition, cases have been made for larger sizes (150 to 800 tons) in support of power generating plant construction, offshore oil drill rig construction, general transportation and rigging, and strip mining. These results are summarized in Tables 1-1 and 1-2. The numbers of HLA presented are, in general, conservative since they assume no ferry requirements, and a full 2000 hours per year utilization. Accounting for possible annual ferry requirements introduces wide variations in these numbers; these variations

TABLE 1-1 HLA Development Summary

HLA DEVELOPMENT MARKETS	PAYLOAD (TONS)	HEAVY LIFT MARKETS	APPROXIMATE TOTAL POTENTIAL HLAs**		REQUIRED VEHICLE CHARACTERISTICS
			25 MPH or	60 MPH	
1	25	Logging, Unloading ships, Tower erection, High rise construction, Remote drilling support.	170*	1120 (if no "75 ton" HLA)	These two market areas are sufficiently large to allow several vehicles to eventually be developed, each one with a set of characteristics suited to a market segment. Generally the required characteristics would be as follows: Cost: As low as possible, relatively unaffected by operating conditions. Altitude: Up to 5-7000, occassionally to 12,000 Temperature: Below freezing to +120°F Elevation Change per cycle: 500 feet to 3-4000 feet Wind: Horizontal and vertical gusts to 30 mph., occassional horizontal gusts and winds to 70-100 mph Precision: Horizontal 1 to 5 feet, Vertical 1 to 5 feet, Descent rate 5 feet per second. Ground riggers to control lateral movement of load. Logistics: Prompt attention to schedule. Load: Aggregate as much as possible (creates high drag) Environment: Improve on helicopter and surface transport capability with respect to – bad weather, bad visibility, day or night, – icing, rain, snow, – rough water and rough terrain. Safety: Static charges, load gyrations, multiple engines, load release, cable snap back, pilot fatigue, ground crew clearance, rotor clearance; load swinging clearance; rigging crew safety on top of high structures.
2	75	Logging Unloading ships Pipeline construction	550*	820 (if no "25 ton" HLA)	
3	150 to 300	Support of power plant construction, strip mining	12	7	These two markets are small and relatively specialized. Possibly can be satisfied by selecting one size in the range of 150 to 300 tons, used in multiples to satisfy the less frequent, heavier lifts. Generally the required characteristics would be as above, plus greater precision in hover, – horizontal and vertical position, within a few inches. – rate of descent, within a few inches per second.
4	500 to 800	Offshore drill rigs, Power generating plants, General transportation	8	7	

*Smaller numbers at lower speeds reflect the reduction in the HLA logging market against conventional competition at these speeds, which opposes any increase in numbers based purely on productivity.

**Assumes 2,000 hours utilization. See Table 1-2

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TABLE 1-2. HLA Market Summary

APPLICATION	ANNUAL MARKET		UNITS	MARKET CAPTURE POTENTIAL	BEST VEHICLE PAYLOAD (TONS)	*POTENTIAL NO OF VEHICLES		PARAMETERS CRITICAL TO REACHING STATED MARKET CAPTURE POTENTIAL
	NORTH AMERICA	WORLD TOTAL				25 MPH	or 60 MPH	
Transportation and Erection of Refinery and Petrochemical Plant Components	0.5×10^6	3.3×10^6	Barrels per day	0	150 200 500 800	0 (1) (1) (2) (1)	0 (1) (1) (2) (1)	If HLA cost can be reduced to 50% of case study estimate, capture potential becomes 100%, resulting in numbers in parentheses.
Support of Construction of Offshore Permanent Drilling and Production Platforms for Oil and Gas	40 to 90	50 to 150	Platforms constructed per year	≈ 100	500	2	2	Low HLA cost, high conventional barge cost, low offshore distance
Movement of Strip Mining Power Shovels	95	Not Available	Shovels moved per year	≈ 700	200 to 300	1	1	Low HLA cost, low round trip distances
Support of High Voltage Power Transmission Line Construction 345 KVA 500 KVA 765 KVA	4000 1300 360	12,800 4,000 570	Miles of line construction per year	≈ 100	25 to 30	12	9	Increase in round trip distance increases number of vehicles
Electric Power Generating Plant Construction	36300	85000	MW generating capacity added per year	100	150 and 200 to 300 and 800	1 (44)* and 10 (32) and 1 (10)	1 (43)* and 5 (27) and 1 (10)	No critical parameters for two sub applications * If the HLA costs on the third sub-application can be reduced by a little over 50%, the numbers in parentheses result
Support of the Construction of Gas or Oil Pipelines	2400 to 2700	10000 to 12000	Added pipeline mileage per year	≈ 100	75	3	4	No critical parameters
Support of the High Rise Construction Industry HVAC. Window Wash. Cranes.	4250 to 5200 5000 to 6000 250 to 300	Not Available	Number of lifts per year	≈ 100	7 to 15 and 25 to 30	1 2	1 2	No critical parameters
Support of Remote Drilling Installations and Operations	34	100	Wells drilled per year	100	25 to 30	6	3	Increase in round trip distance increases number of vehicles
Logging	7300*	75 to 80,000	Millions of cubic feet per year	≈ 100	7 to 15 or 25 to 30 or 75	186** or 112 or 536	150** or 1082 or 600	Increases in yarding distance increases number of vehicles, increase in load/unload time increases number of vehicles
Unloading Cargo in Congested Ports	0	325,000 to 575,000	Number of containers moved per year	≈ 100	25 to 30 or 75	37 or 13	27 or 10	Lower HLA cost, higher cost of competition, all increase number of vehicles. Increased trip distance rapidly decreases 25 ton, 25 mph market, the remainder have sufficient in reserve to be unchanged
Transportation and Rigging of Heavy and Oversized Components	300 to 600	900 to 1800	Number of moves per year	60 to 100 0	500 and 800	5 0	4 0	Reduction of HLA cost of up to 50% would result in 100% market share for both sizes. Number of 500 ton vehicles increases with distance travelled.

* These figures are for an assumed 2,000 hours per year utilization, without ferry. If this utilization is reduced to 1,000 hours, not including ferry, the number of vehicles increases by approximately a factor of 2

** Low numbers at low payload reflect higher unit costs for HLA and low market share. Lower numbers at lower speed reflect lower market due to higher costs, as opposed to increased numbers due to productivity.

depend critically on the specific characteristics of each application. Thus the effect of ferry must be assessed on a case-by-case basis.

Discussion of the study results encompasses operational requirements, features that promote HLA profitability, military compatibility, probable institutional influences on HLA design and development, suggested modification to the current quadrotor point design, and an approach to entry into service.

1.2 Conclusions

The study concludes that several promising civil markets have been identified for heavy-lift airships, notably in logging, relief of port congestion, power transmission line erection, construction of power generating plants, and general transportation. A strong case for military commonality has been identified for a 75-ton payload HLA. The most promising long-term payload size is around 75 tons, for which between 550 and 620 appear to be needed worldwide (10 percent of which occurs on the North American continent) primarily for the logging market, with some additional use in relief of port congestion, and construction of pipelines. The bulk of this market can alternately be served by about 1120 25-ton vehicles, providing they can be operated at relatively high speed (around 60 mph) rather than slow speed (around 25 mph). The 25-ton payload also supports power transmission line construction, high rise construction and remote drilling sites. Larger payload vehicles are required in significant quantities; 6 to 11 200-ton to 300-ton vehicles to support power generating plant construction, and 6 to 7 500-ton vehicles to support offshore oil rig construction, and general transportation. One each of 150-ton and 800-ton can also be used in support of power generating plant construction.

To ensure that the markets identified can be captured, careful and detailed study is required to assess the implications of alternative basing strategies, to more fully define the real life markets, and to optimize vehicle configurations, characteristics and costs. Entry into service may be effected through development of a government-sponsored prototype for military and civil applications, or by purely private development activities. In either event, very close coordination with the potential user community is essential, so as to prepare operational requirements that fully satisfy the potential customer, and to minimize adverse effects that may be introduced by institutional concerns. The earliest entry would appear to be in the logging industry, initially in direct competition with the helicopter, at payloads of about 25 tons. Further definition and refinement of HLA sizes, families and numbers depends on development of a wider technical, marketing, cost and operational data base.

1.3 Recommendations

It is recommended that near-term technology development programs should be developed that are directed toward HLA capabilities from 25 tons to 150 tons for several alternative concepts, but with emphasis on early service entry. It is further recommended that refined studies be undertaken to develop a more complete data base for determining vehicle costs, domestic market characteristics and basing strategies, the locale for early construction, vehicle sizes for development, and foreign market characteristics.

INTRODUCTION

LIST OF FIGURES

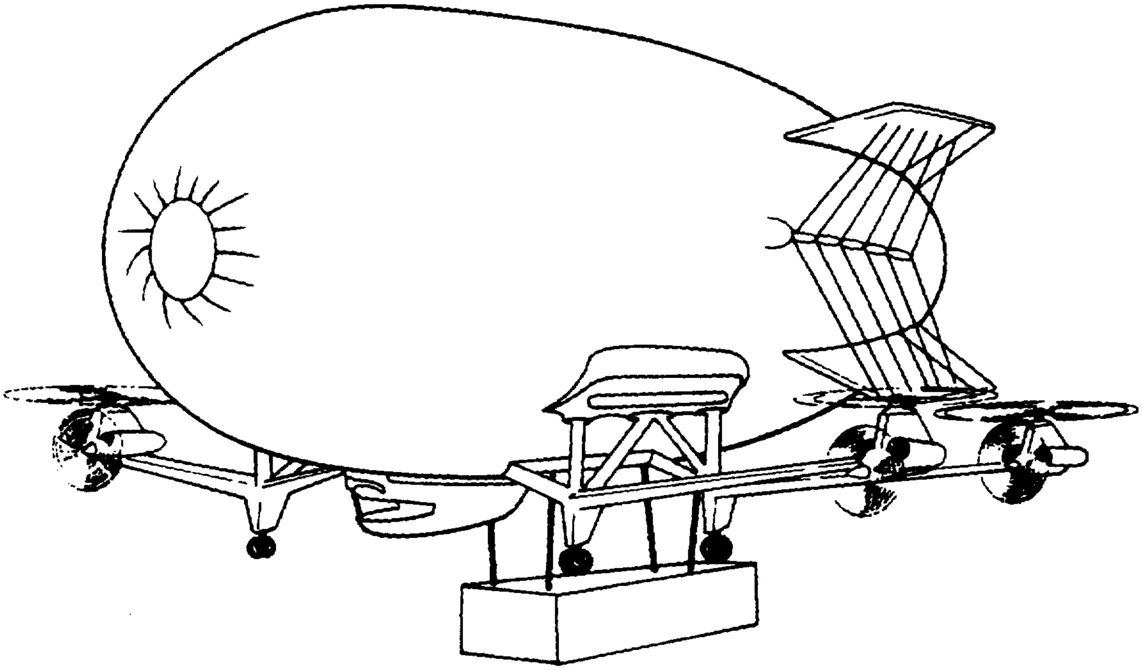
2. INTRODUCTION

The energy crisis has brought about a growing interest in the examination of alternative forms of transportation for many applications. Airships or Lighter-Than-Air craft (LTAs) offer the potential for efficient transportation at relatively low power, with the attendant advantages of low noise and low pollution. Studies have been undertaken (References 1 and 2) under NASA sponsorship to examine the potential missions for which LTAs may be most useful, and the feasibility of designs to perform those missions (Reference 3). As a consequence, a few major LTA missions were identified, one of which was that of "heavy-lift"—moving payloads that are beyond the weight and size limits of conventional transportation, mostly over relatively short distances. In January, 1978, NASA-Ames awarded a contract to Booz, Allen Applied Research, to conduct a study of the civil markets for heavy-lift airships (HLAs), the results of which would contribute to policy development concerning NASA support of R&D for such concepts.

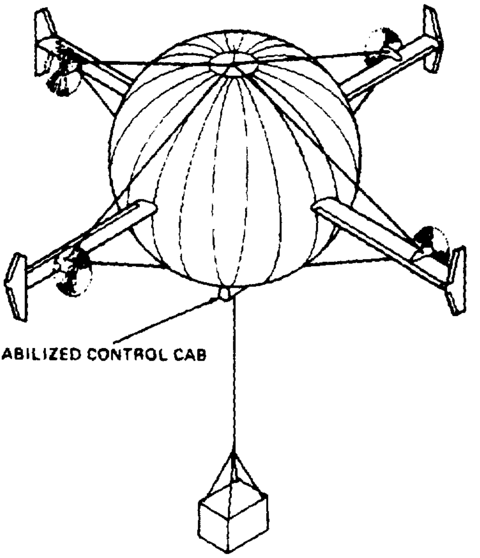
To date the potential market for such heavy-lift airships has been studied in terms of preliminary identification of areas of potential application. Prior to the study reported herein there was a need to evaluate the market size and identify the lift capability range of the vehicles considered for first introduction into service.

The objectives of this study were therefore to: (1) refine the identification and description of the potential civil applications of heavy-lift airships and identify the areas of most likely application, (2) perform a preliminary assessment of the operational suitability of such vehicles for the applications identified, (3) establish the operating economics of heavy-lift airships, (4) estimate the market size for heavy-lift airships by comparing their operational and economic characteristics with those of competing systems and (5) identify the sensitivity of the market size to vehicle lift capability and operational characteristics.

The main feature of all heavy-lift airship concepts consists of the combination of a buoyant-lift envelope and a powered-lift system, together with all control and operational features necessary for an effective air vehicle. In one design approach, the Helistat proposed by Piasecki Aircraft Corporation, and adapted by Goodyear Aerospace Corporation (Figure 2-1), the buoyant envelope is basically a conventional airship hull supporting the vehicle empty weight, while the powered lift system consists of multiple lifting-rotor systems supporting the useful load of cargo and fuel. The buoyant hull is expected to change from a non-rigid envelope design to a rigid envelope design as size increases. The



GOODYEAR QUADROTOR



CANADAIR AEROCRANE

FIGURE 2-1. Heavy Lift Airship Concepts

powered lift is expected to require four S64-size helicopter rotor systems for the 75T payload concept illustrated in Figure 2-1, with increasing rotor size and/or numbers for larger useful loads. Most cargoes would be carried externally, and the HLA would operate in a VTOL mode for most load and unload situations, utilizing a precision hover control technique and a cargo handling system under development for helicopter operations. Auxiliary propulsion would be used where more economical on long cargo transits, or on ferry flights. A second design approach which has been under consideration by Canadair Ltd., is known as the Aerocrane, and consists of a rotating spherical or lenticular buoyant center body, to which are attached four high aspect ratio horizontal wings, radially oriented and equally spaced around the center body. Each wing carries a power plant that drives the rotation, and controls for lift and lateral displacement of the vehicle. The non-rotating crew cabin and cargo hoist are suspended below the rotating body. This concept has been demonstrated by a free flying 1/10 scale model of a proposed design.

Specific guidelines for the study prescribed in the Request for Proposal were as follows:

- Since the study is concerned with relatively undeveloped vehicle concepts and markets, a broad analysis is needed that is not encumbered by existing or supposed regulations or other institutional factors. Safety, environmental, regulatory, and insurance implications should be identified and noted but not used to eliminate or narrow a potential application.

- No new vehicle parametric analysis or design definition work is to be done in this study. This information will be obtained from previous studies. Any additional information relating to the vehicle designs which may be needed will be determined in consultation with the technical monitor. When specific vehicle-related information is required, the HLA concept on which Reference 1 is based, also called the "Helistat," is to be used. This vehicle concept is shown in Figure 2-1.

- The study shall address a time frame that would allow operational vehicles in the 1980-1990 time period.

- The study shall consider vehicles with payloads ranging from 25 tons to 500 tons. In particular, the merits of a vehicle in the 50-100 ton payload range will be established.

- The effects of adverse weather conditions on the use of the vehicles must be accounted for by including the impact of any need to avoid these conditions on the effectiveness of the vehicles in serving the various markets.
- Consideration shall be given to the fact that the vehicles may be required to operate in rough terrain and/or remote areas.
- Vehicles with payloads between 75 and 100 tons shall meet the Navy's operational requirement for a short haul, heavy-lift air system whenever feasible.
- The market study should be as concept independent as possible.
- Both domestic and foreign markets were to be considered in the study. Emphasis, however, was to be placed on the domestic market area.
- A maximum range of 200 miles was to be considered.

During the course of the study the following additional guidelines and guideline clarifications were used.

- In developing the operational and cost analyses it was to be assumed that the vehicle would be operated with open mooring at its base operation (no enclosure required).
- Both Government and private development financing alternatives were to be considered in developing and evaluating costs.

The study was broken down into five task areas as shown in Figure 2-2. The report closely parallels these tasks. In Task 1, literature searches and domestic and international surveys were conducted to develop information with which to identify potential applications, and cost/service characteristics of the HLA and competing systems. Task 2 efforts were directed toward defining the operational characteristics of the HLA. Specifically such items as the number of flight crew and ground support personnel, mooring techniques, facilities maintenance procedures, cargo handling methods and operating limitations were defined. Task 3 was concerned with the development of a cost model for heavy-lift airships. It included such items as nonrecurring costs, development costs, and fabrication costs. The model developed also provided for variations in weight, number of vehicles produced, stage length, and other cost influencing factors. These provisions

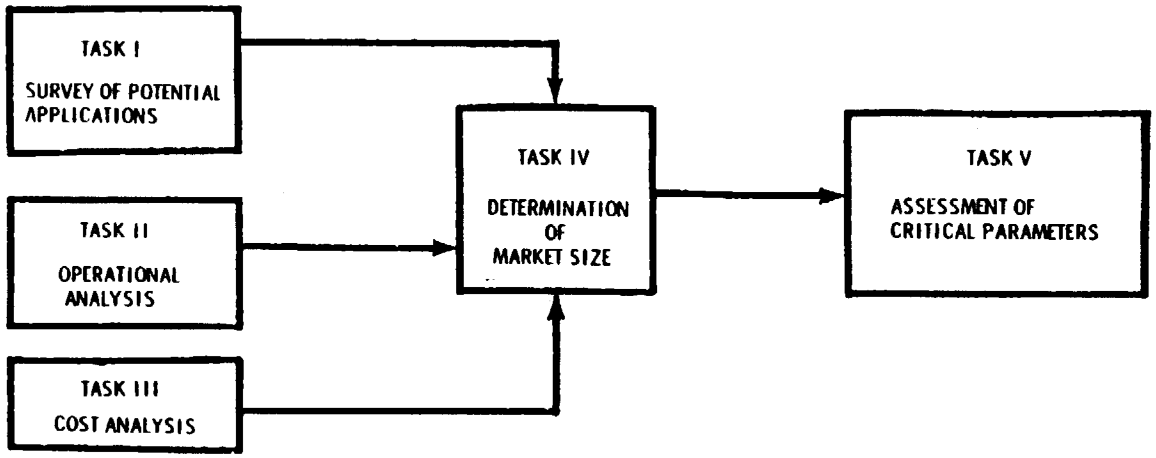


FIGURE 2-2. Study of Civil Markets for Heavy-Lift Airships — Overview of Five-Task Program

were to a large extent based on previously developed parametric relationships. In Task 4, detailed case studies were conducted for those applications which were found to be feasible and to have a high possibility of being competitive with existing heavy-lift modes. These case studies consisted of detailed evaluations of costs of existing modes of performing heavy-lift operations and the establishment of threshold freight rates which must be changed for HLA services in order to be competitive. The cost of operating an HLA in the same scenarios as the existing modes were then developed and compared to the case study results to determine the domestic and worldwide market size. Finally in Task 5, the sensitivity of the HLA market size to its operational characteristics and economics was evaluated and the size and number of heavy-lift airships required to satisfy the market was determined. Additionally, a series of desirable operational and design features were developed and discussed, based on the case studies and sensitivity analyses. These include operational requirements, enhanced profitability features, military compatibility, preferred point design requirements, institutional implications for design and operation, and a strategy for entry into service.

THE COMPETITIVE ENVIRONMENT

CHAPTER 3

3. THE COMPETITIVE ENVIRONMENT

LIST OF FIGURES

LIST OF TABLES

3. THE COMPETITIVE ENVIRONMENT

This chapter describes the overall competitive environment in which an HLA system will have to compete for the heavy and outsized components to be transported and lifted over long and short distances. This environment is described in terms of two major categorizations:

- Economic and transportation infrastructure development
- Capabilities of existing modes of transportation.

This description is followed by an identification of the potential areas of application of the HLA.

3.1 Categorization of Economic and Transportation Infrastructure Development

The economic and transportation infrastructure development of regions are interdependent, and the discussion of one of these factors has to include the other. The categories used in this context are:

- Urban
- Developed
- Undeveloped
- Remote.

Regions falling into these categories are in no way defined by economic and infrastructure developments of entire industrialized nations, and areas fitting the definitions of all four categories may be found in both highly industrialized nations as well as in developing countries. The relative proportion of the four areas is expected to vary greatly between nations and regions of the world.

3.1.1 Urban

The urban area is characterized by a densely populated area in a city with a highly developed transportation infrastructure. This infrastructure is, however, frequently congested by traffic, and the possibility of transporting heavy and outsized cargoes and positioning cranes for their lifting or positioning is restricted either by regulations or limited physical clearances.

The economic activity in terms of requirement for heavy transportation and lift services in the urban areas is often high as a result of the high level of residential and commercial construction activity normally occurring in urban areas and the abundance of cargoes that pass through urban centers as part of port activities associated with major coastal urban centers.

3.1.2 Developed

The developed area is characterized by a highly developed transportation infrastructure capable of accommodating all heavy and outsized loads falling within the weight and dimension regulations and the capabilities of the roads. Cranes and other lifting equipment can gain easy access to perform lifting and erection jobs.

The commercial and industrial activity in the developed areas are high, and areas falling into this category are the origins of most heavy and outsized loads transported to other areas. The developed areas are also the destination of a major portion of heavy and outsized loads for oil refineries and petrochemical plants and other industrial plants.

3.1.3 Undeveloped

The transportation infrastructure in the undeveloped areas is limited and often characterized by unpaved, narrow roads that can carry relatively small loads. Many of the roads are temporary construction site access roads. In cases where heavy or outsize loads have to be transported to these regions, highly specialized transporters are frequently required and road expansions, bypasses, and bridge reconstructions are at times necessary.

The economic activity is low in the undeveloped regions. The principal economic activities that require heavy transportation and lifting service found in these areas are construction of:

- Power plants
- Refineries and petrochemical plants
- Mining sites
- Petroleum and gas pipelines
- Power transmission lines.

In addition to the above list, logging and forestry, and in developing countries, agricultural production are also economic activities in these areas.

3.1.4 Remote

The remote areas are characterized by an infrastructure that is either very limited or nonexistent. Most of these areas are inaccessible by conventional overland modes of transportation, or accessible only during parts of the year. The latter is the case of the muskeg areas in Northern Canada and Alaska, which are accessible only during the winter season when the Muskeg is frozen and covered with snow. The only vehicles that have unlimited access to these regions are free-flying vehicles, like helicopters and airplanes.

The economic activity requiring heavy lift services in remote areas is limited to exploration for oil, gas, and other natural resources, construction of power transmission lines and pipelines, and the preparation of sites for construction projects. In cases where a road infrastructure is constructed to support the economic activity, the status of the area will shift from remote to undeveloped.

Offshore sites are also defined as being remote areas. The only access to the offshore site is by barge, ship, or helicopter. The primary activity requiring heavy transportation and lifting services in the offshore areas is construction of stationary oil and gas drilling and production platforms.

3.2 Existing Modes of Heavy and Outsized Transportation and Lifting

It is unusual for a heavy or oversized component to be used and installed at the place where it is manufactured. Most components have to be hauled or lifted one or more times before reaching final destination. To serve the needs of shippers and consignees, specialized heavy and outsized cargo carriers are offering their services for transportation by rail, truck, barge ship, and through the introduction of the Sikorsky Skycrane helicopters to heavy and outsize transportation, also by air.

In addition, a number of crane rental and rigging operations offer their equipment and services to rig, lift, and position heavy and outsized components once they have reached their destination. A brief discussion of the capabilities and limitations facing these existing modes of transportation and lifting is presented below.

3.2.1 Rail Transportation

The railways have been and are the major transporter of heavy and outsized cargoes. Loads of up to 80 tons can in most cases be carried by conventional railcars. For loads exceeding 80 tons, specially constructed heavy haul railcars have to be employed. Both the railroads and shippers have invested in such specialized heavy haul railcars to transport heavy cargoes. The type and load capacity of railroad and privately owned heavy haul railcars are presented in Tables 3-1, 3-2, and 3-3.

It is significant to note that only two of the 504 railroad-owned railcars have a load capacity exceeding 300 tons, that 38 cars or 7.6 percent of the total have a load capacity between 200 and 300 tons, that 329 cars or 66 percent have capacities between 100 and 200 tons, and that 135 cars or about 26 percent have capacities less than 100 tons. Of the 833 privately owned cars, of which 765 are owned by the Department of Defense, only 14 (2 percent) have a loading capability exceeding 300 tons, and 90 percent of the cars have loading capabilities between 80 and 99 tons.

The relative low availability of specialized heavy haul railcars, particularly in the upper load capabilities, is due to the low annual utilization of these railcars and often long empty hauls to position these cars. Average utilization of most specialized cars is 5.5 to 6 loaded moves per year, both short and long haul, for all these railcars. In 1975, the Association of American Railroads (AAR) recorded 3100 loaded hauls with all railroad and privately and railroad-owned heavy haul cars and in 1976 the number was 3400 moves. This low utilization has made both railroads and private investors such as leasing companies reluctant to invest in these highly capital intensive cars. The cost of construction of these cars averages $0.50 per pound of weight capacity.

The few heavy lift railcars have at times created periods of scarcities. Reservations for use of these railcars, which is coordinated through the AAR, are therefore made well in advance of the time the railcars are required.

In cases where a cargo exceeding the load capabilities or length of any one car has to be carried, special components can be made by distributing the load or the length of the cargo over one or more railcars.

The major limitations imposed upon the use of the railroads are clearances, which is another factor explaining the low utilization of the heavy haul railcars. Many of these railcars

TABLE 3-1. U.S. Railcar Type and Load Capacity

WEIGHT CAPACITY (METRIC TONNES)	RAILCAR TYPE			TOTAL	PERCENT OF TOTAL	
	FD	FM	FW		CLASS	CUMULATIVE
300 and over	–	2	–	2	– – –	0
280 – 299	–	–	–	– – –	– – –	0
260 – 279	–	11	–	11	2	2
240 – 259	–	–	–	– – –	– – –	2
220 – 239	4	16	2	22	4	6
200 – 219	5	–	–	5	1	7
180 – 199	20	18	–	38	8	15
160 – 179	–	11	–	11	2	17
140 – 159	21	7	–	28	6	23
120 – 139	30	41	2	73	14	37
100 – 119	137	18	24	179	36	73
80 – 99	84	22	29	135	27	100
TOTALS	301	146	57	504	100	

FD = Depressed center flatcar
FM = Level bed flatcar
FW = Flatcar equipped with a well or very low profile

SOURCE: Association of American Railroads

TABLE 3-2. U.S. Railcar Loading Platform Length and Load Capacity

WEIGHT CAPACITY (METRIC TONNES)	LOADING PLATFORM LENGTH									TOTALS	. % OF TOTAL	
	-20'	20'1" -25'	25'1" -30	30'1" -35	35'1" -40	40'1" -45	45'1" -50	50'1" -55	-55'1"		CLASS	CUMU-LATIVE
300 and over	—	———	—	1	—	1	—	—	—	2	———	0
280-299	—	———	—	—	—	—	—	—	—	———	———	0
260-279	—	———	—	9	—	—	2	—	—	11	2	2
240-259	—	———	—	—	—	—	—	—	—	———	———	2
220-239	—	3	2	—	—	17	—	—	—	22	5	7
200-219	—	5	—	—	—	—	—	—	—	5	1	8
180-199	—	20	—	—	—	6	7	5	—	38	8	16
160-179	—	———	—	—	—	11	—	—	—	11	2	18
140-159	—	12	11	—	—	—	7	—	—	30	6	24
120-139	17	9	4	—	—	—	26	9	6	71	14	38
100-119	—	107	43	4	—	—	—	18	—	172	35	73
80-99	65	25	23	6	—	9	4	—	—	132	27	100
TOTALS	82	181	83	20	—	44	46	32	6	494	100	
Total	17	37	17	4	—	9	9	6	1			
Cumulative	17	54	71	75	75	84	93	99	100			

SOURCE: Association of American Railroads

TABLE 3-3. U.S. Railcars of Various Load Capacities

WEIGHT CAPACITY (METRIC TONNES)	NUMBER OF CARS	PERCENTAGE	
		CLASS	CUMULATIVE
440 and over	1	–	–
420-439	–	–	–
400-419	–	–	–
380-399	1	–	–
360-379	1	–	–
340-359	7	1	1
320-339	–	–	1
300-319	7	1	2
280-299	4	1	3
260-279	1	–	3
240-259	–	–	3
220-239	11	1	4
200-219	9	1	5
180-199	2	–	5
160-179	11	1	6
140-159	4	1	7
120-139	9	1	8
100-119	13	2	10
80-99	752	90	100
TOTALS	833	100	

SOURCE: The Official Railway Equipment Register National Railway Publication Co.

can be used over a very limited extent over the railroad network. The general width and height clearances in the United States are:

	Width	Height Above Top of Rail
90 percent of the track	10' 8"	15' 6"
Limited interchange	10' 8"	15' 9"
Participating railroads only	10' 8"	17' 0"

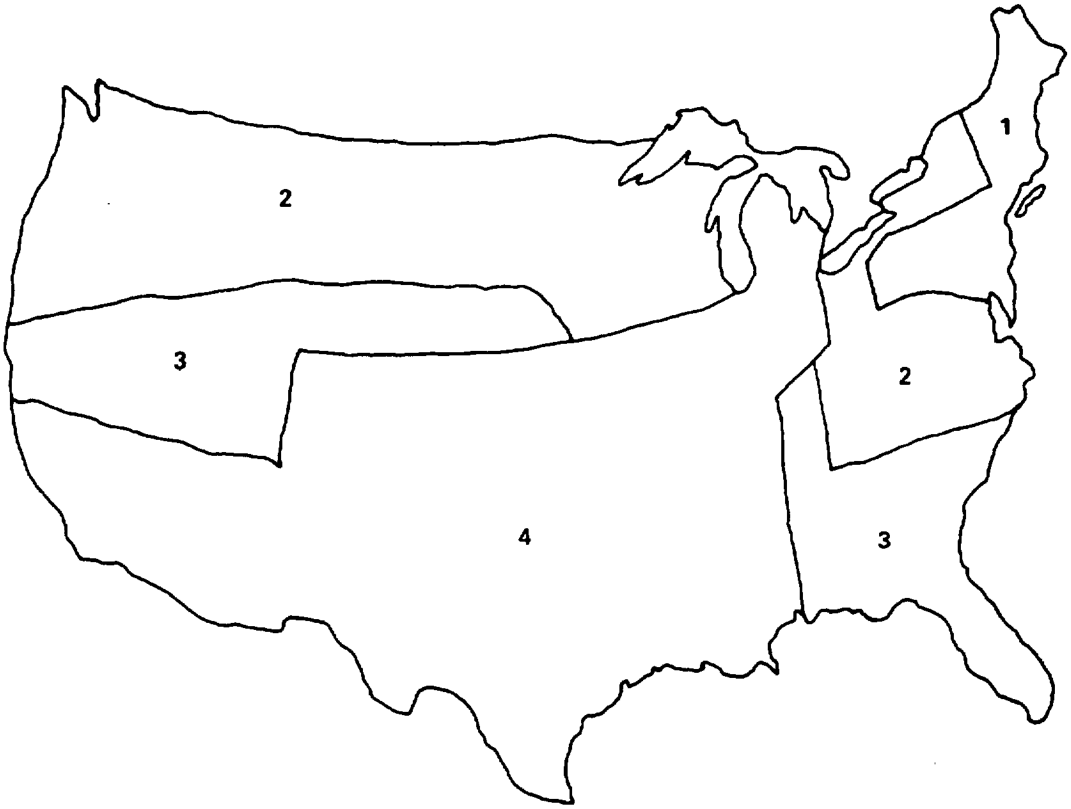
The maximum length of the load is a function of the width and the clearances that are available at each point.

The clearances vary greatly between the different regions of the country, as is shown in Figure 3-1. One of the major problem regions is in the Northeast corridor of the United States, where a major portion of the oldest rail network is located. In this region a lot of narrow bridges, tunnels, and other obstructions are found.

In cases where loads exceeding the general clearances have to be carried, a complete analysis of the alternative routes have to be investigated to avoid lines with obstructions or weak roadbeds. Frequently outsized and heavy cargoes have to be diverted long distances to avoid areas with clearance problems, and at times the railroads have to refuse heavy and outsized cargoes due to limited clearances.

This problem has been aggravated in the Northeast by Conrail's elimination of service on some little used rail lines that were utilized to handle heavy loads. A joint rail industry committee, Rail Industrial Clearance Association (RICA), composed of members from both affected industries and the railroads, was formed to find solutions to these problems, but no major accomplishments have been forthcoming to solve the basic problems of rail clearances.

Clearances in foreign countries are as a rule more restrictive than in the United States. Some examples include the European International Standard Clearance, which is 3.15 meters (10.335 ft.) for width, and 4 meters (13.123 ft.) for height. The West German Federal Railroad (Deutsches Bundesbahn) can accept loads up to 4.65 meters (15.256 ft.) high and the standard European width of 3.15 meters, while the Italian State Railroad can accept loads up to 3.2 meters (10.41 ft.) wide and 4.3 meters (14 ft.) high. Clearances in developing countries are also generally less than those found in the United States.



WIDTH	12'0"	12'10"	
AREA	HEIGHT (maximum)		SHIPPING AREAS
1	17'0"	–	New England
2	19'0"	19'0"	Upper Northwest & Southeast
3	19'3"	19'3"	Lower Northwest & Southeast
4	20'4"	20'4"	Mississippi Valley & Southwest

SOURCE: Combustion Engineering

FIGURE 3-1. Railroad Clearances Generally Available in U.S. Shipping Areas

The cost of railroad transportation of heavy and outsized cargoes varies greatly depending upon the commodity to be transported, the distance, the competition from water modes of transportation, and special equipment required to transport the components. As part of a project sponsored by Lykes Bros. Steamship Co. and the Maritime Administration to investigate the feasibility of U.S. flag heavy-lift ships, a rail freight rate predictor model for heavy and outsized cargoes was developed (Reference 4).

This rate calculator model for U.S. rail freight rates is presented as Table 3-4. The model has been developed based on the rates for the following commodities:

- Machinery: Electrical generation equipment, gas turbines, metalworking machinery, construction machinery, material handling equipment, mining machinery, compressors, engines, dredges, boats

- Class 40: Reactor and petroleum refining vessels, boilers, transformers

- Commodity: Locomotives, earthmoving vehicles, road building equipment, mobile cranes, drill rigs.

The calculation of heavy lift freight rates are based on four components:

- The base distance rate
- Railcar use charges, including demurrage
- Special train service charges
- Extra car charges.

The base distance rate is the charge quoted in the tariff and is based upon the weight of the cargo, the type of commodity, the distance, origins, and destinations of the cargo. The origins and destinations are important because railroads like other businesses, price their services according to the competition for the cargoes. The Lykes study has characterized the rates by four different origins or destinations as follows:

- Origin or destination is a deepwater port. At these points low cost alternatives by barge and ship are available, and rates are consequently low.

- Origin or destination is on a navigable river and low cost alternative transportation by barge is available. The rates are therefore relatively low.

TABLE 3-4. U.S. Railroad Heavy-Lift Movement Costs

BASE CHARGE

(Sum of fixed cost per ton plus fixed cost per ton-mile)

Commodity Rate	(B) (C) or (D)	= $5/tonne	Rate x Weight =
	(A)	= $0	Setup Cost = $ ______
Class 40 Rate } Machy Rate	(B) (C) or (D)	= $24/tonne	
	(A)	= $19/tonne	

Commodity Rate	A, B	@ 3.4¢/tonne-statute mile	Rate x Distance x Weight
	C	@ 3.8¢/t–s.m.	= Distance Cost = $ ______
	D	@ 4.35¢/t–s.m.	
Machy	B	@ 6.0¢/t–m.	
Machy } Class 40	A Only A,B	@ 5.6¢/t–m.	
Class 40	C	@ 6.4¢/t–m.	
Machy } Class 40	D	@ 7.3¢/t–m.	

TOTAL BASE CHARGE $ ______

RAIL CAR USE CHARGE

(2 free days load & 2 for discharge)

$6.70 per metric ton = $ ______

7¼c/stat. mile $ ______

Demurrage (over 2 days)		Loading	Emptying
1st & 2nd	@ $ 59 ea.	______	______
3rd & 4th	@ 118 ea.	______	______
5th & 6th	@ 177 ea.	______	______
7th & 8th	@ 236 ea.	______	______

Total Demurrage $ ______

TOTAL RAILCAR USE CHARGE $ ______

SPECIAL TRAIN SERVICE CHARGE

(for height add 2′ for railcar to height of load)

If height +2′ OR width greater than table, on map;

S.T.S. Charge = $18/mile - Southern

19/mile - Western (Minimum $118) $ ______

20/mile - Eastern

EXTRA CAR CHARGE

(split load or length) (add demurrage above)

Total number cars @ 60′/car = ______ (4 maximum)

Weight charge @ $73/extra car ______ (not 1st car)

Distance charge @ 75¢/mile/extra car ______ (not 1st car)

TOTAL EXTRA CAR CHARGE $ ______

TOTAL RAILROAD BILL $ ______

- Origin or destination is close to a navigable river and cargoes can be trans-shipped to barge after a short haul by overland modes of transportation.

- Origin or destination is such that rail will be the only alternative except for truck. The rates are therefore relatively high.

The rail use charge refers to the cost of using the cars. The charges vary greatly depending upon the type and size of car. The charges presented in the model are an average cost based on the costs of a number of railroad-owned cars.

In cases where the dimensions of the cargo to be transported exceed the clearances on the route, special trains often have to be set up to transport the cargoes. A generalization of the clearances in the United States is presented as Figure 3-1. The height clearance includes the car bed height. To estimate the height clearance of a cargo loaded on a depressed center flatcar, approximately 2 feet has to be added to the height of the cargo.

When the length of the cargo exceeds 60 feet and cannot fit on one flatcar, one or more extra cars are frequently required at either end of the load or in the middle. As many as four extra cars may be required.

It should be noted that the railroad freight rates do not include loading and unloading, because these have to be arranged by either shipper or consignee.

No attempt has been made to draw conclusions on the costs of foreign railroad freight rates, since no published tariffs are available comparable to those published with the Interstate Commerce Commission (ICC) in the United States. It is assumed, however, that foreign railroad freight rates are relatively comparable to those charged by United States railroads.

3.2.2 Ocean and Inland Waterway Transportation

There are virtually no dimension or weight limitations on the heavy and outsized cargoes to be carried by vessels on barges. However, these limitations do exist:

- Accessibility by barge or vessel of coastal or inland waterway port or barge landing.

- Availability of cranes to load and discharge the cargo when the ship or barge is not self-sustaining in terms of cargo handling and equipped with adequate ramps or cranes and derricks.

- Many origins and destinations are not located close to coastal or inland waterways, ports, or barge landings requiring one or more trans-shipments.

The inland waterway system of the United States is an extensive network of canals and waterways to accommodate the U.S. domestic and international trade transported in barges and vessels. Table 3-5 provides a summary of the dimension restrictions that exist in the U.S. waterway system.

The inland waterway system in Europe is centered on the Rhine River and its tributaries. Man-made canals connect the Rhine with other major rivers and canals in West Germany, France, Belgium and the Netherlands. The major European waterways and their dimension restrictions are presented as Table 3-6. Virtually all of these waterways and canals can accept the European standard barges of 80 m x 9.5 m x 2.5 m 262.4' x 30.9' x 8.1'), and upgrading and expansions are constantly undertaken to expand the capabilities of these waterways. Some of the major expansion projects currently underway include:

- The Danube-Main-Rhine Canal, which will connect the Rhine and the Danube rivers and enable barges and small vessels to travel entirely on the waterways between the North Sea and the Black Sea is scheduled to be completed at European gauge by 1981.
- The Amsterdam-Rhine Canal is to accept push-barge convoys of 11,000 tons by 1980.
- The Rhone and Saone rivers are being expanded and are expected to be European gauge (1350 ton capacity) sometime in 1978 between Fos and St. Symphonien.
- In Belgium the Albert Canal between Antwerp and Liege is upgraded to 9000 ton push-barge convoys, and the Meuse and the Juliana canals are expanded to the European gauge.
- Finally the Euscat River is being expanded to link with the canal systems in the Netherlands and France.

The British inland waterway system is characterized by its limited gauge. The only major inland waterway in the United Kingdom that can accommodate barges or ships of European gauge is the lower reach of the Thames River, which is accessible to seagoing vessels up to 11,000 tons dwt and the Manchester Ship Canal. All other waterways have major draft and size limitations, and the majority of these waterways are accessible to laden barges of less than 300 tons.

TABLE 3-5. Restrictions on Small Vessel Navigation in the United States

RIVER	DISTANCE (in miles)	FROM	TO	RESTRICTIVE DIMENSION			
				LENGTH	WIDTH	DEPTH	CLEARANCE
Mississippi	734	Mouth	Memphis, Tenn.			25′	108.7′
	1,166	Mouth	Alton, Ill.	600′	110′	9′	82.4′
	1,463	Mouth	Rock Island Ill.	360′			63.0′
	1,884	Mouth	St. Paul, Minn.				59.6′
Mississippi	1,000	Mouth	Mound City, Ill.	600′	110′	12′	99.7′
& Ohio	1,983	Mouth	Pittsburgh, Penn.			9′	67.9′
& Allegheny	2,005	Mouth	Freeport, Penn.	360′	56′	9′	40.0′
& Monongahela	1,941	Mouth	Morgantown, W. Va.	600′	84′	9′	27.7′
& Kanawha	1,873	Mouth	Charleston, W. Va.	360′	56′	9′	51.3′
Mississippi	1,466	Mouth	Alton, Ill.	600′	110′	9′	82.4′
& Illinois	1,218	Mouth	LaGrange, L & D				69.7′
	1,377	Mouth	Chillicothe				58.8′
	1,388	Mouth	Starved Rock Lock & Dam				39.8′
	1,455	Mouth	Chicago, Ill.		97′		
Mississippi	1,649	Mouth	Knoxville, Tenn.	600′	110′	9′	41.0′ Min
& Tennessee							
Gulf Intra-Coastal	900	Brownsville Texas	Florida	640′	56′	9′ – 12′	60.0′ Norm 48.0′ Min
Hudson River	125	Mouth	Albany, N.Y.	—	—	35′	
St. Lawrence	1,304	Mouth	Duluth, Min.	766′	80′	27′	123′
Columbia	97	Mouth	Portland, Ore.			43′	120′
	126	Mouth	Bonneville, Ore.	500′	76′	27′	135′
	166	Mouth	The Dalles, Ore.	675′	86′	14′	79′
	483	Mouth	Lewiston, Id.			12′	60′
Sacramento	78	Mouth	Sacramento, Calif.	—	200′	32′	110′
Warrior	420	Mouth	Birmingham, Ala.	460′	95′	9′	N.A.
Alabama	340	Mouth	Montgomery, Ala.			?	N.A.

SOURCE: U.S. Army Corps of Engineers

TABLE 3-6. Vessel Restrictions on Western European Waterways

RIVER	SECTION	LENGTH	VESSEL MAXIMUM DIMENSIONS			
			LENGTH	BEAM	DRAFT	HEIGHT
Rhine						
	Rotterdam- Nijmegen	101 Km	185 M. 606' 10"	22.8 M. 74' 8"	3 M. 9' 10"	9.1 M. 29' 7"
	Nijmegen- Karlsruhe	543 Km	185 M. 606' 10"	22.8 M. 74' 8"	2.5 M. 8' 1"	9 M. 29' 4"
	Karlsruhe- Strasbourg	61 Km	180 M. 590' 4"	22.8 M. 74' 8"	2.5 M. 8' 1"	9 M. 29' 4"
	Strasbourg- Basle	121 Km	180 M. 590' 4"	22.4 M. 73' 6"	2.5 M. 8' 1"	7 M. 22' 9"
Seine						
	LeHavre-Rouen	121 Km	180 M. 590' 4"	16 M. 52' 6"	3 M. 9' 10"	7 M. 22' 9"
	Rouen-Paris	214 Km	180 M. 590' 4"	16 M. 52' 6"	3 M. 9' 10"	– – – –
Neckar						
	Mannheim- Stuttgart	202 Km	110 M. 360' 6"	12 M. 39' 3"	2.3 M. 7' 6"	5.1 M. 16' 6"
Main						
	Mainz-Nurenberg	462 Km	190 M. 623' 1"	12 M. 39' 3"	2.5 M. 8' 1"	4.6 M 15'
Elbe						
	Brunsbuttelkoog- Hamburg	89 Km	– – ——	– – – –	10 M. 32' 8"	– – – –
	Hamburg-Berlin (Via Elbe-Havel Canal)	320 Km	80 M. 262' 6"	9.5 M. 31' 2"	1.9 M. 6'	41 M. 13' 6"
Mosel						
	Koblenz-Nancy	348 Km	170 M. 557' 8"	12 M. 39' 3"	2.5 M. 8' 1"	6.4 M. 20' 8"
Weser						
	Bremerhaven- Bremen	65 Km	– – ——	– – – –	8.5 M. 27' 9"	—— ——
	Bremen-Minden	165 Km	80 M. 260'	9.5 M. 30' 9"	2 M. 6' 7"	4.4 M. 14' 3"
Nittelland Kanal						
	Minden-Hannover	131 Km	80 M. 260'	9.5 M. 30' 9"	2 M. 6' 7"	4.4 M. 14' 3"
Escaut						
	Dunkerque-Lille- Valenciennes	197 Km	95 M. 309'	11.5 M. 37' 4"	2.7 M. 8' 8"	4.5 M. 14' 8"
Saone-Rhone						
	Marseilles-Lyon	330 Km	80 M. 260'	12.0 M. 39' 3"	2.0 M. 6' 7"	N.A.
Danube		2450 Km	230 M. 754' 5"	24.0 M. 78' 8"	4.0 M. 13' 1"	N.A.

SOURCE: European Cartographic Institute

The USSR has an extensive network of rivers and man-made canals, which connects its major industrial cities and distribution points with ports located in the Baltic and Black seas. In Asia, the Euphrates and the Tigris rivers are navigable, and both rivers are important features in the transportation infrastructure of Iraq. The rivers of Indus in Pakistan, Hoogly and Ganges in India, Brahmaputra in Bangladesh, Irrawaddy in Burma, Chao Phraya in Thailand are navigable, but most of the river traffic is by primitive river boats. In Southeast Asia, the Mekong River is navigable to oceangoing vessels into Cambodia and Laos via Vietnam.

The two largest rivers in China, the Yellow and Yangtze rivers, along with a major network of ancient and newly constructed canals, figures importantly in the transportation infrastructure of China. Most of the traffic is by primitive boats and craft not capable of carrying heavy cargoes.

In South America the Amazon River is navigable to Iquitos, Peru and scheduled service by ocean liners with heavy lift cranes is available to Manaus, Brazil. Elsewhere in South America the Rio de La Plata/Rio Parana river system of internal waterways and canals is currently under construction in a joint venture of the governments of Brazil, Argentina, Uruguay, and Paraguay. Deep draft oceangoing vessels can currently proceed as far north as Santa Fe, Argentina.

Virtually all existing barges and ships can transport heavy and outsized cargoes in the holds or on deck, if the hatch openings are too small to accommodate the cargoes. In 1975 there were more than 2000 ships worldwide that could lift loads greater than 50 tons, and a total of 52 vessels that could lift more than 200 tons. In cases where the vessel's gear cannot handle the load, a number of major ports are equipped with heavy lift cranes to load and unload cargoes. Many barges and vessels are now equipped with roll-on/ roll-off ramps, over which the heavy and outsized cargoes can be rolled on and off while remaining on a trailer or transporter. In addition, several U.S. and foreign barge and ship-operating companies have invested in specially equipped ships and barges to accommodate the transportation requirements of shippers and consignees of heavy and outsized cargoes. The cost of water transportation, whenever it is available, is with few exceptions lower than transportation by overland modes of transportation.

The study by Lykes Brothers Steamship Company also developed a rate calculator model for estimation of barge freight costs. This barge freight rate calculator model is presented as Table 3-7. A graphical description is presented as Figure 3-2. The barge freight rates are normally calculated based on the distance traveled plus the weight of the cargo preset for a minimum weight. The

TABLE 3-7. U.S. River Barge Cost

Barge Size	Minimum Weight Carriage	 Towing
SeaBee Units of 2 @ 97' x 35'		800' S.T. in 1 or 2 barges
J = 200' x 35' or less	600 S.T.	1200 S.T.
SJ = 200' – 240' x 35' – 45'	1000 S.T.	1800 S.T.
S = 240' x 45' or more	1200 S.T.	2400 S.T.

CARGO WEIGHT ______________________/**MINIMUM** ____________ **USE** __________

TOWAGE ________________________ **CARRIAGE** ________________

RIVER ROUTING =

		DESIGNATORS	BASE CARRIAGE/BARGE SET UP	 RATE	TOWAGE/BARGE SET UP	 RATE
M	=	Main Stream Mississippi and Ohio Rivers	$3,900 +	$6.80/Mile	–$800 +	$6.61/Mile
C	=	Combination M & One Tributary River or Gulf Intracoastal Waterway	$4,800 +	$7.35/Mile	0 +	$6.61/Mile
T	=	Two Tributary or Gulf I.C.W.W. Movements	$5,900 +	$8.90/Mile	+$700 +	$6.61/Mile

BASE RATE = $__________/BARGE = 100% At 1,000 Metric Tonnes

MULTIPLIER = ________________ = ______% For Barge Size & Heavy Lift Weight

MULTIPLIER = ________________ = ______% Actual Weight or Minimum ÷ 1,000 M.T.

BARGING BILL = $__________________/BARGE

EXTRAS FOR CARRIERS BARGES

DECK

HL 200 S.T. OR J = 150%
HL 200 S.T. OR SJ = 200%
HL 200 S.T. OR S = 300%
MINIMUM = $4,184

HOPPER

HL 100 - 200 S.T. = 150%
HL 200 S.T. = 200%
MINIMUM = $4,184

EXTRAS FOR TOWING BARGES

ALL TYPES

J = 100%; MINIMUM $750
SJ = 150%; MINIMUM $750
S = 200%; MINIMUM $1,500
SEABEE UNIT = $700 Loaded;
MINIMUM = $600 Empty
EMPTY = NO CHARGE

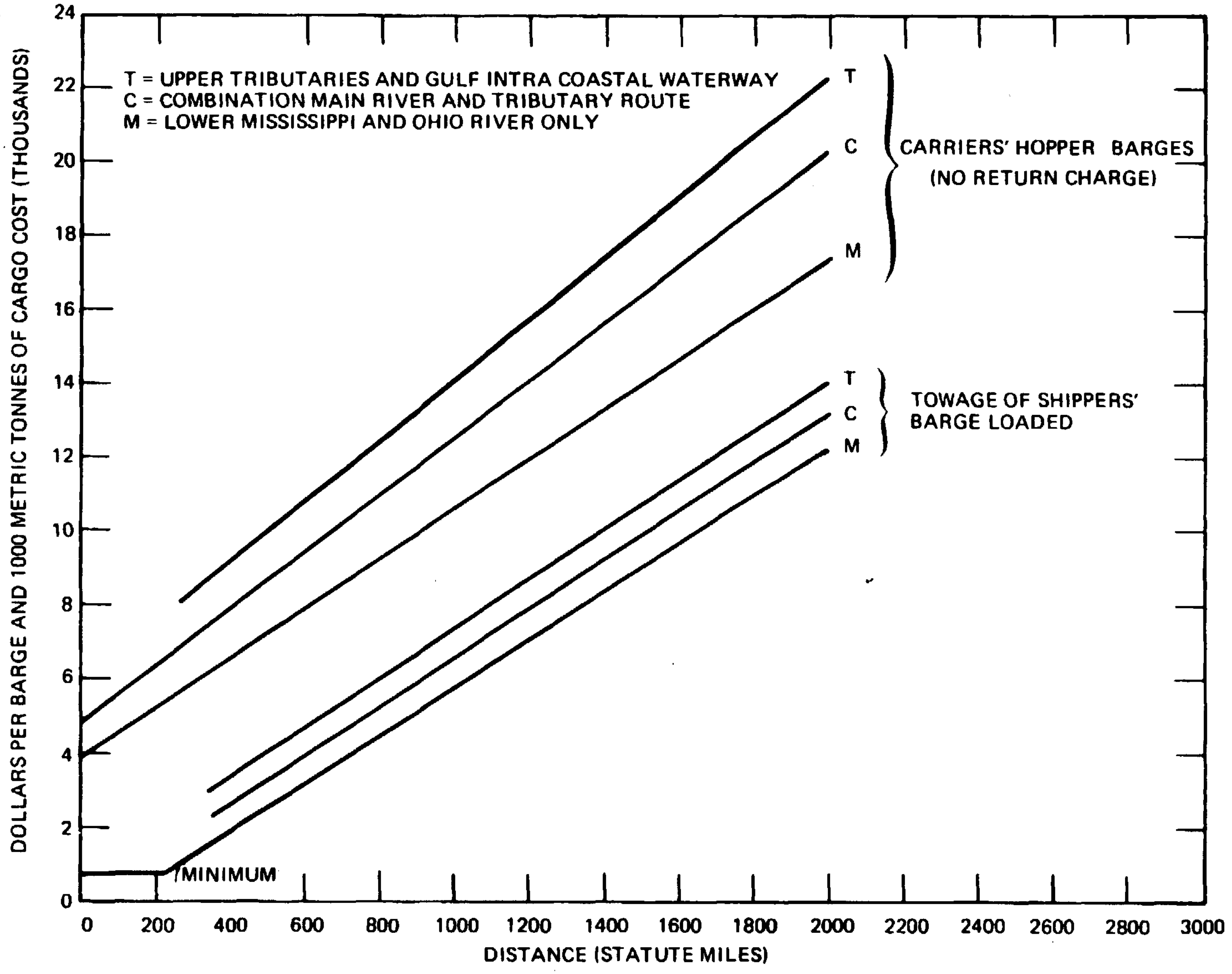


FIGURE 3-2. U.S. Inland and Coastal Barging Charges Base Rates: 1976

rates will differ depending upon the waterways on which the cargo is to be carried. The rates are lower on the main waterways than on the tributary rivers due to the fact that larger tows are possible on the main waterways.

Two different rates are presented:

- Transportation in carrier-owned barges
- Transportation in shipper-owned barges.

When the cargo is transported in a carrier-owned barge, the freight charge covers both the towing charges and the rental of the barge. In the case that the shipper owns barges, he will only have to pay the towage charges. Both these rates are included in the model.

The European barge costs are higher than those charged by companies operating on the U.S. waterways. Charges on various European waterways are presented as Figure 3-3. The charges presented in this figure include only the towage charges. A good estimate of the total barge costs (i.e., towage and barge charter) can be derived by adding the barge costs presented in Table 3-8 to the towage cost in Figure 3-3.

3.2.3 Over-the-Road Handling

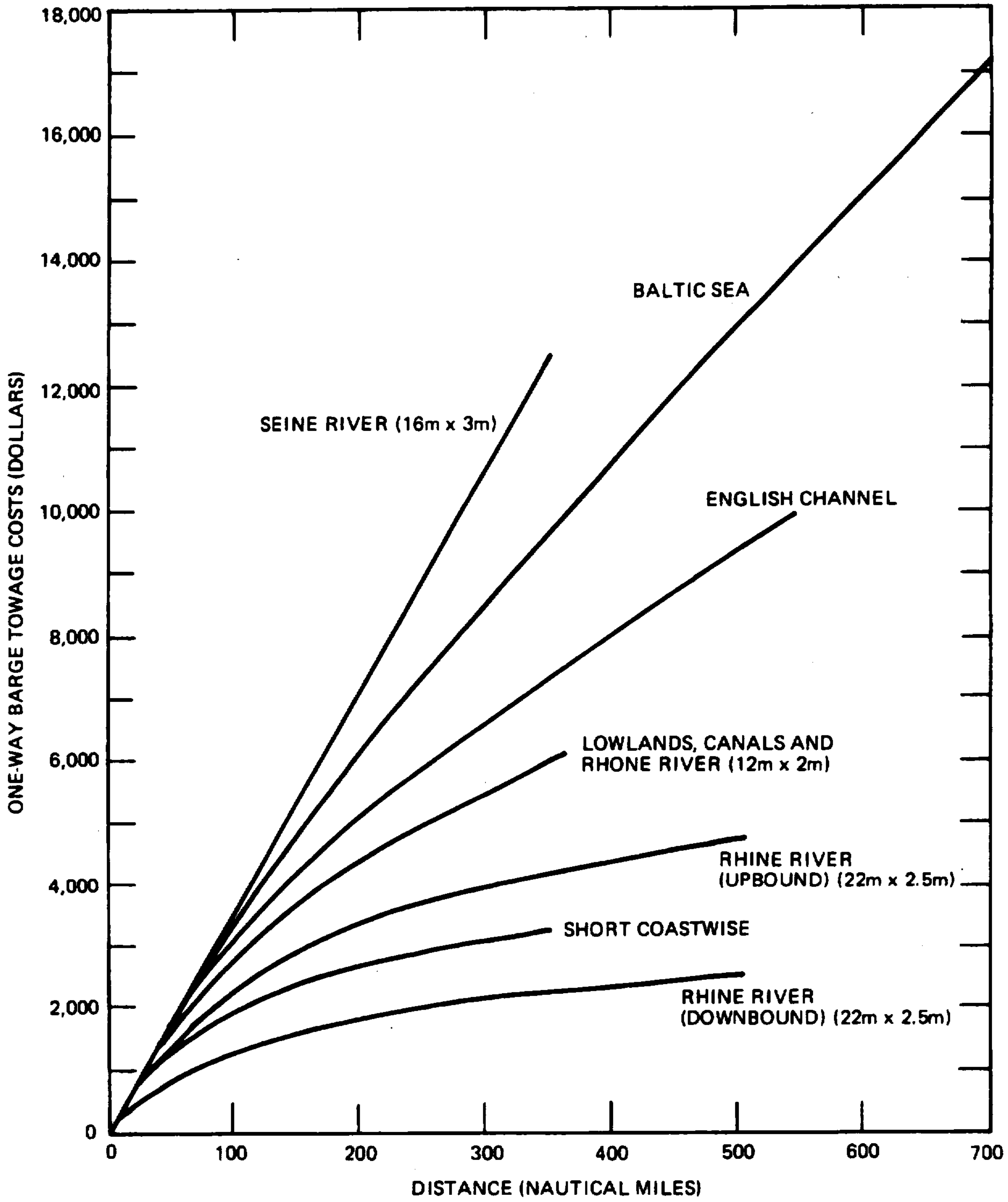
In the United States over-the-road transportation of heavy and outsized cargoes is mainly performed by members of the Heavy and Specialized Carriers Conference of American Trucking Association. The revenues of the operators are estimated to be $2.5 billion per year. The inventory of equipment includes a total of 50,000 power units and 70,000 trailers of which 4000 trailers have a capacity to handle loads of 100 tons or more. The type of heavy lift equipment available to the heavy haulers includes all types of trailers and transporters to handle any conceivable type of load. In cases where no equipment exists to transport the equipment of a customer, the heavy hauler can often engineer special equipment to accommodate it.

The major limitations imposed upon over-the-road haulers are the restrictions imposed by federal, state, and local highway authorities and physical size and weight constraints and clearances imposed by bridges, houses, roads, overhead utilities, and other constraints. Prior to undertaking a transportation job with dimensions or weights exceeding those of the limitations imposed by the regulations or possible physical constraints, the heavy haulers perform a thorough survey of the alternative routes, contact the highway authorities to obtain the necessary permits, and select the best route available under the circumstances. In some states the permits for over-the-road transportation is granted only after evidence is presented that the cargo cannot be accommodated by

TABLE 3-8. Flat Deck, Heavy-Lift, Oceangoing Barges

	SEABEE	SPECIAL SEABEE	JUMBO	SUPER JUMBO	SHORT SUPER JUMBO	SUPER SHORT	SUPER LONG	OCEAN SHORT	OCEAN LONG
Length Overall	97′	115′	200′	239′	200′	200′	300′	200′	300′
Beam, Maximum	35′	35′	35′	45′	45′	50′	50′	70′	70′
Depth Hull	11′	15′	16.5′	15′	15′	15′	19′	15′	19′
Draft, Fresh Water	9.5′	9.5′	12.5′	13.75′	12.5′	12.5′	15.8′	12.5′	15.8′
Deadweight Tonnage	700	810	1900	3260	2460	2740	5320	3870	7500
Lightweight, Tonnes	196	210	430	680	540	590	1000	800	1350
Displacement, F.W.	896	1020	2330	3940	3000	3330	6320	4670	8850
Draft @ 1,000 Tonnes	N.A.	N.A.	7.8′	6.5′	7.2′	5.1′	4.9′	4.3′	4.2′
Total Daily Cost	$151	$163	$267	$381	$314	$335	$518	$421	$658
Capital Cost (Thousands $)	215	240	460	680	560	604	980	780	1250

SOURCE: Lykes Bros. Steamship Co., Inc.



SOURCE: Lykes Bros. Steamship Co., Inc.

FIGURE 3-3. European Barge Towing Charges by Navigation Channel One-Way: 1976 other modes of transportation, i.e., rail, barge, or ship. In some instances the hauler will have to improve and expand existing roads, build bypass roads to avoid physical constraints, strengthen existing bridges or install temporary new bridges, and even relocate houses to enable the load to pass.

Many of the over-the-road haulers have expanded their services to include intermodal transportation by combination truck-rail, truck-barge and truck-ship, whereby the hauler arranges for the total haul by all modes of transportation from origin to destination. Some of the haulers have even expanded their sphere of operation to cover the entire world and offer their services between origins and destinations worldwide through subsidiaries and agents located in all major centers of the world.

A number of variables are used by hauler/riggers to calculate the charges. Each job is different, and it is bid as a total package with loading, unloading, road survey, special equipment, and other charges included. Based on tariffs published by haulers/riggers, Lykes Brothers developed a parametric rate predictor model. This model is presented as Table 3-9. It should be noted that charges for bypass roads, bridge strengthening and reconstruction, expansion of roads, construction of barge landings, and other charges that are peculiar to each situation, will be additional to the charges presented in the parametric model.

3.2.4 Rigging and Crane Operations

The services offered by rigging and crane operators are closely related to the over-the-road haulers, and in many instances these services are performed by the same companies. Like the heavy haulers, most riggers and crane rental operators are members of the Heavy and Specialized Carriers Conference of the American Trucking Association. While the haulers provide the transportation services, the riggers and crane rental operators normally provide the equipment, manpower and expertise to erect, slide, lift, hoist, and emplace heavy and outsized equipment at power plants, transformer stations, refineries and various construction sites, and onto and off railcars, trucks, barges, and ships.

The equipment owned and operated by riggers and crane rental operators ranges from small mobile cranes to gin poles that can lift and erect thousands of tons in addition to hoists, jacks, winches, dollies, powerful forklifts. In some cases, the riggers and crane operators rent the equipment to a customer so that he can perform the job with his own manpower. In most cases the riggers contract to perform the entire job and provide the equipment, skilled manpower, and expertise accumulated through the execution of numerous prior jobs.

TABLE 3-9. Parametric Rate Predictor Model for Heavy-Lift Hauling

BASE CHARGE

Setup Cost = $19.25 x weight (metric tonnes) = $______

Transport Cost = $0.40 x weight x distance (S.M.) = $______

Total Base Charge = $______

SIZE EXTRAS - (use only the highest multiplier for oversize)

Length	Multiplier	Width	Multiplier	Ht. for Ground	Multiplier
45'-55'	1.05	8'-9'	1.05	12'-13'	1.05
55'-65'	1.10	9'-10'	1.10	13'-14'	1.10
65'-70'	1.20	10'-11'	1.15	14'-15'	1.15
70'-80'	1.30	11'-12'	1.20	15'-16'	1.20
80'-100'	1.40	12'-13'	1.25	16'-17'	1.25
100'	1.50	13'-14'	1.30	17'-18'	1.30
		14'-15'	1.35	18'-19'	1.40
		15'-16'	1.50	19'	1.50
		16'-17'	1.65		
		17'	2.00		

GEOGRAPHY EXTRAS

South of Tennessee = 1.00 Multiplier = Base

North East and Midwest = 1.05 Multiplier

Mountainous Areas = 1.10 Multiplier

South West = 0.95 Multiplier

COMMODITY EXTRAS

Steel Fabrications	1.00 Multiplier = Base
Metalworking Machinery	1.10 Multiplier
Rotating Mechanical Machinery	1.20 Multiplier
Rotating Electrical Machinery	1.30 Multiplier

TOTAL BASE AND EXTRAS

$ Base charged x largest size Extra Multiplier x Geography Extra Multiplier x Commodity Extra Multiplier = $______

EQUIPMENT EXTRAS

Two-Way Radios @ $30/tractor = $______

Less than 100 tonnes Special Trailers 35"-40" @ 10¢/Mile ea = $______

Less than 100 tonnes Low-Boy Trailers 6"-35" @ 15¢/Mile ea = $______

If length over 100', or if weight over 150 tonnes, extra driver and tractor @ $12.75/hour loaded. = $______

Special heavy lift trailers @ $2.00/tonne/day = $______

Return of tractor and any trailer @ 74c/Mile empty = $______

Over 3 hours, demurrage for trailers @ $7.00/hour = $______

Over 3 hours, demurrage for tractors @ $13.00/hour = $______

(Dunnage for securing not included.)

LABOR EXTRAS

If over 10 hours, extra driver @ higher 15¢/loaded mile or $15.00/hour = $______

If over 12' wide, escort car @ higher (minimum $50) 66¢/loaded mile or $10.75/hour = $______

If over 16' wide, Flagmen @ $5.50/hour (loaded & empty) = $______

SERVICE EXTRAS

If cargo L 55' or W 10' or H 15' above ground Special Permits @ $18/state = $______

If call at marine terminal, charge @ $4.40/MT = $______

If value $5,500 per metric tonne, insurance at 50¢/$1,000 over = $______

If height or width 20', surveying route @ $1.70/mile = $______

(Raising telephone & power lines not included)

TOTAL EQUIPMENT, LABOR, AND SERVICE EXTRAS = $______

TOTAL UNIT TRANSPORT BILL = $______

SOURCE: Lykes Bros. Steamship Company

The cost of rigging services varies greatly depending on the size of the equipment rigged, and the complexity of the job. Some typical costs for the rigging and short haul of heavy components was provided by one of the major crane and rigging operations in the United States—Williams Crane and Rigging of Richmond, Virginia. These typical costs are illustrated in Table 3-10.

TABLE 3-10. Typical Costs of Rigging and Hauling Heavy Components

EQUIPMENT WEIGHT	TOTAL COST FOR HAUL UP TO 30 MILES	MANPOWER AND RIGGING COST OF TOTAL	EQUIPMENT COST	RIGGING TIME	TOTAL TIME
40-100 tons	$1400-1800	$1000	$400-800	4 hrs	8-12 hrs
100-175	$2200-2300	$1000	1200-1300	4 hrs	8-12 hrs
200-400	$100,000-125,000	50,000-60,000	50,000-65,000	4 days	10-30 days

The above costs include unloading of the components from a Schnabel railcar, and clean-up and reassembling of the railcar. The reassembly of the railcar is necessary because the Schnabel cars have to be disassembled to take the load off. The above cost furthermore includes the haul to the construction site, unloading at the site, jacking the component up into the building and skidding it into place.

Typical port crane rental charges for loading and discharging ships and barges were compiled by Lykes Brothers Steamship Company for rental of various crane sizes. The charges appear in Table 3-11.

TABLE 3-11. Port Crane Rental Rates

CRANE CAPACITY (METRIC TONNES)	DAILY SHORE AND FLOATING CRANE RENTAL COST		
	LOW	TYPICAL	HIGH
100	$ 300	$ 1,700	$ 4,200
200	3,400	5,800	13,000
300	7,600	15,000	26,000
400	7,600	17,000	40,000
500	16,000	21,000	47,000
600	20,000	35,000	54,000

3.2.5 Free-Flying Vehicles

At the present time the only heavy lift free-flying type of vehicles available in the free world is the Sikorsky S-64E "Sky-crane" helicopter. All but one of these helicopters currently in operation is primarily engaging in logging in the Pacific Northwest of the United States. The one "Skycrane" not engaged in logging is operated by Evergreen Helicopters in support of the construction industry. The primary functions performed by this helicopter are:

- Emplacement of preassembled towers for contractors of power transmission lines
- Emplacement of heat/ventilation/air conditioning units on commercial and residential buildings for building constructors.

In addition, the helicopter is performing complex lifting jobs that are impossible, costly, or time-consuming by conventional means of lifting, and transporting equipment for remote construction projects and oil and gas drilling operations.

Outsized dimensions pose no problem for components to be transported or lifted by heavy lift helicopter. There are, however, two major limiting factors for the use of heavy lift helicopters:

- Lifting capability
- Cost of acquisition and operation.

The lifting capability of the Sikorsky S-64E is 18,650 lbs (at 2,000 ft. ISA), which in many cases tend to exclude the Skycrane from possible markets. Sikorsky is currently marketing a civilian version of the CH-54 military helicopter, the S-64F. This craft has a lifting capability of 23,150 lbs. (at 2,000 ft. ISA). To date no commitments for the purchase of the S-64F have been reported.

The high cost of acquisition and operation is the second limiting factor for the marketability of a heavy lift helicopter in competition with conventional means of transportation and lifting. The fixed and variable operating costs per hour of the S-64E and S-64F at various annual utilization factors are presented as Table 3-12. The utilization goal of Evergreen Helicopters for the one Skycrane serving the construction industry is a total of 1000 hours per year including ferry time between each job. At the present time the annual utilization has been between 750 and 900 hours. The average ferry time between each job is 8 hours. The operating hours of the Skycranes used in logging operations are higher and range from 1500 to 2000 hours per year.

TABLE 3-12. Operating Cost for Sikorsky S-64E and S-64F

ITEM	S-64E	S-64F
1. INVESTMENT COST		
Flight Equipment	2,700,000	6,100,000
Support Equipment	35,000	43,000
Spares	212,000	212,000
Dynamic components	"Power by hour"	1,830,000
Total	2,947,000	8,184,000
2. FIXED ANNUAL COSTS		
Depreciation (10 yrs - 25%)	221,025	613,800
Interest (10% - 60% ave. value)	176,820	491,040
Insurance (8% flt equip)	216,000	488,000
Personnel (per single shift)		
Pilots	(3) 105,000	(3) 105,000
Co-Pilots	(3) 75,000	(3) 75,000
Mechanics	(5) 90,000	(5) 90,000
	270,000	270,000
Burden 25%	67,500	67,500
Total personnel	337,500	337,500
Helium replacement	–	–
Env. refurbishment	–	–
Total Fixed Annual	951,345	1,930,340
3. HOURLY COSTS		
Fuel Aero 50 gal/hr x $1.00/gal	262.50	262.50
S-64 525 gal/hr x .50/gal		
Oil	13.12	13.12
Replacement parts A/F	125.00	125.00
Dynamic System O/H	409.60	463.80
Engine O/H & inspect.	210.00	210.00
Misc. equip. O/H	–	–
Total Hourly	1,020.22	1,074.42

TABLE 3-12. Operating Cost for Sikorsky S-64E and S-64F (Continued)

ITEM	S-64E	S-64F
4. Total Cost/Flt hr		
Utilization hrs/yr	1,000	1,000
Fixed cost/hr	951.35	1,930.34
Hourly cost	1,020.22	1,286.89
Total cost/flt hr $	1,971.57	3,217.23
Utilization hrs/yr	1,500	1,500
Fixed cost/hr	634.23	1,286.89
Hourly cost	1,020.22	1,074.42
Total cost/flt hr $	1,654.45	2,361.31
Utilization hrs/yr	2,200	2,200
Fixed cost/hr	509.13	954.13
Hourly cost	1,020.22	1,074.42
Total cost/flt hr $	1,529.35	2,028.55
Utilization hrs/yr	3,000	3,000
Fixed cost/hr	429.62	755.95
Hourly cost	1,020.22	1,074.42
Total cost/flt hr $	1,449.84	1,830.37

3.3 Potential Applications for Heavy-Lift Airships

Based on a literature search, a survey of and discussions with trade associations, government agencies, international organizations, users and purveyors of heavy lift services, equipment, and consultants with interest in the subject of heavy and outsized transportation and lifting, a list of potential applications for the heavy lift airship was developed. The data sources reviewed and the organizations interviewed are presented as Appendix A. Some of the organizations and companies currently involved in some aspect of transportation and lifting of outsized and heavy cargoes were reluctant to disclose information and data on their operation. This reluctance was in most cases apparently due to the fact that these operators had made long term commitments and investments in equipment, which could encounter increased competition or even become obsolete if the HLA should be introduced. The list of potential applications is presented as Table 3-13. In addition to the applications shown in Table 3-13, the following applications and markets were considered:

- New heavy machinery
- Vessels and barges
- Aerospace
- Large iron and steel assemblies
- Railroad locomotives and cars.

For all these market sectors and applications it was considered that the majority of heavy lift and transportation services could be handled with existing technology with minimal restrictions and at costs below those of the HLA. The few special applications in these sectors where the HLA would be competitive are covered as a part of the "Heavy and Outsize Cargo Transportation" application.

The competitive situation of the HLA in these various markets will vary depending upon the transportation infrastructure available and the ability of existing modes of transportation. In order to select the areas of application where the HLA appeared to be able to compete or even have a competitive advantage, and to screen out the areas where it could not be competitive, all applications were arranged in a matrix with the transportation infrastructure and cargo dimensions. In this way, the market for each application could be segmented into subsegments based on the transportation infrastructure and the cargo dimensions and weight.

The transportation infrastructure was divided as indicated in Section 1 of this chapter:

TABLE 3-13. Potential Civil Markets for Heavy - Lift Airships

TRANSPORTATION GEOGRAPHY:	URBAN				DEVELOPED				UNDEVELOPED				REMOTE			
CARGO DIMENSIONS AND WEIGHT:	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
APPLICATION																
Construction Industry Support																
• Refinery and Chemical Plants	L	L	M	H	L	L	M	H	L	M	M	H	NA	NA	NA	NA
• Offshore Oil Production Platforms	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	L	L	M	H
• Mining Sites	NA	NA	NA	NA	L	L	L	L	M	M	M	M	H	H	H	H
• Power Transmission Lines	NA	NA	NA	NA	M	M	NA	NA	H	H	NA	NA	H	H	NA	NA
• Electric Generating Plants	L	M	H	H	L	M	H	H	M	H	H	H	H	H	H	H
• Homes	M	M	NA	NA	M	M	NA	NA	H	H	NA	NA	H	H	NA	NA
• Pipelines	NA	NA	NA	NA	L	L	M	M	M	H	H	H	H	H	H	H
• Heating/Ventilation/Air Conditioning Unit Emplacement	H	H	NA	NA	H	H	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
• Other Construction	M	M	H	H	M	M	H	H	M	H	H	H	H	H	H	H
Oil and Gas Drilling	L	L	NA	NA	L	L	NA	NA	M	M	NA	NA	H	H	NA	NA
Logging and Forestry	NA	NA	NA	NA	NA	NA	NA	NA	H	NA	NA	NA	H	NA	NA	NA
Port Activity	L	L	L	L	L	L	L	L	M	M	M	M	H	H	H	H
General Transportation in Remote and Undeveloped Regions	NA	NA	NA	NA	NA	NA	NA	NA	M	M	M	M	H	H	H	H
Heavy and Outsized Cargo Transportation	L	M	M	H	L	L	M	H	M	M	H	H	M	H	H	H

See text for explanation of L, M, and H.

EXPLANATION OF TERMS:

1 = Up to 50 Tons, 45 feet long, 10 feet wide, 10 feet high
2 = Up to 100 Tons, 80 feet long, 14 feet wide, 12 feet high
3 = Up to 200 Tons, 100 feet long, 15 feet wide, 15 feet high
4 = Over 200 Tons, over 100 feet long, over 15 feet wide, over 15 feet high.

- Urban
- Developed
- Undeveloped
- Remote.

The cargo dimensions and weight criteria were divided with respect to the normal limitations that exist for the various modes of transportation. These are:

Components up to 50 Tons, up to 45 Feet Long, up to 10 Feet Wide and up to 10 Feet High

These components can be transported by all modes of transportation including truck with conventional equipment and without securing special permits from the highway regulatory authorities on encountering clearance problems on the railroads, cranes, derricks, and other lifting and hoisting equipment is normally readily available to lift components within these weight limits.

Components up to 100 Tons, up to 80 Feet Long, 14 Feet Wide, 12 Feet High

These components can normally be transported on a major portion of the U.S. rail network and encounter no major clearance problems on foreign railroads. Special permits are required for transportation over the highways, and specialized trailers are required for transportation to distribute the load. Equipment for lifting and rigging components of these dimensions is available from most rigging and crane operators.

Components up to 200 Tons, up to 100 Feet Long, up to 15 Feet Wide, up to 15 Feet High

These components require transportation on heavy lift railroad cars. Special permits for over-the-road transportation are required, and physical obstacles like bridges, narrow turns, poor roads, etc., may require major re-routings. Equipment for rigging and lifting components of these dimensions and weights is generally possessed only by the major rigging and crane operators.

Components Over 200 Tons, Over 100 Feet Long, Over 15 Feet Wide and Over 15 Feet High

These components require special heavy lift freight cars and frequently special train service is required. Clearance problems in many cases require long rail route deviations, and at times preclude the components being transported by rail.

Highly specialized equipment and the expertise of experienced haulers are required for over-the-road transportation. At times, bridges, narrow or weak roads have to be improved or new ones constructed at great cost to the project. Careful planning and preparation are required by the hauler. Highly specialized crane and rigging equipment and expertise possessed by the major riggers are required to perform rigging on components of these dimensions.

Each of these market subsegments was then ranked on a qualitative basis as to the ability of the HLA to compete with the existing modes of transportation. The qualitative ranks assigned were:

L - The HLA is not competitive with or is at a competitive disadvantage to existing modes of transportation or lifting.

M - The HLA may be competitive in special situations with existing modes of transportation and lifting, but in general it will not be.

H - The HLA is competitive with existing modes of transportation and lifting. In some cases the HLA may have a competitive advantage.

Based on the HLA applications matrix and the qualitative evaluation of the competitive opportunities for the HLA shown in Table 3-13, case studies were selected by which to evaluate the economic feasibility of using the HLA.

OPERATIONAL AND COST STUDIES FOR THE HLA

4. OPERATIONAL AND COST STUDIES FOR THE HLA

LIST OF FIGURES

LIST OF TABLES

4. OPERATIONAL AND COST STUDIES FOR THE HLA

In order to ensure that the market analysis properly reflects the peculiar qualities of HLAs when compared to other forms of transportation, studies were undertaken to define the operational and cost characteristics of HLAs that could seriously influence the results of the market analysis. This chapter describes the purpose, ground rules, assumptions, nature and results of these analyses. Supporting detailed cost information is provided in Appendix B, which is bound separately as it contains proprietary material which is not available for general distribution. A copy is retained in the technical monitor's office (NASA, Ames).

4.1 Operational Studies of the HLA

This section describes the purpose of examining HLA operations in this study, the ground rules used and assumptions made in the analyses, the analyses performed, and the results obtained.

4.1.1 The Purpose of the Operational Studies

The overall purpose is to define the influence of the operational characteristics of HLAs in general on the acceptability of the HLA in civil markets in the United States and abroad. In particular, definition is sought of those characteristics and operational features that:

- Must be provided or deleted, to satisfy a major customer's requirements
- Will significantly influence the total cost of using an HLA to satisfy the customer's requirements.

It is not part of the purpose of this section to attempt an overview of the state-of-the-art in airship design and operations, except where other studies have indicated that improvements in technology over the past 30 to 40 years appear to offer significantly improved capabilities, compared to the previous generation of airships.

4.1.2 Ground Rules and Assumptions

Since HLAs are at present relatively undeveloped vehicle concepts, and since this study is required to be as concept-independent as possible, the primary configuration variables for consideration in this analysis are:

- Vehicle size, as measured by the useful load carried (fuel plus commercial payload)

- Vehicle lift mechanism, as measured by the lift that is non-buoyant, as a proportion of the useful load.

All other operational features are developed through literature review, development of a typical, or generic, operational sequence, and development of services required to support these operations. These analyses are defined for a baseline configuration, and the effect of variations from this baseline are defined. The baseline configuration was defined as the bouyant quadrotor configuration (Figure 2-1) with:

Non-buoyant lift = useful load, and
buoyant lift = empty weight.

Additional operational ground rules defined for the study are that only open mooring need be considered, as opposed to the provision of shelters or hangars, and the effects of adverse weather will be considered.

4.1.3 Operational Studies

The elements of HLA operations are closely tied to the elements of HLA costs, which in turn are of primary significance in determining the viability and competitiveness of the HLA in any potential application and market. In this section, those operational elements that significantly affect cost are examined with respect to customer requirements; the remainder are reviewed briefly and examined in depth only in so far as customer needs demand. The operational elements are identified by hypothesizing the stages of a typical flight as follows:

4.1.3.1 A Typical HLA Operation. The following material details a complete HLA flight operation, identifying as many aspects of the operation as possible, to extract from the operation those features that are critical to customer satisfaction and cost. In general terms, these features fall into the following areas:

- Proper cargo delivery

- Operational safety

- Support facilities, equipment services to maintain a viable operation that meets customer requirements.

A typical sequence of events during HLA operations follows:

- Check maintenance operations.

- Check functional safety of all subsystems.

- Replace consumables; helium check (pressure/quantity), gasoline, oil, air, fire extinguishers; check C.G. of HLA w/o cargo, also gross weight.

- Align vehicle into wind.

- Verify flight plan and operational requirements.

- Attach cargo - position cargo appropriately under/by HLA and hook up as required, (do not lift).

- Verify weather suitability.

- Obtain clearance for take off.

- Verify all clear, release from ground/tower mooring point, bring up rotor pitch to raise HLA. Pick up cargo if at the point of beginning of operation.

- Climb away.

- Turn on course, climb to cruise altitude.

- Monitor ground contact points, to gather data on local turbulence and visibility.

- Establish radio communications with on-site personnel when approaching destination.

- If mooring required, and no mast is at site, hover, and lower expeditionary mast and engineer, to set up mast. Loiter, until mast ready, then approach and moor, using contractor on-site personnel* to handle lines from the HLA to assist in ground maneuvering, and to secure.

- If "precision" placement is required rather than mooring, then approach, lower ground lines (preplanned maneuver), and hover over placement "spot" using precision hover to control vehicle. Contractor on-site personnel will hook up lines to winches or other ground restraint and control devices.

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* "Contractor on-site personnel" here refers to customer crew already at the site that would normally accomplish rigging tasks for a conventional heavy lift operation using a crane. These are not HLA crew especially shipped to the site to handle the HLA during mooring.

- Lower cargo using winch mechanism, and precision hover to hold station, while on-site personnel (e.g., "riggers", if handling large plant components) provides precise lateral control of cargo. Continuous communication for all participants, under control of ground foreman (as in normal crane and rigging operations).

- When positioned, release cables and other connections, raise to HLA, climb clear of obstructions, loiter while flight plans and instructions are exchanged, proceed to either base.

- Two types of bases are envisaged—a temporary or "field" base located in the general vicinity of the destination (e.g., at the destination or within easy reach of all multiple destinations) at which routine maintenance can be performed and the main base for HLA operations, encompassing all facilities for flight and ground operations and support activities.

- At field base - Use expeditionary mooring point and ground crew/engineer to position/locate HLA nose/belly and mooring point. If necessary to prevent possible danger to ground personnel, cut rotors and approach expeditionary field mooring point on auxiliary power.

- Operation from field base, lifting at staging point, positioning on-site - At start of day, repeat preflight check, warm up engines, verify day's schedule with ground activity foreman. Refuel, check clearance for take off, release from mooring mast, engage rotors and lift off to pick-up at staging point. Hover over staging point, lower cables with static discharger. Contractor on-site personnel connect cables to payload. Release restraints when vertical lift by HLA is assured thus eliminating load swing dangers. Climb out vertically, rotate on course then gently accelerate on desired course to cruise speed. On arrival at site follow procedure previously described.

- Returning to main base - Sequence similar to departure from main base, except that flight clearance to main base must be obtained via radio.

- Arrive at main base - Approach into prevailing wind, line up on mooring point, engage mooring point. Cut engines, post-flight check by crew.

4.1.3.2 Significant Operational Elements. From the preceding development of an HLA operation, the following emerge as being of principal concern.

For proper cargo delivery:

- Enroute flight speeds to satisfy delivery schedules
- Cargo handling on the ground
- Equipment to contain the cargo while attached to the HLA
- Cargo attachment to the HLA, with quick release capability in an emergency
- Techniques for adding ballast if necessary in specific situations
- Controllability sufficient to minimize cargo disturbance during the take off
- Cargo protection against weather conditions enroute—rain, hail, snow, sun, freezing temperatures, icing. This may be the responsibility of the customer; however, if the design provides such production at a reasonable cost, it may be more competitive.
- Ability to carry sufficient cargo to minimize time and cost to the customer
- If moored at the delivery point, techniques to restrain HLA movement while unloading the cargo
- If not moored, but hovering, sufficient controllability to prevent undesired cargo displacement while unloading
- Use of ground crew and HLA-mounted restraint cables and winches may be required.

For operational safety:

- Thorough inspection of all flight components, particularly the lift, control, and cargo attach systems
- Proper flight planning to take account of local terrain and weather conditions
- In unprepared terrain, ensure personnel on the ground are protected from dust and dirt transported by rotor/fan down wash during take off and landing. This is not usually a problem with helicopters, and is less so with HLA, due to relatively low disc loadings.

- Minimize pitch and roll motions during landing and take off to reduce risks of rotor striking ground

- Depending on the cargo, the flight plan may have to consider avoiding populated areas, and should identify emergency landing sites in the event of power or buoyancy failure. Note that this consideration is strongly affected by the number of engines used to power the rotors, and the extent of cross-coupling between power units and rotors. This must be designed so that at all times the power is shared evenly among all rotors, even in the event of multiple engine failure.

- When mooring or precision hovering, use contractor personnel on the ground, where possible and available, to aid in ground positioning and obstacle avoidance

- In the event of an emergency landing, the normal flight cover (e.g., pilot, co-pilot, engineer, heavy lift operator) should attempt repars for which they have been trained and are equipped. More extensive repairs would await arrival of a field repair cover from the nearest HLA base; possibly ferried by a replacement HLA.

- One crew member remains on duty with HLA at all times while away from base

- Built-in maintenance diagnostic techniques may be useful to minimize parts inventory and provide long lead time on potential failures, if available and cost-effective

- Static discharge prior to ground crew/flight crew making contact.

For support of HLA system operations:

- At least a "minimum" main base with, the following
  - Fuel, oil and helium storage, and transfer equipment
  - An enclosed facility for power lift/propulsion system maintenance
  - A capability for envelope and structure inspection and repair, and continued maintenance
  - A general maintenance facility for electromechanical pneumatic, hydraulic and other system or component maintenance

- An operating field with a mooring system, and sufficient clearance to approach the mooring point from any direction
- A concrete pad surrounding the mooring point to carry repeated HLA wheel loads, and for loading and unloading cargo
- Ground support equipment and vehicles, for use in maintenance of the envelope and structure and for maneuvering the HLA, its cargo and other equipments around the base
- A facility for maintenance of the ground equipment
- A facility for housing the flight and ground crews, and administrative staff and their equipment
- Flight operations equipment, communications meterological equipment, emergency equipment.

Much of this could be colocated and shared with conventional aircraft facilities on an airfield.

For operations away from base the following are necessary:

- An expeditionary mooring mast, carried on board the HLA
- Spares for simple repairs to be carried out by the flight crew
- Tie-down equipment for use in bad weather
- Extra fuel tanks in lieu of cargo for ferry flights.

4.1.3.3 Relative Cost Significance of Support Items. A review of the costs involved in providing such a minimum base facility and field equipment (detailed in the Cost Analysis Section) shows that these costs, which could be vital to practicality of operations, are small compared to the vehicle operating and financing costs. The cost of such facilities (not including the cost of the HLA maintenance performed in these facilities), when amortized over the anticipated life of an HLA, for reasonable annual utilization, does not exceed 5 to 6 percent of the total cost per HLA of an HLA operation. Even if more bases are added, or a larger base is developed to house more or larger HLAs, this percentage does not change significantly. Consequently, no serious study has been attempted of alternative basing configurations or fleet management considerations. Rather, the remainder of this chapter is confined to study of HLA flight operations and cargo handling, and the effect on these of variations from the baseline configuration.

4.1.3.4 Operational Considerations. The typical customer for HLA services will be primarily interested in moving his cargo a relatively short distance, compared to normal transportation distances, and having it deposited to his specifications as to location, precision, and ground-impact speed (descent rate on touch down). He will be concerned that the cargo not be damaged, and will require that the HLA be sufficiently controllable to ensure cargo safety. He will be more interested in the HLA if it can perform his required task with much savings in time, cost, capital equipment and/or manpower, as has been demonstrated in some specific instances by helicopters. Therefore, operational features and capabilities that ensure cargo delivery in undamaged condition in the location required are of primary interest. The following discussion assumes the buoyant quad-rotor configuration.

Vehicle Size. Since the customer will be unwilling to pay for capacity much beyond his needs, his interest will tend towards a vehicle size for which his lifting needs represent those of the design payload. Any increase in size would have to be justified by, for example, increased controllability in hover due to increased power levels, or by reduced charges for the services provided (a possible result if the larger size has a bigger market and as a consequence is built in larger quantities, or being much more heavily utilized, or has less ferry cost to amortize).

Open Field Mooring. If the loading and unloading of cargo can be accomplished in the hover condition, mooring at the field location may only be required when the HLA is not performing its assigned task. However, there may be situations in the field when such may not be feasible. In that case, the mooring technique must be compatible with the capabilities of the on-board crew, and the HLA controllability. It is anticipated that powered lift and control system development will make it quite feasible for the HLA to be fully controlled from on board. The mooring mast may need to be telescopic to permit varying the loading height under the HLA to accommodate the cargo and its transport during positioning and cargo hook up.

Cargo Handling and Hover Controllability. The most critical operational steps occur at each end of the flight as the cargo is transferred between the HLA and the ground, since major changes in vehicle weight and the corresponding lift forces take place. Figure 4-1 illustrates this concept. Ways must be developed for ensuring that this transition does not bring about a major perturbation of the HLA and can be safely accomplished in windy weather. For the nominal concept, the two operational conditions between which the transition occurs are:

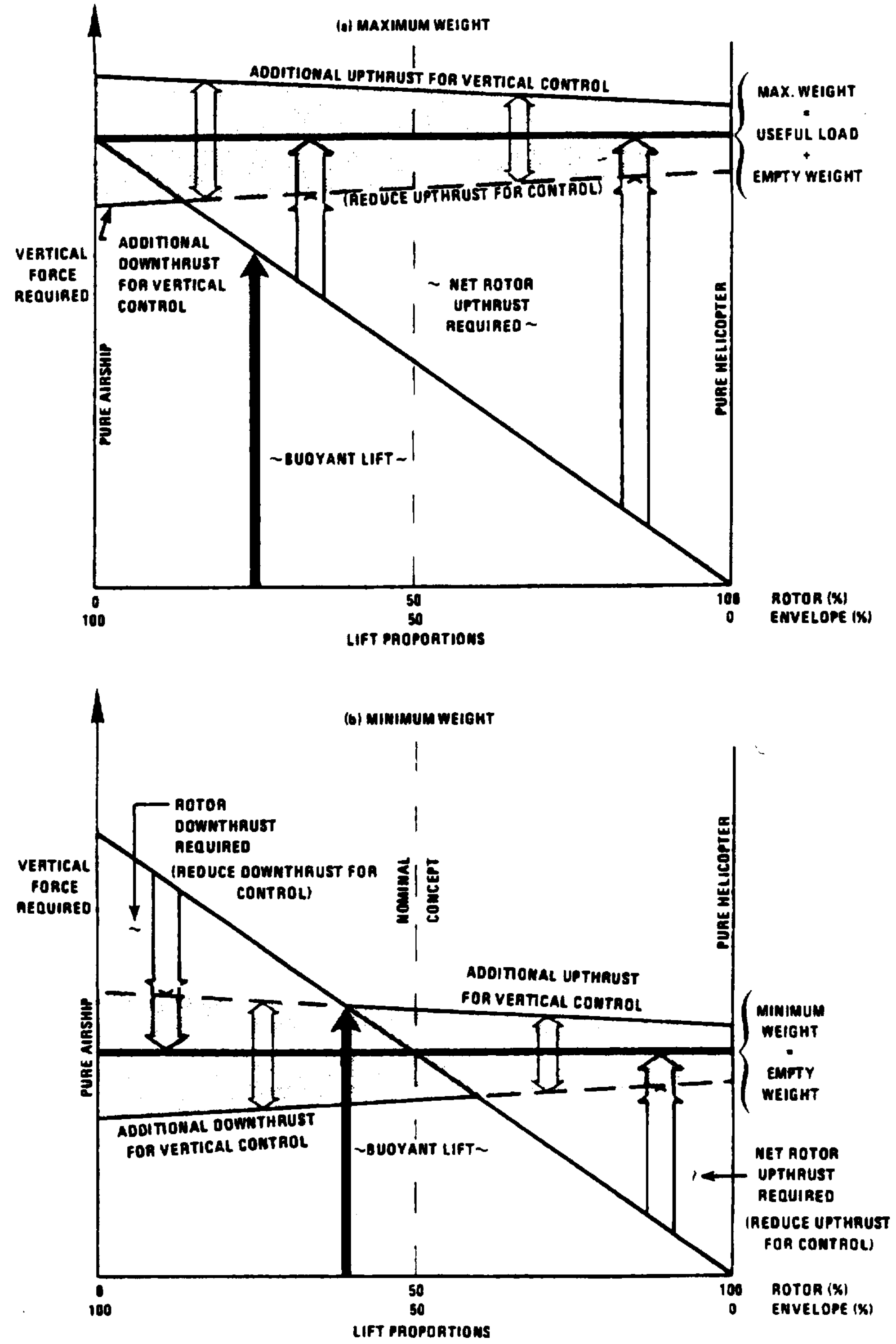

FIGURE 4-1. Equilibrium Forces at Maximum and Minimum Weight vs Rotor/Envelope Lift Proportions

(a) Vehicle at close to maximum gross weight, (the useful load being supported by the powered lift system)

(b) Vehicle at close to empty weight, (being supported almost entirely by the buoyant envelope).

In going from (a) to (b), the vehicle is first lowered, under full control with its heavily loaded rotor system, until the cargo is properly positioned. At this point the cargo is ready for release. If the cargo were released suddenly, the vehicle would immediately jump. To avoid this behavior, before cargo release, the rotor lift of two diagonally opposed rotors is slowly reduced and then reversed to ensure that transfer of the load from the vehicle to ground is gradual until the HLA is no longer supporting the cargo, while maintaining vertical and lateral controllability. At this point, the cargo can be disconnected. The HLA is now in condition (b), hovering with no net rotor contribution to lift. In this condition, controllability requires that the rotors be capable of developing vertical and side thrust while the net vertical rotor thrust is zero; this is accomplished by having each pair of diagonally opposed rotors maintain significant but opposed thrust levels. Modulation of these thrust levels will provide the desired controllability.

In going from (b) to (a), the reverse procedure will be followed. Thus the HLA will be fully controllable at all times.

In the development cycle envisaged for the nominal concept HLA, the first stage would consider using conventional helicopter rotor systems from which only one-way vertical thrust is normally available. As indicated in Figure 4-1, this is entirely feasible for rotor-lift-to-envelope-lift proportions above about 55 percent. These rotors would be generally operating under more lightly loaded conditions than for helicopter operations, with consequently reduced maintenance requirements. Development of reversible-thrust rotors could be considered for a second stage of HLA RDT&E.

The cost impacts of these operational considerations are similar for all potential HLA configurations and are as follows:

- RDT&E costs would arise principally from development of a control system and a rotor system optimized for HLA use. Interim operations are entirely feasible with existing rotor systems (with probable use of ballast)* coupled by a fly-by-wire technology, which must be developed in a prototype. Other development costs result from the use of new materials and design techniques in what is an otherwise well-established design process for airship hulls.

- Investment costs are most strongly impacted by the propulsion/lift and power systems. These are costly and sophisticated engineering products, of substantially greater power levels than would be required for fully buoyant systems. Note that costs lower than for conventional helicopter rotor systems can be anticipated*.

- O&M costs are again most strongly impacted by the propulsion/lift and power system maintenance requirements and fuel costs, which are substantially greater than for fully buoyant systems. Note that costs lower than for current conventional helicopter systems can be anticipated*.

- Note also that design for the engine-out case will affect costs through the engine configuration; the question of cross-shafting vs. multiple engines must be examined with respect to flight safety. The resultant reliability requirements will influence the maintenance cycle, labor, material, and costs.

Altitude Effects: Some potential applications may require operation between two locations within relatively few miles of each other, but with a considerable altitude difference between them. If the task is to carry payload from the higher to the lower elevation, less operational difficulty is anticipated since the real demands on power will be to provide a VTOL capability at the start, and a hover capability at destination. The journey from the higher elevation to the lower with payload would be greatly assisted by gravity, while the reverse journey without payload would be assisted by buoyancy. On the other hand, if heavy loads have to be lifted from a lower to a significantly higher elevation, significant rotor power will be required throughout the delivery flight, and also on the return flight unless ballast is employed. Note that the rotor, power plant and envelope must be sized to satisfy the maximum lift at the higher elevation, in either case.

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* Developments under way on helicopter rotor system maintenance as part of HLH and other programs will result in significant reduction in HLA maintenance costs (approximately a 65% reduction). Rotor design requirements for HLA permit a simpler symmetrical rotor section without twist; less efficient, but cheaper and lighter, with better fatigue properties and simpler maintenance.

It is common non-rigid LTA practice to employ ballonets that can be inflated with air to reduce the helium volume and thus control the lifting capacity of the envelope. Ballonet capacity and the percentage of helium inflation at ground level determine the maximum altitude achievable by the airship. In non-rigid airships, this is called "pressure height" and cannot be exceeded without loss of lifting gas. In general, as the required operating altitude for a given payload is increased, the envelope and ballonet size increases. The installed power must also increase, since the baseline configuration depends on rotor power to support the payload, and both rotor lift and engine power drop off with increases in altitude. Consequently, extended operation at higher altitudes would require a larger vehicle than would be dictated by just the increase in envelope size to accommodate a greater ballonet. In-flight controllability at higher altitudes may become more difficult, since the aerodynamic control and damping forces reduce due to the lower density while the vehicle inertia is either unchanged or increased if a larger vehicle is used. However, in hover, controllability should be unaffected, since the rotor forces are sized to satisfy the lift at altitude.

Consequently, operation at high altitudes or between significant altitude differentials are bound to be more costly to the user, either because a larger number of round trips are required to meet his requirements with a machine not designed to reach the maximum altitude with full payload, or because an appropriately sized machine will have greater investment and development costs, as well as greater fuel cost.

4.1.3.5 The Effect of Variations of the Proportions of Rotor and Buoyant Lift. A principal parameter of the HLA configuration is the distribution of total lift between envelope and rotors. An increase in the proportion of rotor lift would tend to increase costs and complexity and reduce the inherent advantages that the baseline configuration has in competition with the helicopter but possible controllability and operational flexibility. A decrease in the proportion of rotor lift has the opposite tendencies and is perhaps more worth examining.

A reduction in rotor lift means a larger envelope and ballonet and consequently an increase in aerodynamics drag, and responsiveness to gusts. At the same time, although envelope costs will increase, overall acquisition costs will not since rotor power and size are reduced and rotor costs are greater than envelope costs.

At the cargo transfer points, a reduction in rotor lift and an increase in envelope lift can have a significant effect. With the vehicle at close to maximum gross weight, a reduction in rotor lift and an increase in envelope lift has the effect of reducing the rotor force available for controllability. However, with the vehicle at close to empty weight, any increase in the proportion of envelope lift must be counteracted by rotor lift, since in the baseline configuration, the empty weight is balanced by the envelope lift. Consequently, the rotor must be capable of providing both positive and negative lift in steady state conditions. The proportion of positive and negative lift depends on the combination of steady state balance forces, which vary with the proportion of rotor lift assumed. Also the additional controllability forces required increase with vehicle size and inertia.

This variation was summarized in Figure 4-1, which shows the lift and control forces required in the heavy and light conditions, as a function of the proportion of rotor and buoyancy lift.

4.2 Cost Studies of the HLA

This section describes the purpose of examining HLA costs in this study, the ground rules and assumptions made for the analyses, the analyses that were performed, and the results that were obtained.

4.2.1 The Purpose of the Cost Studies

The main purpose of these cost studies is to develop a technique for calculating realistic charges to a potential customer for the use of HLAs, such that these charges would be directly comparable to those for any other competing mode of transportation, so that they can be used in estimating the market potential for the HLA. This technique must at the same time be capable of use in investigating the sensitivity of such charges to variations in the market environment, as defined by the customers requirements, and to uncertainties in estimating the acquisition, operation, and maintenance costs of HLAs.

4.2.2 Ground Rules and Assumptions

In addition to the basic study ground rules and assumptions defined earlier, the following were adopted for the cost analysis:

- No independent cost estimating would be done except as required to extend the data provided, so as to cover a complete range of vehicle sizes.

- Basic cost data would be provided by potential HLA manufacturers to represent their best realistic estimates of practical designs.
- No critical analysis would be made of the data provided, other than to assess its reasonableness by comparison in a general manner with previous HLA assessments and other system costs.
- The manufacturer's cost elements would be varied to represent the effect of uncertainty in their estimates.
- Proprietary data would be made available only to NASA.
- Engineering principles and common sense would be satisfactory as a basis for extrapolating data to sizes for which data were not provided.
- Present-day cost estimates are representative of future costs when escalated by an appropriate index.

Note that because of these assumptions, and the varying degree of optimism from one manufacturer to another, the various cost estimates cannot be used to judge the relative worth of the vehicle concepts.

4.2.3 The Cost Study Methodology

The total cost to a customer for transportation of his cargo from his desired origin to desired destination is made up of the separate costs of individual modes (e.g. barge, truck, rail) plus the cost of loading and unloading between modes and at the origin and destination, as illustrated in Figure 4-2. Multiple modes are required when no single mode is available from origin to destination and invariably such journeys involve circuitous routes in plan and elevation, with corresponding penalties in transit time. Any single transportation process or mode that can replace one or more modes and the associated transfers, and at the same time reduce the overall transit time, is a candidate for modal competition. The system basic operating cost per unit time or distance may be higher than the competing modes, if the overall cost to the customer is reduced. In fact, under some circumstances the actual total transit cost using the new candidate can be higher than for the competing modes, if the savings in time by the new candidate affords the customer significant savings elsewhere in his operation.

Examples of how such savings arise, drawn from the cases in this study, are as follows:

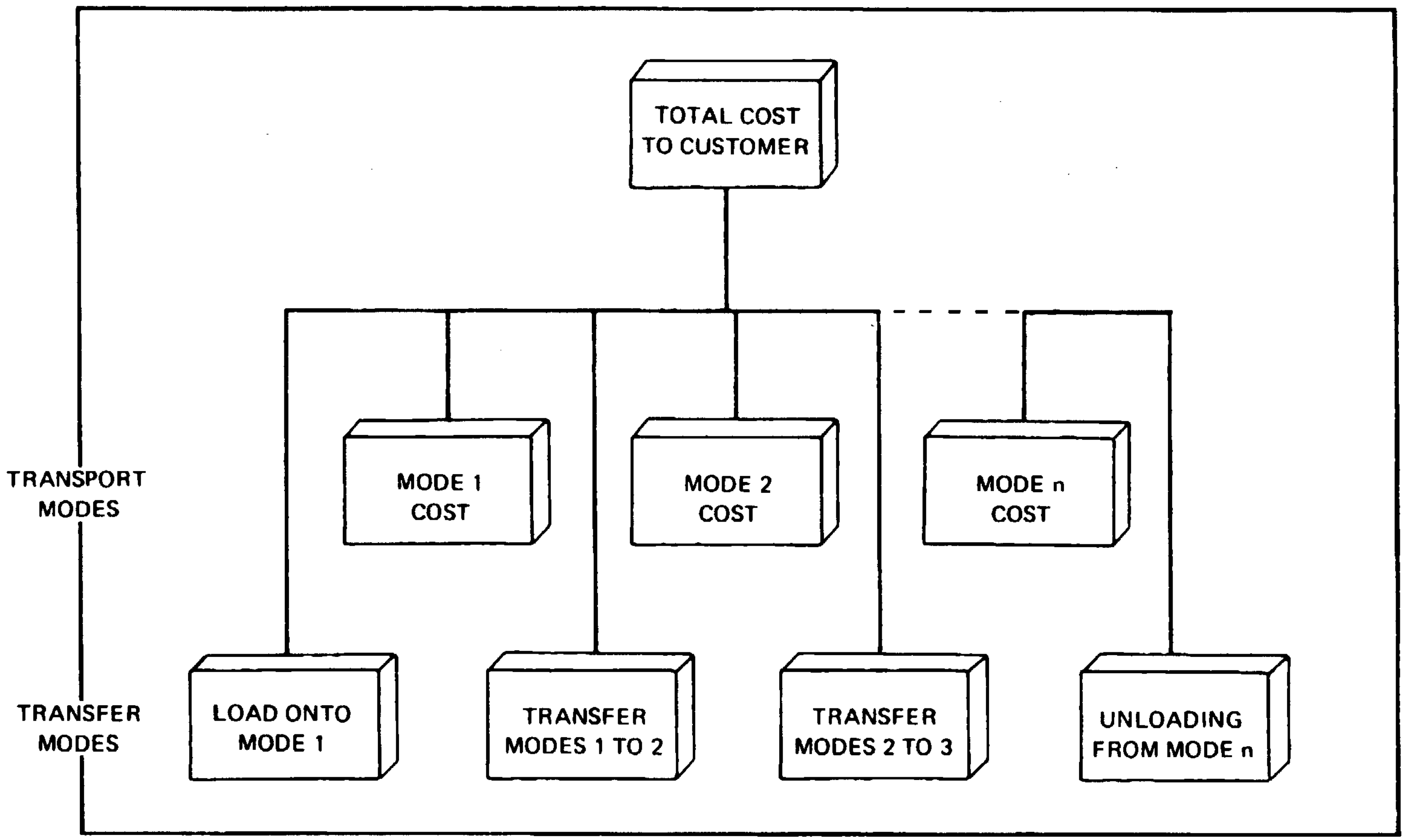

FIGURE 4-2. Main Multimode Cost Elements

- A project that can be completed quicker, through use of HLAs, can have reduced finance charges.

- If the project capital equipment requirements are reduced as a result of the use of HLAs, the finance charges are reduced.

- Consolidation of effort can result from the use of HLAs, resulting in more efficient use of manpower and increased productivity, and a very real savings in labor costs on the project.

- A further savings, less tangible but very significant in a competitive market, can result. The lower cost, shorter project time, and generally more efficient operation may provide the customer with the ability to offer more attractive project proposals than his competition, thus increasing his annual income and profits and attracting investment capital to his operation.

4.2.3.1 The Cost Analysis Framework. In the modes with which the HLA would be most likely to compete (truck, barge, rail, helicopter and the riggers who effect the intermode transfers and final assembly) the practice is to charge a negotiated fee that is assessed through careful review of the elements of the task to be performed. Consequently in this analysis, it is necessary to determine the cost of using the HLA to perform specific well-defined tasks.

In transportation, the basic elements involved are always the same, regardless of the cost methodology employed. These basic elements are:

- The cost of purchasing one or more vehicles

- The cost of purchasing the supporting equipment and facilities for the vehicles, their maintenance and operation

- The cost of operating the vehicles in performing any given project

- The cost of maintaining the vehicles and their subsystems

- The cost of managing the system.

All of these costs must be reflected in the charge to the customer. These broad categories, discussed in more detail in the next section, in general depend on several factors; the number of airships purchased, the extent of government participation in development, the financing alternatives and rates, the hours per year that each HLA is utilized, the proportion of the time that is spent in different modes of flight (ferry, cruise, hover), and the load that is being carried. All these relate together as shown in Figure 4-3, which illustrates the framework of the analysis procedure used for determining the operator's charge to the customer (equivalent to the negotiated tariffs charged by conventional modes).

This framework is divided into two main cost elements: those costs that are accrued annually and are unaffected by the nature of the work to be performed for a customer, i.e. the Annual Fixed Costs (AFC), and those costs that are incurred in meeting the customers requirements, referred to as the Project Operation Costs (POC). The total that the operator must charge the customer is then the sum of the POC, the proportion of the AFC that can be allocated to that project, and the operator's profit. In order to arrive at an equitable proportion of AFC, the operator estimates an annual utilization for his HLAs, and allocates to the customer his share of the AFC based on the proportion of the annual utilization consumed on his project.

The AFC consist of all costs to the operator incurred through acquisition of the system, equipment, and facilities, all operating costs that accrue annually, or independently of any project, and all administrative and marketing costs incurred to maintain a viable competitive business. These costs therefore include any interest and capital payments incurred through financial arrangements made for the initial or on-going acquisition of the system equipment.

The POC consist of all costs incurred in order to accomplish a specific project, and encompasses all costs related to HLA flying hours. These include flight and ground crew, maintenance materials and crew fuel and oil, and labor burden on flight and ground crews. In special situations, the cost of obtaining and using, through lease or purchase, any special equipment necessary for the project but not already in the operator's inventory must also be included.

4.2.3.2 <u>The Cost Analysis Elements</u>. Each of the elements that compose the total required freight rate are described and discussed in this section. The quantitative forms of the elements are not provided since they are specific to particular concepts and are based on proprietary data. They are contained in Appendix B, bound in a separate volume and held in the Technical Monitor's office in NASA, Ames.

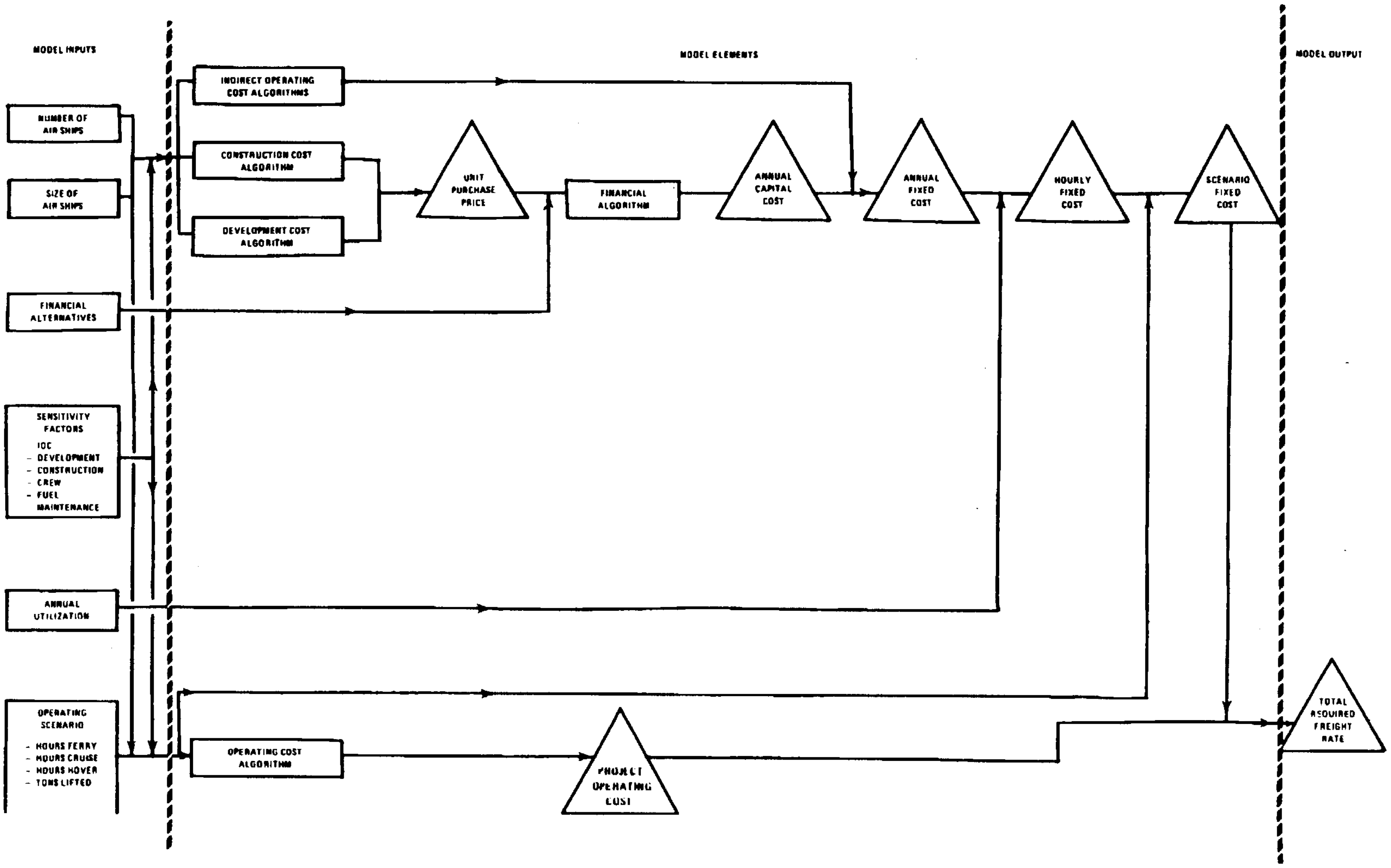

FIGURE 4-3. Cost Analysis—Calculation of Required Freight Rate

Before describing the individual elements, the process by which they are combined into a required freight rate is described algebraically, following the framework in Figure 4-3, and developed in Tables 4-1, 4-2 and 4-3, which should be used as reference in the subsequent discussion.

In Table 4-1, the major elements are defined on a per vehicle basis and related to permit the more detailed descriptions shown in Tables 4-2 and 4-3; these are discussed further below.

Annual Charge for Recovery of HLA Capital Costs. This charge is the means by which the operator either repays capital loaned to permit him to purchase the air vehicles and spares required, or leases the equipment from an original purchaser, or sets aside money to replace the capital he invested himself to purchase the vehicles. Rather than attempt to represent such schemes, it was decided that a single, typical capital recovery factor should be applied to the capital value of the equipment. This factor would then be subject to sensitivity analysis. A typical range of values is 10 to 20%, with a suitable datum value of 15%.

The capital value of the equipment is composed of the cost to complete a production run, plus the cost of spares for refurbishable major components such as engines, plus the cost of development and certification. The sum of these factors divided by the total number of vehicles produced yields the capital value of the equipment per vehicle. An exception to this formulation would arise if the Government absorbed the cost of development and certification; this could have a significant effect for small production runs.

Annual Charge for Helium Replenishment per Vehicle. Leakage of helium is an established part of LTA operation. Ongoing developments may reduce it substantially; however, an allowance is appropriate at present, and is directly related to vehicle envelope size.

Annual Insurance Charges. Insurance of flight vehicles against loss has a well-established precedent for aircraft and helicopters, but not for airships. Consequently this cost is somewhat uncertain. The annual percentage would appear likely to fall between those for aircraft and helicopters, as a compromise between the apparently greater safety of buoyant lift devices, and the current lack of actuarial experience with them. A likely range is from 2% to 6% of the capital cost per year, with 4% as a reasonable baseline.

TABLE 4-1. Operators Charge Elements

Operator's Charge/Vehicle = **Prorated Annual Fixed Costs/Vehicle (PAFC) + Project Operating Costs/Vehicle (POC) + Operator's Profit/Vehicle**

$$\text{PAFC} = \frac{\text{Project Flight Hours (H)}}{\text{Annual Utilization (U)}} \left[\text{Annual Fixed Costs/Vehicle (AFC)} \right]$$

AFC = (Annual Charge for Recovery of HLA Capital Costs/Vehicle (HLA))
\+
(Annual Charge for Replenishment of Helium/Vehicle (HEL))
\+
(Annual Charge for Amortization and Operation of Administration and Operational Support Facilities/Vehicle (FAC))
\+
(Annual Charge for Insurance of HLA/Vehicle (INS))

POC = (Project Charge for Flight Crew/Vehicle (INS))
\+
(Project Charge for Maintenance Labor and Materials/Vehicle (MAINT))
\+
(Project Charge for Direct Labor Burden/Vehicle (BURD))
\+
(Project Charge for Fuel and Oil Consumed/Vehicle (FUEL))

TABLE 4-2. AFC Elements

HLA

HLA = (HLA Capital Costs/Vehicle (HLAC)) (Annual Capital Recovery Factor (CRF))

HLAC = [(Total Flyaway Costs for a production run of N HLA (TCN))
+
(Total Development and Certification Costs (DCC))] /N

$\frac{TCN}{N}$ = (Total Aircraft Cost + Spares, per aircraft (TFAC))

$\frac{DCC}{N}$ = (Development Cost prorated per aircraft (DEV))

$$\therefore \underline{HLA = (TFAC + DEV)(CRF)} = \underline{\left(\frac{TCN}{N} + \frac{DEV}{N}\right)(CRF)}$$

HEL

HEL is as already defined

INS

INS = (HLA Capital Costs/Vehicle (HLAC)) (Annual Insurance Premium (IP))

$$\therefore \underline{INS = (TFAC + DEV)(IP)} = \underline{\left(\frac{TCN}{N} + \frac{DEV}{N}\right)(IP)}$$

FAC

FAC = $[\Sigma_1^m$ (Facilities capital cost item, i) (annual capital cost recovery factor, i)

+ Σ_1^n (Facilities operating cost item, j, per year)] /N

(where the facilities and operations are all of those required to support the HLA fleet; other than fuel, oil, flight and ground crew, HLA maintenance)

$$\therefore \underline{FAC = [\Sigma_1^m (FCC)_i (ACR)_i + \Sigma_1^n (FOC)_j] /N}$$

TABLE 4-3. POC Elements

CREW CREW = (Flight crew cost per flight hour (FC)) (Project flight hours (H))

MAINT MAINT = (Maintenance Labor and Materials cost per flight hour (MLM)) (H)

BURD BURD = (Flight Crew (FC) and Maintenance Labor (ML) costs per flight hour (FCML))
x (Direct Labor Burden factor (DLBF) x (H)

FUEL FUEL = $\sum_{1}^{\ell}$(Fuel and oil cost per hour of flight in mode k) (Hours of flight in mode k)

= (Ferry fuel and oil cost per ferry hour (FF)) (Ferry hours (FH))
+
(Hover fuel and oil cost per hover hour (HF)) (Hover hours (HH))
+
(Cruise fuel and oil cost per cruise hour (CF)) (Cruise Hours (CH))

Annual Charge for Amortization and Operation of Administration and Operational Support Facilities, per Vehicle. The administration and operational support facilities encompass everything involved in the operator's business that has not previously been covered, and that is not accountable for on a "per project hour" basis. The charges fall into two categories: those required to amortize the capital costs of facilities and equipment, and those required to operate and maintain the facilities and equipment. Since this amortization is likely to be arranged separately for each building, item of equipment, and other required facilities, as appropriate to the lifetime of each, an approach similar to that used for the vehicle capital recovery cost was adopted, i.e., an annual facilities capital recovery charge was used. To this is added the annual cost of operation and maintenance, on a per vehicle basis. An estimate has been made at a fairly detailed level of typical costs to support a single vehicle with either a minimum or austere base facility; the cost categories are presented in Table 4-4. The estimate has been expanded to account for variation in size of the single vehicle. It is a reasonable assumption that the cost per vehicle would reduce as the number of vehicles increases. However in this study, the annual per vehicle cost for these facilities and support operations is taken to vary as a function of vehicle size only. The estimates show that such costs can represent only a small proportion of the total operational cost per vehicle, on the order of 5-6%. Since future development of facilities and operations may require a degree of sophistication not considered here, these estimates were subjected to sensitivity variations.

Crew Costs per Vehicle per Flight Hour. These costs are the total costs of both flight and ground crews required to support each vehicle, the cost per hour being determined by sum

TABLE 4-4. Typical Support Cost Categories for an Austere HLA Facility

SUPPORT ITEMS	SUPPORT ITEMS
• Building Costs (Motor Maintenance, Administration, Operations, Storage) • Building Maintenance • Ground Support Equipment** – Lift truck – Scaffolding – Work platforms – Cherry picker – Ladders – General Purpose Hoist • Ground support Equipment Maintenance** • Ground Handling and Mooring Equipment** – Mast – Flood Lights – Ballast Bags • Ground Handling and Mooring Equipment Maintenance** • Support Vehicles – Personnel transport – Base service truck – Maintenance truck – Fuel transporter • Support Vehicle Maintenance • Maintenance Shop Equipment – Mechanical Saw Break Lathe Drill Press Vice Engine Hoist Work Benches Storage Cabinets – Electronics Test Equipment Repair Equipment Work Benches Storage Cabinets	• Maintenance of Shop Equipment • Crews Lounge • Mast Circle** • Operating Equipment – Base Support Equipment Radios Meterological – Base Maintenance Equipment Radios Meterological – Base Maintenance Equipment Mowing Utility Trailer Hand Tools Vacuum, Floor Scrubber • Administration – Employee relations – Employee benefits – Salary – Insurance – Safety – Taxes – Record Keeping – Supplies – Current Aeronautical Charts – FAR Revisions – Weather Briefing – Flight Planning • Fuel and Oil Storage Facilities** • Office Equipment • Real Estate Taxes • Miscellaneous Maintenance • Utilities • Maintenance Burden at 80% Maintenance Dollars

** These items vary with HLA size.

of the appropriate annual salaries, divided by the annual vehicle utilization.

Maintenance Costs per Vehicle per Flight Hour. These consist of all airframe, envelope, power plant, propulsion, rotor and systems maintenance required (both labor and materials) to support each vehicle. This cost is a function of utilization, since increased utilization introduces step increases in manpower requirements.

Direct Labor Burden per Vehicle per Flight Hour. The flight and ground crew have particular administrative needs (e.g., training, insurance, hospitalization, and facilities) that require a different burden rate from the administrative staff.

Fuel and Oil Costs per Vehicle per Flight Hour. These costs derive directly from the requirements of the project scenario (i.e., the payload carried in each of the ferry, hover, and cruise modes, and the flight speeds required).

Flight Hours per Project. The flight hours in each of the three modes, ferry, hover, and cruise, are also determined from the detailed examination of the application of the HLA in each project.

To summarize this review of the cost elements, Table 4-5 lists the inputs required in order to do the cost analysis and whether they are defined parametrically or derived from cost or scenario data. The cost data in turn must be derived from detailed studies of specific HLA concepts, through parametric analysis of more generalized concepts, or by a judicious blending of the two approaches. The latter is the approach adopted in this study and it is discussed next.

4.2.3.3 The Cost Estimation Procedure. An estimating procedure was developed to define the cost of using an HLA to fulfill the needs of any particular job, as defined in detail in the case studies in Section 6. The procedure develops representative HLA costs by averaging the costs of two configurations whose optimum performance regimes are in different portions of the speed range; a relatively high-speed configuration typified by the Goodyear Quadrotor configuration originated by the Piasecki Helistat, and a relatively low-speed configuration typified by the Canadair Aerocrane configuration, originated by the All-American Corporation. The market analyses detailed in Section 6 use two speed conditions, 25 mph and 60 mph, representing these low-speed and high-speed designs. In order to protect the proprietary nature of the data supplied by the potential manufacturers, the HLA costs are estimated for both concepts at both speeds and then averaged for use in the analyses.

TABLE 4-5. The Fundamental Cost Analysis Inputs

FOR PAFC				
Utilization per year	U	hrs.	Defined	P
Project Flight hours, all modes	H	hrs.	Derived	S
Cost of HLA & Spares, per HLA	TFAC	$M	Derived	C
Development cost of HLA, per HLA	DEV	$M	Derived	C
Annual Cost to replenish helium per HLA	HEL	$M	Derived	C
Annual insurance premium	IP	%	Defined	P
Facility buildings costs	FCC_1	$M	Derived	C
Ground support equipment costs	FCC_2			
Ground handling & mooring equipment costs	FCC_3			
Support vehicles cost	FCC_4			
Maintenance shop equipment costs	FCC_5			
Crew lounge costs	FCC_6			
Mooring mast circle costs	FCC_7			
Operating equipment costs	FCC_8			
Maintenance equipment costs	FCC_9			
Capital cost recovery factors	ACR_i	%	Defined	P
Building maintenance costs	FOC_1	$M/ year	Derived	C
Ground support equipment maintenance costs	FOC_2			
Ground handling & mooring equipment maintenance costs	FOC_3			
Support vehicle maintenance costs	FOC_4			
Shop equipment maintenance	FOC_5			
Administration	FOC_6			
FOR POC				
Flight crew cost per flight hour	FC	$	Derived	C
Maintenance labor cost per flight hour	ML	$	Derived	C
Maintenance Labor and Materials cost per flight hour	MLM	$	Derived	C
Direct Labor Burden Factor	DLBF	%	Derived	C
Ferry fuel & oil cost per ferry hour	FF	$	Derived	C
Hover fuel & oil cost per hover hour	HF	$	Derived	C
Cruise fuel & oil cost per cruise hour	CF	$	Derived	C
Ferry flight hours	FH	hrs.	Derived	S
Hover flight hours	HH	hrs.	Derived	S
Cruise flight hours	CH	hrs.	Derived	S
Project flight hours	H	hrs.	Derived	S

P – parametrically varied
C – cost data input
S – scenario data input

The choice of 25 mph and 60 mph as the representative speeds results from estimates of optimum speed with a heavy load suspended beneath the vehicle, a typical configuration for practically every application. It must be strongly emphasized that these estimates are intended to permit reasonable comparisons between the probable costs of using an HLA, and the cost of conventional approaches to fulfilling a particular heavy-lift need, and cannot be used for comparative analysis of potentially competitive HLA concept.

The steps in the cost estimation procedure are as follows:

- Development of a generalized cost model, applied to any HLA concept, that can develop the total cost to an HLA user of fulfilling the need for heavy lift in any application.
- Develop all necessary cost elements for input to the model. This step is based on operational, technical and cost data and is necessarily limited to the HLA sizes and operational conditions provided by the concept designer.
- Where necessary to provide cost data for an adequate range of HLA sizes and operating conditions, these cost estimates are extrapolated with the aid of estimates of power and component weights as a function of size.
- For each HLA application, estimates from the cost model, the HLA job costs for each concept, for the sizes and operational conditions for the application.
- Average the HLA job costs for each concept, to remove proprietary limits to the cost data.
- Determine the effect of costs of varying the non-operational and operational cost parameters.

Each manufacturer provided data in a different form and with different levels of detail; consequently, the level of analysis required was considerably different for each. The goal of these analyses was to prepare analytical cost models, all with the same basic structure, that would provide operator's costs as defined in Section 4.2.3.2, for a range of operational, production, and financial inputs. These models were then programmed on the T159 programmable calculator and printer. The models were used to obtain the cost sensitivity results presented in this section and the cost data for the case studies described in Chapter 6.

The approach used in this work was to first determine the desired cost framework and associated elements described earlier in this section. For each of the data sets provided, a comparison was then made between the data set and the framework/elements to:

- Identify the correlation between the two
- Define any additional data needs
- Determine assumptions and factors that should be kept the same between the two models (e.g., insurance rates).

After developing an adequate data base, using this methodology for each element in the framework, this data base was converted into programmable elements. This usually took the form of curve fitting data points, although in some instances, the manufacturer's relationships were used directly.

The data defined in Appendix B was used to develop simple expressions for each cost model parameter in terms of the pertinent cost drivers:

- Useful load (L)
- Utilization (U)
- Production quantity (N) and
- Payload (P).

Since the level of detail varied considerably, the resulting simplified formulations tended to vary considerably from one concept to another. The elements of the two sets of formulations were then compared and a common general form identified that would support each of the derived formulations with proper choice of coefficients. These general forms are provided in the next section. The specific formulations based on the proprietary data provided are presented only in Appendix B, which is proprietary so as to preserve our legal obligations to the manufacturers.

Some parameters have been assumed to be the same for both concepts. These are:

- The useful load increments of 50, 100, 157, 300 and 450 tons
- The helium replenishment rate of 25% per year
- Helium cost of $26 per 100 cu. ft.
- The insurance rate of 4% per year on the HLA cost (3.5% on HLA cost plus spares)

- Flight crew size is 3 per HLA (1,000 hours per shift per year), and total costs are 77,000 per year
- Burden on direct labor (flight and maintenance crew) of 30%
- Fuel cost of 75 cents per gallon
- Specific fuel consumption of .5 lbs./hr per horsepower
- Oil costs at 5% of fuel costs
- Maintenance man-hour costs of $18,000 per year for mechanics, $22,000 per year for chief mechanics
- Support costs for an austere HLA facility (Table 4-4).

As the flight crew costs represent a small proportion of the total costs it was decided to forego the usual analysis of stepwise increases in crew costs with shifts and the consequent analytical complications. To this end it was assumed that for any utilization that required fractions of a shift, it would be assumed that the flight crews providing those hours would be paid on a per flight hour basis, rather than an annual salary. By this means, a constant figure for flight crew costs per hour was justified.

As described and illustrated in Section 3.1; a basic framework was developed for both cost models. This framework is detailed in Figure 4-4. The rest of the model is common to all concepts; the programming technique used has ensured that the same storage locations are used for the same intermediate and final outputs in all cases. Ready comparability is thus ensured and a common print control can be employed for all concept results.

The program for each concept is introduced by a print routine which provides a record, for each run, of the development costs per HLA (DEV), acquisiton costs per HLA (TFAC), the corresponding prorated, annualized capital recovery costs (LEAS), annual cost of administration and support (IOC), annual cost of insurance (INS), total cost of helium replenishment per year (HEL), the total annual fixed cost (AFC), and the project costs for crew (CREW), direct labor burden (BURD), fuel (FUEL), and maintenance (MAINT), and lastly the total project cost (TOT). Between the print routine and the main program all the sensitivity parameters are initialized to selected values for each run.

In the following section, the rationale and development of the cost estimation methodology are outlined, consisting of the analysis framework, the analysis elements, and the basic cost estimating relationship that result from averaging the two concepts.

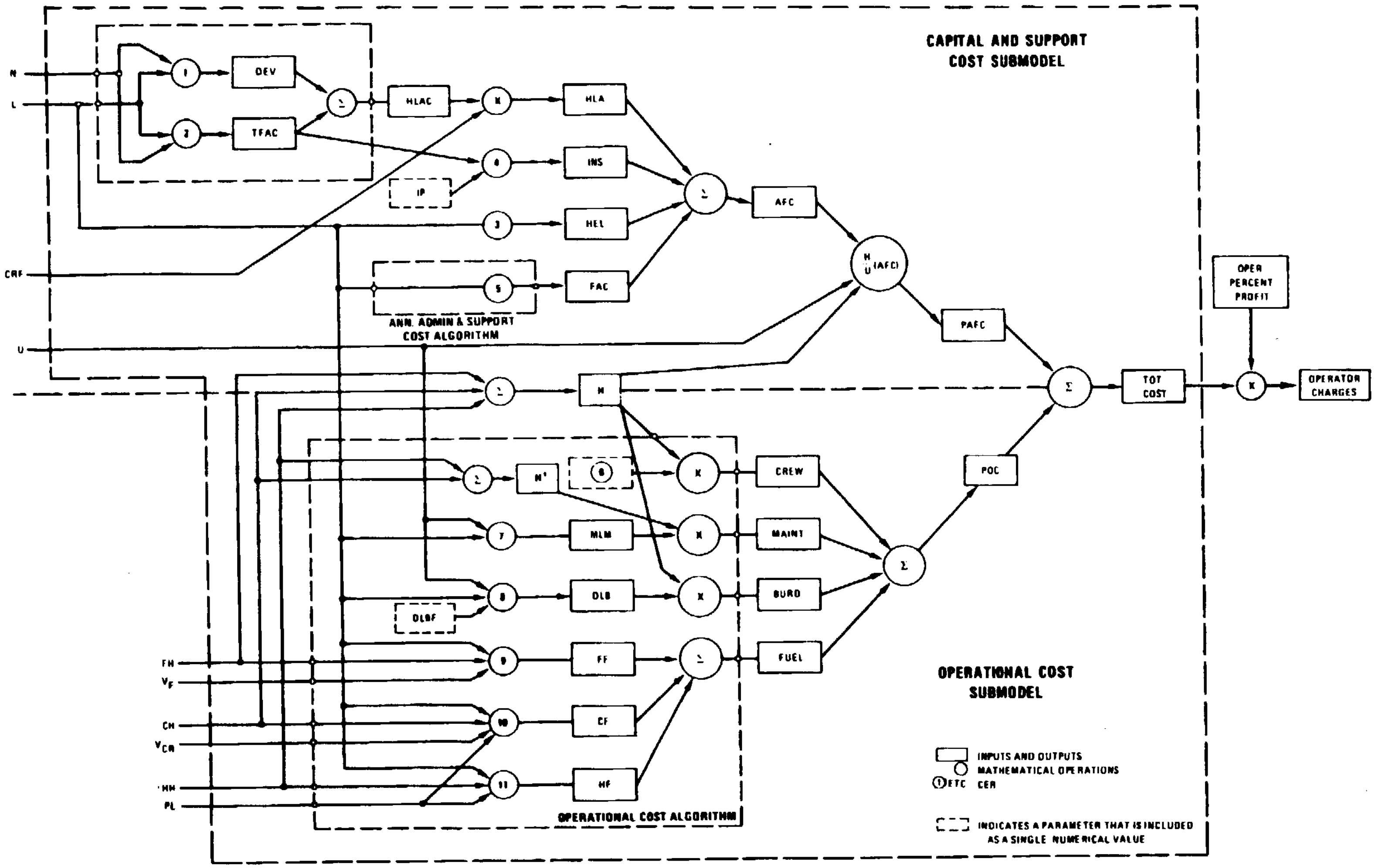

FIGURE 4-4. The HLA Job Cost Model

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* See Tables 4-1, 4-2, 4-3, and 4-5 for definition of cost model parameters.

4.2.3.4 Basic Cost Estimating Relationships. The manufacturer's cost data falls into the following categories:

- Development cost (including certification)
- Flyaway cost vs. quantity produced (including all production associated costs)
- Spare costs
- Vehicle depreciation
- Insurance costs
- Helium replenishment
- Flight crew cost
- Maintenance labor costs
- Maintenance material costs
- Burden on direct labor
- Fuel and oil costs
- Operations support cost
  - Buildings, equipment, vehicles, storage facilities
  - Ground support equipment
  - Ground handling & mooring facilities and equipment
  - Operations support maintenance and maintenance burden
  - Real estate taxes
  - Operations support operating costs
  - Operations support staff costs.

The data as provided by the manufacturers were not necessarily categorized as precisely as listed. They were however, compared to the above list to aid in identifying and supplying any missing material. The data provided and identified as belonging in a particular category varied in detail among manufacturers. These variations reflected differences in vehicle technology development, vehicle size, production quantities, and assumptions with respect to labor and burden rates, insurance rates, depreciation strategies, fuel costs and operations support requirements. In order to ensure that the differences in cost reflect only the differences in concept, all non-concept dependent parameters were standardized. The resulting cost estimates in all categories were generalized to represent a range of vehicle sizes when those data were not provided. Since useful load was a prime determinant of the magnitude of the major system components (powered lift system and envelope size), it was used as the measure of size throughout the studies.

In each concept studied, the manufacturer's data were examined and cost estimating relationships developed. Where the data were provided in sufficient detail, a curve fitting procedure was used to define the cost estimating relationships, as a function mainly of useful load and other parameters appropriate to the particular category.

Where the data supplied were limited to a few sizes, the performance characteristics of other sizes were estimated, by assuming similar weight distributions, extending aerodynamic and propulsion characteristics using basic aeronautical engineering principles to define power requirements and performance, and assuming the same cost per horsepower and cost per pound for the powered and unpowered subsystems respectively.

Manning costs were extended by assuming that the flight crew per aircraft is unaffected by size; but is increased as the number of operating shifts is increased. Crews for complete shifts were assumed hired on an annual basis while crews for partial shifts were hired on an hourly basis. The net cost per hour of utilization remained the same. Maintenance labor estimates were based on past aircraft experience, and reflected a diminishing cost per hour as utilization increases.

In most cases, the relationships developed for each component had the same general form for each concept. In some cases, simpler formulations were possible due to the availability of more complete data. The algebraic general form of the resulting CERs is described and discussed in the following pages, together with the range of values of the coefficients that resulted.

Development and Certification Costs per HLA (DEV). The general relationship developed from the data is

$$10^6 \times [A + B\ (L)]\ /N$$

where L = Useful load (tons)
N = Number of HLAs produced
A, B are coefficients

Where the concepts included a change in envelope structure from non-rigid to rigid as useful load increased, the coefficients were discontinuous. The variation with useful load was slight.

"A" ranges from 25 to 35 for non-rigid and
from 550 to 560 for rigid construction

"B" ranges from .025 to .040

Total Aircraft Costs plus Spares per HLA (TFAC). The relationship is

$$10^6 \times [A + B\ (L)]\ N^C$$

A wide variation in coefficient values reflects the range of complexities of manufacture for the various concepts.

A ranges from 0 to 10
B ranges from 0.2 to 0.5
C is approximately - 0.2 for all concepts

Insurance Cost per HLA per Year (INS). This cost does not depend on the concept to any notable degree, but on the capital cost and the risk. A figure of 4% of the aircraft cost was used throughout, and expressed for convenience as (.035 TFAC).

Helium Replacement per HLA per Year (HEL). This varies with concept, since those utilizing less rotor lift required more helium for a given useful load. Replenishment of about 25% per year was assumed with present technology. The general form was:

$$A\ (L)^B$$

where "A" varied from 70 to 310
"B" varied from 1.0 to 1.2

Flight Crew Costs per HLA per Flight Hour (FC). As discussed earlier, a flat value was taken for FC, based on a fixed crew size (pilot, co-pilot, flight engineer) regardless of vehicle size and concept. This value was:

77

(Note that crew overhead, including training, is covered in the Direct Labor Burden category.)

Maintenance Labor and Material Costs per HLA per Flight Hour. This cost varies considerably with the sophistication and complexity of the concept, with the current and projected costs of maintenance (particularly where helicopter-type rotors were required for a concept), and with annual utilization. The maintenance crew size is approximately

- 18 per 100T for 1000 hrs utilization
- 24 per 100T for 2000 hrs utilization
- 30 per 100T for 3000 hrs utilization

The general form of the relationship was:

$$\left[A + B\ (L)\right]\ (U)^{C}$$

where A varies from 0 to -170
B varies from 6 to 50
C is approximately -.04

Note that the maintenance personnel double as needed for ground handling crew.

Direct Labor Burden per HLA per Flight Hour. This of course varies with the concept, because of the different maintenance requirements; the burden however is a fixed proportion of the labor cost, taken as 0.30 in this analysis. The general form of the relationship is:

$$\left[A + B\ (L)\right]\ (U)^{C}$$

where A varies from 20 to 35
B varies from .6 to .9
C varies from 0 to -.4

Operations Support Costs per HLA per Year. As developed in Appendix B, the cost difference between concepts, because of differences in special equipment required, appears to be negligible relative to the total costs involved. These costs will vary somewhat more strongly with vehicle size, since mooring, storage, and maintenance facilities per HLA will be functions of size. The general form of this relationship is:

$$A + B\ (L)$$

where A is approximately 220,000
B is approximately 180

Fuel and Oil Costs per HLA per Hour. This cost varies with each concept, its operations and its size. In general, an expression relating useful load, payload and speed is required to fully describe fuel and oil consumption. Account must be taken of the appropriate characteristics associated with the ferry, cruise, and hover modes of operation. Such an expression is:

$$\left(A + B(L)\right)\left[\left(C\left|\frac{V}{V_{max}} - D\right|^{E} + F\right) - \left(1 - \frac{\left|\frac{P}{L} + G - J\right|}{K}\right)\left(M(L)^{N}\right)\right]$$

where A, B, C, D, F, G, J, and K are coefficients and E and N exponents.

The first term (A + B(L)) defines fuel cost (proportional to power) at maximum speed and power as a function of vehicle size.

The first term in the brackets

$$C\left|\frac{V}{V_{max}} - D\right|^{E} + F$$

corrects this fuel consumption for operation at speeds other than Vmax, and properly represents the "minimum power speed" (when $\frac{V}{V_{max}} = D$). When V = 0, F ensures that the hover fuel consumption is correctly estimated.

The remaining term in the bracket

$$\left(1 - \frac{\left|\frac{P}{L} + G - J\right|}{K}\right)\left(M(L)^{N}\right)$$

corrects for the variation in fuel consumption with changes in payload, rotor performance and weight budget.

This derivation is quite general and sufficiently accurate for the analyses in this study. It is applicable to operation at cruising speeds up to V_{max} with payloads up to P_{max}. When P = 0, and V is entered as the speed for ferry, it represents operations using the rotor system as the ferry propulsion power, which is valid if the ferry equilibrium condition requires significant rotor power. When rotor power is not required for equilibrium in ferry, then an auxiliary propulsion unit can be employed at some savings in fuel. Hover is represented by V = 0.

Typical values of the coefficients and exponents are:

A		0 to 350
B		5 to 15
C	approximately	1.3
D	approximately	0.3
E	approximately	2.0
F	approximately	0.3
G		0.1 to 0.15
J		0 to 1
K	is given by	$\begin{cases} J, & \text{for } J \geq .5 \\ (1-J), & \text{for } J \leq .5 \end{cases}$
M		0.3 to 0.4
N	approximately	0.25

4.2.4 HLA Job Cost Sensitivities

The sensitivity of the HLA cost costs to variations in the cost model input parameters were determined for operational, case-study-dependent parameters, and for non-operational, case-study-independent parameters.

Sensitivity of HLA costs to operational parameters are developed as appropriate in each case study; the operational parameters are:

- Speed (cruise, ferry)
- Payload
- Time (cruise, ferry, hover).
- Useful load (size) (L)

Non-operational parameters that do not vary from application to application are:

- Production quantity (N)
- Development cost (DEV)*
- Flyaway cost (TFAC)*
- Support cost (FAC)*
- Annual utilization (U)
- Crew cost (FC)* }
- Fuel cost* } Sensitivity Factors
- Maintenance cost* }

Parameters marked with an asterisk can be substantially varied by means of multiplying by a sensitivity factor.

Averaged HLA cost sensitivities to variations in these parameters are presented in Table 4-6, where the cost variations are represented as percentage changes from a nominal value calculated from a representative set of cost model input parameters. The nominal or baseline case values chosen for these parameters represented average HLA operations aggregated over a year. Thus these variations are reasonably typical of the effects of these parameters, which are estimated as part of the Annual Fixed Costs (AFC) and then prorated to each job. Spot checks indicated that detailed examination of these variations for each case was not necessary since the variations from case to case were not sufficient to significantly change these average conclusions.

TABLE 4-6. Averaged HLA Cost Sensitivity

NON-OPERATIONAL PARAMETER	BASELINE VALUE AND VARIATIONS	SENSITIVITY NORMALIZED TO BASELINE COST VALUE	NON-OPERATIONAL PARAMETER	BASELINE VALUE AND VARIATIONS	SENSITIVITY NORMALIZED TO BASELINE COST VALUE
Production Quantity	1 5 75 100	1.77 1.21 1.00 .91	Development Cost Sensitivity Factor	.5 1.0 1.5	.99 1.00 1.01
Capital Recovery Factor (%)	.05 .10 .15 .20	.82 .91 1.00 1.09	Acquisition Cost Sensitivity Factor	.5 1.0 1.5	.83 1.00 1.17
Annual Utilization (Hours)	1,000 2,000 3,000	1.37 1.00 .87	Facility/Support Cost Sensitivity Factor	.5 1.0 1.5	.99 1.00 1.01
Maintenance Cost Sensitivity Factor*	50% 100% 150%	.86 1.00 1.09	Flight Crew Cost Sensitivity Factor	.5 1.0 1.5	.99 1.00 1.01
			Fuel Cost Sensitivity Factor	.5 1.0 1.5	.83 1.00 1.17

*Expressed as percentage of baseline value

C-2

ASSESSMENT OF THE MARKET FOR HEAVY LIFT SERVICES

CHAPTER 5

5. ASSESSMENT OF THE MARKET FOR HEAVY LIFT SERVICES

LIST OF FIGURES

LIST OF TABLES

5. ASSESSMENT OF THE MARKET FOR HEAVY LIFT SERVICES

Assessments of the magnitude of the potential domestic and worldwide markets for heavy lift services are presented in this chapter. The markets corresponding to eleven of the thirteen applications discussed in Chapter 3 were analyzed. The two case studies for which a corresponding market assessment was not performed were the transportation of houses and the transportation of maize in Zaire. The case study results indicated no viable HLA market for the transportation of maize in Zaire. The "transportation of homes" case study revealed a marginal market for the transportation of stick built homes under a restricted set of conditions. Therefore, no assessments were made for these two case study areas.

For each assessment, the background data upon which the assessment is based is first reviewed. The procedure for using this data base to determine projected requirements for heavy lift services in domestic and worldwide markets is then discussed. Finally, the results of the assessments are presented in quantified form.

5.1 The Markets for the Transportation and Erection of Refinery and Petrochemical Plant Components

The requirements for transportation and lifting in the construction of refineries and petrochemical plants vary greatly with the type, design, and size of the plant installed. A general indication of the number of heavy lifts, which typically fall within the range from 100 tons to 500 tons, is one lift for each 2000 bbl/day installed capacity (Reference 4).

The installation of refining capacity varies greatly between different years and various areas of the world depending on the current and expected demand for refined petroleum products and petrochemicals.

Long-term forecasts of expected refinery construction are generally not available. It cannot be accurately estimated based purely on future demand for refined products because in many areas refinery capacity is greatly underused and increased demand could be satisfied both through increased use and new plant construction. Short-term forecasts can be made based on planned construction, since the lead time for most refinery construction is several years. Such short-term forecasts will not be very useful for this project. It has therefore been decided that a reasonable estimate of the refinery expansion in the future can be derived through an estimate of the average annual expansion of over the recent past. The refinery expansion between the period from 1970 to 1978 has been selected as a reasonable estimate of the probable average expansion in the future. The average refinery expansion in the various regions of the world is presented in Table 5-1.

Due to the fact that it is cheaper and easier to transport and handle crude oil than refined products most refineries have been and are expected to be constructed in the major consuming regions of the world. United States, Japan, and Western Europe have therefore been and are expected to continue to present the major markets for new refinery construction.

With the increasing cost of labor, the draft restrictions for crude oil tankers, and the increasing economic and political power, two new trends are emerging in refinery construction. These are:

TABLE 5-1. Crude Oil Refining Capacities in Major Refining Centers Worldwide (1000 barrels per calendar day)

WORLD REGION	1970	1978	AVERAGE ADDITIONS 1970-1978
United States	12,079	16,760	520
Canada	1,355	2,165	90
Western Europe	14,651	20,728	675
Japan	2,796	5,462	296
Far East	2,342	4,715	264
Latin America & Caribbean	5,334	8,427	344
Middle East	1,070	3,506	271
Africa	704	1,467	85
Communist Areas	6,952	13,938	776

SOURCES: 1970 – International Petroleum Encyclopedia
1978 – Oil and Gas Journal, Dec. 26, 1978.

- Expansion of refinery centers in the Caribbean to serve the U.S. market
- Expansion of export refineries in the OPEC member nations.

These two trends have in the recent past and will most likely in the future, increase somewhat the amount of refinery construction that will be undertaken in major oil exporting nations and the major refining centers in the Caribbean.

The projections for potential future markets for the HLA in refinery construction in all the major oil refining areas of the world are presented as Table 5-2.

TABLE 5-2. Potential Annual Additions in Refinery and Petrochemical Plant Construction

WORLD REGION	AVERAGE ANNUAL ADDITIONS TO REFINING CAPACITIES (1000 BBL/DAY)	AVERAGE NO. OF UNITS 100-500 TONS TO BE EMPLACED
United States	520	260
Canada	90	45
Western Europe	675	338
Japan	296	148
Far East	264	132
Latin America & Caribbean	344	172
Middle East	271	136
Africa	85	43
Communist Areas	776	386
Total	3321	1660

5.2 The Market for the Support of Construction of Offshore Permanent Drilling and Production Platforms for Oil and Gas

The exploration and production of oil in offshore areas are highly complex and capital intensive. The technology and techniques used are rapidly changing, and exploration and production are increasingly undertaken at greater water depths at considerable expense and capital requirements.

The construction of offshore platforms was at a peak in 1975 when a total of 217 offshore production and drilling platforms were completed. Since then, the number of platforms completed has dwindled to 88 completions in 1976, and 75 in 1977. In 1978, a total of only 61 platforms are scheduled for completion.

The United States, primarily in the Gulf of Mexico, has consistently been the leading market for offshore platform construction, and between 1974 and 1977, the United States has accounted for between 50% and 67% of the platforms constructed each year. In 1978, the United States will account for 59% of the completions.

The North Sea is the second largest market. In 1974 only one offshore platform was completed in the North Sea area, which accounted for a meager 8% of the worldwide total. In 1975 the number of completed platforms increased to 16% or 7.4% of the world total in that year. In 1976 and 1977, the number of platforms completed declined to 11 and 12, respectively. Due to the general decrease in the market elsewhere in the world, the percentage of the total was 12.5% in 1976 and 16% in 1977. In 1978, 12 North Sea platforms are scheduled for completion, which will account for 16.4% of the world market.

The relative distribution of platform construction between world areas is expected to remain relatively unchanged from the present situation in the late 70's. The United States is expected to present the largest market, although the center of activity may change from the Gulf of Mexico to the currently explored areas off the East Coast and Alaska, depending on the results of this exploration. The North Sea area is expected to remain very active with continued expansion of platforms for existing and new oil and gas field.

Other areas that may develop further include the offshore areas of West Africa and Australia, as a result of the change in political sentiment with respect to offshore exploration and production in these areas.

The total number of platforms to be constructed will fluctuate greatly in future years as in the past as indicated in Table 5-3, which also includes an estimate of future activities based on historical trends. One trend that has been indicated by the industry is towards larger and more complex structures. The construction support industry, i.e., the owners of derrick barges, has responded to this trend by providing barges with cranes and derricks of increasingly larger capacities (Table 5-4). In 1977 a total of 146 construction barges and 46 combination vessels were in existence. Of these 192 vessels, 57 or one-third of the fleet had derrick or crane lifting capabilities exceeding 500 tons, and a large number of the fleet have capacities exceeding 500 tons, and a large number of the fleet have capacities exceeding one thousand tons. The barges (4%) had lifting capacities between 300 and 500 tons, while the great majority of the 127 had lifting capacities of less than 300 tons. The HLA can act as a complement to these latter smaller lifting capacity barges to compete for the construction of platforms involving the larger modules.

5.3 The Market for Movement of Strip Mining Power Shovels

The market for the movement of strip mining power shovels is relatively limited, and the U.S. market is dominated by a few major companies. According to Marion Power Shovel Company at Marion, Ohio, a major manufacturer of shovels, the annual production in the United States is estimated to be approximately 70 per year. These 70 shovels need to be transported from the manufacturing plants to the mine sites.

In addition to the new shovels, there is also a market for the transportation of used power shovels, which at times are transferred from one mine site to another, either as a result of a sale or due to changes in plans of the operator. At the present time there are approximately 500 shovels in existence in the United States. On the average each shovel is disassembled and moved once in its 20-year economic life. Consequently an average of 25 used power shovels are transported every year.

No statistics are available on the total foreign market production. An estimate has been made that the total market might be twice as large as the U.S. market. A number of these shovels are sold in markets that are distant from the place of production. In these instances, they have to be disassembled for transportation by ship from place of production to the mine site. In cases where these shovels will have to be disassembled for transportation by ships, it is doubtful that the use of the HLA would result in saving part of the transportation cost. Table 5-5 summarizes the total market described here.

TABLE 5-3. Platform Construction

OFFSHORE AREA	COMPLETION YEAR											ESTIMATED FUTURE PLATFORM CONSTRUCTION PER YEAR	
	1974	%	1975	%	1976	%	1977	%	1978*	%	1979*	LOW	HIGH
United States	89	67.9	126	58.1	59	67.1	38	50.6	36	59.1	3	4^{o}	9^{o}
Persian Gulf	0	–	9	4.1	3	3.4	11	14.7	1	1.6	1	0	1^{o}
Mediterranean	0	–	7	3.2	0	–	3	4.0	3	4.9	NA	0	7
North Sea	1	.8	16	7.4	11	12.6	12	16.0	10	16.4	4	4	15
Latin America & Caribbean	10	7.6	10	4.6	1	1.1	3	4.0	3	4.9	3	3	10
Southeast Asia and Indonesia	9	6.9	26	12.0	9	10.2	2	2.7	2	3.3	NA	2	9
Oceania	0	–	0	–	2	2.3	2	2.7	0	–	1	0	2
USSR	20	15.3	20	9.2	0	–	1	1.3	0	–	NA	0	1
West Africa	2	1.5	3	1.4	3	3.4	3	4.0	6	9.8	NA	3	6
TOTAL	131	100.0	217	100.0	88	100.0	75	100.0	61	100.0		52	150

*Under construction or planned

SOURCE: Offshore, June 20, 1975, June 20, 1976, June 20, 1977, November 1977.

TABLE 5-4. Barge Lift Capacity

	TOTAL NO. OF BARGES	MAXIMUM LIFT CAPACITY IN TONS		
		500 OR MORE	300-500	LESS THAN 300
Straight Construction Barges	146	27	7	112
Combination Vessels	46	30	1	15
Total	192	57	8	127

SOURCE: Offshore, November 1977.

TABLE 5-5. Estimate of the Market for Transportation of Strip Mining Shovels

U.S. MARKET	No. OF SHOVELS MOVED/YR.
NEW	70
USED	25
FOREIGN MARKET	N.A.

5.4 The Market for the Support of High Voltage Power Transmission Line Construction

For transmission lines of less than 230KV capability, large poles rather than transmission towers are used. These poles are generally light enough to be preassembled at a central site and transported to the site by conventional helicopters or truck/trailers. The potential market for the HLA is presented for the transporting of extra high voltage transmission lines because the towers are large and cannot be preassembled for transport by conventional trucks or existing helicopters. If the towers for the extra high voltage transmission lines (e.g., 345 KV, 500 KV, 750 KV, 1500 KV) are to be preassembled, a freeflying vehicle with a payload capability greater than existing helicopters has to be developed. It should be noted, however, that the Skycrane S-64E helicopter is currently being used to emplace towers in the lower voltage ranges of the extra high voltage transmission lines. In cases where the Skycrane has to emplace the larger towers, e.g., 750 KV lines, for which the towers weigh approximately 25 tons, half of the tower is generally installed in a conventional manner, while the other half with a weight within the load capacity of the Skycrane, is preassembled, transported and emplaced on the site-constructed bottom half of the structure. Based on these observations, this survey of market opportunities was concentrated on identifying construction activity in the upper ranges of the high voltage overhead transmission lines.

The basis for the estimated time requirement is 40 hours of HLA activity for every 60 miles of transmission line capacity installed. This estimate is based on the case studies of transmission line construction.

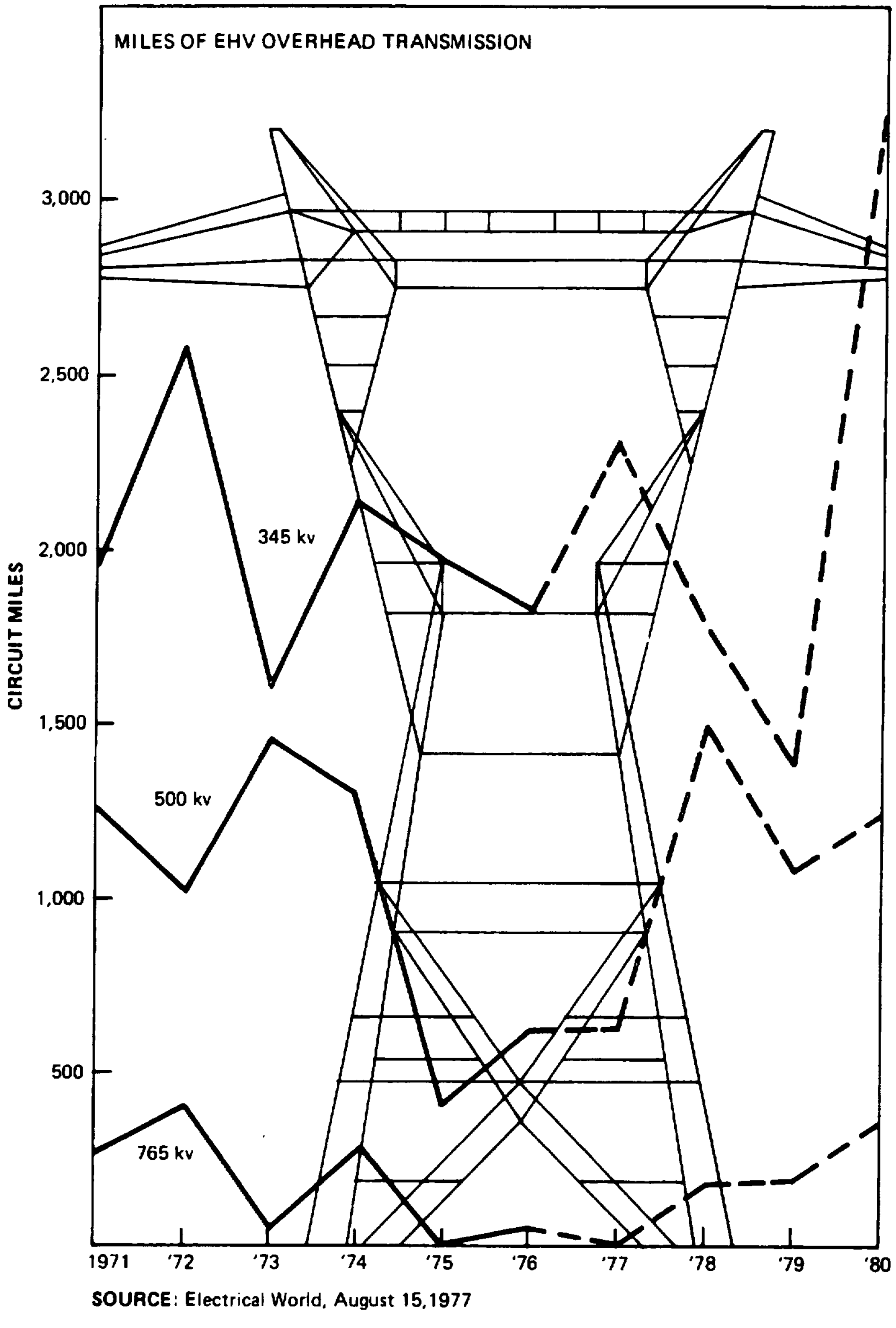
5.4.1 The United States

The United States is the world's leader in installed generating capacity, and is consequently also the leader in the installation of total units of extra high overhead voltage lines of 345 KV, 500 KV, and 765 KV. Historical and planned future circuit miles of line of the three above voltages are presented in Figure 5-1. A total of 1829 miles of 345 KV lines was installed in 1976. A total of 2,305 is planned for 1977, and annual increases up to a 1980 installation of 2,305 miles are planned for this type line. In the 500 KV type line a total of 649 miles was installed in 1976. Increases to annual installations of between 1300 to 1500 miles per year are expected up to 1980. The activity in 765 KV line construction has in the past, and is expected for the future, to be relatively limited. In 1976 a total of 46 miles of 765 KV was constructed. None were planned or constructed for the year 1977. Plans for 1978, 1979, and 1980 call for construction of 172 miles, 181 miles, and 358 miles, respectively.

The recent and immediate future transmission line construction activity is closely correlated with the activity in the construction of new generating capacity. In 1980, the generating capacity is again expected to surge, and high voltage transmission lines will follow this upward trend. It is expected that the construction of extra high voltage overhead transmission lines will be a conservative estimate of the activity in the remainder of the next decade. On this basis the expected heavy lift market opportunities in the United States are outlined in Table 5-6.

5.4.2 Canada

In Canada a total of 807 miles of overhead transmission lines with capacity of 345 KV and above were constructed in 1977. Of this, 680 miles (84%) were constructed in the province of British Columbia. In 1978 462 miles are planned, of which one-third will be installed in Quebec and another one-third in Ontario. The remainder is distributed between Manitoba and New Brunswick.



SOURCE: Electrical World, August 15,1977

FIGURE 5-1. Miles of Overhead Transmission

TABLE 5-6. Installation of High Voltage Transmission Lines, United States

LINE TYPE	PLANNED 1980 CIRCUIT MILES
345 KV	3211
500 KV	1300
765 KV	358
TOTAL	4869

The relatively low rate of installation planned for 1978 corresponds to the low rate of new generating plant additions. The capacity planned for 1980 and beyond corresponds more closely to the additions to plant capacity in 1977. It is therefore expected that the future additions will be similar to those in the year 1977. It is therefore expected that in Canada the average annual addition of 345 KV and over transmission circuit miles for which the HLA will be usable, will be 800.

5.4.3 The Remaining World

The plans for transmission line construction activity in the remainder of the world are not readily available. To obtain this information would require research well beyond the scope of this study. Instead, it was decided to estimate the expected transmission line construction activity based on the planned additions to generating capacity.

The methodology for making such an approximation was obtained from a specialist on electric generating capacity and transmission line construction in the Projects Department of Latin American and Caribbean Regional Office of the World Bank. It should be noted that there are a number of variables in the construction of transmission lines, which this methodology cannot answer. It will, however, give an indication of the relative size of the potential markets that do exist.

This methodology is as follows:

- Out of the total investment in a power generating and distribution system, the high voltage transmission cost represents a cost equal up to 15-25% of the cost of a generating plant. This will vary according to the type of plant. The cost per Kw of installed generating capacity for various types of plants is generally as follows:

- Hydroelectric	$600-$2100
- Steam fossil fuel	$350-$400
- Nuclear	$800-$1000

- Based on the above, the average cost of high voltage transmission lines per Kw of installed capacity can be expected as:

- Hydroelectric	$180
- Steam fossil fuel	$ 75
- Nuclear	$180

- The circuit line lengths can be estimated as follows:

$$\text{Circuit Length} = \frac{\text{Total Transmission Line Cost}}{\$/\text{Mile}}$$

- The estimated unit cost per line for high voltage transmission is:

KV	115	138	161	230	345	500	745
$1000/Mile	72	89	105	121	201	274	362

- The relative distribution of power transmission line installations among the various voltage lines in the United States is assumed to be typical. For the year 1976, the relative distribution of circuit miles and estimated proportion cost of installation in the United States are as follows:

KV Capacity	% of Circuit Miles	% of Total Installed Cost
115	14.5	7.4
138	16.3	10.2
161	3.4	2.5
230	32.4	27.5
345	24.2	34.3
500	8.6	16.6
765	.6	1.5

- Using the above data it was possible to estimate the total transmission lines of various voltages based on the generating capacity additions worldwide. The results of this analysis are presented in Table 5-7.

TABLE 5-7. Market Opportunities for HLA in Power Transmission Line Construction

AREA	ANNUAL ADDITIONS TO GENERATING CAPACITY (MW)	ESTIMATED TOTAL EXPENDITURE FOR TRANSMISSION LINES (IN THOUSANDS $)	ESTIMATED TOTAL CIRCUIT KM		
			345 KV	500 KW	765 KV
OECD Europe					
• Nuclear	7,580	1,364,400	2970	1056	72
• Hydro & Geothermal	163	29,340			
• Steam & Fossil Fuel	4,648	348,600			
Japan					
• Nuclear	3,086	555,480	1504	566	39
• Hydro & Geothermal	761	136,800			
• Steam & Fossil Fuel	3,207	240,525			
Developing World					
• Nuclear	12,956	2,332,080	2036	725	50
• Hydro & Geothermal	3,854	693,720			
• Steam & Fossil Fuel	3,579	268,425			
USSR					
• Nuclear	668	120,240	1486	529	36
• Hydro & Geothermal	1,524	274,320			
• Steam & Fossil Fuel	6,363	477,225			

5.5 The Market for Electric Power Generating Plant Construction

The power generating industry can be divided into three basic sectors:

- Nuclear plants
- Steam fossil fuel, gas turbines, and internal combustion plants
- Hydroelectric plants.

Each of these types of plants has differing requirements in terms of the weight of the components to be brought to the site. The major components to be transported and positioned for a typical nuclear power plant are listed in Table 5-8. In addition, turbine gear, turbine shaft and generators have to be transported and erected and heavy structural girders are required.

TABLE 5-8. Light Water Moderated Reactor Nuclear Steam Supply System Components

3800 MEGAWATT CORE THERMAL POWER									
PRESSURIZED WATER REACTOR					BOILING WATER REACTOR				
ITEM	QUANTITY	WEIGHT (TONS)	DIAMETER (FT)	LENGTH (FT)	ITEM	QUANTITY	WEIGHT (TONS)	DIAMETER (FT)	LENGTH (FT)
Reactor vessel	1	540	22½	41	Reactor vessel	1	731	22¼	62
Reactor vessel head	1	84	18	9	Reactor vessel head	1	90	22	10½
R.V. upper guide structure	1	50	15	11	R.V. core shroud	1	50	16½	22
R.V. core support barrel	1	100	15	32	Core shroud head	1	58	16½	15
CEDM cooling shroud	1	18	14¾	7¾	Steam dryer assembly	1	48	17	17½
Steam generator–2 loop	2	760 each	20½	69½					
or									
Steam generator–4 loop	4	500 each	18½	61½					
5000 MEGAWATT CORE THERMAL POWER									
Reactor vessel	1	800	24	51	Reactor vessel	1	1000	25	70
Reactor vessel head	1	120	20¾	10	Reactor vessel head	1	130	24½	11¾
R.V. upper guide structure	1	70	16¼	16	R.V. core shroud	1	70	18½	24
R.V. core support barrel	1	140	16¼	41	Core shroud head	1	80	18½	16¼
CEDM cooling shroud	1	23	17	8½	Steam dryer assembly	1	67	19	19
Steam generator–4 loop	4	500	18½	61½					

SOURCE: A.J. Keating, the Transport of *Nuclear Power Components, Combustion Engineering,* Paper presented at LTA Workshop, Monterey, California, September 8-17, 1974.

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For a typical 600 MW fossil fuel plant the heavy components required to be transported and erected include:

- 5 girders each 140-175 tons
- 1 generator, 300 tons
- 1 deaerator and tank, 100-120 tons
- 1 main steam drum, 300 tons
- 3 pressure stages, each 70 tons
- 1 turbine, 100-150 tons
- 1 turbine shaft, 100-150 tons.

The hydroelectric plants are of a completely different construction, and the major parts are the turbines and generators. Parts range from between 100 to 300 tons each.

It is recognized that the heavy lift requirements will vary depending on site location, type of plant, size, and a number of other factors. For this analysis, the simplifying assumption is made that for each plant constructed, the requirements will correspond to the requirements enumerated in the case study. The major variable factor will be the size of plants required. The dimension of the vehicle will have to be adjusted to the largest piece of equipment to be transported and lifted. The HLA lifting requirements for each sector of the industry is therefore estimated to be as follows:

- Nuclear plants - 500 tons to 1000 tons
- Fossil fuel plants - 300 tons
- Hydroelectric plants - 300 tons
- Gas turbine plants - 300 tons.

In cases where data on individual plants are not available, the following assumptions are made with respect to average plant size.

	MW Generating Capacity
. Nuclear	1000
. Steam	400
. Hydroelectric	100
. Gas turbine	100

These averages are based upon installed generating capabilities in the United States as follows:

		Plants	Generating Capacity
Nuclear	United States	49	49,880
Gas turbine	United States	524	47,736
Steam	United States	951	385,609
Hydro	Pacific Contiguous States	272	30,143

Source: 1978 Statistical Report, Electrical World, March 15, 1978, p. 95.

This market is discussed in terms of the situation in the United States and the rest of the world.

5.5.1 United States

The construction of nuclear plants in the United States has decreased mainly because of the regulatory constraints imposed and the environmental objections to this type of plant. The historical situation in the nuclear power plant market is presented in Table 5-9.

The future market for nuclear power plants based on commitments currently made is presented as Table 5-10. A forecast by a staff member at Combustion Engineering based on a report by the U.S. Atomic Energy Commission expects that between 13 and 18 pressurized water reactor plants and between 5 and 8 boiling water reactor plants will be completed each year between the years 1990 and 2000 (Reference 5).

The commitments by region of the type of generating plant added in 1977 and planned through 1980 are presented as Table 5-11. A forecast by Electrical World and the Federal Power Commission of future generating capacity up to 1995 is presented as Table 5-12.

The average generating capacity to be added per year (as planned up to 1980 and forecast between 1977 and 1995) are:

	Planned Additions To 1980	Forecast 1977-1995
. Conventional and proposed hydroelectric	3,950MW	1,493MW
. Fossil fuel steam	16,332MW	14,365MW
. Gas turbine	1,523MW	1,493MW
. Nuclear steam	8,582MW	14,167MW

The expected annually added capacity in the United States based upon the average forecasted capacity additions between 1977 to 1980 is presented as Table 5-13.

TABLE 5-9. History of the Domestic Reactor Market

YEAR OF	B&W			C-E			GE			WESTINGHOUSE			TOTAL	
SALE	A	B	C	A	B	C	A	B	C	A	B	C	A	B
1955-1965							10	5,401	72	4	1,690	23	16[1]	7,471[1]
1966	3	2,564	15	2	1,278	8	9	7,746	47	6	5,015	30	20	16,603
1967	5	4,380	17	5	4,118	16	7	6,223	24	13	10,912	43	30	25,633
1968	3	2,177	17	0	–	0	7	6,194	48	4	4,532	35	14	12,903
1969	0	–	0	1	1,070	15	3	2,944	41	3	3,189	44	7	7,203
1970	2	2,426	17	4	4,225	29	3	2,951	21	5	4,664	33	14	14,266
1971	2	1,814	19	0	–	0	4	4,603	28	9	8,705	53	16	15,122
1972	5	5,336	15	2	1,990	6	13	15,450	45	10	11,546	34	30	34,322
1973	3	3,072	8	11	13,554	34	7	7,527	19	14	15,709	39	35	39,862
1974	6	7,119	26	4	4,730	17	6	7,213	27	7	7,996	30	20	27,058
1975	0	–	0	0	–	0	0	–	0	4	4,100	100	4	4,100
1976	3	3,440	100	0	–	0	0	–	0	0	–	0	3	3,440
1977	0	–	0	4[3]	5,100[3]	100	0	–	0	0	–	0	4	5,100
Totals	32	32,328	15	33	36,065	17	69	66,252	31	79	78,058[2]	37	213	213,083

Legend: A. Number of units sold. B. Net capacity sold MW. C. Percent of total market (%)

Notes:

1. Includes 50-Mw La Crosse, sold by Allis-Chalmers in 1962, and 330-Mw Fort St. Vrain sold by General Atomic in 1965.
2. Includes four 1,150-Mw units sold by Offshore Power Systems.
3. Limited to preliminary engineering & licensing work for two 1,250-Mw nuclear steam supply systems (NSSS) for New York State E&G Corp., and preliminary planning & licensing work for two 1,300-Mw nuclear units, designated Palo Verde 4 & 5, for Arizona Public Service Co.

SOURCE: Electrical World, January 15, 1978.

TABLE 5-10. Reactor Commitments

	UNITS	MW
Operating reactors	67	47,727
To operate in 1978	8	7,849
1979	7	7,442
1980	11	11,740
1981	11	12,363
1982	17	18,190
1983	11	12,235
1984	21	24,576
1985	12	13,812
1986	11	12,750
1987	7	7,894
1988	6	6,785
1989	5	5,618
1990	4	4,580
1991	2	2,080
1992	1	1,150
1993	–	–
Indefinite	7	7,577
Total committed	208	204,368

SOURCE: Electrical World, January 15, 1978.

5.5.2 The Foreign Situation

With the exception of Canada and other OECD countries, no comprehensive and detailed forecast of the average generating capacity that can be expected for the future is readily available. It was therefore decided to use the average additions installed in the recent past as an indication of the situation that can be expected in the future.

5.5.2.1 Canada. The capacity added in 1977 and the planned capacities up through 1980 are presented as Table 5-14. The average capacity to be installed between 1977 and 1980 is as follows:

	Average Capacity in MW
• Hydroelectric	2410
• Fossil steam	1164
• Nuclear	1150
• Combustion turbine	208

The expected annually added capacity market for HLA in Canada, is presented in Table 5-15.

5.5.2.2 OECD Europe. The expected electric energy production in OECD Europe between 1974, 1980, and 1985 is described in Table 5-16.

TABLE 5-11. Future Electric Generating Capability Additions by Regions (MW)

	PRIME MOVER	ADDED 1977	PLANNED FOR				TOTAL ADDITIONS NOW PLANNED
			1978	1979	1980	1981 & BEYOND	
New England	Conventional hydro	–	–	–	–	95	95
	Pumped storage	–	–	–	–	–	–
	Fossil steam	–	527	–	–	818	1,345
	Nuclear steam	–	–	–	–	6,831	6,831
	IC	–	11	–	6	27	44
	Comb. turbine	95	–	–	–	191	191
	Total	95	538	–	6	7,962	8,506
Middle Atlantic	Conventional hydro	–	–	–	31	205	236
	Pumped storage	–	–	–	–	1,215	1,215
	Fossil steam	2,372	357	1,132	395	4,085	5,969
	Nuclear steam	1,288	880	1,032	1,870	16,796	20,578
	IC	–	–	–	–	240	240
	Comb. turbine	–	–	–	–	130	130
	Total	3,660	1,237	2,164	2,296	22,671	28,268
East North Central	Conventional hydro	–	–	40	–	–	40
	Pumped storage	–	–	–	–	–	–
	Fossil steam	4,205	4,131	3,082	2,693	13,083	22,989
	Nuclear steam	673	1,283	1,878	1,958	20,727	25,846
	IC	6	20	–	10	15	45
	Comb. turbine	–	213	–	–	–	213
	Total	4,884	5,647	5,000	4,661	33,825	49,133
West North Central	Conventional hydro	–	–	–	–	–	–
	Pumped storage	–	–	160	–	–	160
	Fossil steam	3,196	2,412	1,705	2,686	11,390	18,193
	Nuclear steam	–	–	–	–	5,626	5,626
	IC	4	8	6	16	36	66
	Comb. turbine	266	904	144	198	1,360	2,606
	Total	3,466	3,324	2,015	2,900	18,412	26,651
South Atlantic	Conventional hydro	–	–	–	113	366	479
	Pumped storage	250	340	240	208	3,670	4,458
	Fossil steam	2,044	1,369	515	4,245	13,875	20,004
	Nuclear steam	2,642	1,588	2,342	900	21,122	25,952
	IC	18	–	1	–	38	39
	Comb. turbine	329	288	20	820	820	1,948
	Total	5,283	3,585	2,118	6,286	39,891	52,880
East South Central	Conventional hydro	70	–	–	135	138	273
	Pumped storage	–	1,300	–	–	–	1,300
	Fossil steam	1,300	1,655	460	995	7,280	10,390
	Nuclear steam	1,927	1,148	2,325	3,250	11,381	18,104
	IC	–	–	–	–	–	–
	Comb. turbine	–	–	–	–	50	50
	Total	3,297	4,103	2,785	4,380	18,849	30,117

TABLE 5-11. Future Electric Generating Capability Additions by Regions (MW) (Continued)

	PRIME MOVER	ADDED 1977	PLANNED FOR				TOTAL ADDITIONS NOW PLANNED
			1978	1979	1980	1981 & BEYOND	
West South Central	Conventional hydro	–	–	–	218	–	218
	Pumped storage	–	–	–	–	100	100
	Fossil steam	2,992	4,496	4,238	4,874	14,911	28,519
	Nuclear steam	–	912	–	585	10,584	12,081
	IC	–	–	–	–	–	–
	Comb. turbine	300	–	–	–	1,198	1,198
	Total	3,292	5,408	4,238	5,677	26,793	42,116
Mountain	Conventional hydro	–	98	240	13	1,116	1,467
	Pumped storage	–	–	100	110	1,123	1,333
	Fossil steam	400	825	2,263	1,785	7,687	12,560
	Nuclear steam	–	330	–	–	1,632	1,962
	IC	–	–	–	–	–	–
	Comb. turbine	117	–	190	–	–	190
	Total	517	1,253	2,793	1,908	11,558	17,512
Pacific	Conventional hydro	1,368	6,267	3,570	110	3,029	12,976
	Pumped storage	235	400	135	50	1,470	2,055
	Fossil steam	–	653	683	646	5,507	7,489
	Nuclear steam	–	2,120	2,200	1,198	18,616	24,134
	IC	–	–	–	–	–	–
	Comb. turbine	500	694	56	958	2,550	4,258
	Total	2,103	10,134	6,644	2,962	31,172	50,912
Total Contiguous U.S.	Conventional hydro	1,438	6,365	3,850	620	4,949	15,784
	Pumped storage	485	2,040	635	368	7,578	10,621
	Fossil steam	16,509	16,425	14,078	18,319	78,636	127,458
	Nuclear steam	6,530	8,261	9,777	9,761	113,315	141,114
	IC	28	39	7	32	356	434
	Comb. turbine	1,607	2,099	410	1,976	6,299	10,784
	Total	26,597	35,229	28,757	31,076	211,133	306,195
Alaska & Hawaii	Conventional hydro	–	–	–	–	35	35
	Pumped storage	–	–	–	–	–	–
	Fossil steam	–	–	–	141	46	187
	Nuclear steam	–	–	–	–	–	–
	IC	12	9	15	14	49	87
	Comb. turbine	–	105	85	65	–	255
	Total	12	114	100	220	130	564
Puerto Rico	Conventional hydro	–	–	–	–	–	–
	Pumped storage	–	–	–	–	–	–
	Fossil steam	–	–	–	–	–	–
	Nuclear steam	–	–	–	–	–	–
	IC	–	–	–	–	–	–
	Comb. turbine	200	–	–	–	–	–
	Total	200	–	–	–	–	–

Includes 32 Mw solid waste in 1978. Includes Geothermal: 1978, 161 Mw, 1979, 245 Mw, 1981 & beyond, 1,204 Mw.

SOURCE: 1978 Statistical Report, Electrical World, March 15, 1978, p. 92

TABLE 5-12. Future Generating Capacity

Generating capacity net additions, Mw (Based on date of commercial operation)

	CONVENTIONAL[1] HYDRO	PUMPED HYDRO	FOSSIL STEAM	NUCLEAR STEAM	COMBUSTION TURBINE & I.C.	TOTAL
1966	1,195	–	8,826	1,016	679	11,716
1967	3,135	–	15,420	945	1,909	21,409
1968	2,207	849	16,070	-70	2,750	21,806
1969	796	789	14,901	1,163	4,642	22,291
1970	1,789	313	16,800	2,513	6,126	27,541
1971	624	219	17,564	2,194	5,705	23,306
1972	382	286	18,455	6,613	6,474	32,210
1973	1,594	3,622	24,217	5,770	5,066	40,269
1974	720	1,087	18,874	9,196	6,236	36,113
1975	2,064	305	21,726	7,281	3,524	34,900
1976	300	235	11,908	4,457	2,600	19,500
Forecast						
1977	1,301	675	18,167	8,710	2,037	30,890
1978	1,343	1,860	13,961	5,984	1,507	24,655
1979	1,428	502	12,197	7,751	481	22,359
1980	117	251	13,645	6,528	695	21,236
1981	0	1,125	14,244	7,658	681	23,645
1982	0	0	13,785	10,204	821	24,811
1983	0	1,050	10,984	16,501	1,280	29,815
1984	200	2,100	8,791	20,709	773	32,573
1985	500	260	11,061	20,977	1,380	34,178
1986	800	0	12,625	18,284	1,606	33,315
1987	1,500	0	21,890	13,252	1,731	38,373
1990	1,500	1,000	19,120	19,120	2,457	42,117
1995	1,900	0	28,500	28,500	2,082	51,650

(1) Estimated hydro capacity all assigned to conventional after 1985, except for the Storm King Project.

SOURCE: Federal Power Commission, as Reported in Electrical World, September 15, 1977, p. 55

TABLE 5-13. Estimated Annual Added Capacity in the United States

	AVERAGE FUTURE ADDITIONAL INSTALLED GENERATING CAPACITY	AVERAGE NUMBER OF PLANTS ANNUALLY
Nuclear Power Plants	14,167 MW	14
Fossil Fuel Power Plants	14,365 MW	36
Hydroelectric Power Plants	1,493 MW	15
Gas Turbine Power Plants	1,493 MW	15

The estimated annually added capacity in OECD Europe is presented in Table 5-17.

5.5.2.3 Japan. The expected energy production in Japan according to forecasts prepared by the OECD is as presented in Table 5-18.

Using the same assumptions as for the other areas, we can estimate the annually added capacity in Japan as described in Table 5-19.

5.5.2.4 The Developing World. The projected electric energy consumption in the developing world, including the OPEC countries, is relatively insignificant compared to the industrialized world. It was therefore decided to discuss the electric energy future of these nations as a group.

The forecast of electric energy production is based upon the results obtained by the Workshop on Alternative Energy Strategies (WAES) sponsored by the Massachusetts Institute of Technology (Reference 6). The forecast presented in the next pages represents the electric energy future of the countries listed in Table 5-20.

A number of assumptions were made with respect to the economic development in developing countries, and several potential scenarios were assumed. These assumptions and scenarios are presented as Tables 5-21 and 5-22.

The forecasted electric energy production, which was calculated in terms of millions of barrels per day of oil equivalents, is presented as Table 5-23. The average annual increase in installed capacity per year in MW is presented as Table 5-24.

TABLE 5-14. Generation Added or Planned in Canada

PROVINCE AND PRIME MOVER	MW ADDED 1977	MW PLANNED FOR 1978	1979	1980	AFTER 1981	TOTAL MW PLANNED
Alberta						
Fossil steam	165	165	–	–	1,122	1,287
IC	1	10	2	3	–	15
Comb. turbine	3	–	–	–	–	–
Total	169	175	2	3	1,122	1,302
British Columbia						
Hydro	441	–	350	1,258	1,800	3,408
Comb. turbine	–	54	–	–	–	54
Total	441	54	350	1,258	1,800	3,462
Manitoba						
Hydro	224	476	420	–	1,080	1,976
New Brunswick						
Hydro	–	–	220	–	–	220
Fossil steam	335	–	200	–	–	200
Nuclear	–	–	–	630	–	630
Total	335	–	420	630	–	1,050
Newfoundland-Labrador & P.E.I.						
Comb. turbine	–	–	–	25	–	25
Nova Scotia						
Hydro	–	200	–	–	–	200
Fossil steam	150	–	–	150	450	600
Comb. turbine	120	–	–	–	–	–
Total	270	200	–	150	450	800
Ontario						
Hydro	107	14	–	–	–	14
Fossil steam	1,177	1,263	82	411	3,343	5,099
Nuclear	1,464	537	642	693	8,702	10,574
Comb. turbine	40	19	–	23	141	183
Total	2,788	1,833	724	1,127	12,186	15,870
Quebec						
Hydro	175	579	–	1,959	10,824	13,362
Nuclear	–	–	637	–	–	637
IC	12	18	–	–	43	61
Comb. turbine	108	–	240	202	1,136	1,578
Total	295	597	877	2,161	12,003	15,638
Saskatchewan						
Hydro	–	–	–	–	90	90
Fossil steam	280	–	280	–	280	560
Total	280	–	280	–	370	650
Total Canada						
Hydro	947	1,269	990	3,217	13,794	19,270
Fossil steam	2,107	1,428	562	561	5,195	7,746
Nuclear	1,464	537	1,279	1,323	8,702	11,841
IC	13	28	2	3	43	76
Comb. turbine	271	73	240	250	1,277	1,840
Total	4,802	3,335	3,073	5,354	29,011	40,773

SOURCE: Electrical World, August 15, 1977

TABLE 5-15. Estimated Annual Additional Capacity in Canada

	AVERAGE ADDITIONAL CAPACITY ANNUALLY	AVERAGE NO. OF PLANTS
Hydroelectric	2,410	24
Fossil Steam	1,164	3
Nuclear	1,150	1
Combustion Turbine	208	2

*Average utilization hrs per plant.

The total annual average installed capacity requirements per year in the entire developing world between 1972 and 2000 is less than half that expected for the U.S. in the same time provided even under the most optimistic assumptions of future growth. The expected annually added capacity in all these countries, based on an average of the scenarios to the periods between 1985 and 2000, will be limited, and extensive ferry between the various projects spread around the world will be extensive. The annually added capacity for this segment is presented as Table 5-25.

5.5.2.5 USSR. The USSR is a major producer and consumer of electric energy. No forecasts or plans for energy expansion are available for this country. It is expected that the rapid growth in electric generating capacity experienced in the period from 1970 to 1975 will continue in the near and distant future to support the expanding industrialization of the country. Statistics on the expansion of the generating capacity between 1970 and 1975 and the average growth per year are presented as Table 5-26. In Table 5-27, the expected annually added capacity leading to generating plant construction activity in the USSR, is presented.

5.5.2.6 Power Generating Plant Market Summary. The annual added capacities identified in this section for different areas around the world are summarized in Table 5-28, together with estimates of the number of each type of power plant that these additions represent.

TABLE 5-16. Electric Energy Production in OECD Europe

	1974		1980		AV. ANNUAL CHANGE 1974-1980	1985 REFERENCE CASE		AV. ANNUAL CHANGE 1974-1985
	(1)	(2)	(1)	(2)	(2)	(1)	(2)	(2)
Nuclear	34.0	5542	246.0	40,101	4937	525.0	85,582	7580
Hydro and Geothermal	120.2	19,602	139.0	22,667	438	145.0	23,646	163
Steam Fossil and Other	895.8	146,609	958.0	160,633	2008	1156.0	188,519	4648
Other Electric	1050.0	171,753	1343.0	223,401		1826.0	297,747	

(1) Terawatt hours per year

(2) Megawatt generating capacity required assuming an average load factor of 70%

SOURCE: Energy Prospects for the OECD, Paris, 1977.

TABLE 5-17. Estimated Annual Market in OECD Europe for the HLA

	AVERAGE ANNUAL ADDITIONAL CAPACITY (MW)	AVERAGE NO. OF PLANTS
Nuclear	7,580	8
Hydro and Geothermal	163	2
Steam and Fossil Fuel	4,648	12

TABLE 5-18. Expected Energy Production in Japan

	1974		1980		AV. ANNUAL INCREASE 1974-1980	1985		AV. ANNUAL INCREASE 1980-1985
	(1)	(2)	(1)	(2)	(2)	(1)	(2)	(2)
Nuclear	19.7	3212	86.0	14,024	1544	199.0	32,543	3086
Hydro and Geothermal	84.8	13,829	89.0	14,514	98	117.0	19,080	761
Steam Fossil and Other	354.5	57,811	488.0	78,583	3110	606.0	98,826	3207
Other Electric	459.0	74,853	663.0	108,121		922.0	15,035	

(1) Terawatt hours per year

(2) Megawatt generating capacity required assuming an average load factor of 70%

SOURCE: Energy Prospects for the OECD, Paris, 1977.

TABLE 5-19. Estimated Annual Market in Japan for the HLA

	AVERAGE ANNUAL ADDITIONAL CAPACITY (MW)	AVERAGE NO. OF PLANTS
Nuclear	3,086	3
Hydro and Geothermal	761	7
Steam and Fossil Fuel	3,207	8

TABLE 5-20. Developing Countries in Europe

A. OPEC Countries

- Algeria
- Ecuador
- Gabon
- Indonesia
- Iran
- Iraq
- Kuwait
- Libya
- Nigeria
- Qatar
- Saudi Arabia
- United Arab Emirates
- Venezuela

B. Non-OPEC Developing Countries

i) Lower-Income Countries
(annual per capita income under $200 [1972 U.S. dollars])

South Asia

- Afghanistan
- Bangladesh
- Burma
- India
- Nepal
- Pakistan
- Sri Lanka

Lower-Income Sub-Sahara Africa

- Burundi
- Central African Republic
- Chad
- Dahomey
- Ethiopia
- Guinea
- Kenya
- Madagascar
- Malawi
- Mali
- Niger
- Rwanda
- Sierra Leone
- Somalia
- Sudan
- Tanzania
- Togo
- Uganda
- Upper Volta
- Zaire

ii) Middle-Income Countries
(annual per capita income over $200 [1972 U.S. dollars])

East Asia

- Fiji
- Hong Kong
- Korea (Soutn)
- Malaysis
- Papua New Guinea
- Philippines
- Singapore
- Taiwan
- Thiland

Middle-Income Sub-Sahara Africa and West Asia

- Angola
- Bahrein
- Cameroon
- Congo P.R.
- Cyprus
- Egypt
- Ghana
- Israel
- Ivory Coast
- Jordan
- Lebanon
- Liberia
- Mauritania
- Morocco
- Mozambique
- Oman
- Rhodesia
- Senegal
- Syria
- Tunisia
- Turkey
- Yemen A.R.
- Zambia

Caribbean, Central and South America

- Argentina
- Barbados
- Bolivia
- Brazil
- Chile
- Columbia
- Costa Rica
- Dominican Republic
- El Salvador
- Guatemala
- Guyana
- Haiti
- Honduras
- Jamaica
- Mexico
- Nicaragua
- Panama
- Paraguay
- Trinidad and Tobago
- Uruguay

SOURCE: Energy, Global Prospects 1985-2000 (Reference 10).

TABLE 5-21. WAES Scenario Assumptions

CASE	ECONOMIC GROWTH	ENERGY PRICE	PRINCIPAL REPLACEMENT FUEL
1976-1985			
C	High	$11.50	–
D	Low	$11.50	–
1985-2000			
C-1	High	$11.50-$17.25	Coal
C-2	High	$11.50-$17.25	Nuclear
D-7	Low	$11.50	Coal
D-8	Low	$11.50	Nuclear

SOURCE: Reference 10

TABLE 5-22. Real GNP Growth Rate Assumptions: 1972-2000

PERIOD ECONOMIC GROWTH WAES CASE	1960-72	1972-76	1976-1985 HIGH C	1976-1985 LOW D	1985-2000 HIGH C-1,2	1985-2000 LOW D-7,8
Non-OPEC Developing Countries	5.6	5.1	6.1	4.1	4.6	3.6
I) Lower-Income Countries	3.7	2.3	4.4	2.8	3.1	2.5
II) Middle-Income Countries	6.2	5.9	6.6	4.5	4.9	3.9
OPEC	7.2	12.5†	7.2	5.5	6.5	4.3
Developed Economies* (OECD)	4.9	2.0	4.9	3.1	3.7	2.5

SOURCE: Reference 10

*As derived by WAES analyses of individual countries.
†Preliminary estimate.

TABLE 5-23. Primary Electricity Generation in Developing Countries: 1972-2000

YEAR		1985		2000			
WAES CASE	1972	CASE C	CASE D	CASE C-1	CASE C-2	CASE D-7	CASE D-8
Scenario Assumptions							
Economic Growth		HIGH	LOW	HIGH	HIGH	LOW	LOW
Energy Price		$11.50	$11.50	$11.50-17.25	$11.50-17.25	$11.50	$11.50
Principal Replacement Fuel				COAL	NUCLEAR	COAL	NUCLEAR
Primary Electrical Generation Units							
Of Which:	2.21	5.82	4.81	14.28	16.53	10.20	11.57
Oil	.81	1.13	.95	2.85	1.66	2.00	1.16
Gas	.13	.63	.53	1.28	.47	.57	.35
Coal	.29	1.13	.95	1.45	1.66	1.53	1.16
Hydro	.97	1.76	1.85	4.24	3.50	3.00	2.40
Nuclear	.01	1.17	.53	4.46	9.24	3.10	6.50
Percent Primary Electrical Generation							
Of Which:	100	100	100	100	100	100	100
Oil	37	20	20	20	10	20	10
Gas	6	11	11	9	3	6	3
Coal	13	20	20	10	10	15	10
Hydro	44	31	38	30	21	29	21
Nuclear	–	18	11	31	56	30	56

SOURCE: Reference 10

TABLE 5-24. Average Additional Electric Capacity

	AVERAGE INSTALLED CAPACITY PER YEAR 1975-1985		AVERAGE INSTALLED CAPACITY PER YEAR 1985-2000			
	CASE C	CASE D	CASE C-1	CASE C-2	CASE D-7	CASE D-8
Fossil Fuels	5,141	3,572	7,005	2,343	4,348	625
Hydroelectric	2,351	2,619	6,458	4,531	2,995	1,432
Nuclear	3,452	1,547	8,568	21,016	6,693	15,547
Total	10,744	7,738	22,031	27,890	14,036	17,604

Conversion factor used: 2.4 MBOE = 100 GW installed electric generating capacity

TABLE 5-25. Estimated Annual Additional Capacity in Developing Countries

	AVERAGE ANNUAL CAPACITY INSTALLED	AVERAGE NO. OF PLANTS
Fossil Fuels	3,579	9
Hydroelectric	3,854	38
Nuclear	12,956	13

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TABLE 5-26. Installed Electric Generating Capacity in USSR

U.S.S.R.	1970	1971	1972	1973	1974	1975	AVERAGE INSTALLED 1970 - 1975
Total	166,150	175,365	186,239	195,560	205,442	217,484	8,557
Hydro	36,368	33,448	34,846	35,320	36,978	40,515	1,524
Nuclear	1,591	2,031	2,621	3,509	4,500	5,600	668
Steam Fossil and Other	133,191	139,086	148,772	156,731	163,964	171,368	6,363

SOURCE: United States

TABLE 5-27. Estimated Market for HLA in the USSR

	AVERAGE ANNUAL ADDITION TO GENERATING CAPACITY	AVERAGE NUMBER OF PLANTS
Hydro Plants	1,524	15
Nuclear Plants	668	1
Steam Fossil Fuel Plants	6,363	16

TABLE 5-28. Total Annual Potential Market – Power Generating Plant Construction

TYPE / COUNTRY	HYDRO/GEO		NUCLEAR		STEAM, FOSSIL & OTHER		GAS TURBINES		TOTAL AA	TOTAL N
	AA	N*	AA	N*	AA	N*	AA	N*		
U.S.	1,500	15	14,000	14	14,400	36	1,500	15	31,400	80
Canada	2,410	24	1,150	1	1,160	3	210	2	4,930	30
OECD Europe	165	2	7,580	8	4,650	12	–	–	12,395	22
Japan	760	7	3,086	3	3,210	8	–	–	7,056	18
Developing countries	3,855	39	12,960	13	3,580	9	–	–	20,395	61
USSR	1,520	15	670	1	6,360	16	–	–	8,550	32
Total	10,210	102	39,450	40	33,360	84	1,710	17	84,730	243

*Based on average plant sizes in the U.S. – (Nuclear, 1000 MW; Steam, 400 MW; Hydro, 100 MW; Gas Turbine, 100 MW)

AA = Annual addition to generating capacity (MW)
N = Average number of new plants per year

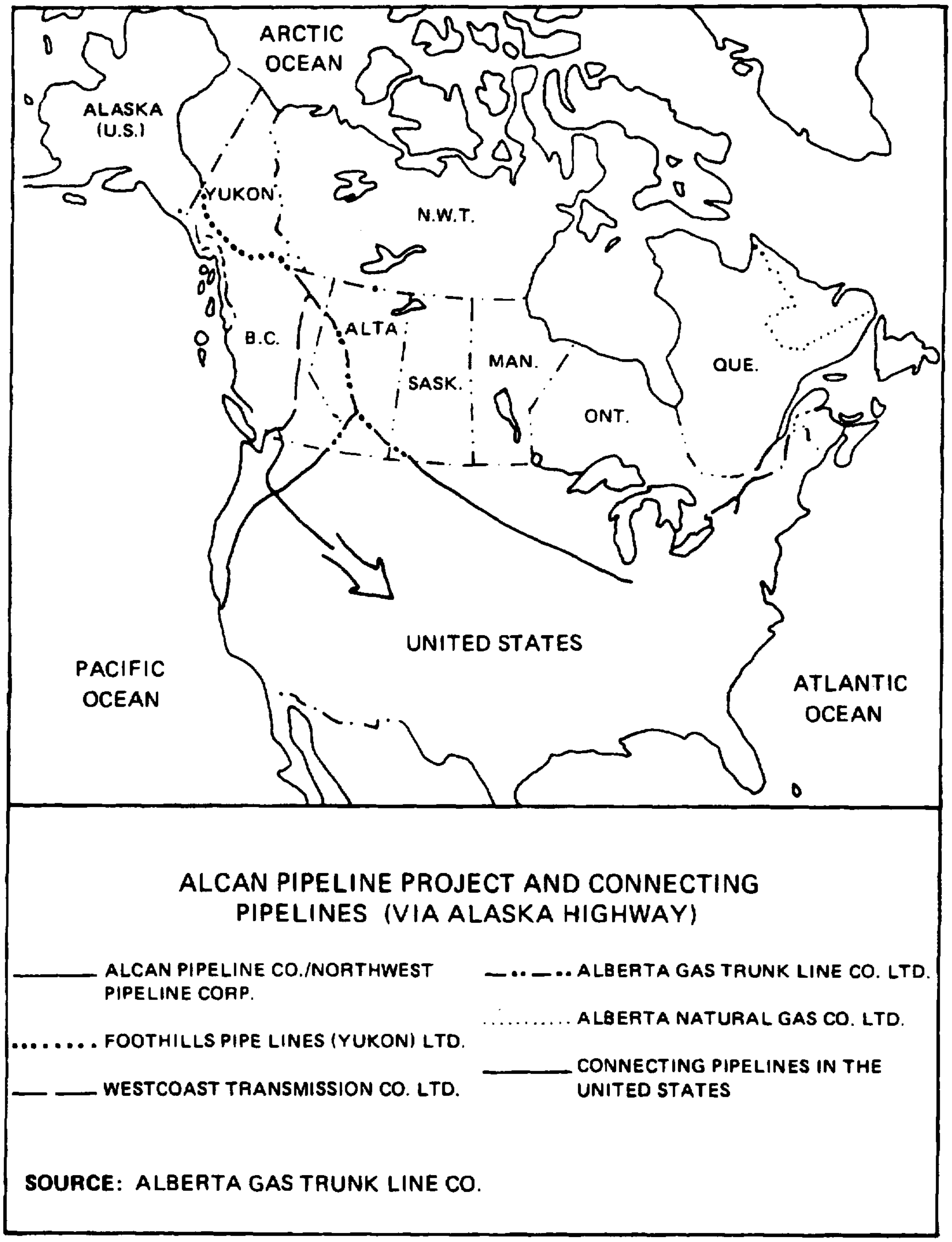
5.6 The Market for the Support of the Construction of Pipelines

Every year between 25,000 and 26,000 miles of new pipelines are laid. Of this total, a relatively small portion is laid in undeveloped or remote regions that cause logistical difficulties to warrant the use of an HLA.

At the present time there is one major planned pipeline construction project for which the HLA concept would be extremely valuable. This project is the Alcan-Foothills pipeline extending 2,754 miles from Prudhoe Bay on the North Slope of Alaska, through Alaska and along the Alaska-Canada highway through the Yukon Territory and British Columbia, and through Alberta to the United States. Data provided by Foothills Pipeline Company, Ltd., one of the members of the consortium formed to construct the planned pipeline, was used for the case study of pipeline construction. At the present time, construction of this pipeline is scheduled to start in 1979, and completion is planned for 1983. A map of this pipeline is presented as Figure 5-2.

Another major pipeline project, for which the HLA could be useful is the pipeline planned by Polar Gas of Toronto Canada. The Polar Gas pipeline will extend from the Canadian Islands in the Arctic Ocean through the Northwest Territories through Manitoba and to Ontario for connection with the Trans Canada Pipeline system. This pipeline is at the present time only in the preliminary planning stage, and construction will not commence until the early 1980's. Total construction time is estimated to be three years.

With the exception of these two pipeline projects, there are no other pipeline projects planned at this stage that would be of interest from a HLA market point of view. However, oil and gas are increasingly explored and discovered in inaccessible and remote areas. New pipeline projects to bring these new resources to market are expected to be constructed in the future. The pipelines completed in 1977 and 1978 are presented as Table 5-29. Of these pipelines, it is expected that only the large diameter lines (i.e., above 22 inches diameter) that require large and heavy special equipment would warrant the use of an HLA. The market opportunities are presented in Table 5-30. In the preparation of this table it was assumed that future pipeline construction volume would be similar to the average of the years 1977-1978. These estimates were made on the assumption by Booz, Allen that between 5% and 10% of the total mileage would be in undeveloped and remote regions.



ALCAN PIPELINE PROJECT AND CONNECTING PIPELINES (VIA ALASKA HIGHWAY)

SOURCE: ALBERTA GAS TRUNK LINE CO.

FIGURE 5-2. Alcan Pipeline Project and Connecting Pipelines

TABLE 5-29. Non-Communist Pipeline Construction, 1977-78*

AREA	4.10 IN. DIAMETER	12.20 IN. DIAMETER	22.30 IN. DIAMETER	OVER 30 IN. DIAMETER	TOTAL MILEAGE
UNITED STATES					
1977	2,395	3,189	1,126	214	6,924
1978	2,541	2,134	1,906	468	7,049
Change	+ 146	−1,055	+ 780	+ 14	+ 125
CANADA					
1977	1,374	3,251	280	137	5,042
1978	762	179	594	140	1,675
Change	− 612	− 3,072	+ 314	+ 3	− 3,367
EUROPE					
1977	731	597	642	574	2,544
1978	824	962	1,196	806	3,788
Change	+ 93	+ 365	+ 554	+ 232	+ 1,244
LATIN AMERICA					
1977	933	1,286	1,166	209	3,594
1978	1,059	1,377	1,274	294	4,004
Change	+ 126	+ 91	+ 108	+ 85	+ 410
MIDDLE EAST					
1977	406	1,134	762	1,506	3,808
1978	418	1,266	1,170	1,941	4,795
Change	+ 12	+ 132	+ 408	+ 435	+ 987
AFRICA					
1977	125	1,082	556	1,016	2,779
1978	141	1,091	874	1,067	3,173
Change	+ 16	+ 9	+ 318	+ 51	+ 394
FAR EAST					
1977	62	71	244	116	493
1978	118	135	416	59	728
Change	+ 56	+ 64	+ 172	− 57	+ 235
TOTAL					
1977	6.026	10,610	4,776	3,772	25,184
1978	5,863	7,144	7,430	4,775	25,212
Change	− 163	−3,466	+ 2,654	+1,003	+ 28

*Excludes utility-distribution and water lines.

SOURCE: Oil and Gas Journal, January 23, 1978, p. 16

TABLE 5-30. Market Opportunities for Heavy Lift Services

WORLD REGION	AVERAGE TOTAL, MILEAGE 22 IN. DIA. & ABOVE	ESTIMATED MILEAGE IN UNDEVELOPED & REMOTE REGIONS	
		5%	10%
United States	1,857	93	186
Canada	576	29	58
Europe	1,608	80	161
Latin America	1,472	74	147
Middle East	2,690	135	269
Africa	1,756	88	176
Far East	418	21	42
Total	10,377	520	1,039

5.7 The Market for the Support of the High Rise Construction Industry

This industry has opportunities for the use of heavy lift aerial vehicles in:

- Roof emplacement of air conditioning, heating, and refrigeration units
- Roof emplacement of window washing units, and
- Dismantling and lowering of construction cranes.

The more stories a high rise building has, the more useful the HLA becomes.

5.7.1 The Market for the Emplacement of Air Conditioning/Heating Refrigeration Units

Data on the foreign refrigeration unit market are not available, and neither is information on the methods used for placing these units in buildings in countries other than the United States. The discussion of this market is therefore limited to the U.S. market place.

In the U.S. market there are two types of airconditioning/ventilation units that require rigging either to place them in utility rooms or on top of the building:

- Condenser type units
- Evaporator type cooling towers.

5.7.1.1 Condenser Type Units. According to a representative of Carrier Corporation, the largest manufacturer of airconditioning and refrigeration units in the United States, Carrier's annual sales of airconditioning units are approximately $1 billion, of which $500 million is for commercial units. The major portion of these commercial units are placed in utility rooms rather than on the roof. The total sales of units that are rigged and placed on the roof account for approximately $10 million per year. The cost of each unit ranges from $3000 - $4000 for the small units to $150,000 for the largest units. The average rooftop unit costs approximately $20,000, and weighs on an average of 15,000 pounds. The largest units weigh 30,000 - 40,000 pounds. Anything larger is impractical to ship in one piece, and is knocked down, shipped in pieces, and assembled at the site.

The approximate number of rooftop units sold by Carrier is estimated to be 500 per year. The representative estimated Carrier's market share to be 30% to 40%. The total market for compressor type airconditioning units to be placed on the rooftops of buildings can be estimated to be between 1250 and 1700 units per year.

5.7.1.2 Cooling Towers/Evaporators. These units are almost exclusively placed on top of buildings or on adjacent open lots. A representative of Baltimore Aircoil Company, one of the major manufacturers of this type of equipment in the United States, estimated that the total market for cooling towers/evaporators ranges between 3000 to 3500 units per year. These units, which weigh up to 67,000 pounds, are generally shipped knocked down due to the limitations of the existing transportation infrastructure and the necessity to rig and lift the units at the site. Each of these towers requires more than one lift ranging in weight from as low as 500 pounds up to 18,000 pounds for the largest component.

The total market for these units to be emplaced on rooftops is as summarized in Table 5-31.

It should be noted that one Sikorsky S-64E Skycrane is operating an average of 375 hours a year serving this market. The average ferry time is 8 hours for each job, and the time of actual operation approximately one-half hour to emplace 20-30 units each weighing 15,000 pounds. The helicopter thus averages in excess of 40 missions each emplacing an average of 25 units for a total of 1000 units per year. This is a relatively large proportion of the total market.

TABLE 5-31. Total Market for Support of Construction

INDUSTRY	NUMBER OF UNITS/LIFTS		
AIR CONDITION/HEAT/VENTILATION UNITS	LOW	HIGH	AVERAGE WEIGHT
COMPRESSION TYPE	1250	1700	15,000 lbs.
EVAPORATION/COOLING TOWER TYPE	3000	3500	15,000 - 60,000 lbs.
WINDOW WASHING UNITS	5000	6000	15,000 lbs.
DISMANTLING CONSTRUCTION CRANES	250	300	50,000 lbs.

5.7.2 The Market for Emplacement of Window Washing Units

A representative of Tishman Construction indicated this to be a significant market for heavy lift, all high rise office and apartment buildings have to have these units installed on the roof, and they are very difficult to install by any conventional means. The anticipated opportunities are approximately 5000 to 6000 units per year, each weighing around 15,000 pounds.

5.7.3 Dismantling Construction Cranes

Again, the Tishman representative estimated the total annual opportunities for crane dismantling to be about 250 to 300 lifts, each divisible into units of about 25 tons each.

5.8 The Market for the Support of Remote Drilling Installations and Operations

Statistical sources do not indicate the number of wells drilled in remote locations. To obtain an indication of the magnitude of this market, the world's largest owner and operator of remote drilling rigs, Parker Drilling Company of Tulsa, Oklahoma, was contacted. A representative of Parker Drilling Company said that his company currently had 35 helicopter rigs operating worldwide, and he estimated that his 15-20 competitors worldwide together had an equal number of rigs. The average rig can drill 3 to 4 wells per year. It should be noted, however, that the operators move their drilling rigs from helicopter operations to conventional operations. In a normal year a total of 100 wells are drilled worldwide where the helicopter is required for transportation. These operations are relatively evenly distributed among three world regions:

- Latin America
- Asia, primarily Indonesia, New Guinea and Malaysia
- Alaska, and Northern and Arctic Canada

as summarized in Table 5-32.

TABLE 5-32. Market for Retransportation of Support of Services of Remote Drilling Sites

AREA	NO. OF WELLS DRILLED IN REMOTE LOCATIONS
LATIN AMERICA	33
ASIA	33
NORTH AMERICA	34
TOTAL	100

The representative from Parker Drilling expected this situation to remain relatively stable in the near future.

5.9 The Market in the Logging Industry

The discussion of the market for logging is divided into a discussion of the market in the United States and worldwide.

5.9.1 United States

The United States is the world's leading producer of forest products. In 1976, the United States accounted for 13.2% of the total worldwide production of roundwood* (Reference 7).

In 1970, a total of 754 million acres of the 2.3 billion acres of land in the United States was forestland. Of this, 500 million acres are commercial timberland that are available and suitable for growing continuous crops of timber and raw materials for other forest products. Of these 500 million acres, the federal government is fully controlling 107 million acres. National forest land accounts for 92 million acres or 18% of the total forest lands in the United States. These areas are generally located in higher elevations with low quality woods, which are relatively inaccessible and costly to harvest. Nevertheless a substantial portion of the timber inventory of the United States is located in these national forests. The area of commercial timberland in the United States in 1970 is presented as Table 5-33, and the areas of various forest types is presented as Table 5-34. Projections prepared by the Forest Service, U.S. Department of Agriculture indicates that the available commercial timberland will decrease over the period from 1970 to 2020 by a total of 10 million acres per decade or a total of 5% over the 50 year period. The projections by regions are presented as Tables 5-35 and 5-36, and by ownership as Tables 5-37 and 5-38. The regional breakdown presented in the statistics are presented as Figure 5-3.

The total supplies of roundwoods (i.e., boxer softwoods and hardwoods) is expected to increase between 1970 and 1980 from 12.2 billion cu. ft. to 15.3 million cu. ft. By year 2020 the total supply is expected to be 19 billion cu. ft. or 57% above the 1970 level (Table 5-35).

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* Roundwood is defined by "The FAO, United Nations" as wood in the rough. Wood in its natural state as felled, or otherwise harvested, with or without bark, round, split, roughly squared or other forms (e.g., roots, stumps, burls, etc.). It may also be impregnated (e.g., telegraph poles) or roughly shaped or pointed. It comprises all wood obtained from removals, i.e., the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses, during the period - calendar year or forest year. Commodities included are sawlogs and veneer logs, pitprops, pulpwood, other industrial roundwood and fuelwood.

TABLE 5-33. Areas of Commercial Timberland in the United States (by type of ownership and section, January 1, 1970)

Type of Ownership	Total United States		North	South	Rocky Mountains	Pacific Coast
	Area	Proportion				
Federal:	*Thousand acres*	*Percent*	*Thousand acres*	*Thousand acres*	*Thousand acres*	*Thousand acres*
National Forest	91,924	18	10,458	10,764	39,787	30,915
Bureau of Land Management	4,762	1	75	11	2,024	2,652
Bureau of Indian Affairs	5,888	1	815	220	2,809	2,044
Other Federal	4,534	1	963	3,282	78	211
Total Federal	107,109	21	12,311	14,277	44,699	35,822
State	21,423	4	13,076	2,321	2,198	3,828
County and municipal	7,589	2	6,525	681	71	312
Forest industry	67,341	14	17,563	35,325	2,234	12,219
Farm	131,135	26	51,017	65,137	8,379	6,602
Miscellaneous private	165,101	33	77,409	74,801	4,051	8,840
All ownerships	499,697	100	177,901	192,542	61,632	67,622

SOURCE: The Outlook for Timber in the United States, Forest Service, U.S. Department of Agriculture, July 1974.

TABLE 5-34. Areas of Commercial Timberland in the Unites States (by forest type groups, 1970)

Type group	Total area	Proportion of total *Percent*
EASTERN TYPE GROUPS		
	Thousand acres	
Softwood types:		
Loblolly-shortleaf pine	52,832	10.7
Longleaf-slash pine	18,315	3.7
Spruce-fir	18,913	3.8
White-red-jack pine	12,168	2.5
Total	102,228	20.7
Hardwood types:		
Oak-hickory	111,861	22.6
Oak-pine	35,028	7.1
Oak-gum-cypress	30,630	6.2
Maple-beech-birch	31,140	6.3
Elm-ash-cottonwood	24,728	5.0
Aspen-birch	20,484	4.1
Total	253,871	51.3
Nonstocked	14,343	2.9
Total East	370,442	74.9
WESTERN TYPE GROUPS		
Softwood types:		
Douglas-fir	30,788	6.2
Ponderosa pine	27,964	5.6
Fir-spruce	17,830	3.6
Lodgepole pine	13,235	2.7
Hemlock-Sitka spruce	10,819	2.2
Larch	2,743	.5
White pine	829	.2
Redwood	803	.2
Total	105,011	21.2
Hardwood types	12,818	2.6
Nonstocked	6,379	1.3
Total west	124,208	25.1
All groups	494,650*	100.0

*Not including 5 million acres of "unregulated" commercial timberlands on National Forests in the Rocky Mountain States.

SOURCE: The Outlook for Timber in the Unites States Forest Service, U.S. Department of Agriculture, July 1974.

TABLE 5-35. Supplies of Roundwood Products from U.S. Forests (by section and species group, 1952, 1962, and 1970, with projections to 2020) (cubic feet, millions)

SECTION AND SPECIES GROUP	1952	1962	1970	PROJECTIONS			
				1980	1990	2000	2020
North:							
Softwoods	603	513	579	803	942	1,109	1,113
Hardwoods	1,378	1,299	1,409	2,428	3,165	3,845	3,799
Total	1,981	1,812	1,988	3,231	4,107	4,954	4,912
South:							
Softwoods	3,048	2,677	3,745	4,622	5,217	5,768	5,788
Hardwoods	1,935	1,606	1,668	2,651	3,009	3,327	3,416
Total	4,983	4,283	5,413	7,273	8,226	9,095	9,204
Rocky Mountains:							
Softwoods	495	684	852	1,044	1,139	1,275	1,231
Hardwoods	11	14	11	46	65	89	89
Total	506	698	863	1,090	1,204	1,364	1,320
Pacific Coast:							
Softwoods	3,239	3,324	3,805	3,642	3,376	3,332	3,491
Hardwoods	35	62	85	82	96	105	114
Total	3,274	3,386	3,890	3,724	3,472	3,437	3,605
Total United States:							
Softwoods	7,387	7,199	8,981	10,111	10,675	11,484	11,622
Hardwoods	3,358	2,980	3,173	5,207	6,334	7,365	7,418
Total	10,745	10,179	12,154	15,318	17,009	18,849	19,040

SOURCE: The Outlook for Timber in the United States Forest Service, U.S. Department of Agriculture, July 1974

TABLE 5-36. Supplies of Sawtimber Products from U.S. Forests (by section and species group, 1952, 1962, and 1970, with projections to 2020) (board feet, millions)

SECTION AND SPECIES GROUP	1952	1962	1970	PROJECTIONS			
				1980	1990	2000	2020
North:							
Softwoods	1,898	1,488	2,115	2,390	3,014	3,793	3,793
Hardwoods	4,300	4,430	6,083	7,648	9,997	12,139	11,994
Total	6,198	5,918	8,197	10,038	13,011	15,932	15,787
South:							
Softwoods	11,337	9,292	14,366	17,586	20,882	23,836	23,919
Hardwoods	7,690	6,139	5,914	7,368	7,602	7,752	7,830
Total	19,027	15,431	20,280	24,954	28,484	31,588	31,749
Rocky Mountains:							
Softwoods	3,126	4,189	5,273	5,585	5,648	5,915	5,511
Hardwoods	15	19	13	108	148	195	191
Total	3,141	4,208	5,286	5,693	5,796	6,110	5,702
Pacific Coast:							
Softwoods	22,439	22,540	25,182	23,264	21,323	20,647	20,722
Hardwoods	122	201	322	380	435	469	503
Total	22,561	22,741	25,504	23,644	21,758	21,116	21,225
Total United States:							
Softwoods	38,800	37,510	46,936	48,825	50,867	54,191	53,945
Hardwoods	12,127	10,788	12,331	15,505	18,182	20,556	20,518
Total	50,927	48,298	59,267	64,330	69,049	74,747	74,463

SOURCE: The Outlook for Timber in the United States Forest Service, U.S. Department of Agriculture, July 1974

TABLE 5-37. Supplies of Roundwood Products from U.S. Forests (by owner class, and species group, 1952, 1962, and 1970, with projections to 2020) (cubic feet, millions)

OWNER CLASS AND SPECIES GROUP	1952	1962	1970	PROJECTIONS			
				1980	1990	2000	2020
National Forest:							
Softwoods	838	1,605	1,926	2,309	2,427	2,547	2,551
Hardwoods	60	79	90	210	287	370	378
Total	898	1,684	2,016	2,519	2,714	2,917	2,929
Other public:							
Softwoods	403	547	685	812	943	1,089	1,142
Hardwoods	125	125	149	318	433	548	547
Total	528	672	834	1,130	1,376	1,637	1,689
Forest industry:							
Softwoods	2,700	2,237	2,918	2,759	2,635	2,805	2,993
Hardwoods	486	597	512	619	725	836	902
Total	3,186	2,834	3,430	3,378	3,360	3,641	3,895
Farm & miscellaneous private:							
Softwoods	3,445	2,810	3,451	4,230	4,670	5,043	4,936
Hardwoods	2,688	2,179	2,423	4,061	4,888	5,611	5,592
Total	6,133	4,989	5,874	8,291	9,558	10,654	10,528
Total United States:							
Softwoods	7,387	7,199	8,981	10,111	10,675	11,484	11,622
Hardwoods	3,358	2,980	3,173	5,207	6,334	7,365	7,418
Total	10,745	10,179	12,154	15,318	17,009	18,849	19,040

SOURCE: The Outlook for Timber in the United States Forest Service, U.S. Department of Agriculture, July 1974

TABLE 5-38. Supplies of Sawtimber Products from U.S. Forests (by owner, class, and species group, 1952, 1962, and 1970, with projections to 2020) (board feet, millions)

OWNER CLASS AND SPECIES GROUP	1952	1962	1970	PROJECTIONS 1980	1990	2000	2020
National Forest:							
Softwoods	5,564	10,402	12,548	14,163	14,672	15,228	14,812
Hardwoods	217	332	359	634	910	1,193	1,194
Total	5,781	10,734	12,906	14,797	15,582	16,421	16,006
Other public:							
Softwoods	2,323	3,348	4,236	4,594	5,140	5,790	5,907
Hardwoods	365	339	497	879	1,273	1,679	1,666
Total	2,688	3,687	4,733	5,473	6,413	7,469	7,573
Forest industry:							
Softwoods	16,003	12,964	16,352	14,001	12,896	13,321	13,865
Hardwoods	1,572	1,724	1,774	1,967	2,213	2,456	2,615
Total	17,575	14,688	18,126	15,968	15,109	15,777	16,480
Farm & miscellaneous private:							
Softwoods	14,910	10,796	13,801	16,068	18,158	19,851	19,360
Hardwoods	9,973	8,393	9,701	12,025	13,786	15,228	15,043
Total	24,883	19,189	23,502	28,093	31,944	35,079	34,403
Total United States:							
Softwoods	38,800	37,510	46,936	48,825	50,867	54,191	53,945
Hardwoods	12,127	10,788	12,331	15,505	18,182	20,556	20,518
Total	50,927	48,298	59,267	64,330	69,049	74,747	74,463

SOURCE: The Outlook for Timber in the United States Forest Service, U.S. Department of Agriculture, July 1974

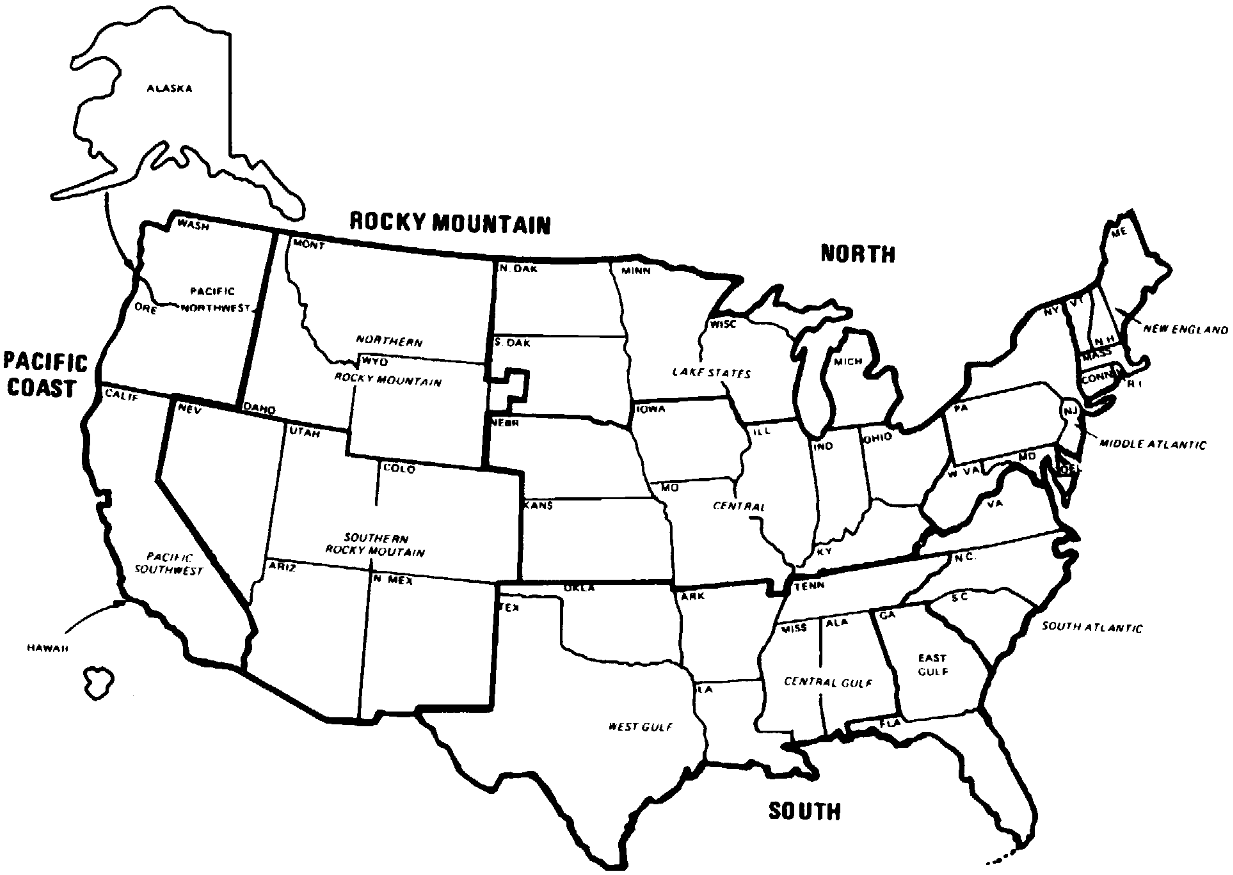

FIGURE 5-3. Sections and Regions of the United States

Of primary interest for the HLA is the supplies of sawtimber. Sawtimber is defined by the Forest Service as follows:

- <u>Sawtimber trees</u>. Live trees of commercial species containing at least one 12-foot saw log or two noncontiguous 8-foot logs, and meeting regional specifications for freedom from defect. Softwood trees must be at least 9.0 inches in diameter breast height, except in California, Oregon, Washington, and coastal Alaska where the minimum diameter is 11.0 inches. Hardwood trees must be at least 11.0 inches in diameter in all States.

These logs are the ones that present the most likely market for HLA logging applications. Projections of sawtimber production presented in Table 5-36 indicates that sawtimber production is expected to increase from 59,267 million board feet (4,.938 million cu. feet) to 64,300 million board feet (5,.360 million cu. ft.), an increase of 13.6%. By the year 2020, sawtimber production is expected to be only 25.6% above the 1970 level, versus 57% for total forest products production. The sawtimber share of total forest product production is therefore expected to decrease from 40% of the total production in 1970 to only 33% in the year 2020.

5.9.2 The Foreign Situation

Most of the potential forest areas in the world have not been surveyed. The total world forests have been estimated at 9,172 million acres on a total of 28% of the total world land area. A large portion of these forest areas are not available for harvesting due to inaccessibility, reservation for other uses, or productivity too low to warrant commercial exploitation. Still a total of 5,636 million acres are available for forest product production (Table 5-39.

The total growing stock in the world is presented as Table 5-40. According to this table, the major forest products resources in the world are located in Latin America and U.S.S.R. The availability of resources does not necessarily correlate with the growing stock available. Factors other than resource availability like the tree species and quality of timber, physical and economic accessibility, and institutional and political restrictions affect the harvest and processing of lumber. As is indicated in Table 5-41 there is virtually no correlation between production and the availability of growing stock. As can be seen from Table 5-41, 46% of total world production was derived from the U.S. Canada, Europe, and USSR, while these countries controlled merely 42.5% of the growing stock and only 43% of the available forest land.

5.9.2.1 <u>Canada</u>. Forest production and timber harvesting in Canada is important with respect to the HLA usage, because the environmental and economic conditions and the methods by which timber is

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TABLE 5-39. Land and Forest Areas in the World (acres, millions)

AREA	TOTAL LAND AREA	FOREST LAND			FOREST LAND AVAILABLE FOR WOOD PRODUCTION
		TOTAL	SOFTWOOD	HARDWOOD	
North America	4,633	1,754	1,087	642	1,013
Latin America	5,109	1,962	86	1,831	862
Europe	1,129	366	213	153	312
Africa	7,339	1,757	10	1,700	729
Asia (except Japan and U.S.S.R.)	6,580	1,233	183	1,016	815
Japan	247	59	25	32	57
U.S.S.R.	5,297	1,824	1,366	432	1,730
Pacific area	2,081	227	7	210	118
World	32,205	9,172	2,978	6,017	5,636

SOURCE: Food and Agriculture Organization of the United Nations. *Supply of wood materials for housing.* World Consultation on the Use of Wood in Housing, Secretariat Pap., Sect. 2. 1971.

TABLE 5-40. Forest Growing Stock in the World (by area and species group) (cubic feet, billions)

AREA	TOTAL	SOFTWOODS	HARDWOODS
North America	2,083	1,395	689
Latin America	4,340	99	4,241
Europe	473	290	184
Africa	1,232	11	1,222
Asia (except Japan and U.S.S.R.)	1,444	212	1,232
Japan	67	35	32
U.S.S.R.	2,807	2,345	463
Pacific area	177	11	166
World	12,623	4,396	8,227

SOURCE: Food and Agriculture Organization of the United Nations. *Supply of wood materials for housing*. World Consultation on the Use of Wood Housing, Secretariat Pap., Sect. 2. 1971.

harvested in Canada is in many ways very similar to the situation in the United States. As indicated in Table 5-42, the total forest land in Canada equals 796 million acres, of which 588 million acres are available for harvesting. An inventory of Canadian timber stock in 1968 indicated an availability of 503 billion cubic feet of softwood and 127 billion cu. ft. of hardwood (see Table 5-43).

A major portion of the timber available for harvest in Canada is located in the undeveloped and remote northern regions of Canada where inaccessibility due to lack of roads and high development costs has severely limited the commercial exploitation of the reserves. The total cut in 1970 of 4.3 billion cu. ft. is well below the total allowable cut of 10.7 billion cu. ft. as indicated in Table 5-44. A forecast of expected production of Canadian timber up to the year 2000 is presented as Table 5-45.

5.9.2.2 Europe. Forest production in Europe is dominated by Finland, France, West Germany, and Sweden. In 1976 these four countries accounted for a total of 48.3% of the total European production. The production methods in these countries are highly mechanized due to the high costs of labor. This combined with environmental concerns may create a good basis for the acceptance of the HLA in the European forest industry. The existence of such circumstances is clearly indicated by the following quotation from a report of the timber committee of the Economic Commission for Europe (Reference 8):

TABLE 5-41. World Production of Roundwood Timber (cubic feet, millions)

	YEAR							
	1961-65		1970		1973		1976	
WORLD	2,121,119	% OF TOTAL	2,387,661	% OF TOTAL	2,506,074	% OF TOTAL	2,524,219	% OF TOTAL
U.S.		14.2	327,945	13.7	335,368	13.4	341,397	13.5
Canada	99,384	4.7	121,435	5.1	143,822	5.8	132,393	5.2
Central America and Caribbean	36,470	1.7	40,145	1.7	42,932	1.7	43,960	1.7
South America	197,207	9.3	227,582	9.5	233,330	9.3	237,294	9.4
Africa	246,778	11.6	293,642	12.3	312,303	12.5	329,456	13.1
Asia	540,776	25.5	639,070	26.8	697,070	27.8	719,275	28.5
Europe	307,060	14.5	325,303	13.6	323,389	12.9	305,818	12.1
Oceania	23,853	1.1	27,538	1.2	30,260	1.2	30,092	1.2
USSR	367,348	17.3	385,000	16.1	387,600	15.5	384,534	15.2

SOURCE: 1976 Yearbook of Forest Products, Food and Agriculture Organization of the United Nations (Rome 1978) p. 3-4.

TABLE 5-42. Forest Land Area in Canada (by Province, 1967) (acres, thousands)

PROVINCE	TOTAL	SUITABLE FOR REGULAR HARVEST	NOT SUITABLE FOR REGULAR HARVEST	RESERVED
Atlantic*	56,685	47,723	8,311	651
Quebec	171,827	121,845	49,920	62
Ontario	120,534	115,471	105	4,958
Prairie**	132,712	119,608	4,979	8,125
British Columbia	138,076	134,838		3,238
Northwest Territories and Yukon	176,512	48,808	127,704	
Total	796,346	588,293	191,019	17,034

*Includes Newfoundland, Prince Edward Island, Nova Scotia, and New Brunswick.

**Includes Manitoba, Saskatchewan, and Alberta.

SOURCE: Manning, Glenn H., and H. Rae Grinnell. *Forest resources and utilization in Canada to the year 2000.* Canadian Forestry Serv. Publ. 1304 80 p. Ottawa, Ont. 1971.

TABLE 5-43. Merchantable Timber in Canada on Inventoried Nonreserved Forest Land (by Province and by Softwoods and Hardwoods, 1968) (cubic feet, millions)

PROVINCE	TOTAL	SOFTWOODS	HARDWOODS
British Columbia**	268,635	261,313	7,322
Prairie Provinces	89,331	55,923	33,408
Ontario	111,423	66,593	44,830
Quebec	130,397	96,954	33,443
Atlantic Provinces	29,612	22,100	7,512
Total	629,398	502,883	126,515

*Includes 445 million acres of inventoried forest land. Excludes Labrador, Yukon, and Northwest Territories.
**Mature timber volumes only.

SOURCE: Manning, Glenn H., and H. Rae Grinnell. *Forest resources and utilization in Canada to the year 2000.* Dept. of the Environment, Canadian Forestry Serv. Publ. 1304, 80 p. Ottawa, Ont. 1971.

> "The rapid increase in the importance attached to environmental problems in Europe may have far-reaching repercussions on the management of existing forest resources, to the extent that environmental requirements may impose certain limitations on forestry's traditional role of supplying wood. These repercussions may be of different types: they may lead to certain forest areas being declared protection, conservation, or recreation areas, with severe restrictions on their commercial exploitation, or they may constitute hindrances to normal management."

The actual production of roundwood lumber in Europe between 1970 and 1976 is presented as Table 5-46. As can be seen from this table, production in Europe has in reality dropped 6% between 1970 and 1976.

5.9.2.3 Other Areas in the Developed World. The USSR, the single largest producer of timber in the world, Japan, Australia and New Zealand are members of this category. These countries also present potential markets for the HLA. The total production in these countries from 1970 through 1975 is presented in Table 5-47.

5.9.2.4 Developing Countries in Latin America, Africa, Asia, and Oceania. A large portion of the forest resources available in these areas are from tropical forests that are relatively inaccessible and expensive to develop and harvest. The Outlook For Timber describes some of the other problems encountered in these regions (Reference 7).

TABLE 5-44. Timber Harvest in Canada and Estimated Allowable Annual Timber Cut (by Province, 1970) (cubic feet, millions)

REGION	ACTUAL 1970 PRODUCTION			ANNUAL ALLOWABLE CUT**					
				GROSS PHYSICAL			ECONOMIC***		
	TOTAL	SOFT-WOOD	HARD-WOOD	TOTAL	SOFT-WOOD	HARD-WOOD	TOTAL	SOFT-WOOD	HARD-WOOD
British Columbia	1,933	1,922	12	3,351	3,321	30	2,950	2,935	15
Prairie Provinces	275	247	28	1,650	1,040	610	1,155	728	427
Ontario	593	468	125	2,626	1,333	1,293	1,534	718	816
Quebec	1,021	854	167	2,249	1,837	412	1,592	1,350	242
Atlantic Provinces	464	416	48	866	649	217	760	570	190
Total	4,285	3,905	380	10,742	8,180	2,562	7,991	6,301	1,690

* Excluding Labrador, Yukon, and Northwest Territories.

** On nonreserved inventoried public and private forest land (506.9 million acres). Some 272.4 million acres had not been inventoried in 1968. Three-quarters of this noninventoried acreage is located in Labrador, Yukon, and Northwest Territories. Includes timber on immature acreage in British Columbia.

*** The annual allowable cut on acres physically accessible or becoming so which could be utilized under June 1972 cost price levels for lumber and plywood and somewhat improved prices for pulp and newsprint.

SOURCES: British Columbia Council of Forest Industries. *Canada's forest resources and forest products potentials.* Vancouver, B.C. 1972. Manning, Glenn H., and H. Rae Grinnell. *Forest resources and utilization in Canada to the year 2000.* Dept. of the Environment, Canadian Forestry Serv. Publ. 1304, 80 p. Ottawa, Ont. 1971.

TABLE 5-45. Production of Selected Timber Production Canada, 1970, with Projections to 2000

YEAR	LUMBER			PLYWOOD (3/8-INCH BASIS)			PAPER AND BOARD			WOOD-PULP	TOTAL TIMBER CUT
	TOTAL	SOFT-WOOD	HARD-WOOD	TOTAL	SOFT-WOOD	HARD-WOOD	TOTAL	NEWS-PRINT	OTHER		
	Billion board feet	*Billion board feet*	*Billion board feet*	*Billion square feet*	*Billion square feet*	*Billion square feet*	*Million tons*	*Million tons*	*Million tons*	*Million tons*	*Billion cu. ft.*
1970	11.3	10.8	0.5	2.1	1.9	0.2	12.8	8.8	4.0	18.3	4.3
1980	14.5	13.8	.7	4.3	3.2	1.1	16.9	10.8	6.2	21.9	5.4
1990	17.4	16.6	.8	6.4	4.4	1.9	22.4	13.2	9.2	28.5	6.2
2000	20.1	19.3 (24.0)*	.9	8.8	6.1 (3.8)*	2.6	27.4	15.3	12.1	35.2	9.1

*Numbers in parentheses are projections of softwood lumber and plywood production in 2000 prepared by the Council of Forest Industries of British Columbia. *Canada's forest services and forest product pontentials.* June 1972.

SOURCE: Manning, Glenn H., and H. Rae Grinnell. *Forest resources and utilization in Canada to the year 2000.* Dept. of the Environment, Canadian Forestry Serv. Publ. 1304, 80 p. Ottawa, Ont. 1971.

TABLE 5-46. Timber Production in Europe (cubic feet, millions)

	1970	1971	1972	1973	1974	1975	1976	AVERAGE PRODUCTION 1970 - 1976
ROUNDWOOD TIMBER PRODUCTION	11,494	11,541	10,958	11,427	11,526	10,654	10,806	11,200

SOURCE: 1970 Yearbook of Forest Products, FAO of UN (Rome 1978)

TABLE 5-47. Timber Production in Other Areas of the Developed World (cubic feet, millions)

	1970	1971	1972	1973	1974	1975	1976	AVERAGE 1970-1976
USSR	13,604	13,594	13,534	13,696	13,696	13,960	13,588	13,667
Japan	1,760	1,660	1,576	1,503	1,407	1,286	1,347	1,506
Australia	475	497	480	476	501	523	475	490
New Zealand	308	300	310	378	306	302	354	323
Total	16,093	16,051	15,900	16,053	15,910	16,071	15,764	15,986

SOURCE: 1970 Yearbook of Forest Products, FAO of UN (Rome 1978)

- Heterogeneity of the available forest resources is the main problem in the Amazon region of Brazil. In one area, 50% of the trees available were found to be distributed among 35 species, while the remaining were distributed among 100 species, each with different characteristics. This problem is also found in Asia and Africa, but to a lesser extent than in Latin America.
- Ecological balance of tropical rainforest has been found to be extremely delicate, and it has been found that areas harvested do not necessarily rejuvenate and reproduce. The tropical rainforests are described by ecologists as a nonrenewable resource.
- Much potential forest land is being cleared to accommodate the needs for agricultural land to grow food products for rapidly expanding populations.
- Much of the timber produced is of low quality.

Despite these dire circumstances the timber harvest in the developing world is increasing, and projections of continued expansion have been made.

The potential for the HLA with its flexibility and minimal environmental impact could in some cases be a major help to improve the productivity of forest product harvesting in the developing world. Table 6-48 presents the total harvests of the developing nations in the years 1970 through 1976.

5.9.3 Worldwide Logging Market Summary

The forecast of the worldwide logging market summarizing the data in this section is given in Table 5-49.

5.10 Markets for Unloading of Cargoes in Congested Ports

Port congestion is generally a result of cargo throughput in excess of the capacity of a port, and it occurs frequently in areas with limited transportation infrastructure to quickly transport cargoes into and out of the port, limited storage facilities and a limited number of berths for ship loading and discharge.

Most ports in the United States, Europe, Japan, Far East, and the Caribbean have invested in modern cargo landing facilities and have adequate transportation infrastructure to absorb increasing cargo flows. In some areas, primarily in the United States and Europe, the competitive environment in attracting cargo and ship

TABLE 5-48. Timber Production in Developing Countries of Latin America, Africa, Asia and Oceania (cubic feet, millions)

	1970	1971	1972	1973	1974	1975	1976	AVERAGE 1970-1976
ROUNDWOOD TIMBER PRODUCTION	40,496	41,710	42,745	43,734	44,218	44,781	45,116	43,257

SOURCE: 1970 Yearbook of Forest Products, FAO of UN (Rome 1978)

TABLE 5-49. Summary of Annual Logging Market (Millions of Cubic Feet)

COUNTRY	TIMBER TYPE	YEARS							AVERAGE	PROJECTED			
		1970	1971	1972	1973	1974	1975	1976	70-76	1980	1990	2000	2020
UNITED STATES	ROUNDWOOD [incl. Sawtimber]	12154 [4039]							13800 [5200]	15318 [5361	17009 5754	18849 6229	19040 6205]
CANADA	ROUNDWOOD [incl. Sawtimber]	4300 [1780]							4900 [2100]	5400 [2304	6200 2988	9100 3660]	
EUROPE	ROUNDWOOD	11496	11541	10958	11427	11526	10654	10806	11200	NOTE: ANTICIPATED FUTURE TREND. SAWTIMBER PROPORTION DECREASES AS MORE OF TOTAL LUMBER IS UTILIZED, BUT SAWTIMBER BECOMES MORE ATTRACTIVE TO LOGGING AS HIGH VALUE MARKET.			
USSR	ROUNDWOOD	13604	13594	13534	13696	13696	13960	13588	13667				
JAPAN	ROUNDWOOD	1760	1660	1576	1603	1407	1286	1347	1506				
AUSTRALIA	ROUNDWOOD	475	497	480	476	501	523	475	490				
NEW ZEALAND	ROUNDWOOD	308	300	310	378	306	302	354	323				
DEVELOPING COUNTRIES	ROUNDWOOD	40496	41710	42745	43734	44218	44781	45116	43257				
TOTALS	ALL ROUNDWOOD								89143				
	US & CANADA SAWTIMBER REST ROUNDWOOD								77743				
	ASSUMED FOR THIS STUDY								75000 to 80000 MILLION CUBIC FEET PER YEAR				

operators to their facilities led some port authorities to construct port capacity in excess of what was needed, causing underutilization of some facilities. Port congestion is therefore virtually non-existent in these countries. Situations of temporary congestion may occur as a result of equipment breakdown, labor disputes, and other situations.

The world trouble spots in terms of congestion have primarily been concentrated in three areas:

- The Inner Mediterranean and North Africa
- The Persian Gulf
- West Africa.

In all these areas major port congestion has occurred with regular frequency. All these areas have planned major port expansion projects, which are expected to cure most of the ills leading to port congestion, except in some of the OPEC nations. A report prepared by the CACI for the Maritime Administration has predicted that despite the vast port expansion programs to be undertaken by the OPEC member nations in the Persian Gulf and North Africa, it is expected that the increase in the waterborne trade of some of these countries will grow faster than the progress of their port expansion projects. The existing and planned additions to the port facilities in the North African and the Persian Gulf OPEC nations is presented in Table 5-50. The capacities of these future facilities are presented as Table 5-51. The definitions of the capacity terms used in Table 5-51 are (Reference 9):

- Nominal Capacity. The annual tonnage a port is expected to process while operating 14-16 hours/day, 280 days/year after weather losses and holidays. No congestion is presumed to occur.

- Extended Capacity. The annual tonnage a port is expected to process in 20-23 hours/day, 310 days/year. Some congestion is inevitable, but it is not serious. Berthing delays are from 0 to 2 days.

- Maximum Capacity. The tonnage per year a port could process if 1975-1976 performance could be sustained. Congestion is severe. Storage areas are also congested. Berthing delays, depending on the port, range from 15 to 30 days.

The expected congestion in these countries is presented for the years 1980 and 1985 in Tables 5-52 and 5-53. Data in these tables suggest that minimal congestion is expected in 1980 for all countries except Saudi Arabia and Libya. By 1985, however, this

TABLE 5-50. OPEC Ports-Likely Completion Schedules for Planned Commercial Port Facilities by Country, 1980 and 1985

	TOTAL NUMBER OF BERTHS[a]				1980				1985			
	1976	1978	1980	1985	GENERAL CARGO BERTHS	CONTAINER BERTHS	RO/RO BERTHS	BULK BERTHS	GENERAL CARGO BERTHS	CONTAINER BERTHS	RO/RO BERTHS	BULK BERTHS
Iran[b]	37	51	70	81	55	8	2	5	58	10	2	11
Saudi Arabia[c]	31	56	123	150	103	4	12	4	130	7	9	4
Iraq[d]	19	26	36	36	29	3	0	4	29	3	0	4
Kuwait[e]	23	23	29	33	25	4	0	0	29	4	0	0
Qatar[f]	4	11	11	21	11	0	0	0	21	0	0	0
UAE[g]	33	43	53	147	42	9	1	1	115	14	2	16
Algeria[h]	NA	NA	(4)[i]	(14)[i]	(4)[i]	(0)[i]	NA	NA	(13)[i]	(1)[i]	NA	NA
Libya[j]	NA	NA	(25)[i]	(25)[i]	(22)[i]	(2)[i]	(1)[i]	NA	(22)[i]	(2)[i]	(1)[i]	NA

[a] For every country, data exclude (1) tanker-loading points, (2) product-loading points, (3) LNG- and LPG-loading points, (4) bunkering berth areas, and (5) some "designated" berths, for example, five chemical product berths in Kuwait and three in Iran that currently exist.

[b] The berths at the existing Bandar Abbas port (8, all general cargo) are included through 1978 and excluded in 1980 and 1985 when they are to be controlled by the Iranian Navy. Government plans specify 1980 operation for all 81 Iranian berths. CACI estimates suggest a later date, 1982, for elements of the new Bandar Abbas port and the Bushahr extension. No announcements have been made for the 1981 period. Subsequent expansion is probable.

[c] Saudi Arabian plans specify a 1981 completion schedule. CACI expects construction to continue through 1983-1984 if the full program is pursued. Possible program cuts are considered in the Saudi chapter later in this volume and also later in this summary. Excluded from the table: seven berths of unspecified type in the industrial section of Juball scheduled for 1980-1981.

[d] The Iraqi port program covers 1976-1980. Projects will be completed as planned. More construction is expected although not shown in the 1985 data because plans have not been released. A CACI estimate suggesting a minimum requirement for construction beyond 1980 status is described in a following table and in the chapter for Iraq.

[e] Kuwait's plans are ambiguous. The desired tonnage capability could be achieved with the berths indicated. However, as many as 18 additional berths may be intended for 1981. No program beyond 1981 has been announced.

[f] Qatar will complete ongoing construction in 1978. Planned but not yet contracted expansion is assumed to be in operation by 1985. Completion by 1983 is feasible if work begins no later than mid-1978.

[g] Only 8 of the 147 total berths planned will not be in operation in 1981 according to official statements. A major, 74-berth port is expected to be finished in 1981. For convenience, none of those berths are included in the 1980 data, although berths would probably enter service over the 1980-1983 period. Program cuts that would not affect the country's ability to process imports and exports are discussed in the UAE chapter and summarized in a following table.

[h] Algerian port plans are elements of a major maritime survey finished in 1975. Few details of the assessment and resulting expansion program have been released. Compounding the problem, information regarding 1975-1976 construction has been generally unavailable. For example, of the 62 total berths at Algiers, only 34 have depths greater than 8 m, and many of those are very short. Relatively low effort could create more deepwater berths but not one-for-one from existing shallow draft berths. Tabular data limited to new berths scheduled for service in 1980 and 1985 are estimated from partial reports.

[i] Partial data are only for new dry cargo berths constructed after 1976 (see notes h and j).

[j] Libyan port programs are concentrated on Benghari and Tripoli. At Benghari, 16 berths are now under construction and should be complete by late 1980. A second set of 16 berths is included in the master plan. These are not counted in the 1985 projection because no construction schedule has been announced. Berths are also to be constructed at Tripoli and Darsa.

NA = Not Available. Inconsistent or incomplete reports have not been used.

SOURCE: CACI

TABLE 5-51. Aggregate Capacity Ratings of Commercial Ports by Country, 1980 and 1985

PLANNED PROGRAMS	1980			1985		
	NOMINAL CAPACITY	EXTENDED CAPACITY[b]	MAXIMUM CAPACITY[b]	NOMINAL CAPACITY	EXTENDED CAPACITY[b]	MAXIMUM CAPACITY[b]
Iran	20.4	23.8	30.9	25.1	32.5	37.9
Saudi Arabia	38.7			45.0		
Iraq	8.1	10.2	12.2	8.1	10.2	12.2
Kuwait	5.1	5.8		8.5	10.0	
Qatar	1.8	2.3		4.1	5.0	
UAE	13.5			32.8		
Algeria	11.8	12.8		15.6	19.6	
Libya	13.6			13.6		
REVISED PROGRAMS						
Saudi Arabia (cutbacks)[c]	18.6			24.2		
UAE (cutbacks)[c]	13.5			17.9		
Iraq (more berths)[d]	8.1	10.2	12.2	12.6	14.5	15.2

[a] In addition to capacities at commercial ports, most countries have berths used primarily for loading certain products, for example, fertilizers, chemicals, and sometimes mineral ores. These berths are not controlled by national port authorities, do not accept traffic in general, and hence are excluded from totals.

[b] Blanks indicate that no estimate was made.

[c] Both Saudi Arabia and the UAE will have port capacity well in excess of their respective requirements. To illustrate the excess, revised programs for both countries have been formulated. Details are found in the respective chapters. In essence, every project scheduled after 1980 has been cut completely or reduced drastically. No program at major existing ports in 1978 has been changed. Delayed schedules for 1980 projects have been imposed.

[d] Iraqi planners have stated their intentions to make Umm Qasr a larger port than Basrah. Although no plans have been announced, the recent rate of Umm Qasr's development, together with reasonable construction schedules, has been used to extrapolate a 1985 port with 16 berths handling 8 million tons/year with container equipment, bulk discharge equipment, and bulk-loading equipment. Existing plans specify an 8-berth port by 1979. The current total is four berths.

SOURCE: CACI

TABLE 5-52. Projected Port Status of OPEC Countries in the Middle East and North Africa, 1980

COUNTRY	TOTAL TRADE	NOMINAL COMMERCIAL PORT CAPACITY	ESTIMATED PORT THROUGHPUT	COMMENTS ON PORTS
Iran	31.6	20.4[a]	24.9 (South) 0.5 (Caspian)	Minimal congestion with use of overland routes
Iraq	12.4	8.1	10.2	Minimal congestion with use of overland routes
Saudi Arabia	10.0	18.6[b]	9.9	No congestion (only 53% of capacity utilized)
Kuwait	6.9	5.1[a]	6.2	Minimal congestion
Qatar	2.7	1.8[a]	2.4	Minimal congestion
UAE	4.0	13.5[b]	3.9	No congestion (only 29% of capacity utilized)
Algeria	20.7	11.8[c]	20.4	Minimal congestion
Libya	11.7	13.6	11.6	No congestion (only 85% of capacity utilized)

[a] Excludes 1-2 million tons of capacity at fertilizer-loading berths.

[b] Based on a hypothetical reduced port program estimated by CACI.

[c] Excludes ore-loading berths at Annaba and Oran with a combined capacity of 4.6 million tons.

SOURCE: CACI

TABLE 5-53. Projected Port Status of OPEC Countries in the Middle East and North Africa, 1985

COUNTRY	TOTAL TRADE	NOMINAL COMMERCIAL PORT CAPACITY	ESTIMATED PORT THROUGHPUT	COMMENTS ON PORTS
Iran	49.1	25.1[a]	37.0	Periodic severe congestion
Iraq	17.6	12.6[b]	14.5	Minimal congestion
Saudi Arabia	14.7	24.2[c]	14.6	No congestion (only 60% of capacity utilized)
Kuwait	11.1	8.5	10.4	Minimal congestion
Qatar	4.1	4.1[b]	3.8	No congestion (only 80% of capacity utilized)
UAE	5.4	17.8[c]	5.1	No congestion (only 29% of capacity utilized)
Algeria	31.0	15.6[d]	30.5	Periodic severe congestion
Libya	13.7	13.6	13.6	No congestion (100% of capacity utilized)

[a] Excludes 5-6 million tons of capacity at fertilizer and petrochemical berths.

[b] Excludes 3-4 million tons of capacity at fertilizer and petrochemical berths.

[c] Based on a hypothetical reduced port program estimated by CACI.

[d] Excludes 10-12 million tons of capacity at ore-loading berths.

SOURCE: CACI

situation is expected to change quite dramatically. Periodic severe congestion is expected in Iran and Algeria. In Iran, the expected cargo throughput is expected to exceed the unusual port capacity by 11.9 million tons, while in Algeria the excess cargo is expected to be 14.9 million tons, or almost half of the total throughput. Minimal congestion is expected in Iraq and Kuwait, while maximum utilization is expected for Libya. Underutilization of capacity is expected for Saudi Arabia, Quatar and United Arab Emirates (UAE). The total expected cargo congestion in the Middle East in 1980 and 1985 is summarized in Table 5-54.

The HLA is limited to handling containerized cargoes, which in the case of the waterborne trade of these nations is currently a relative minor proportion of the total trade volume. The major proportion of the non-petroleum trade consists of construction materials and machinery, fertilizers, petrochemicals, and bulk grain. The total market for loading and discharge of containerized cargo in the congested ports in 1980 and 1985 will therefore be only a proportion of the total market, which is presented in Table 5-50. In 1977, close to 40% of the total trade to this area moved in liner vessels. It is estimated that approximately 80% of these cargoes were containerizable. Thus, containerizable commodities constituted approximately 30% of total trade volume to this area. In developing the market estimate it is assumed that containerizable cargoes will constitute the same proportion of the congested trade as is represented by the total trade. Thus containerized congestion is estimated at 30% of total congestion. The market for heavy-lift services based on this estimate is presented as Table 5-54.

TABLE 5-54. Estimated Container Cargoes in Congested Ports

	1980			1985		
	TOTAL CARGO CONGESTION (MILLION TONS)	CONTAINERIZED CARGO CONGESTION (MILLION TONS)	NUMBER OF * CONTAINERS (THOUSANDS)	TOTAL CARGO CONGESTION (MILLION TONS)	CONTAINERIZED CARGO CONGESTION (MILLION TONS)	NUMBER OF * CONTAINERS (THOUSANDS)
Iran	5.0	1.5	94	11.6	3.5	219
Iraq	2.1	0.6	38	1.9	0.6	38
Kuwait	1.1	0.3	19	1.9	0.6	38
Quatar	0.6	0.2	13	–	–	-
Algeria	8.6	2.6	163	14.9	4.5	281
	17.4	5.2	327	30.3	9.2	576

*Number of containers based on an average load of 16 tons per unit.

5.11 The Market for the Transportation and Rigging of Heavy and Outsized Components

Trade and transportation statistics that separate heavy and outsized component information are not generally available. These components are as a rule aggregated into larger categories that make them difficult to identify. The HLA market for transportation of heavy and outsized components are therefore based on the estimates of people with intimate knowledge of this industry.

The wide diversity of types of products and components requiring specialized transportation and rigging and their maximum weights and dimensions are indicated in Table 5-55.

5.11.1 United States

According to the Heavy and Specialized Carriers Conference of American Trucking Associations, the heavy and specialized truck hauling industry in the United States generates revenues of a pproximately $2.5 million per year, while the crane and rigging industry has total revenues of $2.4 million. The railroads, which control the major share of the heavy and outsized transportation market, have no similar estimate available. The only statistics available indicating the magnitude of the United States railroad market for heavy and outsized transportation are the number of loaded moves by the specialized flatcars. In 1975, a total of 3100 loads were moved on specialized flatcars and in 1976 the total number of loads was 3400. No estimates on the total number transported by barge or ships on the inland waterways are available.

In cases where loads can be rigged and transported by rail, truck, barge, and ship without major complicating factors, the HLA cannot be competitive. It is only in cases where major complications in the form of major route diversions, bridge strengthening, road improvement, and highly specialized and costly rigging are required that the HLA can possibly be competitive. When such complications are introduced, the transportation and rigging job is normally referred to one of the dozen highly specialized rigging and hauling companies in the United States that has the skill, equipment, and resources available to handle such complicated jobs.

Williams Crane Rigging Company, one of the major specialized rigging and hauling companies in the United States, has estimated that the total number of highly complex transportation and rigging jobs involving heavy or outsized components transported by trucks varies between 600 and 1200 per year in the United States. Included in this estimate are components for petrochemical plants and electric generating stations, which are described in Sections 5.1 and 5.5. These two sectors are expected to account for approximately

TABLE 5-55. Maximum Size Units by Industry

ITEM	WEIGHT (METRIC TONNES)	LENGTH (FEET)	WIDTH (FEET)	HEIGHT (FEET)	VOLUME (CFT)	VOLUME / WEIGHT (CFT/MT)	WEIGHT / DK. AREA (MT/FT^2)
I. INDUSTRY NO. 1 – STEAM ELECTRIC POWER							
Generator Rotor	265	69	9	8	4,963	19	0.43
Turbine	300	27	26	26	18,252	61	0.43
Boiler (Complete)	455	100	23	24	55,200	121	0.20
Generator Stator	450	44	14	14	8,624	19	0.73
Turbine Generator	250	30	12	12	4,320	17	0.69
Generator (Complete)	860	62.5	14.6	14.6	13,323	15	0.94
II. INDUSTRY NO. 2 – NUCLEAR POWER							
Boiling Water Reactor (Complete)	1122	56	26	26	37,856	34	0.77
Pressurized Water Reactor (Complete)	555	73	13½	14$^{2/3}$	14,454	26	0.56
Nuclear Reactor	900	75	30	30	67,500	75	0.40
Neutron Shield Tank	182	41	28	28	32,144	177	0.16
Biological Shield Wall	910	80	35	35	98,000	103	0.33
III. INDUSTRY NO. 3 – GAS TURBINE – ELECTRIC POWER							
Gas Turbine – Generator	228	35	15	14	7,350	32	0.43
Gas Turbine	140	50	18	18	16,200	116	0.16
Gas Turbine Compressor Module	182	100	40	40	160,000	897	0.05
IV. INDUSTRY NO. 4 – HYDROELECTRIC MACHINERY							
Hydroelectric Generator	408	76	40	45	136,800	335	0.13
V. INDUSTRY NO. 5 – INTERNAL COMBUSTION ENGINES							
Diesel Generator	330	68	30	40	78,000	236	0.17

TABLE 5-55. Maximum Size Units by Industry (Continued)

ITEM	WEIGHT (METRIC TONNES)	LENGTH (FEET)	WIDTH (FEET)	HEIGHT (FEET)	VOLUME (CFT)	VOLUME/WEIGHT (CFT/MT)	WEIGHT/DK. AREA (MT/FT^2)
VI. INDUSTRY NO. 6 – ELECTRIC TRANSMISSION EQUIPMENT							
Dry Three-Phase Transformer	439	39	13	15	7,605	17	0.187
Transformer	600	43	13	17	9,503	16	1.07
IX. INDUSTRY NO. 9 – REFINERIES AND CHEMICAL PLANTS							
Pressure Vessel	209	165	29	29	140,397	153	0.49
Towers	450	164	36	36	212,544	472	0.08
Reactor	410	70	23	23	37,030	90	0.25
LPG Storage Tanks	55	100	12	12	14,400	262	0.05
Heat Exchangers	255	200	14	14	39,200	154	0.09
Columns	150	121	17	17	34,969	233	0.07
Absorbers	230	131	9	9	10,611	46	0.20
Separators	345	118	20	21	49,560	144	0.15
Converters	507	71	12	13	11,076	22	0.90
Evaporators	150	39	13	13	6,591	44	0.30
Oil Splitter	220	113	28	28	88,592	403	0.07
Gas Compresser	250	60	40	40	96,000	384	0.10
CO_2 Stripper	319	200	20	20	80,000	251	0.08
VIII. INDUSTRY NO. 8 – METALWORKING MACHINERY							
Steel Press (1 Piece)	209	40	14	20	11,200	54	0.37
Oxygen Furnace Vessel	164	60	26	26	40,560	247	0.11
Mill Housing	228	35	7½	18½	4,856	21	0.87
X. INDUSTRY NO. 10 – TEXTILE AND LEATHER MACHINERY							
Spinning Machinery	137	100	12	8	9,600	70	0.11

TABLE 5-55. Maximum Size Units by Industry (Continued)

ITEM	WEIGHT (METRIC TONNES)	LENGTH (FEET)	WIDTH (FEET)	HEIGHT (FEET)	VOLUME (CFT)	VOLUME / WEIGHT (CFT/MT)	WEIGHT / DK. AREA (MT/FT^2)
XI. INDUSTRY NO. 11 – FOREST PRODUCTS MACHINERY							
Cylinder Dryer	122	16	16	12	3,072	25	0.46
Log Stacker	86	42'7"	14'10"	18'8"	13,174	153	0.14
Paper Pulp Digester	204	100	15	15	22,500	110	0.14
Calender Roller	120	16	5	5	400	3	1.50
XII. INDUSTRY NO. 12 – CONSTRUCTION MACHINERY							
Crane Girder	36	120	10	18	21,600	600	0.03
XV. INDUSTRY NO. 15 – OFF SHORE OIL PLATFORMS & EQUIPMENT							
Deckhouse	455	80	80	15	96,000	211	0.07
Mud Reconditioning	400	62	26	56	90,272	226	0.25
Flow Station	279	86	17	44	64,328	231	0.19
Platform Modules	882	66	66	30	130,680	148	0.20
Compressor Modules	273	90	40	45	162,000	593	0.08
Platform Jacket	910	200	160	80	2,560,000	2,813	0.03
Gas Compressor	391	52	50	60	156,000	399	0.15
Mooring Winches	137	15	15	20	4,500	33	0.61
Blowout Preventer Stack	148	12	12	35	5,040	34	1.03
XVII. INDUSTRY NO. 17 – RAILROAD LOCOMOTIVES & CARS							
Diesel-Electric Locomotive	143	73	12	14	12,264	86	0.16
XIII. INDUSTRY NO. 13 – MECHANICAL HANDLING EQUIPMENT & MACHINERY							
Rotary Portal Crane	164	68	32	30	65,280	398	0.08
Container Crane	546	80	60	120	576,000	1,055	0.11
Bulk Unloader	728	80	60	100	480,000	659	0.15
Truck	162	53	23'10"	16'2"	20,423	126	0.13

TABLE 5-55. Maximum Size Units by Industry (Concluded)

ITEM	WEIGHT (METRIC TONNES)	LENGTH (FEET)	WIDTH (FEET)	HEIGHT (FEET)	VOLUME (CFT)	$\frac{\text{VOLUME}}{\text{WEIGHT}}$ (CFT/MT)	$\frac{\text{WEIGHT}}{\text{DK. AREA}}$ (MT/FT^2)
XIV. INDUSTRY NO. 14 – MINTING AND MINERALS MACHINERY							
Hauler	97	78'1"	18'8"	15'22"	23,207	239	0.07
Crusher	91	20	30	30	18,000	198	0.15
Shovel Assembled	410	40	14	65	36,400	89	0.73
Rotary Converter	255	22	15½	15½	5,286	21	0.75
Kiln Rings	100	5	24	24	2,880	29	0.83
Mill Shell	182	24	34	34	27,744	152	0.22
Kiln Section	91	80	18	18	25,920	285	0.06
XIX. INDUSTRY NO. 19 – VESSELS – BOATS, DREDGES, BUOYS, BARGES							
Barge	1,347	175	42	8	58,800	43	0.18
Dredge – 30"	1,547	160	48	6	46,080	30	0.20
Ro–Ro Ramp	73	125	24	5	15,000	205	0.02
Tug Boat	305	151	31	34	159,154	522	0.07
Buoy	250	28	54	54	81,648	327	0.17
Vessel	148	75	22	48	79,200	535	0.09
Ferryboat	240	133	38	36	181,944	758	0.05
XX. INDUSTRY NO. 20 – MILITARY EQUIPMENT							
LCM 8	60	73'8"	21	13	20,112	335	0.04
LCU	184	119	34	17– 3/4	71,817	390	0.05
Causeway	61	90	21¼	5	9,563	157	0.03
Larc 10/X	90	62½	26'7"	15'4"	25,467	283	0.05

SOURCE: Lykes Bros. Steamship Co., Inc.

half the total jobs in this area. Thus, if we deduct these two sectors, a total market of between 300 and 600 jobs will be generated for specialized rigging and hauling in sectors other than the electric generating, refinery, and petrochemical plant construction in the United States.

5.11.2 Western Europe

In Western Europe, the total number of heavy and outsized components requiring specialized transportation per year for the period 1980 to 1985 has been estimated (Reference 10)* as follows:

Components Weight (tons)	Number of Items
35 - 100	6550
100 - 300	990
300 - 500	450

The great majority of these components can easily be transported and rigged without complication by conventional means of transportation and lifting. It is estimated that specialized carriers have to be employed for partial or complete rigging and transportation of a number of jobs equal to that in the United States (i.e, between 600 and 1200 per year). In Western Europe, as in the United States, it is expected that the electrical generating, and petrochemical plant construction projects, which already have been accounted for in previous sections, will account for approximately half of these jobs. Thus the total number of other jobs in which an HLA could potentially become active would be between 300 and 600 jobs per year.

5.11.3 The Remaining World

Good estimates on the total number of highly complex transportation and rigging jobs in the remainder of the industrialized and developing world have not been found. It is a fact, however, that the United States and Western Europe together account for more than 2/3 of the total economic activity in the world. The transportation and rigging of heavy and outsized components are closely related to the total economic activity. On this basis, it can be estimated that the total market for specialized rigging and hauling services in the world outside of the United States and Western Europe where an HLA can be competitive will be approximately equal to the average of the market size in these two areas, or between 300 and 600 jobs per year.

The total worldwide market for general transportation services where the HLA can be competitive is summarized in Table 5-56.

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* G.S. Nesterenko and V.I. Narinskiy, "Modern Aerostatic Flight Vehicles", NASA TM-75092, May 1978, P. 35.

TABLE 5-56. Market for Transportation and Rigging of Heavy and Oversized Components

COUNTRIES	NUMBER OF MOVES	
	LOW	HIGH
United States	300	600
Europe	300	600
Other World	300	600
Total	900	1800

5.11.4 Other Potential Markets for HLAs

As can be seen from the above market for general transportation and rigging services, the use of the HLA in competition with existing modes of transportation is limited. The greatest market potential for the HLA, however, may come from opportunities that currently do not exist.

With the exception of barges, all currently existing modes of transportation have highly restrictive limitations on the weight and dimensions of the cargoes to be transported. A number of cargoes therefore have to be subdivided into smaller components for transportation and then reassembled at the destination. This disassembly and reassembly can be quite costly and have been estimated to account for up to 35% of the cost of the delivered products for a highly complex product like a turbine and shaft for an electric generating station.

There have also been indications of cases where components have had to be redesigned to enable subdivision into smaller components for transportation. Such changes have resulted in increases to both design and manufacturing costs.

It has been indicated by the people interviewed that the preference of manufacturers is to preassemble their products into the largest possible modules that can be accommodated by the capabilities of the existing transportation infrastructure and equipment, because substantial savings can be achieved by raising products preassembled in a factory compared to field conditions. The trend is towards larger and heavier components.

An indication of the prevalence of having to disassemble components for shipments is also indicated by the study sponsored by MARAD and Lykes Brothers Co. (Reference 4). Table 5-57 presents a tabulation of items that could be shipped assembled, but are disassembled due to the limitations of the transportation infrastructure.

An assessment of the ability of the HLA to compete for this market is indicated in the case studies on the construction of electric generating plants and transportation of shovels for strip mining. A further assessment of this potentially large market will require an extensive investigation which is beyond the scope of this study. No attempt has therefore been made to quantify this market.

5.12 The Potential Military Market

Possible applications for HLAs in the military are any short-range lifts of heavy or oversize cargoes in situations where local air superiority is assessed. Such situations are most typified by the follow-up ship-to-shore movement of cargoes in an amphibious assault. These cargoes would include standard military containers, heavy, earth moving equipments, vehicles, structural sections, and POL.

The greatest volume of ship-to-shore traffic is that of delivering containers. Reference 11 describes a comparison between several current techniques for providing a typical level of ship-to-shore such as would be required to supply an amphibious operation. In order to be competitive, an HLA would need to be able to carry an aggregate payload of at least 3 full containers over an average one-way two-mile trip in less than 7 minutes. This corresponds to a 75 ton payload and a block speed of approximately 25 to 30 mph assuming turnaround times at each end of about 2 to 2-1/2 minutes, and inflight accelerations and decelerations of about .05 to .10 g.

5.13 Concluding Remarks

In the preceding sections of this chapter the markets for heavy-lift services in which the HLA might compete have been quantified and expressed in terms peculiar to each area of application. These markets are summarized in Table 5-58. This information provides the basis for determining the size of the market for HLA services, the HLA sizes, and the number of each size required. The methodology used and the results obtained in this final step of market evaluation are described in the next chapter.

TABLE 5-57. Items That Could be Shipped Assembled

ITEM	KNOCKED DOWN				ASSEMBLED			
	WEIGHT	LENGTH	WIDTH	HEIGHT	WEIGHT	LENGTH	WIDTH	HEIGHT
INDUSTRY II:	**NUCLEAR ELECTRIC POWER MACHINERY**							
Reactor Pressure Vessel	118 MT	--	--	--	1,147 MT	--	--	--
	73 MT	--	--	--				
Nuclear Reactor	95 MT	8'	30'	30'	819 MT	75'	30'	30'
	100 MT	16'	28'	28'				
INDUSTRY VII:	**METALWORKING MACHINERY**							
Oxygen Furnace	173 MT	28'	28'	20'	364 MT	28'	28'	35'
	127 MT	20'	20'	15'				
	32 MT	20'	20'	8'				
	32 MT	20'	20'	8'				
Oxygen Furnace	319 MT	33'	33'	23'	728 MT	33'	33'	36'
	319 MT	33'	33'	23'				
	46 MT	28'	28'	11'				
	46 MT	28'	28'	11'				
Metalworking Press	209 MT	40'	14'	20'	573 MT	72'	16'	46'
	205 MT	48'	16'	24'				
	159 MT	--	--	–				
INDUSTRY IX:	**CHEMICAL PLANTS AND REFINERIES**							
Gold Box	91 MT	15'	11'	111'	546 MT			
	64 MT	9'	11'	44'				
	36 MT	7'	11'	25'				
	27 MT	7'	10'	13'				
INDUSTRY XIII:	**MECHANICAL HANDLING EQUIPMENT**							
Port Crane	55 MT	140'	21'	13'	546 MT	140'	21'	13'
Crawler Tractor	9 MT	15'	4'	7'	48 MT	19'11"	11'2"	11'
Truck Crane	53 MT	(5,904 cubic feet)			137 MT	--	--	--
	1 MT	30'	6'5"	6'5"				
Truck	19 MT	27'7"	7½'	10'2"	159 MT	48'	25½'	21'2"
	17 MT	26'1"	12'8"	10½'				
	15 MT	38'7"	11½'	12¼'				
	12 MT	38'7"	11½'	12¼'				
	10 MT	10'11"	5'9"	6½'				
	7 MT	25¼'	10'4"	7½'				

TABLE 5-57. Items That Could be Shipped Assembled (Continued)

ITEM	KNOCKED DOWN				ASSEMBLED			
	WEIGHT	LENGTH	WIDTH	HEIGHT	WEIGHT	LENGTH	WIDTH	HEIGHT
INDUSTRY XIV:	**MINING AND MINERALS MACHINERY**							
Gasifier (for coal)	27 MT	14′	14′	8′	245 MT	14′	14′	40′
Kiln	82 MT	40′	18′	18′	– –	500′	18′	18′
Mill Shell	46 MT	33′8″	16′2″	12′	200 MT	34′	34′	24′
4 @	39 MT	– –	– –	– –				
Hauler	27 MT	31′	11′	10′3″	102 MT	38′9″	20′1″	19′
	8 MT	22′9″	11′	6′7″				
	7 MT	8¼′	5′8″	5′9″				
	3 MT	8′10″	4′7″	6½′				
	1 MT	8′9″	6′	5′11″				
Dragline 2 @	84 MT	40′	10′	16′	2,152 MT	(159, 186, cubic feet)		
2 @	59 MT	46′7″	13′1″	9′8″				
	44 MT	47′1″	12′8″	8′10″				
	42 MT	49′11″	12¼′	9¼′				
2 @	41 MT	20′10″	2′11″	14½′				
Dragline	121 MT	70′	15′5″	10′	7,735 MT			
	106 MT	70′	13′2″	10′				
	105 MT	39′	11′10″	14′3″				
	92 MT	47′	14′	11′7″				
	90 MT	47′	14′	11′7″				
	88 MT	51′9″	11′10″	8′9″				
INDUSTRY XV:	**OFFSHORE OIL PLATFORMS AND EQUIPMENT**							
Fixed Oil Tower	139 MT	– –	– –	– –	355 MT	100′	30′	30′
	129 MT	– –	– –	– –				
	87 MT	– –	– –	– –				

TABLE 5-57. Items That Could be Shipped Assembled (Concluded)

ITEM	KNOCKED DOWN				ASSEMBLED			
	WEIGHT	LENGTH	WIDTH	HEIGHT	WEIGHT	LENGTH	WIDTH	HEIGHT
INDUSTRY XV:	**OFFSHORE OIL PLATFORMS AND EQUIPMENT (CONTINUED)**							
Gas Production Platform	319 MT	– –	– –	– –	1,092 MT	160'	40'	60'
	364 MT	– –	– –	– –				
	410 MT	– –	– –	– –				
Derrick 2 @	455 MT	30'	30'	20'	1,820 MT	– –	– –	– –
	228 MT	70'	33'	20'				
	341 MT	– –	– –	– –				
	341 MT	– –	– –	– –				
Platform Rig 10 @	91 MT	20'	20'	– –	910 MT			
INDUSTRY XIX:	**VESSELS**							
30" Dredge	137 MT	– –	– –	– –	1,183 MT	150'	45'	34'
4 @	36 MT	70'	– –	– –				
2 @	55 MT	55'	14'	10'				
6 @	– MT	55'	16'	10'				
Dredge	40 MT	45'	10'	15½'	107 MT			
	8.2 MT	55½'	5.4"	5'9"				
	8.2 MT	55'8"	5'2"	5'9"				
2 @	5.1 MT	34'	1½'	1½'				
2 @	2.1 MT	15½'	6'	1½'				
	1 MT	17½'	11½'	2½'				
	300 MT	8'9"	8'5"	5"				
	9.2 MT	36'	8'7"	5'2"				
2 @	18.4 MT	30'	14'	10'				
	12.2 MT	23¼'	8'	10'8"				

SOURCE: Lykes Bros. Steamship Co., Inc.

TABLE 5-58. Summary of Markets Requiring Heavy Lift Services

APPLICATION	ANNUAL MARKET		UNITS
	NORTH AMERICA	WORLD TOTAL	
Transportation and Erection of Refinery and Petrochemical Plant Components	0.5×10^6	3.3×10^6	Barrels per day
Support of Construction of Offshore Permanent Drilling and Production Platforms for Oil and Gas	40 to 90	50 to 150	Platforms constructed per year
Movement of Strip Mining Power Shovels	95	Not Available	Shovels moved per year
Support of High Voltage Power Transmission Line Construction 345 KV 500 KV 765 KV	 4000 1300 360	 12,800 4,000 570	Miles of line construction per year
Electric Power Generating Plant Construction	36300	85000	MW generating capacity added per year
Support of the Construction of Gas or Oil Pipelines	2400 to 2700	10000 to 12000	Added pipeline mileage per year
Support of the High Rise Construction Industry HVAC. Window Wash. Cranes.	 4250 to 5200 5000 to 6000 250 to 300	Not Available	Number of lifts per year
Support of Remote Drilling Installations and Operations	34	100	Wells drilled per year
Logging	7300*	75 to 80,000	Millions of cubic feet per year
Unloading Cargo in Congested Ports	0	325,000 to 575,000	Number of containers moved per year
Transportation and Rigging of Heavy and Oversized Components	300 to 600	900 to 1800	Number of moves per year

ESTIMATION OF VEHICLE SIZES AND NUMBERS TO SATISFY EACH APPLICATION

CHAPTER 6

6. ESTIMATION OF VEHICLE SIZES AND NUMBERS TO SATISFY EACH APPLICATION

LIST OF FIGURES

LIST OF TABLES

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6. ESTIMATION OF VEHICLE SIZES AND NUMBERS TO SATISFY EACH APPLICATION

6.1 Introduction

The previous section contained assessments of the total market potential for heavy lift transportation in areas where the HLA could be competitive. These assessments were preceded by operational and cost analyses. The effort reported in this section builds on that data through case studies to suggest how the HLA might enhance its competitive position in these markets, and the potential market share that might be acquired by HLA operators.

The procedure employed was to develop, through a case study for each application, the threshold cost characteristics and the HLA cost characteristics for the applications discussed in Chapter 5. The variation of the market share with savings occurring from HLA usage, and the resulting number of HLAs required to support the anticipated market share, were determined. The results for all cases are then combined into a total market and the effects of varying the major parameters on this market are identified. The HLA requirements that would enhance the overall market, HLA sizes, market areas for earliest introduction, and the potential for military application are also discussed.

6.2 Market Assessment Logic

The following defines the logic used to determine the number of HLAs to satisfy the market defined in Chapter 5.

6.2.1 Relationship Between Market and HLA Operational Characteristics

In order to develop a firm quantifiable relationship between HLA operational characteristics and any market, a major parameter must be defined for each market that describes the size of that market in terms that can be directly related to the ability of HLAs to carry heavy lift items in that market. For example, logging is characterized by "cubic feet logged per year", which is directly relatable to the rate of logging attainable with an individual HLA. Any given market may have several uses for HLA's with different characteristics, each of which must be dealt with separately, and then aggregated to define the total market.

6.2.2 Definition of Market Share for HLAs

Having defined the market in HLA related terms, and identified the HLA use, the results of the threshold and cost sensitivity analyses of Sections 4 and 5 are used as the basis for determining the market share. A necessary preliminary step is to characterize the response of each market to the introduction of a system with potential for reducing costs. An in-house review of past study work and the experience of professionals in the general transportation field coupled with responses from the shippers and operators interviewed, provided the basis for development of a simple but representative algorithm relating market share to money saved by using a given transport mode. The industry associated with each case study was reviewed to define, on the basis of industry conservatism, innovativeness, competitiveness, and the value of goods to be handled by the HLA, two market features:

- The minimum percent savings (A) over the current threshold costs that must be achieved before the HLA can begin to share in the market
- The percent savings (B) beyond which the HLA would be assured of virtually the whole market.

With these two features defined, a relationship between "HLA percent market share" and "Savings through HLA, (percent threshold costs)" can be readily hypothesized. The initial variation of market share with percent savings would be gentle. Subsequent rates of increase in market share would grow until 100% of the market is reached. An algorithm reflecting such behavior is:

$$M = 100 \left[\frac{1}{1-0.632 \left(\frac{S-A}{B-A} \right)} \right]$$

where M is percent market share, and S is savings (percent threshold cost).

The values for A and B that resulted from the discussion are given in Table 6-1. The market share is thus obtained, once the savings is determined from the threshold and HLA costs for the case study.

TABLE 6-1. Percent Earnings Required to Enter and Capture Market

CASE STUDY	% SAVINGS TO	
	ENTER MARKET (A)	CAPTURE MARKET (B)
Logging	0	30-35
Port Congestion,Cargo Unloading	20	50
Transmission Line Towers Construction Support	0	30-35
Remote Drilling Rigs Support	5-10	20-30
Power Plant Construction Support	20-25	50
Oil & Gas Production Platforms	20	50
High Rise Construction Industry Support	0-5	25-30
Home Building	20	50
Refinery Construction	20-25	50
Transportation of Damage Sensitive Components	25-30	50-60
Transportation of Damage Insensitive Components	10-15	35-40
Transportation of Agricultural Products	15-20	30-35
Pipeline Logistic Support	20-25	30-40
Strip Mining Shovel Transport	10-15	35-40

6.2.3 Relationship to Real Life Competition

The approach used to determine numbers of HLAs recognizes that competition between conventional and alternative heavy lift concepts will exist. It attempts to reflect that competition in such a way that the effect of varying the elements of the competition can be assessed, at least qualitatively. The numbers of HLA will vary as the "share" relationship varies in form, content and likelihood; this relationship is assumed to be linear in the study. Through the mechanism of that relationship, the numbers will also vary as the financial arrangements made to finance or subsidize the operator's purchase of HLAs, are varied. The numbers will also vary as the efficiency of the HLA as a heavy lifter is changed, as reflected in operating cost, in ferry costs, and in productivity. It is recognized, however, that none of these variations can substitute for a rigorous examination of market trends, financial status, profit potential of the HLA, and capital equipment investment, such as an operator has to undertake in real life. With that in mind, it is suggested that the numbers generated here represent an upper bound to the likely HLA market.

6.2.4 Definition of Free-Flying Vehicle (HLA) "Threshold Cost"

Consider that the same task involving heavy lift is to be performed by either a combination of conventional techniques, or a combination of techniques including use of a free-flying vehicle. The costs for performing the task conventionally can be estimated from experience with the conventional techniques, while the cost of performing the task in the second approach (assuming a specific combination of techniques) can be estimated for all elements except that of the free-flying vehicle (FFV) itself. Thus, a break-even value for the cost of using the FFV can be defined by equating the two sets of costs, so that the cost of the task when using the FFV does not exceed the cost of doing it conventionally. The cost of the FFV that would be required to satisfy this break-even cost is the threshold cost of the FFV in performing the task, and can be directly compared with the actual HLA cost incurred in performing its part of the overall task.

These approaches to performing the task may differ considerably because the FFV can be operated such that traditional difficulties normally overcome by conventional techniques no longer exist (such as physical obstacles that must be bypassed, use of heaving lifting machinery that must be transported to the site, preparation of a route to the site and the site itself, to permit use of the machinery). Because the FFV can be operated in this manner, many of the ground system costs can be dramatically reduced through reductions in the need for machinery, in the need

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for route and site preparation and in the need to restore the route and site to minimize ecological or social impact. In addition, because a FFV can operate more quietly and over a more direct path than ground systems, task times can be reduced, thus reducing labor costs, financing costs, storage costs and costs from pilferage and deterioration. Finally, because maximum size restrictions on components can be relaxed when using an FFV designed to carry the full weight of a component, the component need not be designed to be dismantled for transportation and reassumbly on site; by eliminating this step through use of an FFV, manufacturing costs are reduced through increased productivity, and task costs are further reduced by eliminating disassembly and assembly time. Use of an FFV may, however, incur some additional costs from the use of ground system support not previously required, such as specially-trained crews at the site where the heavy lift is to be placed to aid in hook-up, positioning the load, and disconnecting from the FFV. These are in addition to the costs of the use of the FFV itself.

These elements and their relationship to HLA Threshold Cost as defined above are illustrated in Table 6-2. From this table, at break-even conditions,

$$\text{Total cost of approach } \textcircled{1} = \text{total cost of approach } \textcircled{2}$$

$$\text{that is} \quad \sum\textcircled{1} = \sum\textcircled{2} + \sum\textcircled{2}^{*}$$

$$\text{and FFV (HLA) threshold cost} = \sum\textcircled{1} - \sum\textcircled{2} = \sum\Delta\text{'s}.$$

Consequently, the FFV or HLA Threshold Cost, is the sum of <u>all</u> the differences in cost between the two techniques, excluding the direct charges for the HLA itself.

In determining the Threshold Cost in the ensuing analyses, these differences in cost are carefully identified and defined so that subsequent analysis can consider their significance and uncertainty with respect to the final determination of the numbers of HLAs required to satisfy world-wide heavy-lift needs.

6.3 Generalized Assessment Methodology for Number of Vehicles to Fulfill a Particular Heavy Lift Need

The total number of vehicles (N_V) is a product of the number of HLA vehicles to satisfy the total need for heavy lift services ($\bar{N}_V$) and the share of that market that can be acquired by HLA operators (M).

TABLE 6-2. Elements of Job Costs for Conventional Techniques and for Alternative Techniques Using Free Flying Vehicles

JOB COST AND TIME COMPONENTS						
		COMPONENTS	APPROACH ① USING ALL CONVENTIONAL TECHNIQUES	APPROACH ② USING TECHNIQUES THAT INCLUDE FREE FLYING VEHICLES		HLA THRESHOLD COST (= HLA JOB COST WHEN COSTS OF THE TWO APPROACHES ARE EQUAL)
				GROUND ACTIVITIES BY CONTRACTOR	HLA JOB COSTS	
TO DO JOB	ON SITE	EQUIPMENT	JE_1	JE_2	JE_2^*	ΔJE
		LABOR	JL_1	JL_2	JL_2^*	ΔJL
		FUEL/OIL	JF_1	JF_2	JF_2^*	ΔJF
JOB SUPPORT	ON SITE	CONSUMABLES	SC_1	SC_2	SC_2^*	ΔSC
		FACILITIES	SF_1	SF_2	SF_2^*	ΔSF
		STORAGE/HOLDING	SS_1	SS_2		ΔSS
		SITE PREPARATION	SP_1	SP_2		ΔSP
		SITE RESTORATION	SR_1	SR_2		ΔSR
	TRANSP. TO SITE	EQUIPMENT	TE_1	TE_2		ΔTE
		SUPPLIES	TS_1	TS_2		ΔTS
		MEN	TM_1	TM_2		ΔTM
		ROUTE PREPARATION	TP_1	TP_2		ΔTP
		ROUTE RESTORATION	TR_1	TR_2		ΔTR
		MANUFACTURING COST ‡	P_1	P_2		ΔP
		JOB FINANCING	F_1	F_2		ΔF
		THEFT/DAMAGE/SPOILAGE				
TOTALS			Σ①	Σ②	Σ②*	

‡ FUNCTION OF PRODUCTIVITY, EXTENT OF ASSEMBLY/DISASSEMBLY, LOST PRODUCTION TIME

Each term depends directly on the number of hours per year that each HLA vehicle can be earning revenue in performing heavy lift work; that is,

- The number of vehicles required to fulfill the total heavy lift need ($\bar{N}_V$) increases, as the productive hours per vehicle per year decreases
- The market share that can be acquired by HLA vehicles (M) decreases, as the operators cost and therefore his price for a heavy lift job increases with decreasing productive hours per year per vehicle.

These two terms are in conflict; their interaction must be explored, since the consequence is valid for all applications.

6.3.1 The Number of Vehicles Required to Fulfill a Total Heavy Lift Need

Let the heavy lift needs be defined in terms of H units per year (where H could be "events logged," "towers lifted," "ships unloaded," etc.).

Let the annual utilization for the HLA be U operating hours per year.

Let the non-productive (mainly ferry) operating time be T_F hours per year.

Then the required heavy lift rate that all HLA together must achieve is

$$\left[H/(U - T_F)\right] \text{ vehicle—units per hour}$$

Each HLA can achieve a particular rate of heavy lift operations for a specific application which can be described as

"h" units per hour

Consequently, the number of HLA required to satisfy the specific heavy lift need is

$$\bar{N}_V = \frac{H}{hU\left[1 - \frac{T_F}{U}\right]} = \bar{N}_{V_{NF}} \Big/ \left(1 - \frac{T_F}{U}\right)$$

assuming the HLA can capture 100 percent of this application (Note that $\bar{N}_{V_{NF}}$ is the total number of vehicles if no ferry is required, i.e., $T_F = 0$).

6.3.2 The Market Share to be Acquired by HLA

As defined earlier, the market share that an HLA can acquire is governed to a significant degree by the savings an HLA can generate relative to the threshold costs for an HLA in that application. The nonlinear algebraic relationship defined earlier reflects closely the probable manner in which the share would vary as the savings increased. For convenience in analysis, that relationship has been simplified to the following,

$$M = \left[(S - A)/(B - A)\right]100$$

with little loss in the validity of the results.

The savings, S, generated by the HLA in a particular application, is the difference between the Threshold Cost for the job (TC), and the HLA cost for the job (HLAC)

$$\text{i.e.,} \quad S = \left(\frac{TC - HLAC}{TC}\right)100 = \left(1 - \frac{HLAC}{TC}\right)100$$

Since ferry costs must be recovered, the cost of ferry must be included in HLAC. However, at this stage in HLA development, ferry costs for a particular job are speculative, since no national base locations have yet been defined. A rational way of defining ferry costs per job is to assume a level of ferry costs per year, and prorate a share to the job

$$\text{i.e.,} \quad HLAC = HLAC_{NF} + \left(C_F \cdot T_F\right)\frac{T_J}{U}$$

where

$HLAC_{NF}$ is the job cost without ferry

T_F is the annual hours of ferry (assumed)

T_J is the time to complete the job

U is the annual HLA utilization

C_F is the cost per ferry hour.

Combining all terms, the market share M can be defined as

$$M = \left\{\left[1 - \left(\frac{HLAC_{NF} + \frac{C_F T_F T_J}{U}}{TC}\right)\right] - A\right\} \Big/ (B - A)$$

$$= \frac{\left(1 - \frac{HLAC_{NF}}{TC}\right) - A}{B - A} - \left(\frac{C_F T_J}{(B - A)\,TC}\right) \frac{T_F}{U}$$

$$= M_{NF} - \left(\frac{C_F T_J}{(B - A)\,TC}\right) \frac{T_F}{U}$$

$$M = M_{NF}\left[1 - \left(\frac{C_F T_J}{(B - A)\cdot TC\cdot M_{NF}}\right) \cdot \frac{T_F}{U}\right] = M_{NF}\left[1 - \frac{C_F}{C_F^*}\,\frac{T_F}{U}\right]$$

6.3.3 Number of Vehicles Required to Fulfill HLA Share

Combining the two relationships

$$N_V = \bar{N}_V \cdot M$$

$$= \left(\frac{H}{hU} \cdot M_{NF}\right)\left[\frac{1 - \frac{C_F}{C_F^*}\,\frac{T_F}{U}}{1 - \frac{T_F}{U}}\right]$$

Note that the first term defines the number of vehicles required if no unproductive HLA hours are spent per year, (i.e., $\bar{N}_{V_{NF}}$) while the second term provides the modification that accounts for the effect of non-productive hours.

Examining this relationship, it can be seen that when $\frac{C_F}{C_F^*} = 1$, the number of vehicles required is unaffected by the increase in unproductive hours since the share decreases at the same rate as the number of vehicles for the total share increases. When $\frac{C_F}{C_F^*} < 1$, N_V increases with T_F at a rate depending on $\frac{C_F}{C_F^*}$; when $\frac{C_F}{C_F^*}$ decreases below 1, N_V decreases, until $\frac{C_F}{C_F^*} = \frac{U}{T_F}$, at which point $N_V = 0$, because the increase in nonproductive costs has reduced the market share to zero. These relationships are shown in Figure 6-1.

6.3.4 The Characteristics of the Parameter $\frac{C_F}{C_F^*}$

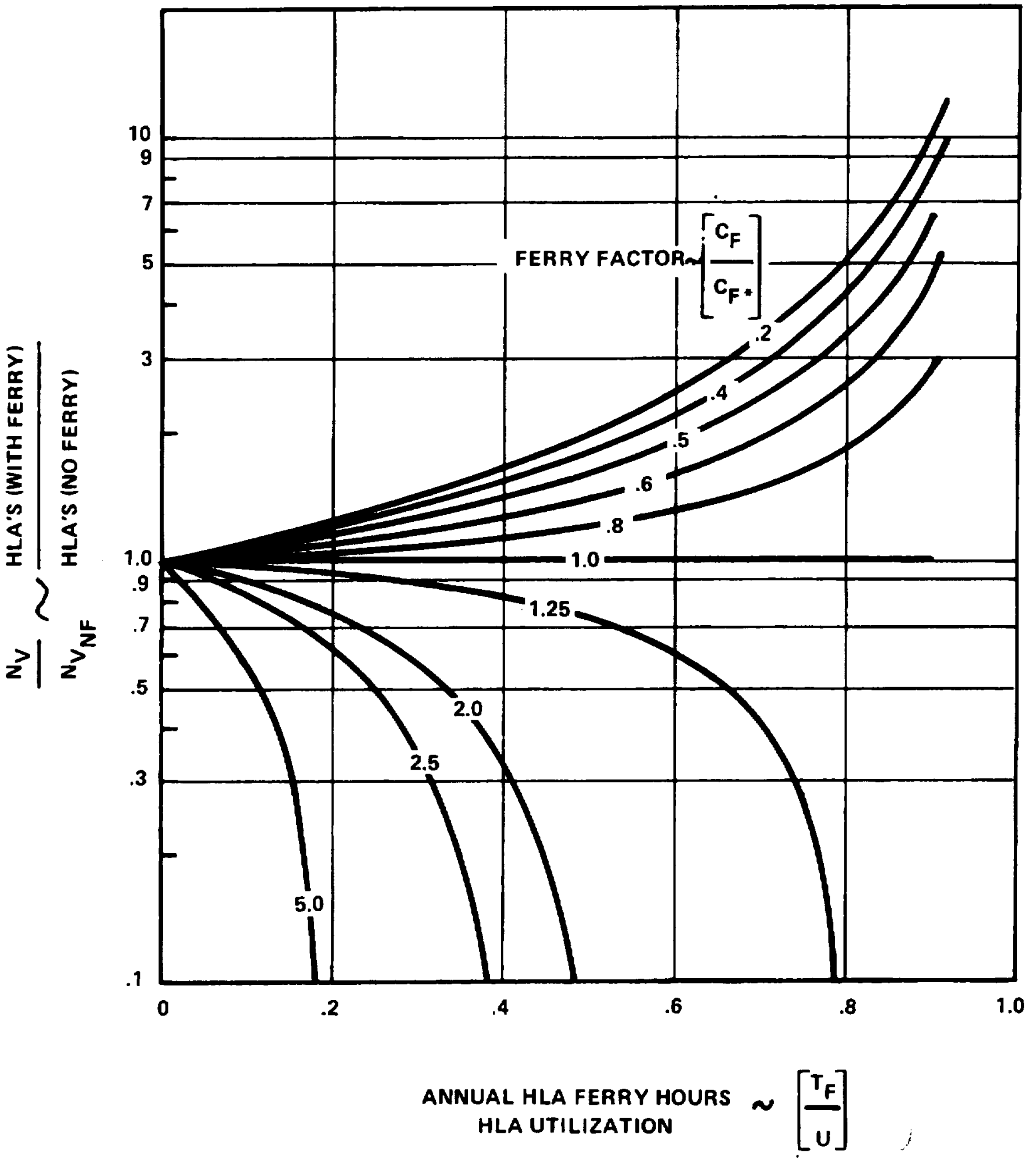
As defined above

$$\frac{C_F}{C_F^*} = \frac{C_F}{\left[(B - A)\cdot\frac{TC}{T_J}\cdot M_{NF}\right]}$$

$$= \frac{C_F}{[(S_{NF}) - A\ TC]/T_J}$$

$$= \frac{\left[\frac{C_F\ T_J}{TC}\right]}{[S_{NF} - A]}$$

FIGURE 6-1. The Effect of Ferry on the Number of HLA



As previously defined, $(S_{NF} - A)TC$ is margin between the HLA job cost and the minimum cost at which the HLA can enter the market

$$\text{i.e.,} \quad \frac{C_F}{C_F^*} = \frac{(\text{Ferry Cost})/(\text{Ferry Time})}{(\text{Job Cost Margin})/(\text{Job Time})}$$

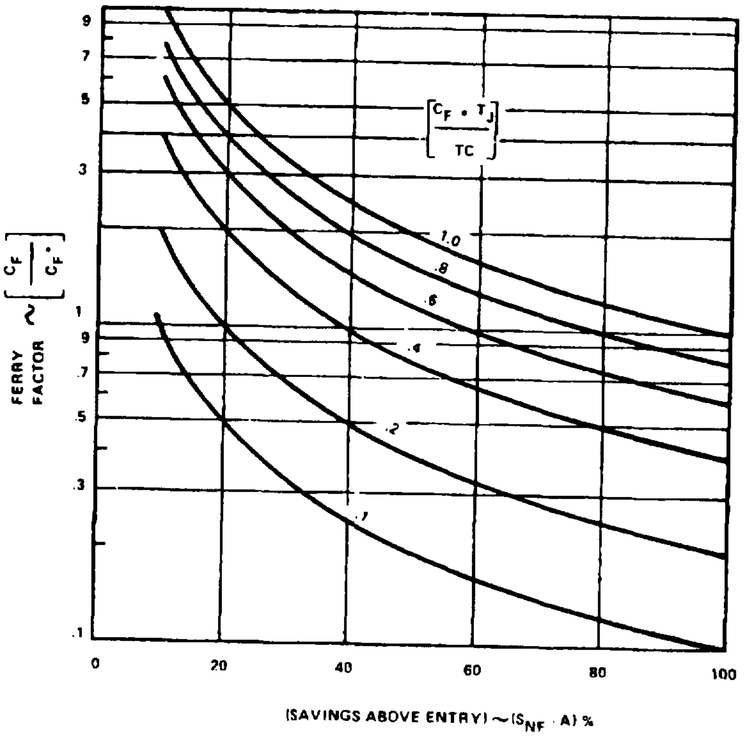
Thus $\frac{C_F}{C_F^*}$ varies with $\left[\frac{C_F\ T_J}{TC}\right]$ and $\left[S_{NF} - A\right]$ as in Figure 6-2

$\left[\frac{C_F\ T_J}{TC}\right]$ and $\left[S_{NF} - A\right]$ can be defined for each application in turn.

$\left[\frac{T_C}{T_J}\right]$ is also the same as $\left[\text{Threshold cost per hour}\right]$

Thus $\left[\frac{C_F\ T_J}{TC}\right]$ is the same as the ratio $\left[\frac{\text{Ferry cost per hour}}{\text{Threshold cost per hour}}\right]$

FIGURE 6-2. Effect of Ferry Factor on Variations in Market, Ferry and Job Parameters



6.3.5 HLA Kinematics

In general, HLA operations in any heavy lift activity consist of two major stages:

- Transportation from the base to the operating area—the ferry activity
- Transportation and hovering to fulfill the heavy lift needs in the operating area.

"Ferry" transportation is conducted as economically as possible in the configuration appropriate to the heavy lift task. Such economical ferry may be best achieved by the use of separate propulsion power plants, rather than development of forward thrust through rotor tilt. Fuel consumption and time,in acceleration and climbout to ferry speed and altitude and deceleration and descent at the end of the ferry, may be considered small relative to the fuel and time required in the ferry mode, so that the ferry block speed is almost equal to the ferry flight speed.

In the operating area activities, such an assumption cannot be made, because the transportation distances are in many cases very small. The block speed in these cases depends strongly on the distance travelled, the effective HLA acceleration and deceleration that occur at each end of the trip, and the turnaround time required to pick up and deposit the payload (effectively the total hover time per trip)

This dependency is expressed as follows:

Given D = the one-way trip distance

t_{TA} = the turnaround time for the one-way trip

V = the steady cruise speed

f = the acceleration and deceleration at each end of the trip. (Assumed equal magnitude.)

V_{ave} = (trip distance/trip time)

The one-way trip time is

$$\left[\text{Acceleration time } \left(t_A\right) + \text{cruise time } \left(t_C\right) + \text{deceleration time } \left(t_D\right)\right]$$

This can be written

$$\left[\left(\frac{V}{f}\right) + \left(\frac{D - \frac{1}{2} \cdot \frac{V^2}{f} - \frac{1}{2} \cdot \frac{V^2}{f}}{V}\right) + \left(\frac{V}{f}\right)\right]$$

which becomes

$$\left[\frac{V}{f} + \frac{D}{V}\right] = \left[.00076 \frac{V_m}{n} + 60 \frac{D_m}{V_m}\right] \text{minutes}$$

where D_m is D in miles

V_m is V in miles per hour

n is f in g's

The block time for a one-way trip is thus

$$\left[\frac{V}{f} + \frac{D}{V} + t_{TA}\right]$$

For some very short trips, the distance may be insufficient to allow the HLA to accelerate to V. Then the distance is given by

(Distance to Accelerate to V) + (Distance to Decelerate from V)

This is

$$D = \left[\frac{V^2}{2f} + \frac{-V^2}{-2f}\right] = \frac{V^2}{f} = \left(.00001265 \frac{V_m^{\ 2}}{n}\right) \text{miles}$$

The corresponding trip time is

$$t = 2\left(\frac{D}{f}\right)^{\frac{1}{2}} = .4268 \left(\frac{D_m}{n}\right)^{\frac{1}{2}} \text{ minutes}$$

Note, that when $D = \frac{V^2}{f}$, the expressions for trip time are the same

$$\left.\begin{aligned} \left[\frac{V}{f} + \frac{D}{V}\right] &= 2\left(\frac{V}{f}\right) \\ \text{and } 2\left(\frac{D}{f}\right)^{\frac{1}{2}} &= 2\left(\frac{V}{f}\right) \end{aligned}\right\} = .00152 \frac{V_m}{n} \text{ minutes.}$$

At this point, D_m and t_m are as in Table 6-3

TABLE 6-3 One-Way Trip Distance, D_m, and Time, t_m, at Which Cruise Speed V_m Can Just be Reached With Acceleration and Deceleration of n

V_m (mph)			10	25	40	60	80	100
D_m	n	.075	.017	.105	.270	.600	1.08	1.68
		.100	.013	.078	.200	.450	.80	1.25
		.125	.010	.063	.160	.360	.64	1.00
t_m		.075	.202	.506	.810	1.216	1.622	2.024
		.100	.152	.380	.608	.912	1.216	1.518
		.125	.121	.304	.486	.730	.912	1.214

Now the average trip speed, V_{ave}, is the one-way trip distance divided by the one-way trip time. If V_{ave} is not significantly different from V then the effects of deceleration and acceleration can be neglected. Let this difference be .10V; i.e., let

$$V_{ave}^{\ast} = .90V.$$

From the earlier expression

$$\frac{V_{ave}^{\ast}}{V} = \frac{D}{\left[\frac{D}{V} + \frac{V}{f}\right] V} = \frac{1}{1 + \left(\frac{V^2}{D_f}\right)}$$

Thus

$$\frac{V_{ave}^{*}}{V} = 0.9$$

$$\frac{V^2}{D^{*} f} = .1111, \text{or } \frac{V_m^{2}}{D_m^{*} \cdot n} = 8783.5$$

This limit is shown in Table 6-4. At distances and speeds beyond these limits $V_{ave} \doteq V$ and the one-way trip time becomes almost equal to $\lfloor D/V \rfloor$

TABLE 6-4. Distance D_m at which $(V_{ave}/V) = 0.9$, for Cruise Speed, V_m, and Acceleration and Deceleration, n

V_m (mph)			10	25	40	60	80	100
D^{*}_m	n	.075	.1519	.9488	2.429	5.465	9.715	15.18
		.100	.1139	.7116	1.8216	4.0986	7.2864	11.385
		.125	.0911	.5693	1.458	3.279	5.829	9.108

The one-way trip times are shown in Table 6-5 on the following page. The single figures are those where (V_{ave}/V) .90, and the shaded areas are those where the HLA cannot reach the indicated cruise speed. The maximum speed attainable for these conditions is given by:

$$V_{max} = \left(D_f\right)^{\frac{1}{2}} = 281.1 \left(D_m \cdot n\right)^{\frac{1}{2}}$$

This is given in Table 6-6

TABLE 6-6. Maximum Speed, When HLA Cannot Reach Cruise Speed V_m

D_m (MILES)			.10	.30	1.0
V_{max}	n	.075	24.3	42.1	76.8
		.100	28.1	48.7	88.9
		.125	31.4	54.4	99.3

TABLE 6-5. One-Way Trip Times versus Cruise Speed, V_m, and Acceleration/Deceleration, n

D_m (MILES)				0.1	0.3	1	3	10	30	100	300
V_m (mph)	10	n (g's)	.075	.701	1.8	6	18	60	180	600	1800
			.10	.676							
			.125	.661							
	25		.075	.4917	.973	2.4	7.2	24	72	240	720
			.10	.430	.910						
			.125	.392	.872						
	40		.075	.4917	.855	1.905	4.5	15	45	150	450
			.10	.4268	.754	1.804					
			.125	.3817	.693	1.743					
	60		.075	.4917	.8516	1.608	3.608	10	30	100	300
			.10	.4268	.7392	1.456	3.456				
			.125	.3817	.6611	1.365	3.365				
	80		.075	.4917	.8516	1.5549	3.061	7.5	22.5	75	225
			.10	.4268	.7392	1.358	2.858				
			.125	.3817	.6611	1.236	2.736				
	100		.075	.4917	.8516	1.5549	2.812	7.012	18	60	180
			.10	.4268	.7392	1.3497	2.559	6.759			
			.125	.3817	.6611	1.2070	2.407	6.607			

NOTE: SHADED AREA IS WHERE HLA CANNOT REACH V_m FOR CRUISE IN DISTANCE D_m.

These data, particularly in Table 6-5, can be used in analyzing an HLA application to determine whether the operational requirements must account for acceleration and deceleration, or whether these can be neglected. Note that the times quoted are one-way trip times and thus do not include turn-around time. Note also that successive but different one-way trip times can be aggregated, such as could occur if the application called for the HLA to carry a heavy payload only one way, and the HLA configuration permitted a significantly different acceleration and cruise speed for the return journey.

6.4 Case Study No. 1
Construction of Oil Refineries and Petrochemical Plants

6.4.1 Current Operations

In the construction of refineries and petrochemical plants a number of oversized and heavy components have to be transported to and erected at the site. The maximum weights and dimensions of major components required in a refinery and petrochemical complex are described in Table 6-7.

TABLE 6-7 Maximum Weights and Dimensions of Components for Refineries and Petrochemical Plants

ITEM	WEIGHT (METRIC TONNES)	LENGTH (FEET)	WIDTH (FEET)	HEIGHT (FEET)
Pressure Vessel	920	165	29	29
Towers	450	164	36	36
Reactor	410	70	23	23
LPG Storage Tanks	55	100	12	12
Heat Exchangers	255	200	14	14
Columns	150	121	17	17
Absorbers	230	131	9	9
Separators	345	118	20	21
Converters	507	71	12	13
Evaporators	150	39	13	13
Oil Splitter	220	113	28	28
Gas Compressor	250	60	40	40
CO_2 Stripper	319	200	20	20
Ethylene Fractionator	300	NA	NA	NA
Propylene Fractionator	400	NA	NA	NA

SOURCE: Lykes Bros. SS Co.

The number of heavy lifts varies for each project according to the type and size of plant. Some industry rules of thumb include:

- In oil refinery construction each 2,000 bbl/day capacity involves approximately one heavy lift over 100 tons. As an example, a 50,000 bbl/day refinery will require an average of 25 lifts over 100 tons.

- In the construction of ammonia plants the following rules are indicated:
    - For a 1,000 ton/day plant, 8 heavy lifts over 100 tons are required including one 350 ton converter
    - For a 1,500 ton/day plant, 20 heavy lifts over 100 tons are required including a 620 ton converter
    - For a 2,500 ton/day plant, 35 heavy lifts over 100 tons are required.
- The construction of a 500,000 ton/year capacity ethylene plant will require approximately 40 heavy lifts over 100 tons.

The major requirement in this industry is for precision placement on bolts or other guides with a maximum clearance of 1 to 2 inches. It was also stressed that the impact of the components and the base has to be minimal.

It should be noted that the very large components, i.e., 400 to 800 tons, are the exception rather than the rule in the refinery and petrochemical industry. The major portion of the heavy lifts are usually in components weighing up to 400 tons.

According to Mr. James Johnson, chief rigger of Fluor Corporation in Houston, Texas, typical erection costs at a construction site for equipment of varying sizes are:

Component Weight	Equipment Used	Estimated Cost
700-800 tons	4 poles	$120,000
200-700 tons	2 poles	60,000
Up to 150 tons	Crane	10,000

Some typical examples of transportation and erection of refinery and petrochemical components include the following:

6.4.1.1 <u>Example (1): Pressure Vessel</u>. A pressure vessel of 200 tons, 200-foot length and 22-foot diameter for a refinery in the U.S. gulf was manufactured in Japan and transported to a U.S. port by Ro/Ro vessel. At the port it was offloaded and moved on conventional rubberized equipment to the refinery site 15 miles away by a roundabout road route. The air distance was less than 5 miles. The total cost of the transportation was approximately $90-100,000, plus $15,000 to upgrade the road. The latter cost was prorated over the movement of several other components subsequently transported on the same road.

Once at the site, crane poles were installed to erect the tower. The erection cost was approximately $120,000.

6.4.1.2 Example (2): Refinery Reactor. A 820-ton refinery re- arrived by a Ro/Ro barge at a temporary barge landing close to a refinery site in the U.S. gulf. The cost of the temporary landing was approximately $25,000. The refinery vessel was placed on crawlers rather than conventional rubberized equipment due to the extreme weight of the load. Once the load was on the crawler, it was transported one mile to the refinery site, and erected. The cost of the transportation and rigging was $125,000.

6.4.1.3 Example (3): Refinery Towers. At a refinery expansion in the Gulf of Mexico, four towers were to be installed:

- 1 50-ton tower
- 1 75-ton tower
- 1 100-ton tower
- 1 150-ton tower.

The length of the longest unit was 160 feet. These towers were to be unloaded from a railcar, moved one-half mile to the site and erected at the site. The job was opened for competitive bids by the construction company. The winning bid for the total job was $100,000. The total job took three weeks. Once the crane was in place, each tower took two hours to install.

6.4.1.4 Example (4): Petrochemical Vessels. For a petrochemical plant in Port Arthur, Texas, the following four petrochemical vessels were transported:

- 1 504-ton vessel
- 1 256-ton vessel
- 1 80-ton vessel
- 1 260-ton vessel

The vessels were unloaded from barges and transported two and one-half miles to the site. On the route, one bridge had to be passed and the rigger had to put down steel beams on the bridge to carry the load. Each move required a total of six hours excluding the rigging and waiting time. Total manpower required was six men. Total cost of the hauling job was $272,000.

6.4.2 Potential HLA Applications

The transportation and erection of refinery and chemical plant components require transportation equipment and cranes, derricks, poles or other lifting equipment to be brought to the site and installed. The HLA can perform both the lifting and the transportation of the components, and as such it can potentially compete with the conventional modes of transportation and lifting for the refinery and chemical plant heavy lift business.

6.4.2.1. Application 1: Short Haul Transportation and Erection of Refinery Components. The HLA is used to transport and erect the components involved from a barge landing or rail freight yard, to the refinery site.

(1) Scenario

A major expansion of a refinery and petrochemical complex is to take place at a location on the coast of the Gulf of Mexico, to provide an added annual capacity of 20,000 bbls/day. All the components described in cases 1 through 4 have to be transported to the site. The construction company has received bids from various riggers at the prices described in these cases. They are also investigating the economic feasibility of using an HLA as an alternative to the conventional methods of transporting and installing these components.

In addition, the contractor is planning to erect the vessels described in example 4, using his own manpower. His estimates of the cost of this operation are:

Weight	Estimated Cost
1 504-ton vessel	$60,000
1 256-ton vessel	60,000
1 260-ton vessel	60,000
1 80-ton vessel	10,000

(2) Assumptions

Williams Crane & Rigging has given the following general guidelines as to the manpower requirement for rigging of various loads as follows:

Component Weight	Rigging Time Per Component	Manpower	Approx. Cost Per Component
40-100 tons	4 hours	3 ironworkers 1 crane/rig oper. 1 oiler	$ 500 (min. $1000/day)
100-175 tons	4 hours	10 ironworkers 1 crane/rig oper. 1 oiler	$ 1,200
200-400 tons	4 days	10 ironworkers 1 crane/rig oper. 1 oiler	$ 9,600
over 400 tons	4 days	up to 14 ironworkers 1 crane/rig oper. 1 oiler	$ 12,800

The costs are based on a rate of $200 per man per day. A minimum of a full day's pay is required even though the job lasts for only part of a day. The time includes all work that is required to prepare the components, set up the required ground equipment and do all necessary rigging work.

It is assumed that these estimates are reasonable approximations of the manpower, time and cost required to rig and prepare these loads for transport and erection using the HLA either with personnel supplied by a rigger or the contractor.

It is furthermore assumed that all work will be scheduled so that the HLA can perform the jobs without waiting time or other delays.

(3) Potential Savings with HLA

There are no savings with the HLA other than the possibility of not having to construct barge landings, improve roads or reinforce bridges. Although such costs can be saved with the HLA, they are accounted for in the cost of the conventional methods and are thus in the threshold cost outlined below.

(4) HLA Threshold Cost

The threshold cost for the HLA in each case will be the cost of the current operation minus the cost of rigging these components, since it was assumed that the same amount of rigging would be required whether the components were lifted by the HLA or a crane. The threshold cost for each case will therefore be:

Case	Total Cost	Estimated Rigging Cost	HLA Threshold Cost
Case (1)	$220,000	$ 9,600	$210,400
Case (2)	150,000	12,800	137,200
Case (3)	100,000	2,400	97,600
Case (4)	462,000	33,000	429,000

(5) Potential Operating Scenario of the HLA

The towers and vessels that are to be erected are lifted off the transportation vehicle from a horizontal position to a vertical position. To avoid damage to the vessel, it is rigged with a winch or a crane that will lift the bottom part off the rail/truck/barge while the HLA is used to upright the component.

The following time requirements are estimated for vessels of varying sizes:

Component Size	Hook-up and Transportation Time	Erection Time	Total Time
Less than 150 tons	1 hour	1 hour	2 hours
150-700 tons	2 hours	2 hours	4 hours
More than 700 tons	2 hours	3 hours	5 hours

The total operating time for each of the cases can thus be estimated to be:

Case	Total Time Required
Case (1) Pressure vessel (200 T)	4 hours
Case (2) Refinery reactor (820 T)	5 hours
Case (3) Four refinery towers (50 T, 75 T, 100 T, 150 T)	8 hours
Case (4) Four petrochemical vessels (80 T, 250 T, 260 T, 504 T)	14 hours

Note that in this operation, vehicle speed is not important since short distances are involved, combined with significant hover time.

6.4.3 Estimate of HLA Needed to Satisfy the Potential Market

This estimate assumes four different HLA payload sizes matched to the components to be lifted.

6.4.3.1 The Annual Market. From Section 5, the annual market is described as $3.3 \text{ x } 10^6$ barrels per day of added capacity worldwide.

6.4.3.2 Required HLA Capabilities. The case study typifies the HLA task by four separate payload requirements (200T, 820T, 150T, and 500T) with a need for hover capability, forward speed being relatively unimportant. These four payload lifts are needed to satisfy the building of a refinery addition of approximately 20,000 bbl/day. The total operating time for each payload size consists almost entirely of hover or low-speed operations, and is as stated in the previous section.

6.4.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. Total number of each payload size to satisfy 100 percent of the market

$$= \frac{\text{(refinery additions per year)(operating hours per addition)}}{\text{annual utilization per vehicle}}$$

$$= \left(\frac{33\text{x}106}{20{,}000}\right) \begin{bmatrix} 4 \\ 5 \\ 8 \\ 14 \end{bmatrix} \Big/ \begin{bmatrix} 1000 \\ 2000 \end{bmatrix} \text{ for payloads of } \begin{bmatrix} 200 \\ 820 \\ 150 \\ 504 \end{bmatrix} \text{ tons,}$$

as given in Table 6-8 below:

TABLE 6-8. No-Ferry Number of Vehicles for 100% of the Refinery Market

MAX PAYLOAD (TONS)			200	820	150	504
$\bar{N}_{V_{NF}}$	ANNUAL UTILIZATION	1000	1	1	2	3
		2000	1	1	1	2

6.4.3.4 <u>"No-Ferry" Share of the Market,</u> M_{NF}. The total threshold cost (per 20,000 bbl/day added capacity) is, from the previous section, $0.874M.

The total average HLA cost (to support the addition of 20,000 bbl/day capacity) is $0.750M.

The market share factors are

A = 22.5 B = 50

Thus from the expression derived earlier

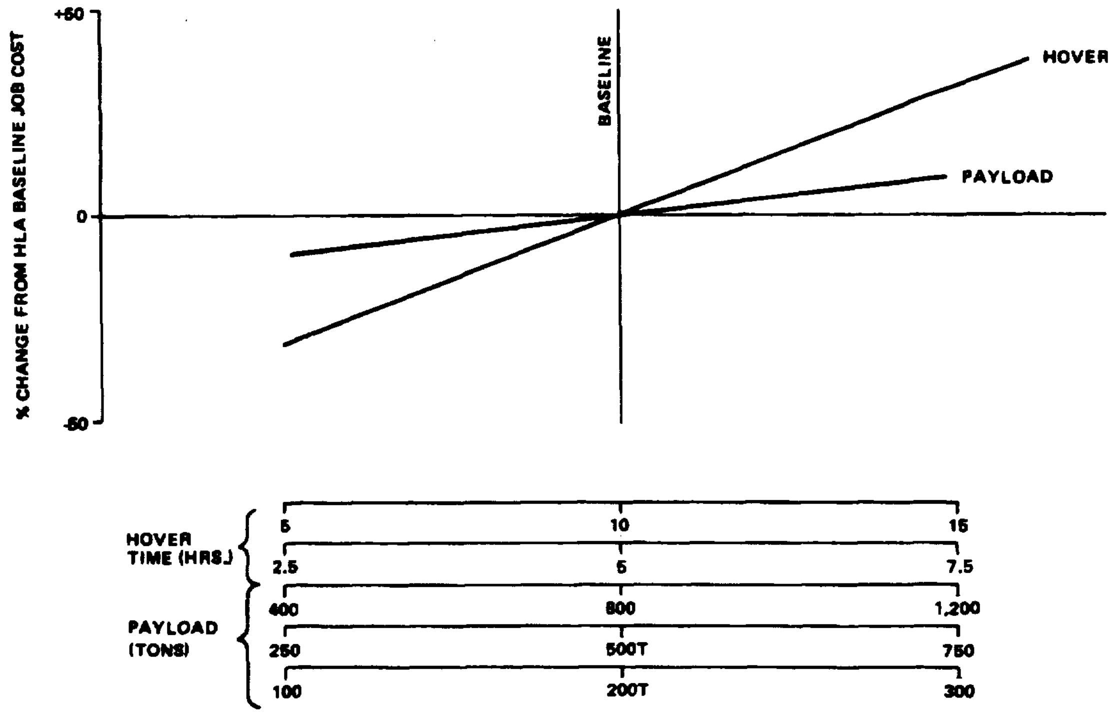
$$M_{NF} = \left\{ \frac{\left[1 - \frac{.750}{.874}\right] \times 100 - 22.5}{50 - 22.5} \right\} 100$$

$$= -30.2 \quad = \quad 0$$

Note that if the job cost of the HLA can be reduced to $0.437M (a reduction to 58 percent of the average value used) Figure 6-3 indicates how the estimated HLA cost varies with the scenario parameters of hover time and payload, illustrated for initial values as indicated by the baseline and case run.

Calculation of ferry effect is unnecessary, since the possible numbers are small.

FIGURE 6-3. Sensitivity of HLA Costs to Scenario Parameters (Construction of Oil Refineries and Petrochemical Plants)



6.5 Case Study No. 2
Construction of Offshore Oil and Gas Production Platforms

6.5.1 Current Operations

The principal areas of oil and gas activities offshore are:

- Exploration and drilling
- Production platform construction
- Production.

For the two principal activities, exploration and drilling and production, a lot of equipment and supplies are brought in which are all transported by supply vessels at low cost and lifted onboard by small cranes installed on the platform. The charter cost for these supply vessels, which have cargo carrying capacities ranging from 800 to 2000 tons and speeds of approximately 14 to 16 knots, ranges from $2,000 to $3,000 per day depending upon the market conditions. Under normal circumstances, the HLA concept will not be economically competitive with these vessels. A limited opportunity might be presented for the HLA to supply spares and replacement components in emergencies. Work stoppages on offshore drilling and exploration and production platforms are very costly and the HLA may be employed to supply vital parts, despite its higher cost of operation. Such emergencies are infrequent, and according to experts familiar with offshore operations, would occur once or twice annually in each major offshore production area (e.g., Gulf of Mexico, North Sea, etc.).

The major potential use for the HLA in this market is in support of the construction of fixed production platforms. This case study is therefore devoted to a discussion of the opportunities presented to the HLA in this market segment.

6.5.1.1 Production Platform Construction. There are three distinct phases in the construction of offshore platforms:

- Placement and precise positioning of the jacket
- Driving of the piles
- Placement of the deck sections and structures.

For the construction of an offshore oil and gas production platform the services of a crane barge are required. The crane barges have lifting capabilities typically ranging from 500 to 1000 tons. Crane barges with lifting capabilities of less than 500 tons and more than 1000 tons are also available. In addition to lifting heavy components and equipment, the crane barge is used as a base of operation for platform construction and provides the following services:

- Accommodation for crew
- Storage of equipment
- Work and maintenance shop
- Communications center
- General support platform.

It should be noted that the maximum capacity of the crane is normally used only four to five times during the entire construction period of 60 days. The remainder of the lifts range up to 150 tons.

The cost of a 500-ton crane barge with a crew of 60 men is approximately $60,000 per day. This cost may vary greatly depending upon the supply and demand in the marketplace. Positioning cost with a skeleton crew (i.e., crew required for barge operation only) will average $50,000 per day. The cost of the construction crew is therefore $10,000 per day. The positioning speed is 5 to 6 knots.

The design and construction of the modules and components are to a large extent based upon the lifting capability of the crane barge that will be available for the job.

Phase 1: Emplacement of Jacket

The jacket is normally constructed ashore and skidded onto a deck barge for transportation to the platform site. The size of the jacket is heavily dependent upon the depth of water. The size of the overall production platform could range from 1,000 tons up to 40,000 tons (dry) steel weight.

At the platform site the jacket is skidded off the barge, uprighted through the use of ballast and correctly positioned on the ocean bottom. The crane on the crane barge assists in the positioning of the jacket. The actual emplacement procedure requires 8 to 12 hours of crane service.

Phase 2: Pile Driving

This phase takes approximately 20 days. During this period the crane is used to lift the pile driving hammers and to position the steel piles. The driving hammers can weigh up to 150 tons. The piles are inserted through the legs of the jacket, welded together and driven down with the driving hammers.

Phase 3: Positioning of Deck Sections

The deck sections are prefabricated and assembled ashore. Due to the economics of preassembly, the sections are designed to conform to the maximum lifting capability of the crane available at the work site. Typically, two deck sections weighing 500 tons each are required to be transported to the site and lifted onto the jacket. In addition, one or two prefabricated modules or structures weighing 500 tons each need to be transported to the platform. All these structures are currently placed on deck barges and moved out to the platform site, where they are lifted onto the jacket structure using the barge mounted crane. One critical factor in the positioning of the modules is the impact velocity of the deck sections when placed on the jacket. Currently the velocity can be no greater than a few inches per second. This requires calm seas and limited winds. During adverse weather conditions the barges with the sections may remain idle for extended periods.

Total crane time required during this phase is 8 to 12 hours for each heavy item of which 1 to 2 hours is actual lifting time. Typical charter cost for the large deck barges and the powerful tugs required to transport the deck section and modules to the platform site is:

- 250 feet x 75 feet deck barge: $1,500/day 3600 hp tug for above: $3,500/day
- 400 feet x 100 feet deck barge: $4,000 to $5,000/day 4800 hp tug for above: $4,800/day.

Some rules of thumb used in the industry are:

- Charter cost for tugs normally is $1 dollar per horsepower per day. A 3600 horsepower tug therefore costs an average of $3,600 per day.
- Charter cost for a deck barge is normally one-thousandth of the capital cost per day. A barge built for $1.5 million will therefore charter for $1,500 per day and a $4 million barge will charter for $4,000 per day.

The supply/demand balance in the marketplace will cause fluctuations around these values. In the summer, when demand is high and equipment becomes scarce, prices tend to go up, and conversely, in the winter, the prices go down due to low demand.

Under normal conditions the tugs are able to push the loaded barges at speeds up to 7 knots. The barges and tugs are normally sitting at the job site for three days, and transit time ranges from 2 to 10 days depending on the distance between the base and the job site. It should be noted that foul weather may seriously delay both the transportation to the site and the positioning of the modules on the jacket. Such conditions, which are not infrequent in the offshore area, will increase the time for which the barges are under charter, and consequently, the cost.

The jacket is normally carried on one barge and the deck sections and the other modules on another. Piles for the pile driving barge are either carried on the barge carrying the jacket or on a separate barge.

6.5.2 Potential HLA Applications

There are two possible scenarios for the use of the HLA:

- The HLA is used to lift the deck sections and modules from the deck barge and position them on the platform
- The HLA is used to transport the deck sections and modules from place of production ashore to the platform site, and position them directly on the platform jacket or deck.

6.5.2.1 Application 1: Positioning of Modules. One of the major costs incurred during the construction of an offshore production platform is the chartering of a crane barge. The larger the capacity of the crane, the higher the cost. Therefore, if it is possible to substitute a smaller crane barge with a smaller crane, cost savings can be achieved.

(1) Scenario

Since the maximum lifting capability is required only four to five times during the 60-day construction period, all other lifts never exceed 150 tons, the following hypothetical scenario is construed:

- The 500-ton crane barge is replaced with a crane barge with a lift capability of 75-150 tons
- A 500-ton HLA is brought in to perform the lifts above 150 tons, i.e., five lifts during the first 30 days of the 60-day construction period.

(2) Assumptions

It is assumed that the annual costs of the crane barges are as follows:

- 500 to 1,600-ton crane barge: $40,000 to $60,000 per day
- 150 to 350-ton crane barge: $20,000 to $34,000 per day.

The approximate costs for crane barges in the Gulf of Mexico area were obtained from two different sources. These costs include rugs, a full construction crew and crew accommodations. Thus, all types of barges provide the identical support functions with the exception of the crane.

Other assumptions include:

- The two deck sections and the two modules are placed on the jacket in two successive operations
- All necessary rigging both on the jacket and the modules has been performed by the construction crew prior to the arrival of the HLA.

This preparatory rigging includes:

- All arrangements for hook-up to the HLA.
- All arrangements both on the module and on the jacket/deck to allow the riggers to control or winch the module down onto the jacket or deck. The HLA will have only limited hover time while the pre-arranged rigging is set up.
- The distance from shore to the site ranges from 70 to 200 nautical miles.
- Total time for construction is 60 days, during which the crane barge is sitting at the site.

(3) Potential Cost Savings with HLA

The cost savings under this scenario is the difference between the two cranes. The potential range in saving per day of construction is therefore the difference in cost between the 500 to 1600-ton crane barge and 150 to 350-ton crane barge. This difference is:

- 500 to 1600-ton crane barge from $40,000 to $60,000 per day
- 150 to 350-ton crane barge from $20,000 to $34,000 per day
- Potential saving per day is from $6,000 to $40,000.

Total savings over the 60-day construction period can therefore range from $360,000 to $2.4 million.

(4) HLA Threshold Cost

The threshold cost of the HLA in this case is expected to be equal to the potential savings from the trading down of the crane barges, i.e., $360,000 to $2.4 million.

(5) Potential Operating Scenario for HLA

The HLA has to be used in support operations during Phases 1 and 3.

Phase 1

The HLA is used as a complement to the crane to position the jacket:

Ferry to site, 70 to 200 miles:	Fast HLA	1 - 3 hours
	Slow HLA	4 - 10 hours
Assist in positioning the jacket		3 - 5 hours
Ferry to base:	Fast HLA	1 - 3 hours
	Slow HLA	4 - 10 hours
Total time:	Fast HLA	5 - 11 hours
	Slow HLA	11 - 25 hours

Phase 3

The following operations will have to be repeated twice:

Ferry to site, 70 to 200 miles:	Fast HLA	1 - 3 hours
	Slow HLA	4 - 10 hours
Lift & position sections, total times for each section, 1-2 hours:		2 - 4 hours
Ferry time to base:	Fast HLA	1 - 3 hours
	Slow HLA	4 - 10 hours
Total for each operation:	Fast HLA	4 - 10 hours
	Slow HLA	10 - 24 hours

Since it is assumed that the two deck sections and the two other modules will be attached during two separate operations, the total estimated time will be 8 to 20 hours for fast HLA, or 20 to 48 hours for slow HLA.

Thus, total operating times for the HLA in this application is expected to be 13 to 31 hours for fast HLAs, or 31 to 73 hours for slow HLAs.

6.5.2.2 Application 2: Transportation of Modules to Site. Currently the jacket, pilings, deck sections and additional modules are transported from the shore fabrication and supply base to the offshore platform site using deck barges and tugs. This equipment is relatively expensive and the transit time is slow. It therefore might be possible for the HLA to compete with the barges and tugs due to the higher productivity of the HLA.

(1) Scenario

In addition to the previously described scenario the HLA replaces the deck barges and the tugs for the transportation of the four 500-ton modules from the construction base to the production site. The jacket and pilings will still have to be transported in the conventional manner.

(2) Assumptions

All the assumptions remain the same as in the previous application. In addition, the following assumptions are made:

- All preparatory rigging is performed by the construction crew at the construction site. The HLA can therefore hook up the load with minimal hovering time.

- The four modules are airlifted and emplaced at the construction site in two operations with two consecutive trips in each operation.

(3) Potential Cost Savings with HLA

The cost saving described in the previous section from using a smaller crane barge is still applicable. However, additional direct savings will be possible by eliminating one of the deck barges and one tug.

(4) HLA Threshold Cost

The cost of the current operation that the HLA could replace is estimated to be:

- Small deck barge used for operation:
  - 255 ft x 75 ft barge/day $1500
  - 3600 hp tug/day $3600
  - Total cost per day $5,100.

- Large deck barge used for operation:
  - 400 ft x 100 ft deck barge/day $4000
  - 4800 hp tugboat/day $4800
  - Total cost per day $8800.

	70 miles Offshore	200 miles Offshore
Small barge, positioning/ loading time, 1 day	$ 5,100	$ 5,100
Round transit time, 7 knots	4,100	12,000
Waiting time at site, 3 days	15,300	15,300
Total cost	$24,500	$32,400

	70 miles Offshore	200 miles Offshore
Large barge, positioning/ loading time, 1 day	$ 8,800	$ 8,800
Round trip transit time, 7 knots	7,400	21,000
Waiting time at site, 3 days	26,400	26,400
Total cost	$42,600	$56,200

The threshold cost will be the cost saving from the trading down of the barge plus the above costs of the current operations.

(5) Operating Scenario

Two consecutive trips will be required, each as follows:

Rigging and loading at shore construction site	1 hour
Transportation to offshore base	Fast HLA 1 - 3 hours Slow HLA 3 - 8 hours
Positioning of sections on jacket	1 - 2 hours
Return to shore construction base	Fast HLA 1 - 3 hours Slow HLA 3 - 8 hours
Total time required per trip.	Fast HLA 4 - 9 hours Slow HLA 8 -19 hours

6.5.3 Estimate of HLAs Needed to Satisfy The Potential Market

6.5.3.1 The Annual Market. From Section 5, the annual market is represented by the construction of from 50 to 150 new platforms per year.

6.5.3.2 Required HLA Capacities. Based on the case study, support of one platform will require one 500T payload HLA which will both transport modules and hover to aid in positioning deck modules. The required job times were given in the previous section for a typical rig construction, and consist of round trip transportation from 70 to 200 miles offshore, together with hover at the drilling to assist in positioning.

6.5.3.3 <u>"No-Ferry" Number of Vehicles</u>, $\bar{N}_{V_{NF}}$. Total number of 500-ton payload vehicles to satisfy 100 percent of the market

$$= \left(\begin{matrix}\text{Rigs constructed} \\ \text{per year}\end{matrix}\right)\left(\begin{matrix}\text{Operating hours} \\ \text{per rig}\end{matrix}\right)\Big/\left(\text{Annual Utilization}\right)$$

as shown in Table 6-9.

TABLE 6-9. No-Ferry Number of Vehicles to Satisfy 100% of the Offshore Drilling Rig Market

AV. HLA SPEED (MPH)					25		60	
OFFSHORE DISTANCE (MI.)					70	200	70	200
TOTAL HLA OPERATING HOURS PER PLATFORM					46.2	111	21.7	50.3
$\bar{N}_{V_{NF}}$	PLATFORMS PER YEAR	50	ANNUAL UTILIZATION	1,000	3	6	2	3
				2,000	2	3	1	2
		100		1,000	5	12	3	6
				2,000	3	6	2	3
		150		1,000	7	17	4	8
				2,000	4	9	2	4

6.5.3.4 <u>"No-Ferry" Share of the Market</u>, M_{NF}. The total threshold cost per rig is, from the previous section, a function of the cost of the barge that is eliminated by using the HLA. The total HLA cost to support construction of a rig is a function of the required HLA capabilities previously outlined. The market share factors are A = 20 and B = 50. Thus from the expression derived earlier, the market share is given in Table 6-10.

6.5.3.5 <u>"No-Ferry" Number of Vehicles for Market Share</u>. From the previous two tables, the number of vehicles can be defined to satisfy the market, assuming no ferry. (Table 6-11)

TABLE 6-10. HLA Market Share for Offshore Drilling Rigs

AV. HLA SPEED (MPH)					25		60	
OFFSHORE DISTANCE (MI.)					70	200	70	200
TOTAL AVERAGE HLA JOB COST ($M)					.998	1.739	.671	1.311
M_{NF}	BARGE SAVINGS PER RIG ($K)	13.6	THRESHOLD COST PER RIG ($M)	.84	0	0	0	0
		20.8		1.25	0	0	81.6	0
		22.4		1.34	12.2	0	100	0
		27.6		1.64	52	0	0	0
		33.9		2.0	100	0	100	36.7
		37		2.17	100	0	100	54.4
		44.8		2.62	100	34.3	100	100
		59.8		3.48	100	100	100	100

TABLE 6-11. No-Ferry Number of HLA to Satisfy the Drilling Rig Market

AV. HLA SPEED (MPH)					25					60					
OFFSHORE DISTANCE (MI.)					70			200		70			200		
MARKET SHARE (%)					0	50	100	0	13	0	50	100	0	50	72
BARGE SAVINGS (MIN. 6, MAX. 40) ($K)					20.8	27.3	33.9	37	40	13.6	18	22.4	27.6	36.1	40
$N_{V_{NF}}$	PLATFORMS PER YEAR	50	ANNUAL UTILIZATION (HRS.)	1,000	0	2	3	0	1	0	1	2	0	2	2
				2,000	0	1	2	0	1	0	1	1	0	1	1
		100		1,000	0	3	5	0	2	0	2	3	0	3	4
				2,000	0	2	3	0	1	0	1	2	0	2	2
		150		1,000	0	4	7	0	3	0	2	4	0	4	6
				2,000	0	2	4	0	2	0	1	2	0	2	3

Since the number of vehicles are small, the effect of ferry is unimportant.

6.6 Case Study No. 3
Transportation of Power Shovels Used in Strip Mining

6.6.1 Current Operations

Power shovels used to extract coal, iron ore and other natural resources in surface mining operations require transportation under the following circumstances:

- Delivery of a new shovel to a mining site
- Delivery of used shovels sold or transferred to another mine site
- Local shifting of shovel within a mine site.

Each of these transportation requirements is discussed below.

6.6.1.1 Delivery of New Shovels. The power shovels are assembled and tested at the factory prior to shipment to ensure that everything is operating properly. Fully assembled, a typical intermediate size power shovel weighs approximately 1.2 million pounds or 600 tons and costs close to $1 million. Due to its enormous dimensions the shovel has to be disassembled for transportation by rail or truck. According to a representative of Marion Power Shovel Co. of Marion, Ohio, the cost of disassembling the shovel to components and to prepare these components is approximately $15,000. The average domestic shipping cost of the components by rail is $3,000 plus $21 per mile for an intermediate size power shovel.

At the destination the shovel has to be reassembled under field conditions. Several of the components have to be shipped completely knocked down due to the clearance limitations imposed by the railroads. Therefore, a lot of welding of components has to be performed in the field. The total cost of erection averages $100,000 and takes two to three weeks. The total cost of disassembly at the factory, transportation and assembly in the field is an average of $163,000.

6.6.1.2 Delivery of Used Shovels Sold or Transferred to Another Mine Site. Most power shovels are dedicated to one mine site in their entire economic life. Occasionally, shovels are replaced with new equipment, sold or transferred to another mine site. In such a case the shovel has to be broken down into components that can be transported by either truck or rail, transported to the new site and reassembled. The cost of the disassembly and assembly averages $50,000 to $60,000 according to a representative of Mesabi Service and Supply Company of Hibbing, Minnesota, which is a major dealer in new and used strip mining shovels. Transportation cost by truck or rail is extra. The total time required for the disassembly, transportation and assembly at the new site under optimal conditions would be two to three weeks. Time intervals of six weeks between start of disassembly and completion of assembly are not uncommon.

These shovels are delivered to all major mining sites in the U.S. and Canada.

6.6.1.3 Local Shifting Within Mine Site: The power shovels are equipped with crawlers to move at slow speed within the mine site. Occasionally the option is selected to move the shovel to avoid natural obstructions or to position it at a new seam. If this move is entirely within the compound, it is accomplished by using a large truck trailer. According to Mesabi Service and Supply Co. the move is normally completed within two to three hours at a cost of $250 per hour.

If the local move requires transportation over official roads no matter how short the distance, the entire shovel has to be disassembled, loaded on trucks and reassembled at the new site at a cost of $50,000 to $60,000. Operators try to avoid such an occurrence, but occasionally it is necessary in order to position the equipment.

6.6.2 Potential HLA Applications

A power shovel would be at best cumbersome and at worst impossible to transport as one piece using any conceivable method. According to Mr. Tod Pillow of Marion Power Shovel Co., a typical intermediate size shovel could be conveniently transported as three components with an HLA. These components are:

- Boom and handle, weight: 100 tons
- Upper frame, weight: 250 tons
- Lower frame, weight: 150 tons.

The total time for disassembly and assembly could then be cut from two to three weeks to a maximum of two days and the total cost could be reduced to a minimum. The HLA can therefore completely change the way the power shovels are transported currently, and it can be used both to transport new and used equipment.

6.6.2.1 Application 1: Delivery of New and Shifting of Used Shovels. Shovels that currently have to be disassembled at the factory for shipment after having been tested can be knocked down to three major components rather than many smaller components.

(1) Scenario

A major manufacturer of power shovels shipping equipment to all major mining sites has decided to investigate the possibility of shipping the shovels as three major components with a HLA rather than as a multitude of small components using rail or truck.

(2) Assumptions

The following assumptions are made:

- The HLA components are rigged and prepared for lift by employees of the shovel manufacturer
- The necessary rigging on the ground at the mine site is performed by the personnel of the mine operator
- The average cost of $3,000 plus $21 per mile is representative of the cost of rail transportation for the typical 600T shovel transported.

(3) Potential Savings with HLA

The major realized savings that can be achieved with the HLA is that the machine can be shipped and received virtually fully assembled. A representative of Marion Power Shovel Co. said that the total disassembly cost at their plant of $15,000 could be saved with the HLA. He further estimated that approximately half of the $100,000 field erection cost could also be saved. The remaining $50,000 would be required for miscellaneous work to be performed and additional installations required for field operations. The total savings that can be realized in terms of disassembly and assembly cost is therefore $65,000 per power shovel.

In terms of a used shovel, less work is required for its disassembly for shipment and reassembly at the new site. Virtually all of the $50,000 to $60,000 cost of disassembly and reassembly can be saved by separating the shovel into three pieces for shipment. In addition, savings can be realized if a company can use the additional time made available by having the shovel delivered assembled in three pieces rather than in components.

In an iron ore strip mining operation in the midwest, an intermediate shovel can dig approximately 12,000 tons of crude product per day. Out of these 12,000 tons, 1/3 or 4,000 tons of ore are extracted. This ore sells for $35 to $38 per ton, and a reasonable estimate of profit is $2 to $3 per ton. If the time of disassembly, transportation and assembly of the shovel could be reduced from two weeks to two days and the time saving could be used for full production, gross revenues of $1.68 million to 1.824 million or net profits of $96,000 to $144,000 could be realized.

The stripmining of coal and other resources differs somewhat from that of iron ore. It is expected, however, that the magnitudes of the potential savings will be similar to those that can be achieved by an iron ore operation if conditions are such that the additional productive time of the shovel resulting from HLA use could be utilized for full production.

(4) HLA Threshold Cost

The cost of transportation of a shovel to the typical destination is $3,000 plus $21 per mile. The shovel weighs 1.2 million pounds. Total transportation cost over 1,600 miles is therefore $36,600. The savings associated with not having to disassemble a shovel for shipment and then reassemble at the site are $65,000 for new shovel and $50,000 for a used one. The threshold cost is therefore $101,600 for transporting a new shovel and $86,600 for a used shovel.

If the mine operator could realize the benefit of having the shovel in production for the time saved by the HLA over the time required for a field assembly, the threshold cost could potentially be considerably higher.

(5) Potential HLA Operating Scenario

The HLA will have to make three round trips and also assist in the assembly at the site when all components have been brought to the site. It is expected that total hovering time at both origin and destination to disassemble and assemble will be one hour.

6.6.3 Estimate of HLA Needed to Satisfy the Potential Market.

6.6.3.1 The Annual Market. From Section 5, and the case study, the annual market is represented by the movement of 95 600-ton shovels per year.

6.6.3.2 Required HLA Capabilities per Platform. Based on the case study, transportation of one 600-ton shovel will require one 250-ton payload HLA to make three round trips, over round trip distances that may be anywhere from 10 to 1,000 miles. No hover time is required.

6.6.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. Total number of 250-ton payload vehicles to satisfy 100 percent of the market

$$= \left(\begin{array}{c}\text{Shovels moved}\\ \text{per year}\end{array}\right)\left(\begin{array}{c}\text{Operating hours}\\ \text{per shovel moved}\end{array}\right) \Big/ \left(\text{Annual utilization}\right)$$

as shown in Table 6-12.

TABLE 6-12. No-Ferry Number of Vehicles to Satisfy 100% of the Strip Mining Market

AV. HLA SPEED (MPH)			25			60			
RD. TRIP DISTANCE (MI.)			50	100	150	100	150	200	250
TOTAL HLA OPERATING HOURS PER PLATFORM			6	12	18	5	7.5	10	12.5
$\bar{N}_{V_{NF}}$	ANNUAL UTILIZATION	1,000	1	2	2	1	1	1	2
		2,000	1	1	1	1	1	1	1

6.6.3.4 "No-Ferry" Share of the Market, M_{NF}. From the two previous sections, the total threshold cost per movement is a function of the round trip distance, whether a new or an old shovel is being transported, and the profit to be gained when the time saved is put to production use. The total HLA cost to effect movement of a shovel is a function of the total movement distance and speed. The market share factors are A = 12.5 and B = 37.5. Thus from the expression derived earlier, the market share is as given in Table 6-13.

TABLE 6-13. No-Ferry HLA Share of the Strip Mining Market

AV. HLA SPEED (MPH)		25			60			
RD. TRIP DISTANCE (MI.)		50	100	150	100	150	200	250
THRESHOLD UNIT COST ($M)	OLD SHOVEL, LOW PROFIT	.153	.154	.155	.154	.155	.156	.157
	NEW SHOVEL, HIGH PROFIT	.216	.217	.218	.217	.218	.219	.220
AV. HLA UNIT JOB COST ($M)		.088	.176	.264	.0790	.1185	.158	.1975
M_{NF}	OLD SHOVEL, LOW PROFIT	100	0	0	100	44	0	0
	NEW SHOVEL HIGH PROFIT	100	26	0	100	100	62	0

6.6.3.5 <u>"No-Ferry" Number of Vehicles for the Market Share</u>. From the previous two tables, the number of vehicles can be defined to satisfy the market, assuming no ferry. (Table 6-14)

TABLE 6-14. No-Ferry Number of Vehicles to Satisfy the HLA Share of the Strip Mining Market

AV. HLA SPEED (MPH)				25		60		
RD. TRIP DISTANCE (MI.)				50	100	100	150	200
$N_{V_{NF}}$	OLD SHOVEL, LOW PROFIT	ANNUAL UTILIZATION (HRS)	1,000	1	0	1	1	0
			2,000	1	0	1	1	0
	NEW SHOVEL, HIGH PROFIT		1,000	1	1	1	1	1
			2,000	1	1	1	1	1

Since the number of vehicles required is small, the effect of ferry is unimportant.

6.7 Case Study No. 4
Power Transmission Line Construction

6.7.1 Current Operations

This case is based upon the construction of the hypothetical, but typical, 60-mile 750 KV power transmission line. The 60-mile length of the typical power line is the length of line that can be constructed within one year by the company providing most of the data in this case study.

In the typical construction job, there are three distinct phases:

- Phase 1 - Construct tower foundations. Time required: 3 months
- Phase 2 - Construct and install towers. Time required: 8 months
- Phase 3 - Stretch cable. Time required: 1 month.

6.7.1.1 Phase 1: Construction of Tower Foundations. During this phase, three bulldozers with operators work full time to clear access roads to the right-of-way and to provide access to the tower sites. Once a road is cleared earthboring machines or shovels weighing approximately 20 to 25 tons each are brought to the site on flatbed trailers. The trailers are used to transport these machines from site to site.

The cost of a bulldozer with operator is \$50/hour or \$400/day. The cost of the flatbed truck with operator is estimated to be \$250/day.

At each tower site, concrete is needed. The total requirement for concrete is approximately 12 cubic yards. There are four bases at each site for a total requirement of 48 cubic yards of concrete. The average density of concrete is 144 pounds per cubic foot or 3,888 pounds per cubic yard. Thus, a total of approximately 93 tons of concrete is required at each site. The capacity of a concrete truck is 9 cubic yards and it is used by suppliers of the concrete to truck the concrete to the site. It has been indicated by concrete suppliers that there would be no difference in the price whether the concrete is delivered to the staging area or to the site of the foundation itself. The contractors contacted commented that delivery to the staging area might complicate rather than facilitate the pouring of the concrete.

On the average, four to five foundation sites are built per mile of line. The rate at which the foundations could be built varies greatly with the terrain. In flat country 30 foundations could be built per week while in mountainous terrain it would be difficult to build more than four foundations per week. On the average, approximately 20 foundations are completed per week. Staging areas for supplies and equipment are normally cleared every seven to eight miles along the line.

6.7.1.2 <u>Phase 2: Construction and Installation of Towers.</u> During this phase of construction the towers are preassembled at the staging areas to the extent possible with the limitations imposed by the flatbed trucks used to haul them to the site. These structural modules are then hauled to the site by the flatbed trucks, lifted into place by a mobile crane and assembled by the field crew.

The crane used for this purpose normally has a lifting capacity of 45 to 75 tons. The cost of the crane, according to Hoosier Engineering, of Columbus, Ohio, is $67/hour, plus an operator at $18/hour. This crane has to be used during this entire phase. In addition, a number of smaller cranes are required.

Midland Construction Company estimates the total time of handling the structural steel for the towers at the staging area and hauling to the site at 1.5 man-hours per ton of steel. The cost per man-hour of field labor is $28 or a total of $42 per ton of steel. Approximately half of this amount, or $21 per ton, is estimated to be the hauling cost from the staging area to the site. The cost of transporting the steel for a 25-ton tower between the staging area and the site is therefore approximately $525.

Midland Construction Company had figures indicating that a 7.8-ton tower required 170 man-hours of field labor to construct, and that a 18.76-ton tower required 250 man-hours of field labor. The cost is $28 per man-hour. The total cost in terms of manpower for a 25-ton structure is therefore in excess of $7,000.

Over the past few years, the Sikorsky S-64 Skycrane has been used in the emplacement of towers. The lifting capacity of the Skycrane is limited to 12 tons. In cases where the towers weigh more than this, the lower section of the towers is assembled in a conventional manner, while the upper section of the towers is assembled at the staging areas.

The latter is the case in a project undertaken by Evergreen Helicopters in May 1978. In this project the Skycrane set the towers on a 175-mile 350 KV line stretching between Breckenbridge, Minnesota to Buffalo, Minnesota, south of St. Cloud, Minnesota. On this stretch the helicopter will set 650 towers. Each tower weighs 24,000 pounds and is 180 feet high. Due to the limits on the lifting capability of the Skycrane, the contractor has had to set the bottom half of the towers 90 feet high and 12,000 pounds using conventional cranes, while the helicopter will set the top half (90 feet and 12,000 pounds.)

Evergreen has based its project cost estimate on the expectation that the helicopter will be able to place an average of four towers per hour, i.e., 15 minutes per tower. The range will vary from 3 to 8 in an hour depending upon the terrain and the conditions. The average round trip distance between staging/assembly area and the tower foundation is 2.5 miles.

Harold Symes of Evergreen mentioned, however, that if he had a machine available that could lift the whole tower rather than only the top, he anticipated that he could easily increase his productivity to placing one tower every eight to ten minutes. This is based on his experience in Quebec, Canada, on a 750 KV line, where he placed the whole tower in one operation. The towers in this operation were of an unusual configuration, and were considerably lighter than the conventional types of towers.

6.7.1.3 Phase 3: Stretching Cable. This phase of the operation commences as soon as the towers are up, and is completed on an average of one month after the last tower is constructed.

The conventional method of stretching the lead line for the wire is to use a bulldozer. Lately, small helicopters are increasingly used for this operation. Four miles of wire are normally stretched at a time using one wire stretching machine weighing approximately 50 to 55 tons at each end. Normally, it takes approximately 14 days to stretch 4 miles of wire, after which one of the machines is moved in a hop-skip fashion 8 miles to the next site. The machines are moved on flatbed trailers.

Wire is stored at each staging area. Fifty-two reels of wire are needed for a 60-mile stretch of 750 KV line. Each reel weighs about 9 tons. The wire is currently transported from the marshalling yard to the site by trucks.

6.7.2 Potential HLA Applications

It has been indicated by W.F. Hilsman, president of Hoosier Engineering Company of Columbus, Ohio, one of the major power line construction companies in the U.S., that the use of an HLA in power transmission line construction could have several benefits:

- Shorten construction schedule for the typical 60-mile line. It would be reduced from 1 year to 9 to 10 months
- Render construction environmentally acceptable
- Reduce costs compared to conventional construction.

Overall, he foresaw that the HLA could radically alter the way that power transmission line construction is currently being performed.

The HLA is expected to have extensive application in Phase 2 of the construction, where it can assist in both reducing the time for construction and saving construction cost. In Phases 1 and 3, it is doubtful that the HLA will be useful because the cost of the HLA will far outweigh the potential savings of the equipment that it can replace. The cost of the equipment replaced, i.e., bulldozers for road construction and flatbed trucks for equipment transportation possibly will account for $30,000 to $40,000 of the total cost. No or minimal savings will be achieved by delivering the concrete to a central staging area rather than directly to foundation site. During Phase 1, foundations for a total of 240 towers are constructed. Thus, the earthboring equipment has to be positioned a total of 240 times during a three-month period. During the same period more than 20,000 tons of concrete have to be transported to these sites. It has been indicated by concrete contractors that delivery of concrete to a central site rather than the tower site will be impractical if not impossible. The problems are maintaining consistency of the concrete and preventing its settling. It will therefore only be in very special situations where environmental considerations or extremely difficult terrain prevents the use of conventional methods that the HLA may be considered as a possibility for support in Phases 1 and 3.

The potential for the use of the HLA in power line transmission line construction has therefore been concentrated on support in Phase 2 of the construction. In this phase of the construction, the HLA can be used to transport preassembled towers from staging areas to the foundations and to emplace the towers at the site.

6.7.2.1 Application 1: Transportation and Emplacement of Preassembled Towers. Currently, the towers are assembled into modules to the extent possible for loading onto a truck for transportation to the site and for lifting into place at the construction site. It has been indicated that savings in cost and time can be achieved by preassembling the towers at the central sites for transport to and erection at the tower site. Until the introduction of the Sikorsky Skycrane helicopters, this operation was considered impossible. The use of the Skycrane has shown that cost and time savings can be achieved. It is anticipated that the HLA can at least duplicate and most likely improve upon the performance of the helicopter due to their larger lifting capability.

(1) Scenario

The following scenario is assumed to exist:

- The towers, each weighing approximately 25 tons, are preassembled at the staging areas by a crew of workers dedicated to this task
- Upon completion of the foundation work, the HLA is brought to the site to transport the towers to the foundations and emplace them at the site
- Crews of workers working their way from site to site follow the progress of the HLA and bolt the towers to the foundations after they have been emplaced.

(2) Assumptions

The following assumptions are made:

- The towers are fully assembled and rigged at the staging areas ready for pick up by the HLA.
- The HLA will emplace each tower at an average distance from staging area to foundation site of 2.5 miles.
- The HLA can duplicate the Skycrane hover capability in emplacing each tower, allowing a turnaround time of 3 to 5 minutes per cycle.
- The 45 to 75-ton capacity crane normally brought to the site is not required.

- The cost of the crane at $67 per hour, plus the operator cost of $18 per hour (as indicated by Hoosier Engineering) is a reasonable approximation of the cost in the industry. The total cost of the crane for the eight-month period required is therefore approximately $108,000 (32 weeks each 40 hours = 1,280 hours x $85 per hour).
- The cost of $21 per ton of steel transported from staging area to foundation site is representative of the industry average.
- The manpower requirement of 250 hours of field labor at $28 per hour to construct a 25-ton tower is representative for the industry.

(3) Potential Cost Savings with HLA

The potential cost savings with HLA fall into two areas:

- Increased productivity and thus reduced costs of tower construction labor
- Reduced field labor and financial costs through shortened construction time.

The productivity of the labor force will increase significantly when work is shifted from the field to a central site with repetitive functions being performed by the same crew. General Electric estimated that labor productivity would increase by a factor of between 1.5 and 4 when shifting electric power generating plant construction crews from field conditions to an industrial park with repetitive work functions being performed. Mr. William Hilsman, President of Hoosier Engineering, conservatively estimated that the manpower requirement can be reduced by 30 to 35 percent by shifting the assembly of the transmission line towers from the field to the staging areas. By using this estimate, the manpower cost of $7,000 per tower can be reduced by between $2,100 and $2,450. With a total of 240 towers for a 60-mile stretch, the savings from a manpower reduction of 30 to 35 percent could amount to between $504,000 and $588,000. Even with lower estimates of manpower reduction through productivity increases, the cost savings can be substantial:

Manpower Reduction in Percent	Cost Savings in Dollars
5	84,000
10	168,000
15	252,000
20	336,000
25	420,000
30	504,000
50	840,000

In addition to the savings as tower construction labor productivity increases, there will also be savings in the financing costs due to the shorter construction period and in the labor costs of the field crews that install the towers. It is assumed that a reasonable estimate of the cost of the 60 mile, 750 KV line used in this hypothetical example is approximately $20 million. The financial savings that can accrue due to the shortening of the construction period by two months (for construction costs varying between $10 and $30 million and cost of capital or interest rates of 8 to 12 percent per year) can range from $70,000 to $320,000.

(4) HLA Threshold Cost

The threshold cost for the HLA will be the previously outlined financing cost savings plus the cost of the conventional method of performing the task. The HLA can completely replace both the cost of transportation to the site and the cost of the heavy duty crane. The cost of these items is:

. Hauling cost - $525 per tower x 240 towers	$126,000
. Crane and operator cost, 8-month period	$108,000
. Total cost of conventional method	$234,000

Even with the most conservative estimates of productivity increases, and financing and labor cost savings, the threshold cost can be more than double the above number.

(5) Potential HLA Operating Scenario

It is expected that the HLA can exceed the demonstrated mission performance of the S-64 Skycrane helicopter by emplacing one complete 25-ton tower each cycle, as opposed to only the top section of the tower.

Typical operating times are as follows:

Hover & pickup at staging area		1.0 minute
Travel 2.5 miles to tower site	- Fast HLA	2.5 minutes
	- Slow HLA	6.0 minutes
Hover & emplace tower at site		2-4 minutes
Return to staging area	- Fast HLA	2.5 minutes
	- Slow HLA	6.0 minutes
Total cycle time		8-17 min.

This is equivalent to 75 to 35 towers per working day, or a total of 3.2 to 7 days to emplace <u>all</u> towers.

6.7.3 Estimate of HLA Needed to Satisfy the Potential Market

6.7.3.1 <u>The Annual Market</u>. From Section 5, and the case study, the annual market is represented by the annual placement of

- 12,800 miles of 345 KV line
- 4,000 miles of 500 KV line
- 570 miles of 765 KV line.

With 4 tangent towers per mile, and 1 deadend tower to every 9 tangent towers, on average; the deadend towers are roughly twice the size of tangent towers, which permits them to be carried in two separate parts, each requiring the same lifting capability as for the individual tangent towers. Thus each of the above market segments represents

$$\frac{9}{10}(4M) + \frac{2}{10}(4M) \text{ lifts i.e. } 4.4M \text{ lifts}$$

where M is the number of miles. Therefore the market is as follows:

- 56,320 13T payload lifts (345 KV)
- 17,600 17T payload lifts (500 KV)
- 2,508 25T payload lifts (765 KV.

6.7.3.2 <u>Required HLA Capabilities per Lift</u>. The case study typifies this HLA task by payload size sufficient to pick up a tangent tower or half a deadend tower at the staging area, transport it to the tower site (average 2.5 miles), place the tower in position on site, and return to the staging area.

6.7.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. The total number of vehicles required to satisfy 100 percent of the market

$$= \sum_{\text{All Payloads, P}} \begin{pmatrix}\text{Lift per year}\\ \text{of Payload, P}\end{pmatrix} \begin{pmatrix}\text{operating hours}\\ \text{per lift}\end{pmatrix} \Bigg/ \Big(\text{Annual Utilization}\Big)$$

as shown in Table 6-15.

TABLE 6-15. No-Ferry Number of Vehicles to Satisfy 100% of the Transmission Tower Placement Market

AV. HLA SPEED (MPH)						25			60		
AV. DISTANCE TO SITE (MILES)						1	2.5	4	1	2.5	4
*ROUND TRIP TRANSPORTATION (MINUTES)						4.8	12	19.2	3	7	8
TOTAL HOVER TIME (MINUTES)						3 TO 5			3 TO 5		
TOTAL CYCLE TIME (MINUTES)					MIN.	7.8	15	22.2	6	10	11
					MAX.	9.8	17	24.2	8	12	13
$\bar{N}_{V_{NF}}$	PAYLOAD (T)	13	ANNUAL UTILIZATION (HOURS)	1,000	MIN.	8	15	21	6	10	11
					MAX.	10	16	23	8	12	13
				2,000	MIN.	4	8	11	3	5	6
					MAX.	5	8	12	4	6	7
		17		1,000	MIN.	3	5	7	2	3	4
					MAX.	3	5	8	3	4	4
				2,000	MIN.	2	3	4	1	2	2
					MAX.	2	3	4	2	2	2
		25		1,000	MIN. OR	1	1	1	1	1	1
				2,000	MAX.	1	1	2	1	1	1

*THE EFFECT OF ACCELERATION AND DECELERATION OF APPROXIMATELY 0.1G IS INCLUDED.

6.7.3.4 "No-Ferry" Share of the Market, M_{NF}. The total threshold cost per tower is, from the previous section, the sum of (1) any cost savings resulting from shortened project time and increased productivity, and (2) the direct costs of performing the task conventionally.

Financial savings from a shortened project time

$$= \quad (\text{Interest for 12 month project}) - (\text{Interest for } M_o \text{ months})$$

where M_o is the new project time.

This savings can be closely approximated by

$$C_J \cdot \left(\frac{r_m}{1200}\right) \cdot \Delta n \left\{ \frac{1}{2} + \frac{1}{6} \left(21 - \Delta n\right) \left(\frac{r_m}{1200}\right) \right\}$$

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where C_J is the total conventional cost cost ($)

r_m is the annual capital cost of money (%)

Δn is the reduction in job time with the HLA.

Savings due to increased productivity is

$$\frac{m}{100} \cdot C_{MT} \cdot N_T$$

where m is the % increase in productivity with HLA

C_{MT} is the cost of current tower construction manpower ($ per tower)

N_T is the number of towers.

The net direct costs of performing the task conventionally consist of the conventional handling cost, plus the conventional (crane) implacement costs. These are

$$C_{HT} \cdot N_T + C_o \cdot M_o$$

where C_{MT} is the hauling cost per tower

C_o is the crane cost per month

M_o is number of months of conventional task time.

The total threshold cost is the sum of all these terms, and comes to $.745 for a representative "baseline" set of values for each parameter in the above expression. The sensitivity of this threshold cost to possible variations in these values has been assessed by varying each one, one at a time, holding all others at their baseline value. This sensitivity is illustrated in Figure 6-4. Also shown are HLA threshold costs where a helicopter is the competition, as discussed next. If instead of conventional techniques, a helicopter is used against which the HLA must compete, the threshold cost is different. Because of the payload limitations of the currently or potentially available helicopters*,

- 18,8000 pounds for the S64E
- 23,000 pounds for the S64F

(at 2,000 feet altitude, 70°F, with crane, pickup equipment, and 40 minutes fuel) only a portion of any of the 13T, 17T or 25T towers can be carried on a round trip. Thus the remaining portion

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* The S64E has been in production and could possibly be oontinued, while the S64F can go into production if orders warrant.

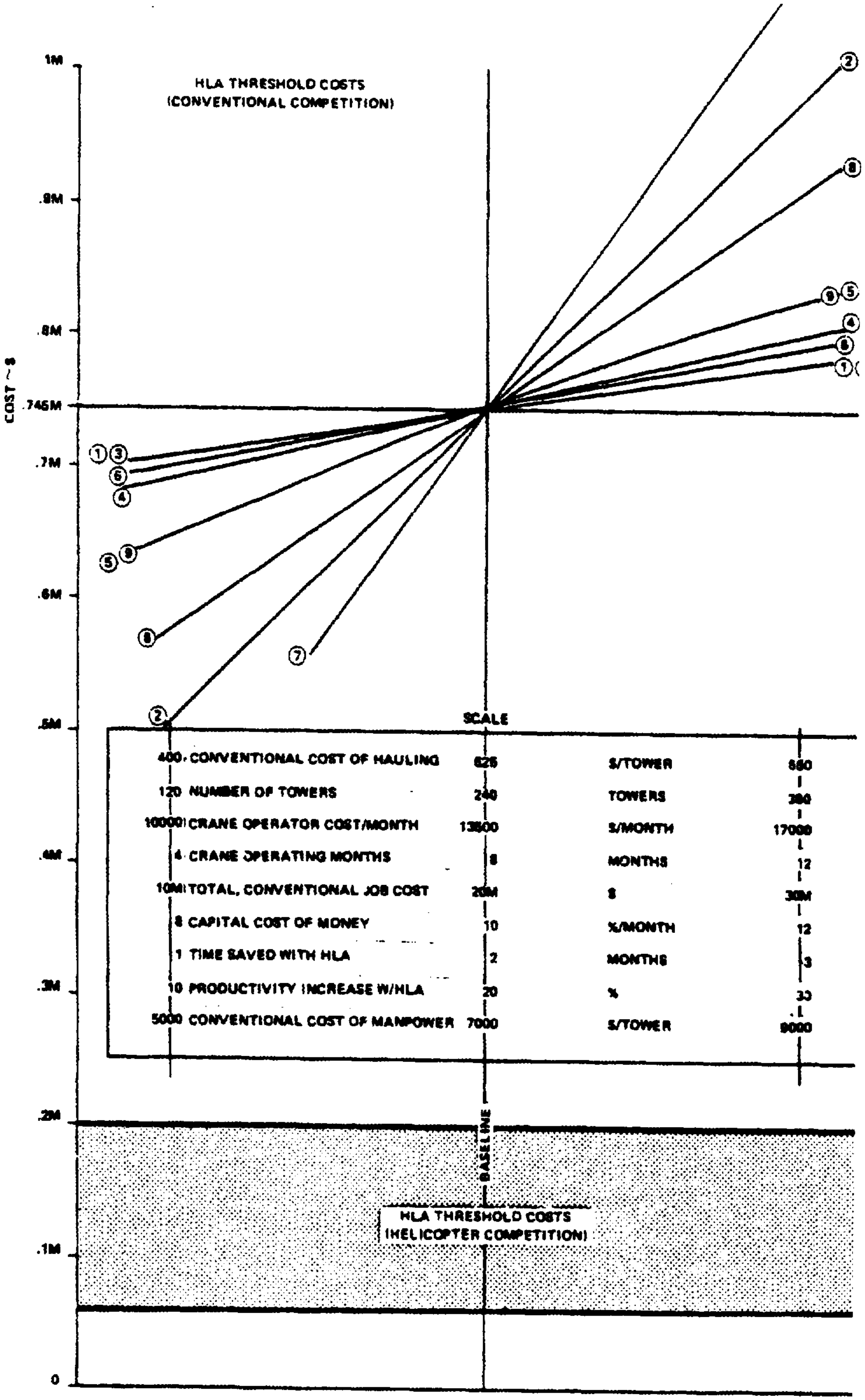

FIGURE 6-4. Threshold Cost Sensitivity (Transmission Tower Placem

of each tower must be carried either on a second trip, by the helicopter, or concurrently by ground equipment. The second alternative eliminates most of the project time saved by using a free flying vehicle, as discussed below.

The conventional job time on the towers is assessed at approximately 8 months for 240 towers or 30 towers per month, or 1 tower per 8 hour shift. This involves much hauling and use of cranes, and assembly of components. The free flying vehicle (FFV) can substitute for any and all hauling and lifting within its payload capacity. It will lift the tower from the staging area, carry it to the foundation, position it on its base with the aid of the ground crew, release the hookup, and return, in a matter of minutes per tower. The constraint in the number of towers emplaced would be the availability of ground crew at a foundation when the FFV would arrive. This would be satisfied by careful planning and grading of trails between foundations for rapid travel by offroad or trail vehicles.

However, the current experience with helicopter FFVs is to use them for only one small part of the operation, i.e., hauling and placing tower tops, while the flatbed trucks and cranes haul and place the tower bases. This ground operation is the pacing item, accounting for the long period in Phase II using trucks and cranes and the relative small reduction in Phase II time (1 to 3 months out of 8 months) when a helicopter is used as described.

With an HLA, on the other hand, the time spent in hauling and lifting is completely replaced by the time spent in using the HLA, and the time for Phase II could be reduced from 8 months to roughly 240 round trips. Round trip times vary as indicated earlier in Table 6-15, from 7 minutes to 32 minutes which for 240 towers results in 4 to 16 8-hour days. Conventionally, it takes 8 months to place 240 towers. This is approximately $\frac{2}{3} \times 350$ calendar days or $\frac{5}{7} \times \frac{2}{3} \times 350 = 167$ 8-hour working days. This corresponds to $\frac{167}{240} \times 8 = 5.56$, say 5 to 6 hours per tower, compared to somewhere between 7 and 32 minutes per tower with a free flying vehicle (15 minutes per tower is currently anticipated for an S64 helicopter).

Thus the construction time of 8 months can be reduced in proportion to the flight time per tower, provided an FFV is used that can carry a complete tower, and totally substitute for flatbed trucks and cranes. Therefore, Phase II time can be reduced by at least 90 percent to as much as 98 percent, by 7.50 to 7.84 months. This implies a very significant effect on HLA threshold costs, as identified in Figure 6-4, shown earlier.

If the helicopter performs the two round trips to effect tower placement, the threshold cost becomes the cost of the helicopter to perform its task, assuming ground support costs and other savings are comparable, as given in Table 6-16, below.

TABLE 6-16 HLA Threshold Cost vs. Skycrane Competition

SKYCRANE TYPE			S 64 E			S 64 E		
OPERATING HOURS/YEAR			1500	2200	3000	1500	2200	3000
COST PER HOUR			1654	1529	1450	2361	2029	1830
JOB* COST ($M)	N_T	120	.0660	.0612	.0595	.0944	.0812	.0732
		240	.1320	.1224	.1190	.1888	.1624	.1464
		360	.1980	.1836	.1740	.2832	.2436	.2196
MAX. TOWER SIZE* (T)			18.8			23		

*ASSUMING TWO ROUND TRIPS PER TOWER

The maximum tower size essentially eliminates the current helicopter from contention for the larger lines, but it remains available for competition for the 345 and 500 KV lines.

The threshold cost is thus a significant variable. However, by examining the average HLA cost to do the job, the critical regions of the threshold costs can be isolated.

The market share factors for this application are A = 0 and B = 32.5 From

$$M_{NF} = \frac{S-A}{B-A}$$

Then for $M_{NF} = 100$

$$S \geqslant B \geqslant 32.5\%.$$

Since

$$S = \left[1 - \frac{HLAC}{TC}\right] 100.$$

$$TC \geqslant HLAC \Big/ \left(1 - \frac{S}{100}\right)$$

$$\geqslant HLAC \, / .675$$

This threshold cost and the average 25-ton payload HLA job cost (HLAC) are given in Table 6-17.

TABLE 6-17 Threshold and Average HLA Job Costs (Transmission Tower Placement)

AVERAGE HLA SPEED (MPH)	25			60		
AVERAGE DISTANCE TO SITE (MILES)	1	2.5	4	1	2.5	4
RD. TRIP TRANSPORT TIME (MINS.)	4.8	12	19.2	3	7	8
HOVER TIME (MINS.)	3 5	3 5	3 5	3 5	3 5	3 5
AVERAGE HLA JOB COST ($M)	.053 .067	.102 .116	.151 .165	.039 .052	.065 .078	.091 .104
THRESHOLD FOR M_{NF} = 100 ($M)	.079 .099	.151 .172	.224 .244	.058 .077	.096 .150	.163 .193

The threshold HLA costs given in Figure 6-4 are roughly one-half to one order of magnitude greater than this limit, and the 25-ton market would be a virtual certainty. Even the helicopter costs (which are the HLA threshold costs for competition against the helicopter) would be greater than these since the HLA costs were calculated for a 25-ton payload machine, rather than the 13-ton and 17-ton payloads that the helicopter is suited to. Thus it would appear that the 25-ton HLA has the potential for capturing the complete market with the total number of vehicles, assuming no ferry requirements, shown in Table 6-18.

TABLE 6-18. No-Ferry Number of HLA to Satisfy the HLA Share of the Transmission Tower Placement Market

AVERAGE HLA SPEED (MPH)					2.5			6.0	
AVERAGE DISTANCE TO SITE (MILES)				1	2.5	4	1	2.5	4
TOTAL HOVER TIME (MINS.)			**MIN.**	3			3		
			MAX.	5			5		
$N_{V_{NF}}$ (25T)	**ANNUAL UTILIZATION (HOURS)**	**1,000**	**MIN.**	12	21	29	9	14	16
			MAX.	14	22	32	12	17	18
		2,000	**MIN.**	7	12	17	5	8	9
			MAX.	8	12	18	7	9	10

6.7.3.5 The Effect of Ferry on the Number of Vehicles. From Section 6.3, the ratio between the number of vehicles required with ferry, to the number assuming no ferry, is given by

$$\left[\frac{1-\left\{\dfrac{\dfrac{(\text{Ferry cost/hr})(\text{Hours per job})}{(\text{Threshold cost per job})}}{\left(\%\ \text{Savings for 100\% market}\right)\left(\begin{matrix}\text{No-ferry}\\ \text{market share}\end{matrix}\right)}\right\}k}{1-k}\right]$$

where k is the proportion of the annual utilization consumed in ferry. ferry.

This can be written, as in Section 6.3, as

$$\left[\frac{1-\left(\dfrac{C_F}{C_F^*}\right)k}{1-k}\right]$$

and $\left(\dfrac{C_F}{C_F^*}\right)$ is developed in Table 6-19.

TABLE 6-19. $\left[\frac{C_F}{C_F^*}\right]$ for the Transmission Tower Placement Market

AVERAGE HLA JOB SPEED (MPH)				25			60		
AVERAGE DISTANCE TO SITE (MILES)				1	2.5	4	1	2.5	4
TOTAL JOB TIME (HOURS)	MIN.			7.8	15	22.2	6	10	11
	MAX.			9.8	17	27.2	8	12	13
$\frac{\text{THRESHOLD COST}}{\text{JOB TIME}}$ ($K/HR.)	MIN.			6.3	4.7	4.3	8.3	8.0	10
	MAX.			6.9	5.4	4.3	8.9	8.4	10
FERRY COST AT BEST FERRY SPEED ($K/HR.)		ANNUAL UTILIZATION (HOURS)	1,000	2.4					
			2,000	1.6					
(% SAVINGS) x ("NO FERRY" SHARE)			–	32.5					
$\left(\frac{CF}{CF^*}\right)$ (SEE SECTION 6.3.3)	MIN.		1,000	1.17	1.57	1.72	.89	92	.74
			2,000	78	1.05	1.14	.59	.62	.49
	MAX.		1,000	1.07	1.37	1.72	.83	.88	.74
			2,000	.71	.91	1.14	.56	59	.49

Reference to Figure 6-1 in Section 6.3, shows that these values of $\left(\frac{C_F}{C_F^*}\right)$ permit an increase in number of vehicles for the 60 mph case, but of a low order unless a large number of ferry hours per year are required. The 25 mph vehicle numbers required may be expected to decrease as a result of the conflicting effects of ferry cost and ferry time. Note that in both cases the effect of reducing annual utilization is to reduce the number of vehicles required. On balance, the no-ferry values of Table 6-18, provide the best estimate in the absence of definitive ferry and utilization information.

6.8 Case Study No. 5
Transportation of Equipment for and Construction of Steam Electric Generating Plants

6.8.1 Current Operations

This case describes the construction of a typical 600 MW fossil fuel steam electric generating plant at a site in the Southwestern United States. In this type of construction there are three principal activities:

- Transportation of heavy and outsized equipment from the place of manufacturing to the lay-down area or the construction site
- Transportation of heavy and outsized components in addition to other supplies from the lay-down or staging area to the construction site and emplacement of same at the site
- Lifting and erection of heavy components and modules at the construction site.

The heavy components required for a typical 600 MW electric generating plant include:

- 1 generator - 300 tons weight
- 1 deaerator heater and tank, which can weigh up to 120 tons
- 1 main steam drum - 300 tons
- 5 heavy girders to be placed on top of boiler structures - weight up to 125-140 tons each.

In addition there are several components that currently have to be shipped knocked down due to the limitations of the existing transportation infrastructure:

- One each of: turbine and shaft, assembled weight of each, 100-150 tons
- One each of: high pressure, intermediate pressure and low pressure stages, assembled weight of each, 70 tons.

The above components are assembled at the factory, tested, knocked down for shipment, and then finally assembled and installed at the construction site. The total current cost of the turbine and shaft is $12 million, and the cost of each of the stages is $5 million for a total of $15 million.

The final large component is a condenser. This component will, however, have to be shipped knocked down, and assembled at the site. This is due to the particular construction requirement of this component and its surrounding structures.

In addition to the heavy equipment, approximately 30,000 tons of miscellaneous components, equipment and supplies are required for the construction project.

In a typical power plant construction job two areas are set aside:

- Lay-down area. This is the storage and staging area where all supplies, components and equipment are stored in a carefully defined grid area. This site is normally located next to a railroad freight yard, good road, or a barge landing that are easily accessible. The lay-down area is within 3/4 to 1 mile of the construction site.

- Construction site. This is the actual site of the construction. The equipment, components and supplies are transported to the site from the lay-down area by trucks, cherry-pickers and other means of transportation.

All equipment, components and supplies are offloaded from their transport and placed in their grid in the lay-down area.

The cost of transportation of the heavy components from the origin to the lay-down area is covered in case study No. 13 dealing with parametric costs from different means of transportation. Some typical costs for transporting components from railcar to the construction site including erection at the construction site were given by Williams Crane & Rigging of Richmond, Va. as follows:

Size of Component	Total Cost
40-100 tons	$1400-$1800
100-175 tons	$2200-$2300
200-400 tons	$100,000-$125,000

In the remote areas and wetlands in the southwest United States, major problems are often encountered in storing and transporting the equipment, components and supplies. The problems are both of finding a suitable lay-down area and of transporting these items between the lay-down area to the construction site. In the case of the generating plant constructed by Bechtel for the Lower Colorado River Authority in La Grange, Texas, a two-mile rail spur had to be constructed from an existing rail yard to the lay-down area, in order to bring in two trainloads of supplies per week. The cost of the spur was approximately $1 million.

At the construction site itself a 500-ton crane is installed to handle the lifting of the large components. The maximum capacity of the crane is used only for the previously mentioned large components, i.e., approximately 10 lifts during the entire construction period of approximately 2.5 years. The remainder of the time the crane is handling structural parts weighing up to 30 tons. The rental charge for a 500-ton crane is typically $1200 per day.

6.8.2 Potential HLA Applications

There are three possible scenarios for the application of the HLA in the transportation of components for and construction of the power plant:

- Transport the fully assembled turbine and shaft, and the three pressure stages from the manufacturing plant to construction site
- Transport the heavy components from the lay-down area to the construction site and perform erection at the site
- Lift fully assembled structural modules from assembly yard and position same at the construction site.

6.8.2.1 Application 1: Transport Fully Assembled Components. The turbine and its shaft and the three pressure vessels have to be assembled at the manufacturing plant, tested and then disassembled or knocked down for shipment. The disassembly is necessary because the awkward and outsized dimensions of the fully assembled modules preclude their transportation by existing modes of transportation. At the construction site these components have to be reassembled and installed. The HLA is not constrained from transporting large, awkward components, and can therefore transport the components fully assembled with great potential savings in cost.

(1) Scenario

Since the HLA can transport the outsized and awkward components, the following hypothetical scenario was constructed:

- After the components have been fully assembled and tested at the manufacturing plant, they are positioned, prepared and rigged for transport by HLA.
- The HLA transports the fully assembled components to the construction site.

(2) Assumptions

The following simplifying assumptions pertaining to this operation are made:

- The manufacturing plant has facilities to allow the internal movement of the fully assembled components to a site in the plant that can be accessed by the HLA
- The rigging at the manufacturing plant is performed by employees of the manufacturer
- The cost of this rigging does not exceed the cost of preparing the knocked-down components for shipment
- The rigging at the lay-down area is performed by employees of the construction firm.

(3) Potential Cost Savings with HLA

The potential cost savings resulting from the use of the HLA for the transportation of the fully assembled turbine and shaft and the three pressure vessels are due to the elimination of two time consuming and costly operations:

- The disassembly of the components at the manufacturing plant
- The reassembly of the same components at the construction site using higher cost labor with less productivity due to the relatively primitive conditions existing at a field construction site compared to a manufacturing site.

Experts from Bechtel Power Corp. have estimated cost savings resulting from the elimination of the two above operations to amount to at least 30 to 35 percent of the total cost of the components. The potential cost savings for a typical electrical generating station can be estimated as follows:

Component	Approximate Cost	Estimated Cost Saving
Turbine and shaft	$12 million	$3.6 million
High, medium and low pressure stages	$15 million	$4.5 million

This estimate is supported by a recent study performed by the General Electric Co. In this study, it was found that great savings could be achieved by creating energy parks having several nuclear power generating stations in one central location where all components are produced and assembled in on-site factories. General Electric concluded (Reference 12):

> "Use of an on-site factory and modular, production line type construction indicates a potential for nuclear generation plant capital cost savings of the order of 25 percent in the reference park compared to dispersed sites used in the study."*

This particular study assumed that the modules would be assembled in on-site factories and installed on the site. It is reasonable to assume that similar savings can equally well be derived by assembling modules in a centrally located factory for transportation and emplacement at a power plant.

(4) HLA Threshold Cost

The threshold cost for the HLA is the above saving cost plus the cost of shipping the components via conventional means of transportation. The turbine and the shaft are shipped separately as two components plus additional parts and the three pressure stages are shipped as three separate components plus supporting materials. Estimated transportation costs for these components are $100,000, giving a threshold cost of $8.2M.

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* Assessment of Energy Parks vs. Dispersed Electric Power Generating Facilities, final report, Vol. I, prepared for the Office of the Science Advisor, Energy R&D Office, by Center for Energy Systems, General Electric Co., (May 30, 1977) pp ES-4 to ES-9.

(5) Potential Operating Scenarios for HLA

The HLA operating times will be a direct function of HLA cruise speed and typically one-way distances from platn to construction site or laydown area of 200 to 600 miles.

6.8.2.2 Application 2: Transportation and Erection of the Heavy Components. When electric power generating plants are constructed in remote areas or in areas with difficult terrain, as in the wetlands of the Gulf of Mexico, it is at times costly and time consuming to transport the heavy components from the lay-down area to the construction site. At the construction site it is necessary to have a heavy-lift crane (350-500 ton capacity) whose capacity is used approximately 10 times during the entire construction period. At other times this crane is lifting loads up to 30 tons. The HLA can therefore be a potential cost and time-saving device in the transportation of the components between the lay-down area and the construction site. In addition, it can completely replace the heavy-lift crane.

(1) Scenario

The following scenario is construed:

- The HLA replaces the trucks/crawlers and cranes that are used in transporting the heavy components from the lay-down area to the construction site
- At the construction site the HLA is used to emplace the component at the site. The heavy-lift crane on the site is not required and all other lifts are made with mobile cranes and cherry-pickers used on the site for other purposes.

(2) Assumptions

The scheduling and the actual progress of the construction jobs will differ. For the hypothetical construction site the following assumptions as to the operation have been made:

- The cost of transportation and erection will be similar to the costs of the case defined earlier. It is assumed that the manpower required for the rigging both at the lay-down area and at the site will be the same as with conventional transportation. The HLA will thus replace the transport vehicle and possibly reduce the time for the operation.

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- The heavy-lift crane at the site can be completely eliminated. The lifts of up to 30 tons performed by the crane can be performed by other cranes on the site.

- The construction work is so scheduled and the site has been built so that the places where the component is to be emplaced are accessible by the HLA.

- The cost of the 500-ton crane is assumed to be $1200 per day. This crane normally remains on the site for the entire construction period of 2.5 years.

- Under conventional operation, an independent rigger is contracted to perform the unloading, hauling and erection of the components. The average costs indicated by Williams Crane & Rigging Co. of Richmond, Va. are assumed to be representative of these operations. Their costs are:

Weight of Component	Manpower	Equipment	Total
40-100 tons	$1000	$400-$800	$1400-$1800
100-175 tons	$1000	$1200-$1300	$2200-$2300
200-400 tons	$50,000-$60,000	$50,000-$60,000	$100,000-$125,000

- It is assumed that there are six different shipments, each consisting of the following:
  - 5 girders each 125-140 tons
  - 1 generator, 300 tons
  - 1 deaerator and tank, 100-120 tons
  - 1 main steam drum, 300 tons
  - 3 pressure stages, each 70 tons
  - 1 turbine and 1 turbine shaft, each approximately 100-150 tons

  The HLA is therefore required to make six separate trips to the job site to transport these components.

(3) Potential Cost Savings with HLA

With the exception of cost benefits that may be derived from the convenience of unloading, transporting and emplacing the components faster, there are no actual cost savings that can be attributed to the use of the HLA. These intangible benefits of convenience are difficult or impossible to quantify, and we have made no attempt to do so.

(4) HLA Threshold Cost

The HLA can replace two relatively costly components:

- The on-site high capacity crane
- The lifting and hauling equipment required in unloading, transporting and emplacement of the heavy components.

The primary cost item that can be eliminated and replaced with the HLA is the high capacity on-site crane. The cost of a typical 500-ton crane used in this operation is $1200 per day. Over the 2.5-year construction period the total cost saving is $1,095,000.

Other cost items that can be eliminated and replaced with the HLA are the jacks, cranes, and transportation equipment required for moving the equipment from railcar to construction site. According to William Crane & Rigging, a typical breakdown of equipment costs for different sized hauls and rigging jobs are as follows:

Weight of Component	Equipment Cost	No. of Components	Potential Saving
40-100 tons	$400-$800	3	$1200-2400
100-175 tons	$1200-$1300	8	$9600-$10,400
200-400 tons	$50,000-$60,000	2	$100,000-120,000
Total potential saving			$110,800-$132,800

The threshold cost with the HLA is therefore the sum of the cost of the equipment that is replaced. In this case the threshold cost is in the range from $1,205,800 to $1,227,800.

(5) Potential Operating Scenario for HLA

The total time required for the HLA will vary with the weight of the components to be erected. The transportation distance is short so that speed effects are not important. These categories have been selected based upon the operating experience of conventional rigging operators. The three operators' experience regimes are:

- Less than 100 tons
- 100 tons up to 200 tons
- 200 tons and more.

The operating scenario is expected to be:

- Unload from railcar, transport, position at site, and return to railcar:

Components less than 100 tons	1/2 hr.
Components 100 to 200 tons	1 hr.
Components 200 tons and more	2 hrs.

The expected total time requirement for the six shipments are thus expected to be:

Shipment (1) 5 girders each 125-140 tons	5 hrs.
Shipment (2) 1 generator 300 tons	2 hrs.
Shipment (3) 1 deaerator & tank 100-125 tons	1 hr.
Shipment (4) 1 main stream drum, 300 tons	2 hrs.
Shipment (5) 3 pressure stages, 70 tons each	1-1/2 hrs.
Shipment (6) 1 turbine & 1 turbine shaft each 100-150 tons	2 hrs.
Total operating time	13-1/2 hrs.

6.8.2.3 Application 3: Lift and Position Fully Assembled Structural Modules. The conventional method of construction is to bring the structural steel to the construction site, lift it in place with on-site cranes and weld it. Experts from Bechtel Power Corp. have indicated that great cost savings can be achieved if structural modules were prefabricated in a fabrication site close to the construction site. This cost saving operation has been precluded to a large extent because of the difficulty of erecting these structures at a construction site using conventional transport equipment and cranes. The HLA has the potential for solving the problem of moving the structural modules between the fabrication yard and the site, and to emplace the modules at the site.

(1) Scenario

An on-site fabrication yard to assemble structural modules is established in close proximity to the construction site and the lay-down area. At this fabrication yard all the structural steel material is assembled into modules weighing from 100 tons up to 300 tons. The actual weights of the modules will be adjusted to the lifting capability of the HLA selected for the application. The HLA is used to move the modules from the fabrication yard to the construction site and to erect and emplace the modules at the site.

More than 100 modules are required for the construction of the typical 600 MW power generating station. The progress of the overall construction job and the fabrication of the modules is scheduled, so that the HLA is brought to the site in four time increments throughout the 2.5-year construction period. In each of these time increments the HLA is used for a full 8-hour working day for a continuing period of one to three weeks.

The arrival of the heavy components, described in application 2, and the construction work are scheduled so that the unloading from the train, transportation from the site plus erection can be accomplished as part of the work performed by the HLA in the four increments.

(2) Assumptions

The assumptions made for application 2 above remain the same with respect to unloading, transporting and positioning the heavy components. In addition, the following assumptions are made:

- All rigging both at the fabrication yard and at the construction site is performed by the normal complement of construction workers. No additional workers are required for the rigging operation.
- The scheduling of the construction work and the arrival of the heavy components are set so that the HLA will have minimal unproductive waiting time. Furthermore it is assumed that construction work is performed and scheduled so that the HLA will have unobstructed access to areas, where components and modules are to be emplaced.

(3) Potential Cost Savings

Great savings in cost can be derived from the increased productivity by transferring construction work from field conditions to an assembly and fabrication yard. The study performed by General Electric (Reference 12) concluded:

> "The major savings will accrue from shifting of construction labor from the field construction site to the on-site modular factory combined with benefits from repetitive work sequences (learning curve) resulting in an increase in productivity by a factor of 1.5 to 4."

Experts from Bechtel Power Corp. proposed that the total construction budget of $75 million for a typical 600 MW power plant could conservatively be decreased by $5 million if an on-site fabricating yard were made feasible by the existence of the HLA.

(4) HLA Threshold Cost

The HLA threshold cost in this case is the sum of the total cost savings of $5 million plus the cost of the replaced equipment. The latter was estimated from the previous application to be in excess of $1.2 million. The HLA threshold cost for this application is therefore estimated to be in excess of $6.2 million.

(5) Potential Operating Scenario for HLA

It is anticipated that the HLA will be required in four time installments each lasting from one to three weeks or an average of two weeks for each time installment. In this time the HLA will be used continually for 8 hours per day. Total operating time excluding ferry between base and construction site, for the HLA is expected to be:

- Operating time: 14 days x 8 hrs. x 4 times: 448 hrs.

6.8.3 Estimate of HLA Needed to Satisfy the Potential Market.

This estimate assumes three different payload sizes selected to accommodate the following categories of components

- Major nuclear plant components - 750 tons
- Major non-nuclear plant components - 300 tons
- Other components - 150 tons.

6.8.3.1 The Annual Market. From Section 5, the annual market is summarized as 85,000 MW of generating capacity added per year. Application 1 refers to pressure stages, which are components associated with nuclear and fossil fuel power generation, and to turbines and turbine shafts which are associated with these and with hydroelectric power generation. The nuclear and fossil fuel added annual capacity is 73,000 MW, while nuclear, fossil and hydros come to about 83,000 MW. The majority of the components lifted in Application 2 are required for all forms of power plant, as are the structural modules lifted in Application 3; for these two cases the total annual added capacity of 85,000 MW is appropriate.

6.8.3.2 The Required HLA Capabilities. Study of the component characteristics given in Section 5 for the various generating plant types and sizes enables estimates to be made of the number of heavy lifts per year required for each payload size and application.

(1) Application 1

For this application, using 300-ton payload HLAs, 3 pressure stages must be lifted together for every 600 MW of added nuclear and fossil fuel generating capacity, and 1 turbine and 1 turbine shaft together for every 600 MW of added nuclear, fossil and hydro generating capacity. To satisfy the added annual capacity for these cases would require

- 122 pressure stage lifts per year
- 139 turbine and shaft lifts per year.

(2) Application 2

From the data in Section 5, the component weights per MW, and the distribution of these weights are as shown in Table 6-20.

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TABLE 6-20. Power Generation Plant Component Weights and Distribution

COMPONENT WEIGHTS	**NUCLEAR PLANTS**	– 0.5 T/MW				
	STEAM, HYDRO, GAS TURBINE PLANTS	– 2.2 T/MW				
COMPONENT WEIGHT DISTRIBUTION	**COMPONENT WEIGHTS (T)**	**0**	**150**	**300**	**500**	**1000**
	NUCLEAR PLANTS	17%	–	–	83%	
	STEAM, HYDRO, GAS TURBINE PLANTS	85%	15%	–	–	

From this information, and the annual generating capacity added for each power source, the number of lifts required per year are given in Table 6-21.

TABLE 6-21. Number of Lifts Per Year to Support Application 2

GENERATING SYSTEM		**ADDED ANNUAL CAPACITY (MW/YEAR)**	**TOTAL HEAVY LIFT (T/YEAR)**	**NUMBER OF LIFTS/YEAR**		
				150T	**300T**	**750T**
NUCLEAR	THERMAL SUPPLY	39,500	20,000	23	–	23
	STEAM GENERATOR		89,600	264	–	66
STEAM		33,400	73,400	416	37	–
HYDRO		10,200	22,400	127	11	–
GAS TURBINES		1,700	3,800	22	2	–
TOTAL		84,800	209,200	852	50	89

(3) Application 3

An average 600 MW station requires approximately 20,000T of structural modules. Thus the total added annual capacity of 84,000 MW will require 2.83×10^6 tons of structural modules. The alternative lifts are as given in Table 6-22.

TABLE 6-22. Number of Lifts Per Year to Support Application 3

PAYLOAD SIZE (T)	150	300	750
LIFTS PER YEAR	18,870 OR	9,435 OR	3,774

The annual operating hours in each application are as follows:

(1) Application 1

This is transport time from plant to site and return; the 300T round trip time for this lift is given in Table 6-23.

TABLE 6-23. Operating Time for Application 1 (hours)

ONE-WAY DISTANCE (MILES) \ HLA SPEED (MPH)	25	60
200	32	13.3
400	64	26.7
600	96	40

(2) Application 2

This is on-site transportation and erection; the times are given in Table 6-24 for a 600 MW plant.

TABLE 6-24. Operating Time for Application 2 (hours)

COMPONENT WEIGHTS (T)	0-100	100-200	≥200	PAYLOAD (T)		
HOURS PER COMPONENT TO UNLOAD, TRANSPORT, POSITION & RETURN	0.5	1.0	2.0	150	300	750
5 @ 125 → 140T	–	5	–	5	–	–
1 @ 300T	–	–	2	–	2	–
1 @ 100-125T	–	1	–	1	–	–
1 @ 300T	–	–	2	–	2	–
3 @ 70T	1.5	–	–	1.5	–	–
2 @ 100-150T	–	2	–	2	–	–
SUBTOTALS	1.5	8	4	9.5	4	–
TOTAL TIME	13.5			13.5		
AVERAGE TIME PER LIFT	—			0.864	2	2

(3) Application 3

The time required to lift and position fully assembled structural modules is given in Table 6-25 for a 600 MW plant, based on 448 hours for 100 200-ton modules.

TABLE 6-25. Operating Time for Application 3 (hours)

PAYLOAD SIZE (T)	150	300	750
NUMBER OF MODULES	134	67	27
OPERATING TIME (HRS)	597	299	119

6.8.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. Total number of each payload size to satisfy 100 percent of the market

$$= \sum_{\text{Applications}} \frac{(\text{Lifts per year})(\text{Hours per lift})}{\text{Utilization}}$$

and this is given in Table 6-26.

TABLE 6-26. No-Ferry Number of Vehicles to Satisfy 100% of the Power Generation Market

	APPLICATION	PAYLOAD (T)				150	300		750
		HLA SPEED (MPH)					25	60	
$\bar{N}_{V_{NF}}$	1	ONE-WAY DISTANCE	200	ANNUAL UTILIZATION	1000		10	4	
					2000		5	2	
			400		1000		18	8	
					2000		9	4	
			600		1000		26	12	
					2000		13	6	
	2					1	1		1
	3	ANNUAL UTILIZATION (HOURS)			1000	85	43		17
						OR		OR	
					2000	43	22		9

6.8.3.4 "No-Ferry" Share of the Market, M_{NF}. From the 600 MW case study, the threshold cost ($M) for each application is as follows:

Application 1: TC = 8.2
Application 2: TC = 1.22
Application 3: TC = 6.2

The average HLA job cost ($M) is as follows:

Application 1: HLAC = .113
Application 2: HLAC = .065
Application 3: HLAC = 6.85

The market share factors are A=22.5 and B=50. Thus from the expression derived earlier,

Application 1: M_{NF} = 100 percent
Application 2: M_{NF} = 100 percent
Application 3: M_{NF} = 0.

(Note for the market share in Application 3 to become 100 percent, HLAC would have to become no more than about half the estimted HLAC.

6.8.3.5 "No-Ferry" Number of Vehicles for Market Share, $N_{V_{NF}}$.

Since the market share is clearly 100 percent in the first two applications, and 9 percent for Application 3, the number of vehicles are in Table 6-26 for those two applications. Note that if the HLAC cost can be reduced roughly 50 percent, the number of vehicles required can increase substantially.

6.8.3.6 The Effect of Ferry on the Number of Vehicles. Using the expression and data derived in Section 6.3,

$$\frac{N_V}{N_{V_{NF}}} = \frac{1 - \left(\frac{C_F \cdot T_J}{TC} \Big/ (B-A) M_{NF} \right) \cdot k}{1 - k}$$

the ferry ratio ranges from 1.16 to 1.4 for k=.3 and ranges from 1.56 to 2.48 for k=.6. Thus in general, as ferry is required, the number of vehicles required will increase by roughly a factor of 2.

6.9 Case Study No. 6
Pipeline Construction in Northern Canada

6.9.1 Current Operations

This case is based on the planned construction of the Foothills Pipelines Company Ltd. portion of the Alcan-Foothills 42-inch gas pipeline extending 2754 miles from the Prudhoe Bay gas fields in the artic area of Alaska through the Yukon and British Columbia and the United States to Alberta. All cost figures and other data are based on data given to Goodyear Aerospace by officials of Foothills Pipeline Company Ltd. of Calgary, Alberta.

The construction of a pipeline requires a major logistical support network to assure that all equipment, pipeline materials, and other supplies are at the right place at the right time. Even minor delays may cause lost construction time at tremendous costs. In the climatically hostile and difficult terrain of Alberta and the Northwest Territories, the logistical support function is even more of a challenge than in most other areas. This case study will be limited to the description of three areas of logistical support where the HLA could potentially perform a valuable service:

- Transport of equipment from winter sites to enable an extension of the winter construction season
- Transport of construction equipment and personnel across internal obstructions along the pipeline right-of-way (ROW)
- Transport of pre-assembled or modularized compression stations from railroad lay-down areas, from heavy-lift trucks on major highways, or directly from manufacturing plants.

The currently planned functions for each of these areas are described below.

6.9.1.1 Winter Construction. Under currently planned operations, Foothills will establish three winter construction sites each winter season during the total construction period. Each of these sites will have a total of approximately 85 pieces of construction equipment valued at $17 million. The weight of each piece of equipment ranges from 25 tons up to 65 tons. The average piece of equipment weighs approximately 40 tons. Very large units are often knocked down or disassembled into smaller pieces for transportation to and from the sites. The total manpower requirement is planned at 550 men including supervisory personnel at each of the three sites.

Construction of approximately 30% of the total lengths of the pipeline in Canada, i.e., 130 miles in Alberta, 250 miles in British Columbia, and 100 miles in the Yukon must be constructed exclusively during the winter when the ground is frozen solid to enable movement of the heavy equipment. The total winter construction season is estimated at 100 days, during which an average of 60 productive workdays are expected. At the end of the winter construction period, while the permafrost is still in the ground, the equipment will be transported out of the construction sites. Heavy trucks will be used for this operation. All construction workers, except supervisory personnel, which account for approximately 10% of the work force, are laid off in the non-productive time during the summer.

It is estimated that the cost of transporting the equipment to and from the winter site is estimated at $500,000 per site or $1.5 million for the three sites.

6.9.1.2 Natural Obstruction Bypasses. When natural obstructions such as rivers are encountered, a temporary suspension is established to enable the laying of the pipe across this obstruction. Once this temporary suspension has been established, the construction crew and the equipment are transported back down the right-of-way (ROW), to the first public highway cutting across the ROW. This highway is followed up to the next public highway crossing the ROW on the other side of the river or obstruction. The ROW is followed back to the crossing. The reason for this somewhat cumbersome method of crossing is that Foothills has made a commitment not to construct temporary bypass roads. The average distance for each bypass is estimated at 100 miles. It is also estimated that each bypass will involve the loss of one day of productive time for the entire construction crew of 550 men. Since the full working day is 10 hours at $30/hour the cost of the productive time lost is $165,000.

A total of 85 pieces of equipment needs to be transported by truck. It is estimated that a total of 10 trucks will be required for each bypass at a cost of $30 per hour for the driver and $4 hourly truck operating cost. Assuming an average speed for the trucks of 30 mph, the truck operating cost will be $19,300. The total cost for the bypass operation is therefore $184,300.

An alternative that was considered by Foothills was to construct temporary bypass roads at each end of the obstruction. The cost of construction of the bypass road and restoring the land after completion of the operation is estimated at a cost of $10,000 per mile. A bypass with an average length of 10 miles would have to be built and restored for each at a cost of $100,000 per bypass. In this case the truck transportation would be reduced to $1,930. The total cost of the bypass operation under this alternative plan will be $184,430, assuming that only one-half day of production time will be lost.

6.9.1.3 Compressor Stations. Compressor stations have to be built every 100 to 120 miles along the pipeline. Access roads are constructed from the main highway to the compressor stations. These roads are generally constructed to handle normal loads up to 20-25 tons. The components will be either transported by rail to a laydown area for further transportation by truck to the compressor site, or by truck all the way from the manufacturing plant to the station site. The total compressor station weighs approximately 375 tons. An alternative considered by Foothills Pipeline is to pre-assemble the compressor stations into five components weighing 75 tons each. It is estimated that a total saving of $400,000 could be achieved through this modularization. The problem with this approach, is however, that the access road will have to be strengthened at an incremental cost of $750,000 to accommodate vehicles carrying the 75-ton modules.

6.9.2 Potential HLA Applications

The HLA has potential for use in logistical support in each of the three areas described above. Three potential scenarios can be formulated:

- The HLA can transport equipment from the winter construction sites after the permafrost has melted, thereby extending the winter construction season.
- The HLA can transport equipment and personnel across natural obstructions such as rivers and avoid delays or stoppages in the construction.
- The HLA can transport modularized compressor stations from a railroad staging area or from a major highway.

6.9.2.1 Application 1: Winter Construction Season Extension. The current plan for winter construction calls for a total construction season of 100 days. In order to ensure that all equipment and supplies are evacuated before the permafrost thaws in the spring, the construction is stopped and demobilization takes place during a period which potentially might have been the most favorable time for construction. If some means existed to evacuate the camp after the thaw of the permafrost, it is estimated that the construction season could be extended for at least another 20 days.

(1) Scenario

Foothills Pipelines Company Ltd. has contracted with an HLA operator to transport all equipment from the three winter construction sites to the nearest all year highway for further transportation to a new staging area. Officials of the Foothills Pipelines Company expect that this operation will enable extension of the winter construction season by 20 days. It is estimated that the productivity of the work force will be increased by 10% as a result of this extension, since construction can be conducted under very favorable conditions in the spring.

(2) Assumptions

The following assumptions are made:

- The benefits derived from the extension of the season and the resulting productivity increases are realized by reducing the total work force, rather than by increasing the total work output. The total work output will remain 33,000 man-days for each site or a total of 99,000 man-days for the season
- The equipment is transported to the winter construction sites by conventional methods at a cost of $250,000 for each site, for a total of $750,000 for the three winter sites
- The average distance from the sites to the major highway accessible with conventional trucks is 50 miles
- The labor cost is $30 per hour, and the normal working day is 10 hours.

(3) Potential Cost Savings with HLA

The major cost saving that will accrue as a result of the HLA is the overall productivity increase estimated at 10%. This will imply that the work that would require a total of 99,000 man-days can be achieved with 90,000 man-days with a saving of 9,000 man-days of work. At a cost of $300 per man-day, the total savings in labor cost is $2.7 mission.

(4) HLA Threshold Cost

The cost of demobilizing the equipment is estimated at $250,000 per site for a total of $750,000 for three sites. The total threshold cost for extending the winter construction season and transporting the equipment out with the HLA is expected to be the labor cost savings of $2,700,000 plus the transportation costs of $750,000 for a total of $3,450,000.

(5) HLA Operating Scenario

At each site 85 pieces of equipment will have to be evacuated for a total of 255 pieces of equipment. The total time required for each piece of equipment is as follows:

. Hover at origin for hook up		2 minutes
. Loaded travel, 50 miles	- fast HLA	50 minutes
	- slow HLA	120 minutes
. Hover at discharge point		2 minutes
. Return voyage	- fast HLA	50 minutes
	- slow HLA	120 minutes
. Total time per round trip	- fast HLA	104 minutes
	- slow HLA	244 minutes

For 255 pieces of equipment, the total operating time will be 26,520 minutes for the fast HLA or 62,220 for the slow HLA. In addition ferry time to the site will be required.

6.9.2.2 Application 2: Bypass of Natural Obstructions. At the present time, the plan for the construction of the Foothills' pipeline is to bypass natural obstructions like rivers, gorges, and other obstructions by loading the equipment onto trucks, backtracking on the ROW to the nearest public highway, and then bypassing the obstruction. This method is time consuming causing costly construction delays. The HLA could provide a potential solution to this problem which is faced by virtually all pipeline construction programs.

(1) Scenario

When a natural obstruction is encountered, the HLA is brought to the site to ferry both equipment and personnel across the obstruction. Construction can continue with minimal delays and cost.

(2) Assumptions

The following assumptions are made:

- The total construction team consists of 550 men and 85 pieces of equipment.
- The cost per labor hour is estimated at $30 per hour.
- The average diversion distance is 100 miles. Equipment and manpower are transported by 10 trucks at an average speed of 30 m.p.h. and at a cost of $30/hr for the driver and $4/hr for the truck.
- No man-hours will be lost with the HLA, while an average of one working day of 10 hours will be lost for each man under the conventional system.

(3) Potential Cost Savings With HLA

The major cost savings that can be achieved with the HLA will be the cost of productive labor. It has been estimated that an average of one day of productive labor will be lost due to a conventional bypass operation. This cost, for a labor force of 550 men working 10 hours at $30 per hour, will be $165,000.

(4) HLA Threshold Cost

The HLA threshold cost will be the above labor cost saving plus the cost of the trucking for the bypass operation. The trucking cost will be approximately $19,300. The threshold cost is therefore $184,300.

(5) HLA Operating Scenario

The distance that each piece of equipment will have to be transported will be limited, on the order of 0.3 to 1 miles, and the maximum speed will be low, around 10 to 25 mph. The major operating time will be for hover at each end of the bypass. The following working scenario is envisioned:

. Hovering at loading point	2 minutes
. Loaded transport	2 minutes
. Hovering at discharge point	2 minutes
. Return trip	2 minutes
Total time	8 minutes

A total of 85 pieces of equipment will have to be transported across. Total time for the operation will therefore be 11 hours and 20 minutes, in addition to the ferry time to the bypass point.

6.9.2.3 Application 3: Transportation of Modularized Compressor Stations. The assembly of compressor stations under field conditions is an expensive proposition, and great cost savings could accrue, if it were possible to transport pre-assembled modules to the field. In many cases this is not possible, due to the increased cost of constructing access roads capable of accommodating the large loads of modularized components. The introduction of the HLA could solve this problem.

(1) Scenario

The modularized compressor station components each weighing approximately 75 tons are transported from the manufacturing plant to the access road or a major staging area by heavy-lift truck or flatbed railcar. At this point the modularized components are picked up by an HLA, transported to the compressor station site, and emplaced.

(2) Assumptions

The following assumptions are made:

- The cost savings that will accrue by pre-assembly of the compressor station into five 75-ton components at a centralized factory is approximately $400,000. This figure is based on estimates proposed by pipeline construction officials.
- The transportation costs for delivering the compressor station in components to the staging area will be similar to the costs of transportation as modular units.

- Cost of truck transportation from staging area to site is estimated at $30 per hour for the driver plus $4 per hour for the truck at an average speed of 30 mph and a payload of 75 tons.
- The average distance from the staging area or major highway to the compressor station is 30 miles.
- The modular components have been rigged by pipeline labor prior to the arrival of the HLA.

(4) HLA Threshold Cost

The cost of transporting the 375-ton compressor station will require a total of 15 truck round trips at a cost of $68 per round trip for a total cost of $1020. The total threshold cost will therefore be $1020 plus the assembly cost savings of $400,000 for a total of $401,020 per compressor station.

(5) HLA Operating Scenario

The following operating scenario can be envisioned:

Hover to hook up payload		2 minutes
Transport to destination	- fast HLA	30 minutes
	- slow HLA	72 minutes
Precision to hover at destination to emplace component		5 minutes
Return to staging area	- fast HLA	30 minutes
	- slow HLA	72 minutes
Total per component	- fast HLA	67 minutes
	- slow HLA	151 minutes

Since a total of five components will be required, a total time for each compressor station exclusive of ferry time will be 5 hours 35 minutes for the fast HLA, or 12 hours 35 minutes for a slow HLA.

6.9.3 Estimate of HLA Needed to Satisfy the Potential Market

This estimate assumes the same payload size for all three applications. Since the payloads for the first two applications range from 25 tons to 65 tons and the payload for the third application is considered to be 75 tons, this is used as the payload size for this market.

6.9.3.1 The Annual Market. Worldwide, a total pipeline mileage per year of 10,000 is a reasonable estimate of current growth in pipelines of 22" diameter or more. The worldwide locations span all climates, including:

- Harsh winter (i.e., snow, permafrost in Canada and Alaska)
- Moderate, temperate in the United States, Europe, and Latin America
- Desert in Middle East and Africa
- Tropical in North Latin America, Africa and the Far East.

Application 2, Obstacle Bypass, is needed whenever pipelines are constructed. However, Application 1, Winter Season Extension, and Application 3, Compressor Station Transportation, are only needed where adequate conventional surface transportation to the construction site and compressor stations is not available without significant right-of-way preparation. From Section 5, this condition is estimated to exist for approximately 1000 miles of pipeline, worldwide.

Thus, the market for heavy-lift services can be summarized as follows:

- 2 winter sites per year, based on supporting those sites on the 1000 miles of pipeline that are inaccessible by road
- 100 to 200 obstacles per year, based on an obstacle occurring once every 50 to 100 miles
- 8 to 10 compressor stations placed per year, based on the requirement for one station every 100 to 120 miles along the 1000 miles of pipeline that are inaccessible by road.

6.9.3.2 The Required HLA Capabilities. This case study typifies Application 1 as transportation of 85 modules of equipment per site (ranging from 25 tons to 65 tons) over 50 miles, with 2 minutes of hover at each end for hook up and discharge. Application 2 consists of transportation of 550 men and 25 modules of equipment over a very short distance (2 minutes of low speed transport) with 2 minutes of hover at each end. Application 3 consists of transportation of 5 75 ton compressor modules per station over 30 miles, with 2 minutes to hook up to the payload, and 5 minutes to emplace the modules at the destination. The operating times for each application for one site are detailed in Table 6-27.

TABLE 6-27. Operation Times for the Pipeline Construction Applications

APPLICATION	AVERAGE HLA SPEED (MPH)	25			60		
1	ONE-WAY DISTANCE (MILES)	30	50	70	30	50	70
	ROUND TRIP TIME PER SITE (HOURS)	204	340	476	85	142	198
	HOVER TIME PER SITE (HOURS)	5.67					
	OPERATING TIME PER SITE (HOURS)	210	346	482	91	148	204
2	ROUND TRIP TIME PER OBSTACLE (HOURS)	5.67					
	HOVER TIME PER OBSTACLE (HOURS)	5.67					
	OPERATING TIME PER OBSTACLE (HOURS)	11.33					
3	ONE-WAY DISTANCE (MILES)	20	30	40	20	30	40
	ROUND TRIP TIME PER STATION (HOURS)	8	12	16	3.3	5	6.7
	HOVER TIME PER STATION (HOURS)	.583					
	OPERATING TIME PER STATION (HOURS)	8.6	12.6	16.6	3.9	5.6	7.3

6.9.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. The number of vehicles required to satisfy 100 percent of the market are, for each application,

$$= \left(\begin{matrix}\text{Number of}\\ \text{situations}\end{matrix}\right)\left(\begin{matrix}\text{Operating hours}\\ \text{per situation}\end{matrix}\right)\Big/\left(\text{Annual Utilization}\right)$$

as shown in Table 6-28.

TABLE 6-28. No-Ferry Number of Vehicles to Satisfy 100% of the Pipeline Construction Market

APPLICATION	AVERAGE HLA SPEED (MPH)				25			60		
1	ONE-WAY DISTANCE (MILES)				30	50	70	30	50	70
	OPERATING HOURS PER YEAR				420	692	964	182	296	408
	$\bar{N}_{V_{NF}}$	ANNUAL UTILIZATION (HOURS)	1,000		1	1	1	1	1	1
			2,000		1	1	1	1	1	1
2	OPERATING HOURS PER YEAR			MIN.	1133					
				MAX.	2266					
	$\bar{N}_{V_{NF}}$	ANNUAL UTILIZATION (HOURS)	1,000	MIN.	2					
				MAX.	3					
			2,000	MIN.	1					
				MAX.	2					
3	ONE-WAY DISTANCE (MILES)			–	20	30	40	20	30	40
	OPERATING HOURS PER YEAR			MIN.	69	101	133	32	45	58
				MAX.	86	126	166	39	56	73
	$\bar{N}_{V_{NF}}$ (FOR ALL UTILIZATION, AND OPERATING HOURS)				1					

6.9.3.4 "No-Ferry" Share of the Market, M_{NF}. The threshold costs for each application were developed earlier in this section, and are as follows:

- Application 1, \$1.15M per site
- Application 2, \$ .185M per obstacle
- Application 3, \$ .40M per station.

The average HLA costs for each application are functions of the required HLA capabilities previously outlined. Thus from the expression derived earlier, the market share is as given in Table 6-29.

TABLE 6-29. No-Ferry HLA Share of the Pipeline Construction Market

APPLICATION	AVERAGE HLA SPEED (MPH)	25			60		
1	ONE-WAY DISTANCE (MILES)	30	50	70	30	50	70
	AVERAGE HLA JOB COST ($M)	.918	1.414	1.910	.428	.703	.992
	M_{NF}	0	0	0	100	100	0
2	AVERAGE HLA JOB COST ($M)	.047					
	M_{NF}	100					
3	ONE-WAY DISTANCE (MILES)	20	30	40	20	30	40
	AVERAGE HLA JOB COST ($M)	.0367	.0516	.0665	.0196	.0267	.0338
	M_{NF}	100	100	100	100	100	100

6.9.3.5 "No-Ferry" Number of Vehicles for Market Share. From the previous two tables the number of vehicles can be defined to satisfy the market assuming no ferry. The vehicles are the same as those described previously in Table 6-28, with the exception that no vehicles are now required at 25 mph in Application 1.

6.9.3.6 Effect of Ferry. Since there are so few vehicles for these applications, the effect of ferry is of little consequence to the total number required.

6.10 Case Study No. 7
Heating/Ventilator/Air conditioning Unit Emplacement

6.10.1 Current Operations

In the construction industry many lifts are required. Most of these lifts, however, are repetitive lifts of small quantities for which on-site cranes are the least expensive and most efficient. There are two areas for which conventional cranes are not necessarily the least expensive and most efficient method. These are:

- Emplacing air conditioner/heating/ventilation units on the roof of buildings
- Emplacing window washing units on the roof of buildings
- Dismantling cranes from highrise buildings.

In these areas the operations of the Sikorsky Skycrane helicopters, primarily Evergreen Helicopters, Incorporated of Atlanta, Georgia, have proven to the construction industry that these jobs can be performed by the Skycranes at competitive costs.

6.10.1.1 Emplacement of Air Conditioner/Heating/Ventilation Units and Window Washing Units. These units can be lifted by helicopter in competition against conventional crane emplacement up to building height limits set by the capability of the cranes. A typical heating/air conditioning/ventilating unit is 20 ft. W x 48 ft. L x 15 ft. H and weighs 60,000 pounds. Due to the current restrictions for over the road transport by the highways and the lifting capabilities of construction cranes and helicopters, these units are normally broken down into four modules each weighing 15,000 pounds and measuring 12 ft. x 12 ft. x 15 ft. Normally two trailers are used to transport these units to their destination.

The number of units required for each building varies greatly and is dependent upon the size of the area to be ventilated and the climatic conditions in the area. Typically these units are installed in office buildings, warehouses, factories, shopping centers, and similar structures.

Window washing units are installed on building roofs, and weigh about 15,000 pounds.

Construction estimators have two choices in the selection of the installation method when cranes can be employed:

- Conventional cranes
- Skycrane helicopters.

The rule of thumb used by construction estimators is to allow up to $2000 for the emplacement of each 15,000 pound module on top of the building. This rule of thumb estimate is based on the average cost of bringing in and using a conventional mobile crane.

Evergreen Helicopters estimates that the required revenue to operate the Skycrane is $5000 per hour. This is based on 750 total operating hours per year including ferry time. The average ferry distance for each job is 800 miles at a speed of 100 mph. Thus, the ferry cost alone on each job is $40,000. For that reason, Evergreen does not bid jobs with less than 24 unit modules to be lifted. The exception is when the company can cluster several jobs. In those instances it can allocate the ferrying cost and thus stay competitive.

At the construction site, ground personnel from Evergreen make all preparations at the site in advance of the helicopter's arrival to insure the highest possible productivity. The goal is to be able to place one unit every 3 to 5 minutes, or an average of 15 lifts per hour (range from 12 to 20 per hour). The units are normally lifted from a nearby parking lot and placed directly on the roof by the helicopter with the assistance of the construction crew. The total flying distance is 1,000 feet or less.

The minimal mission time for the helicopter is thus:

.	Ferry - 8 hours at 100 mph	8 hrs.
.	Lift - 15 lifts/hr ea. 15,000 lbs x 24 (min)	1.6 hrs.
	Total mission time	9.6 hrs.

For all jobs exceeding 24 units the helicopter is highly competitive with the conventional cranes and profitable for the operators.

6.10.1.2 Application 2: Emplacement of Units Beyond Crane Height Limits. For emplacement of air conditioning, window washing and other units on buildings beyond the limits of conventional cranes, even rooftop cranes become undesirable because of the difficulty of controlling the motion of the load, and the potential for damage to the load and the building. Thus the competition for HLAs lies in the use of helicopters. Since the need for this kind of installation is much less than for installation on less tall buildings and shopping centers, the cost of the helicopter per installed unit is greater. Tishman Construction advised that it is current practice to rent the services of a Skycrane helicopter for a day at a cost of $25,000, in order to install one 15,000 pound window washing unit. The same cost would apply for the multiple lifts required for installation of a 60,000 pound air conditioning, heating and ventilating unit.

6.10.1.3 Dismantling Construction Cranes. The conventional method of dismantling and lowering construction cranes from high-rise buildings is to install a small derrick crane on top of the building. This derrick crane then lowers the parts of the crane on the outside of the building. Another method is to lower the components down the elevator shaft. Both methods are time consuming and costly.

One case is presented with the dismantling and lowering of a construction crane from the top of a recently constructed hotel in the Peach Tree Center in Atlanta, Georgia. The contractor had estimated that the cost of dismantling and lowering the crane using conventional methods would be approximately $50,000. This contractor was running behind schedule and risked incurring penalties for late performance. The dismantling and lowering the crane by conventional means would have further delayed the completion of the construction job. The potential of lost revenues to the hotel owners, the inconvenience of having to cancel planned events in the hotel and the penalties that would accrue to the contractor made consideration of other means imperative. The contractor in this case contracted with Evergreen Helicopter to dismantle and lower the crane. In a time span of two hours the Evergreen Skycrane was used to dismantle and lower to the ground 11 pieces weighing between 12,000 and 16,000 pounds. The total charges for the job was somewhat less than $50,000.

The cost of the crane in question was $200,000. The expenditure of $50,000 by the contractor to be able to reuse the crane at another construction site was therefore well invested. On the other hand, if the cost of a new crane had been $50,000 or less, it is likely that the contractor might have chosen to scrap the crane by cutting it into pieces small enough to be lowered to the ground.

6.10.2 Potential HLA Applications

Both of the above applications were considered impossible to be performed until Evergreen Helicopters conceived the idea to use a Sikorsky Skycrane helicopter to perform special and difficult jobs. The Skycrane's lifting capability is limited to about 20,000 pounds and the operating costs per unit of lifting capacity is higher than the HLA. It is therefore hypothesized that the HLA can perform the same type of missions that are currently done with the Skycrane.

6.10.2.1 Application 1: Emplacement of Units Within Crane Height Limits. Currently, the components or modules are limited in weight to the lifting capability of helicopters or conventional cranes. The HLA will have the potential to at least duplicate the services provided by the helicopters and cranes and most likely provide improved productivity through the increased lifting capability.

(1) Scenario

Two possible scenarios can be hypothesized:

- The HLA is brought in to duplicate the services provided by helicopters and conventional cranes
- The modules are preassembled at the ground into larger modules to capitalize on the larger lifting capability of the HLA.

(2) Assumptions

Under the first operating scenario it is assumed that the HLA operation will be identical to that of the helicopter described in the previous pages.

For the second scenario the following assumptions are made:

- The modules are assembled into complete units weighing approximately 30 tons by labor provided by the contractor
- These units are rigged to be ready for pick-up and emplacement on the roof using the HLA
- No significant slowdown in the turnaround time will result due to the larger weights carried.

(3) Potential Cost Savings With HLA

There are no cost savings provided by the HLA beyond those already being realized by the helicopter.

(4) HLA Threshold Cost

The HLA threshold cost under both scenarios will be the cost of conventional emplacement, i.e., $2000 per 15,000 pound module or $8000 for each 60,000 pound unit emplaced.

(5) Potential Operating Scenario for HLA

The operations under the first scenario are expected to be identical to that of the helicopter. Once at the site, the HLA will be able to emplace one 15,000 pound section every three to five minutes or an average of 15 per hour. Under the second scenario productivity will increase fourfold by the fact that the HLA will lift one complete unit of 60,000 pounds every three to five minutes.

6.10.2.2 Emplacement of Window Washing Units. Since these units are not modular, the same descriptions apply as in Application 1 above, for the scenario where the HLA duplicates the helicopter services. In this case, however, the HLA threshold cost is $25,000 per unit.

6.10.2.3 Application 3: Dismantling of Construction Cranes. As with the previous application the HLA can either duplicate or increase the productivity achieved with a helicopter.

(1) Scenario

Two scenarios can be hypothesized:

- The operations currently being performed by the helicopter are duplicated by the HLA
- The crane is disassembled to the largest feasible subassemblies and either lowered to the street below or to an open area within a short distance of the construction site.

(2) Assumptions

It is assumed that the operations required under the first scenario will be identical to that of the helicopter. In addition, it is assumed that sufficient space is available for the HLA to lower the components to the street.

Under the second scenario, the above is supplemented by the following assumptions: The total 75-ton weight of the crane can be subdivided into three components weighing approximately 25 tons each. These components can be lowered into the street to an adjacent parking lot or empty space. The larger components will not measurably affect the productivity of the HLA compared to the lowering of the smaller components.

(3) Potential Cost Savings With HLA

It is expected that the use of the HLA will not result in cost or time savings beyond those that can be realized by the Skycrane helicopters currently in use.

(4) HLA Threshold Cost

The HLA threshold cost will be the cost of lowering the crane by conventional methods. This cost is approximately $50,000.

(5) Potential HLA Operating Scenario

When the HLA has arrived at the scene, the operation is expected to be identical to that of the helicopter. The helicopter required a total of two hours to lower 11 components weighing between 12,000 and 16,000 pounds each. The average time required for each component was 10 to 11 minutes.

Under the second scenario three pieces each weighing 25 tons are lowered. With an average time requirement for each piece of 10 to 11 minutes, the total job can be performed in slightly more than one-half hour.

6.10.3 Estimate of HLA Needed to Satisfy the Potential Market

This estimate assumes three payload sizes selected to match the required lifts.

6.10.3.1 The Annual Market. From Section 5, the annual market consists of

- Application 1: Alternative (a) 4750 to 5200 7.5T lifts

  Alternative (b) 3250 to 4200 7.5T lifts, plus 250 30T lifts

- Application 2: 5000 to 6000 7.5T lifts
- Application 3: 250 to 300 25T lifts.

6.10.3.2 The Required HLA Capabilities. In each application, the distance to be traveled is so short that the transport speed is low and the operation is essentially all hover. All lifts average about 4 minutes each.

6.10.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. The total number of each payload size to satisfy 100 percent of the market

= (Lifts per year)(Hours per lift)/(Annual Utilization)

The total number of 7.5 tons vary from 8000 to 11,000, plus 250 to 300 25-ton lifts. These numbers require only 1 vehicle of each payload size, if ferry is not considered.

6.10.3.4 "No-Ferry" Share of the Market, M_{NF}. From the case study, the threshold cost ($K) for each application is as follows:

- Application 1 (a), $2,000 per 7.5T lift
  1 (b), $2,000 per 7.5T lift, and
  $8,000 per 30T lift
- Application 2, $25,000 per unit
- Application 3, $50,000 per crane.

In Applications, 1 and 2, HLA average costs for 4 minutes of hover are $150 per lift for a 25-ton payload machine, with no ferry costs included. In Application 3, requiring approximately 30 minutes of hover time with a 25-ton payload machine, average no-ferry costs are $950 per crane.

Thus, with no allowance for ferry costs or the cost of other non-productive time, the market is very close to 100 percent. It is also clear that in all applications, significant non-productive time per lift can be accepted before the HLA would become non-competitive. In view of the small number of potential vehicles, the effect of ferry on these numbers is unimportant.

6.11 Case Study No. 8
Oil and Gas Drilling in Remote Areas

6.11.1 Current Operations

In areas where an adequate road infrastructure is available, the drilling rig equipment and supplies are transported in by truck. Most of the oil and gas reserves located in easily accessible regions with an adequate road network have already been explored and are currently in the production stage. Increasingly, the oil companies are forced to explore for oil and gas, and drill in remote areas with limited transportation infrastructure. The areas explored range from the jungles of southeast Asia, Africa, and South America to the tundra of the north slope of Alaska. For oil and gas drilling operations, the helicopter has proven itself to be an efficient and viable means of transportation and the drillers have adapted their operations to the capabilities of the helicopter.

The type of helicopters normally used for remote drilling operations are:

- Bell 205 - payload capacity 4,000 pounds
- Bell 215 - payload capacity 4,250 pounds.

The cost of chartering these helicopters range from $400 to $500 per hour.

In a typical remote drilling operation a staging area is established next to a barge landing, road, or railroad spur. The rig, all equipment and supplies are unloaded from the conventional means of transportation at this staging area. The average distance from the staging area to the drill site is 50 km (30 miles). The following equipment and supplies are moved by helicopter in 4,000 pound increments from the staging area to the drill site:

6.11.1.1 <u>Drilling Rig</u>. The drilling rig has been constructed so that it can be dismantled into 4,000 pound modules. A total of 110 to 115 lifts each of 4,000 pounds would be required. Total: 440,000 to 460,000 pounds.

6.11.1.2 <u>Drill Pipe</u>. Total quantity required:

- 500 lengths drill pipe and drill collar 4.5" 30 foot length - each 500 pounds. Total: 250,000 pounds

- 40 drill joints - each 4,000 pounds. Total 160,000 pounds.

6.11.1.3 Drill Casing.

- 3,000 to 4,000 foot casing - weight: 54 pounds/foot. Total 160,000 to 220,000 pounds
- 10,500 foot 9-5/8 inch casing - weight: 32 pounds/foot. Total: 336,000 pounds
- 14,000 - 15,000 foot 7-7/8 inch casing - weight: 29 pounds/foot. Total 405,000-435,000 pounds.

6.11.1.4 Fuel. The drill rig consumes 30 pounds fuel per day, and the total time of operation is 45 days up to 120 days. The fuel is brought to the site in a rubber bladder. Weight of the bladder is 250 pounds empty and holds 4,000 pounds of fuel and the total weight is 4,250 pounds.

6.11.1.5 Crane. A 5,000 pound capacity crane is brought into the site. This crane is dismantled, brought to the site and disassembled. Weight of the crane is approximately 8,000 pounds.

The total weight, which the helicopter has to transport to the site is therefore between 1,763,000 pounds and 1,873,000 pounds. The helicopters have to make between 440 and 460 trips to carry the equipment and supply requirements to the site.

Once the drilling operation is concluded, the rig and the crane have to be transported out again. This will require another 110 to 115 lifts. Total lifts for the project will therefore be between 550 and 585.

Assuming that each round trip will require an average of 45 minutes of flying time, and that the project is charged only for actual flying time, the cost of the helicopter is expected to be between $165,000 and $219,000.

6.11.2 Potential HLA Applications

One of the major limitations of a helicopter is its limited payload capacity and the necessity to make an inordinate number of trips in cases where large quantities of materials have to be transported. It is also at times inconvenient and costly to disassemble components at the origin to conform to the payload capacity of the helicopter and then reassemble at the destination. The HLA can alleviate this problem through its larger payload capacity.

6.11.2.1 Application 1: Transportation of Drilling Rig and Supplies. The HLAS has operating characteristics that are similar but superior to that of the helicopter. It can therefore replace the helicopter to transport the rig and supplies between staging area and the drilling site.

It has been indicated by the drillers that the largest practical components into which the drilling rig can be divided are 20-25 tons. The reason is that a 25-ton crane weighing approximately 20 tons is the largest practical unit to bring to the site to lift the components of the rig in place. The other supplies are brought to the site in increments suited to the maximum capacity of the HLA.

(1) Scenario

The scenario for the use of the HLA will be identical to that of the helicopter with the exception that the payload per trip with the HLA is increased from 4,000 pounds per trip to 50,000 pounds (25 tons).

(2) Assumptions

The following assumptions are made:

- The drilling rig can be shipped in relatively uniform components of 25 tons each
- The round trip distance between the end of the road and the drilling site is 100 km (60 miles).

(3) Potential Savings with HLA

Significant savings will accrue with the use of the HLA by being able to transport the components faster to and from the site, thereby reducing the overall time required for the project. With continuous operation eight hours per day, it will take the helicopter at least 10 days to bring the rig to the site, and another 10 days to take it from the site at the completion of the drilling operation. This is based upon eight-hour day continuous operation by the helicopter, which according to a driller with extensive experience using helicopters, is reasonable. The total cost to the driller both during the transportation and assembly of the rig and supplies, and during drilling operations is $15,000 to $20,000 per day. The costs are the same whether drilling is performed or not, because in both cases all personnel and support services are required.

An HLA carrying the rig in 25-ton components can carry everything to the site in less than one day, and the same time to take from the site. It is therefore possible to reduce the total time required for the operation by at least 18 days (i.e., 20 days to bring the rig in and out with helicopter vs. 2 days with HLA). At a cost of $15,000 to $20,000 per day, the cost savings that can be achieved using the HLA is therefore from $270,000 to $360,000.

(4) HLA Threshold Cost

The threshold cost for the HLA will be the sum of the cost of the helicopter plus the savings that will accrue by using the HLA. In this case it will be:

	low	high
. Cost of using helicopters	$165,000	$219,000
. Potential cost savings with HLA	$270,000	$360,000
. Total HLA threshold cost	$435,000	$575,000

(5) Potential Operating Scenario for HLA

The operating scenario will be as follows:

. Round trip travel time	fast HLA	66 minutes
	slow HLA	162 minutes
. Hover time per round trip		9 minutes
. Total	fast HLA	75 minutes
	slow HLA	171 minutes

The average load to be lifted by the HLA will be 25 tons. The total lifting requirement of the project can be therefore accomplished with 44 to 47 round trips. The total time required will be between 55 and 59 hours of actual operating time for the fast HLA, and between 125 to 134 hours for the slow HLA.

6.11.3 Estimate of HLA Needed to Satisfy the Potential Market

This estimate assumes that the crane segment dictates the payload size, which is assumed to be 25 tons.

6.11.3.1 The Annual Market. From Section 5, the annual market is estimated to consist of 100 remote sites at which exploration can take place.

6.11.3.2 The Required HLA Capabilities. From the earlier sections, the task at each site will consist of 44 to 47 round trips, with a total hover time of 9 minutes per round trip. The total operating time per site is given in Table 6-30.

TABLE 6-30. Operating Times for Remote Drilling Site

AVERAGE HLA SPEED (MPH)	25			60		
ROUND TRIP DISTANCE PER SITE (MILES)	30	60	90	30	60	90
ROUND TRIP TIME PER SITE (HOURS)	1.2	2.4	3.6	.5	1	1.5
AVERAGE TOTAL OPERATING TIME PER SITE (HOURS)	60.75	105.75	168.75	29.25	51.75	74.25

6.11.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. Total number of vehicles to satisfy 100 percent of the market is given by

$$\frac{(\text{Number of sites per year})(\text{Hours per site})}{(\text{Annual Utilization})}$$

and this is given in Table 6-31.

TABLE 6-31. No-Ferry Number of Vehicles to Satisfy 100% of the Remote Drilling Site Market

AVERAGE HLA SPEED (MPH)			25			60		
ROUND TRIP DISTANCE PER SITE (MILES)			30	60	90	30	60	90
$\bar{N}_{V_{NF}}$	ANNUAL UTILIZATION (HOURS)	1,000	7	11	17	3	6	8
		2,000	4	6	9	2	3	4

6.11.3.4 "No-Ferry" Share of the Market, M_{NF}. From the case study, the threshold cost is from $0.435M to $0.575M. The average HLA cost is given below. The market share factors are A=7.5 and B=25. Thus the market share is 100 percent as given in Table 6-32, and the number of vehicles are as previously defined.

TABLE 6-32. HLA Market Share for the Remote Drilling Site Application

AVERAGE HLA SPEED (MPH)			25			60		
ROUND TRIP DISTANCE (MILES)			30	60	90	30	60	90
AVERAGE HLA COST PER SITE ($M)			.12	.21	.30	.05	.09	.13
M_{NF}(%)	THRESHOLD COST ($M)	.435	100	100	100	100	100	100
		.575	100	100	100	100	100	100

6.11.3.5 Effect of Ferry on the Number of Vehicles. Using the expression and data derived in Section 6.3, the ratio $\frac{N_V}{N_{V_{NF}}}$ and the number of vehicles with ferry are as shown in Table 6-33, as a function of k, the ratio of annual ferry hours to annual utilization.

C-4

TABLE 6-33. Ratio of "Vehicles With Ferry" to "No-Ferry Number of Vehicles"

AVERAGE HLA SPEED (MPH)						25			60		
ROUND TRIP DISTANCE PER SITE (MILES)						30	60	90	30	60	90
(ANNUAL FERRY HOURS) ÷ (ANNUAL UTILIZATION)	.33	THRESHOLD COST $M	.435	ANNUAL UTILIZATION (HOURS)	1,000	.863	.39		1.194	.958	.721
					2,000	.586			1.066	.718	.373
			.575		1,000	1.018	.661	.21	1.27	1.24	.916
					2,000	.806	.285		1.167	.916	.661
	.66		.435		1,000	.45			1.77	.829	
					2,000				1.26		
			.575		1,000	1.069			2.08	1.95	.66
					2,000	.222			1.66	.66	
N_V	.33		.435		1,000	7	5	0	4	6	6
					2,000	3	0	0	3	3	2
			.575		1,000	8	8	4	4	8	8
					2,000	4	4	0	3	3	3
	.66		.435		1,000	4	0	0	6	5	0
					2,000	0	0	0	3	0	0
			.575		1,000	8	0	0	7	12	6
					2,000	1	0	0	4	2	0

6.12 Case Study No. 9
Logging and Forestry

6.12.1 Current Operations

Forestry has come a long way from the time when easily accessible areas were cleared down to the stump and the logs transported out by the cheapest method available without regard to reforestation, soil cultivation, and environmental considerations. Currently, forestry is both an art and a science using modern agricultural and engineering methods to cultivate the land and to harvest the timber. It is recognized that the variables in modern forestry and logging practices are many. This case study will highlight some of the harvesting methods currently used under conditions that exist in the Pacific Northwest region of the United States and Canada. The case study will describe the methods, quantity, and reasonable or typical costs of these systems to provide a basis for comparison with the use of a heavy-lift airship in logging operations.

6.12.1.1 Definition of Logging Functions. The total process of logging or harvesting of timber consists of a number of interrelated functions and subfunctions. Each of these functions is described below* (Reference 13):

(1) Felling

Felling describes the process of cutting down the tree. In most cases this is accomplished with power saws or other mechanical equipment.

(2) Bucking

Bucking is the process used to cut a felled tree into segments. The segments of the tree after it has been bucked are called bolts or logs. If only the top of the tree is removed, it is called a tree-length log.

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* All definitions are based on Steve Conway, "Logging Practices. Principle Timber Harvesting Systems" (Miller Freeman Publications, Inc.), 1976, pp. 50-54.

(3) Measuring

Prior to bucking the tree, the tree is measured to insure proper length of the logs. The length is dependent upon the final use of the log and can vary from bolts of 100 inches to logs in excess of 50 feet in length.

(4) Skidding or Yarding

Once the trees have been bucked they have to be hauled to a landing area for further transportation to a lumber mill or pulp plant. This primary transportation from the stump to the landing area is called skidding. When cables, helicopters, or other aerial systems are used, the skidding process is often referred to as yarding.

(5) Loading

Loading refers to the placing of the logs or bolts on a haul vehicle at the landing area to further transportation to a transfer point for reloading onto another mode of transportation or directly to the lumber mill or pulp plant. The loading at the landing area and the transfer points is normally accomplished with mechanized equipment.

6.12.1.2 Variables Affecting Logging Operations. There are numerous variables that affect the logging operations. Some of the major variables affect the selection of skidding and yarding methods (Reference 13).

(1) Volume Per Acre

Volume per acre refers to the density of trees per acre. This variable will have great influence on the overall cost on logging a tract because there is an inverse relationship between the volume per acre and the logging cost. The volume per acre variable will affect the cost of the operation with minimal regard to the method of logging used.

The definition of high and low volumes per acre are highly dependent upon the type of cut (clearcut, partial cut, or salvage cut), the logging system utilized, and the geographic location of the cut. In the Pacific Northwest a volume of 30,000 to 35,000 board feet per acre is considered good for an area to be clearcut. A company operating in the southern states of the United States considers 800 to 1,000 board feet per acre a sufficient volume to start operation on selective cutting. A comparable company in the Pacific Northwest, on the other hand, would be reluctant to start a selective cutting operation with a volume per acre of less than 8,000 to 10,000 board feet.

(2) Volume Per Stem

This variable is closely related to the volume per acre. Volume per stem refers to the volume per tree in an area. Generally, the logging cost increases with decreasing tree size because more trees will have to be handled per unit of output. This variable will also affect the selection of equipment for the operation.

(3) Defect

Defect refers to the difference between the gross and the net scale or cubic measurement of the log. Loggers are always paid on a net scale which is the gross scale or measurement of the log with deductions made for defects in the logs. Defects may be caused by the felling, skidding, or transportation. The cost of operation per unit will be seriously affected with large amounts of defect in the timber. Thus, if it costs a logger $25 per 1,000 board feet to deliver to a mill with no defect, the cost will increase to $35 per 1,000 board feet for the same lumber with 30 percent defect (i.e., $25/.7 = $35).

(4) Topography or Terrain

The topography or terrain will, to a large extent, determine the type of logging methods that can be applied and also the extent to which logging can be performed, if at all. This will be both a matter of economic and technical feasibility of the various available methods. In steep grades, the efficiency of conventional skidding systems becomes low. In many cases, conventional skidding is completely impossible, and higher cost cable systems may have to be employed.

(5) Environmental Variables

Environmental variables refer both to the soil and the weather conditions in an area. Both have an impact on the logging methods that are to be employed. Environmental considerations regarding the soil conditions and the possibility of reforestation of an area may preclude the use of certain equipment. An example is logging in the Alaskan muskeg areas. Tracked machines and skidders cannot be used under these circumstances, and logging roads have to be carefully constructed. Alaskan loggers have used both cable systems and helicopters for yarding of the felled logs.

Similarly, weather can seriously affect the logging operations. Wind, snow, rain, and humidity may slow the operation considerably in some regions. In northern Canada, for example, the hauling of logs is limited to 110 days per year during the winter season, when the ground is solidly frozen.

(6) Weight of Logs

A major variable in selecting a skidding or yarding system is its capacity to carry the logs. Although most logs are measured in terms of their cubic measurement as cords, cunits, or board feet, weight is the important factor in the skidding or yarding operation. Table 6-34 presents the weight per cubic foot of some commercial species of lumber:

TABLE 6-34. Weight per Cubic Foot of Selected Commercial Species

SPECIES	LBS/FT^3	SPECIES	LBS/FT^3
Red alder	46	Western larch	48
Yellow birch	58	Red oak	63
Alaska cedar	36	White oak	62
Western red cedar	27	Longleaf, shortleaf, and slash pine	62
Douglas fir (coastal)	38	Loblolly pine	62
Noble fir	30	Lodgepole pine	39
Red fir	48	Ponderosa pine	45
White fir	47	Western white pine	35
Black gum	45	Yellow poplar	38
Red gum	50	Black spruce	32
Eastern hemlock	50	Sitka spruce	33
Western hemlock	41	Sweetgum	50
Hickory	63	Black walnut	58

SOURCE: Caterpillar Tractor Co. 1972, p. 17.

6.12.1.3 Comparison of Conventional Logging Systems. A recent study by the Forest Engineering Research Institute of Canada (FERIC) (Reference 14)* performed a detailed analysis of different logging systems in one 3,400 acre section of land in British Columbia. The volume per acre in this area is 120 cunits** of lumber. Logging of this area was simulated using five main logging systems:

- Highlead logging
- Running skyline with fixed spar
- Running skyline yarding crane
- Balloon
- Heavy lift free flying vehicle.

In each case, the main system was utilized to its optimal capabilities and supplemented with other yarding or skidding systems to the extent that these systems could be used more effectively than the main system. For each system, cost per cunit was calculated with respect to:

- Road construction
- Falling
- Yarding or skidding
- Loading
- Hauling.

The input cost data for each of these functions were based on actual cost data derived from logging operations in terrain similar to that to be logged in the simulated 3,400 acre area.

Logging is a system of closely interrelated functions, and the method used in one of these functional areas will affect all the other functions. The FERIC study presented a comparison of such logging systems and quantified the effects and costs of each on the overall system. The data in this study has been presented in a fashion that enables a direct comparison of the technical and economic feasibility of various yarding systems to an area which is considered relatively difficult to log. It was therefore decided to use this FERIC study as the basis for this present case study. One exception has been made in the description of existing logging systems. In the FERIC study, the Aerocrane is used as the vehicle representing a heavy lift, free flying vehicle, and the cost data are based on hypothetical operating costs. In this present case study the Aerocrane has been replaced with a Sikorsky

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* B.J. Sander and M.M. Nagy, "Coast Logging: High Lead Versus Long Reach Alternatives," Forest Engineering Research Institute of Canada, Technical Report No. TR-19, December 1977.

** 1 cunit = 100 cubic feet

S-64E Skycrane and the S-64F helicopters. With the exception of vehicle performance and cost data, all operating assumptions used in the FERIC study for the Aerocrane operation are used for the helicopter operation.

The highlights of the findings of the FERIC study are presented next.

(1) Highlead Logging or Cable Logging

Highlead or cable logging is used in difficult logging areas all over the Pacific Northwest. The system is simple and can be adapted to a variety of operating systems. The results of analysis showed:

- A total of 34.9 miles of road had to be constructed. The average road costs were $5.40 per cunit
- With the road network and accessability with this system the average falling cost was estimated to be $4.70 per cunit
- Three different methods of yarding were used. Grapple yarding was used within a 50-foot right-of-way at either side with productivity of 160 cunits per shift. Grapple loaders were also used to within 400 feet where applicable at a rate of 400 cunits per hour. The yarding costs are summarized as follows:

	Acres Yarded	Cost $/cunit (average)
Right-of-way	412	3.61
Grapple yard	813	7.34
Highlead	2,427	10.82
Total:	3,652	($9.23)

The total cost of this method can thus be summarized as follows:

Road access and landing construction	$5.40/cunit
Falling	4.70/cunit
Yarding	9.23/cunit
Loading	4.15/cunit
Hauling	6.37/cunit
Total:	$29.85/cunit

(2) Running Skyline With Fixed Spar

The running skyline system used in this example is illustrated in Figure 6-5. It consists of a three-drum yarder and a slackpulling carriage. The main function of the yarder is to supply the power for the system and the drums on the yarders are used to wind the wire used in the system.

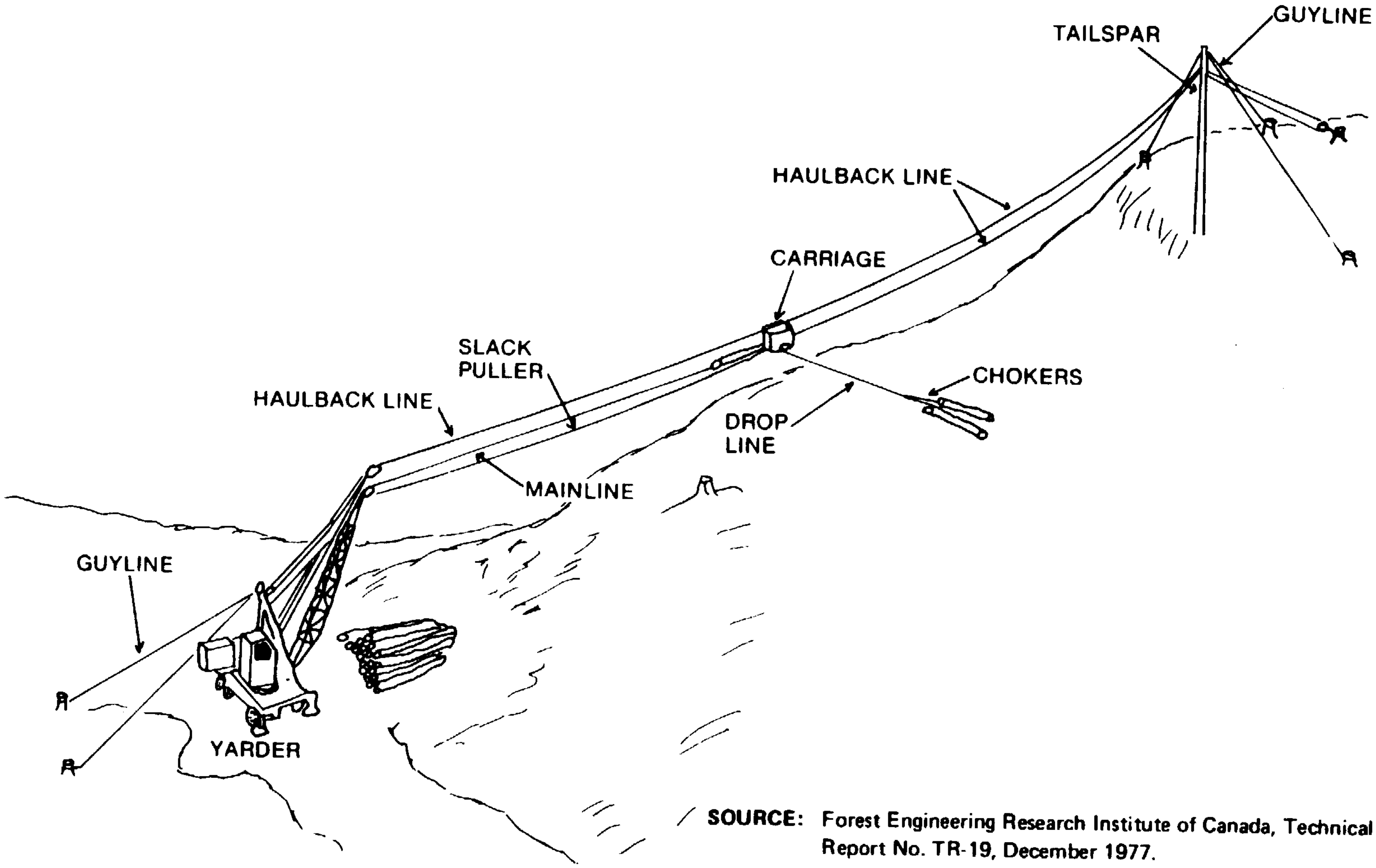
The analysis of the logging with this system showed the following results:

- A total of 24.5 miles of roads were necessary compared to 34.9 miles with the highlead because skyline yarding allows wider spacing of roads. The cost of access roads was estimated to be $3.50 per cunit
- The falling cost was estimated at $4.81 per cunit
- All of the yarding methods shown in the previous case was used wherever applicable and effective with the skyline. The yarding costs are summarized as follows:

	Acres Yarded	Cost $/Cunit (average)
Right-of-way	287	3.61
Grapple yard	513	7.34
Highlead	1,653	10.63
Skyline	1,177	13.98
	3,630	($10.69/cunit)

- The average loading cost from the various loading cost from the various systems used was estimated at $3.26 per cunit
- The average hauling distance was 13.13 miles and the average cost was $6.31. The cost of this system can be summarized as follows:

Road access	$ 3.50/cunit
Falling	4.81/cunit
Yarding	10.69/cunit
Loading	3.26/cunit
Hauling	6.31/cunit
Total:	$28.57/cunit



SOURCE: Forest Engineering Research Institute of Canada, Technical Report No. TR-19, December 1977.

FIGURE 6-5 Running Skyline System

(3) Running Skyline With Mobile Yarder

The basic difference between this system and the skyline system described above is that the yarder is mobile. This allows further flexibility of the system, which can reduce costs in all aspects of the logging operation. The results of the analysis were:

- Road building can be reduced to a total of 19.5 miles of roads with an average cost of $2.88 per cunit.
- The average falling cost was estimated at $4.91 per cunit
- Yarding was performed by only two methods. The right-of-way 50 feet on each side of roads were cleared with a grapple loader and loaded directly onto trucks at a cost of $3.61 per cunit. A total of 267 acres were yarded this way. The remaining 3,295 acres were yarded with the mobile yarder at a cost of $10.38 per cunit. Average cost of the operation was estimated at $9.87 per cunit
- A hydraulic heel-boom loader was assumed to be operating with the yarder and the average loading cost was estimated at $3.31 per cunit
- The average hauling distance was 12.5 miles at a cost of $5.05 per cunit.

The summary of the costs with this system are therefore:

Road Access	$ 2.86/cunit
Falling	4.91/cunit
Yarding	9.87/cunit
Loading	3.31/cunit
Hauling	5.05/cunit
Total:	$26.00/cunit

(4) Balloon Logging

The first successful experiment using a balloon for logging was performed in Sweden in 1956. Several other successful experiments have been performed since that initial try. Currently, four commercial logging operations in the United States use balloon logging. The system used by these operations is depicted as

Figure 6-6. Basically, the balloon logging system is a high lead cable system, where the balloon is providing additional lift to enable yarding at distances of 3,000 to 5,000 feet. The balloon system can thereby reduce the length of the access roads and the environmental impact of logging.

The cost of balloon logging was estimated as follows:

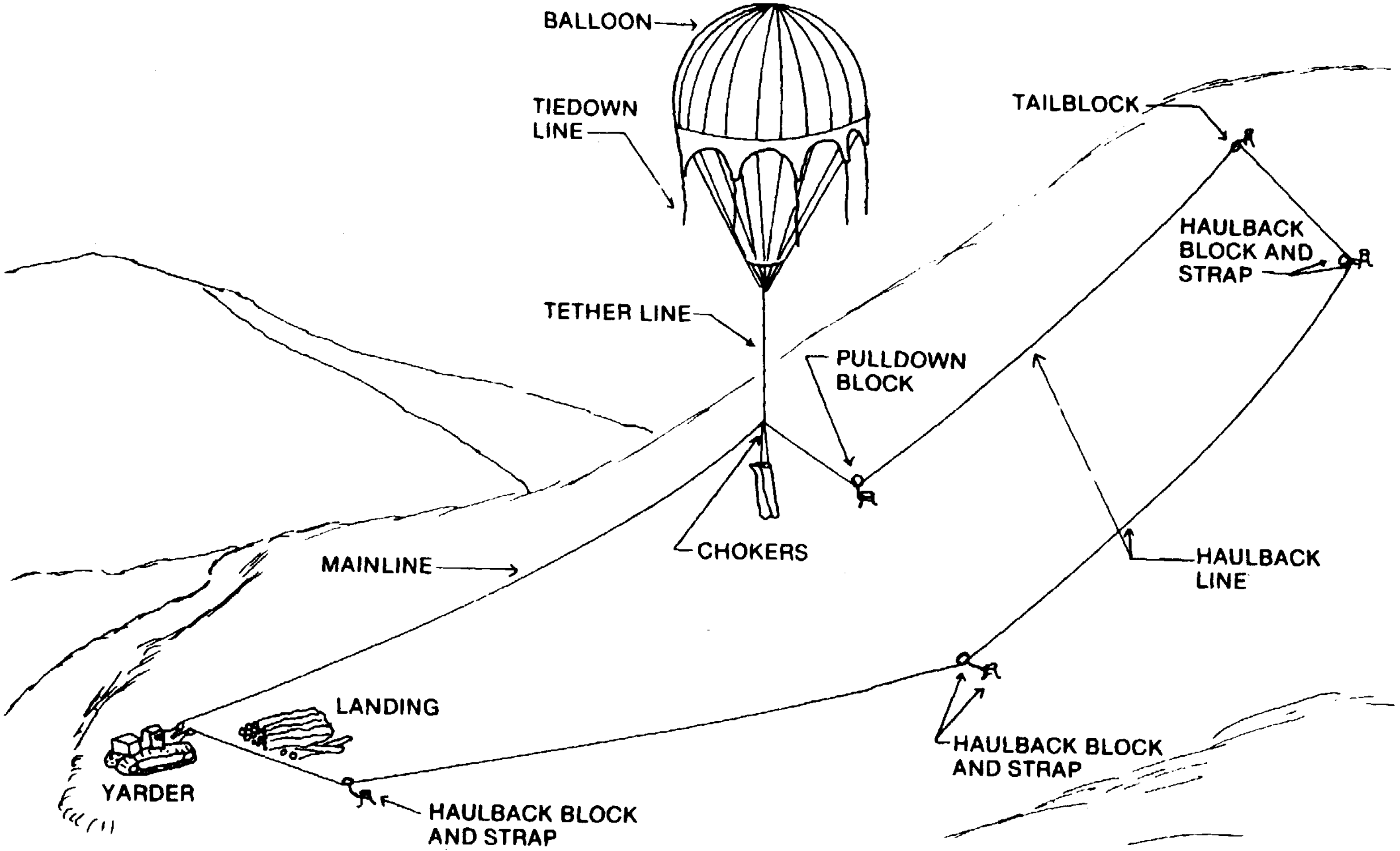
- A total of 19.4 miles of access roads was necessary to log the entire area. Average cost of access roads was estimated at $2.92 per cunit
- The falling costs for this system were estimated at $5.14 per cunit
- In addition to the balloon, three other yarding systems were used. These were mobile grapple, direct loading of logs along the 50-foot right-of-way on either side of roads and highlead spear cable yarding. The balloon yarded 1,504 acres and the conventional systems 2,148 acres. The average cost was $15.07 per cunit
- Loading costs with this system were estimated at $3.71 per cunit.

The cost of this operation can be summarized as follows:

Road access	$ 2.92/cunit
Falling	5.14/cunit
Yarding	15.07/cunit
Loading	3.71/cunit
Hauling	6.29/cunit
Total:	$33.13/cunit

(5) Heavy-Lift Free Flying Vehicles

As mentioned previously, the FERIC study used the Aerocrane as the concept representing current state-of-the-art of heavy-lift free flying vehicles. The operating cost of the Aerocrane was based on preliminary cost estimates. For this case study, it was decided to evaluate the Sikorsky S-64-E as the current heavy-lift free flying vehicle system since several of these helicopters are currently used in logging operations and present a fine alternative to an HLA. In addition, the Sikorsky S-64F version was also evaluated. None of the S-64F helicopters



SOURCE: Forest Engineering Research Institute of Canada, Technical Report No. TR-19, December 1977.

FIGURE 6-6 Balloon, Highlead System

are currently used, but Sikorsky has expressed interest in producing these vehicles for commercial operations. Operating cost data are available for both these vehicles. The operating costs are based on data supplied by Sikorsky presented as Table 6-35. The yarding costs for the helicopters alone, under assumptions of various operating hours per year, are summarized in Table 6-36.

There are some problems that are peculiar to a helicopter logging system that do not exist with conventional systems. The major problems are:

- The helicopter is more sensitive to adverse weather conditions than conventional systems
- The aircraft requires more maintenance than conventional systems
- The bucking loss can be considerable as is depicted in Figures 6-7 and 6-8

The major advantages of helicopter logging are:

- Areas that previously were inaccessible can be logged with a helicopter
- The environmental impact will be minimal.

With the exception of the vehicle operating costs, all operating costs and assumptions were kept identical with the FERIC analysis. A summary of the costs and assumptions used in the FERIC analysis are:

- A total of 43 landings were assumed, and a road length of 8.3 miles were required to reach these landings. The cost of access roads and landings was estimated at $1.51 per cunit.
- A total of 3,400 acres were accessed with this system. The average falling cost was estimated at $5.20 per cunit.
- A total of 1,160 acres were yarded using conventional methods. The area yarded with conventional methods was limited to 700 feet from road access. The methods used were highlead spar cable system, grapple yarder in addition to direct loading in the 50-foot right-of-way on either side of the road. The remaining 2,240 acres were logged by a

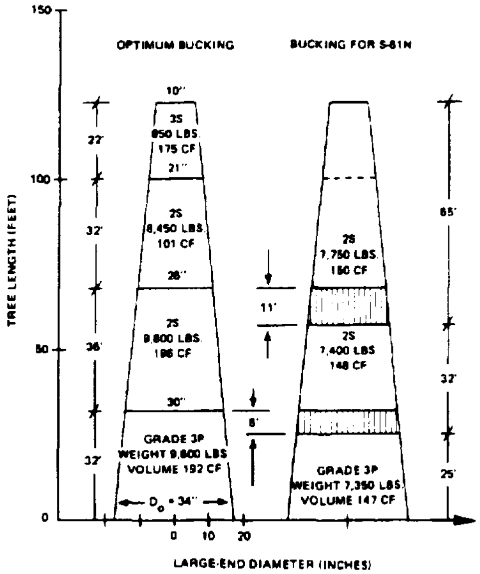
TABLE 6-35. Operating Costs - Sikorsky S-64E and S-64F

ITEM	S-64E	S-64F
1. INVESTMENT COST		
Flight Equipment	2,700,000	6,100,000
Support Equipment	35,000	43,000
Spares	212,000	212,000
Dynamic components	"Power by hour"	1,830,000
Total	2,947,000	8,184,000
2. FIXED ANNUAL COSTS		
Depreciation (10 yrs - 25%)	221,025	613,800
Interest (10% - 60% ave. value)	176,820	491,040
Insurance (8% flt equip)	216,000	488,000
Personnel (per single shift)		
Pilots	(3) 105,000	(3) 105,000
Co-Pilots	(3) 75,000	(3) 75,000
Mechanics	(5) 90,000	(5) 90,000
	270,000	270,000
Burden 25%	67,500	67,500
Total personnel	337,500	337,500
Helium replacement	–	–
Env. refurbishment	–	–
Total Fixed Annual	951,345	1,930,340
3. HOURLY COSTS		
Fuel Aero 50 gal/hr x S1.00/gal	262.50	262.50
S-64 525 gal/hr x .50/gal		
Oil	13.12	13.12
Replacement parts A/F	125.00	125.00
Dynamic System O/H	409.60	463.80
Engine O/H & inspect.	210.00	210.00
Misc. equip. O/H	–	–
Total Hourly	1,020.22	1,074.42
4. Total Cost/Flt hr		
Utilization hrs/yr	1,000	1,000
Fixed cost/hr	951.35	1,930.34
Hourly cost	1,020.22	1,286 89
Total cost/flt hr S	1,971.57	3,217.23
Utilization hrs/yr	1,500	1,500
Fixed cost/hr	634.23	1,286.89
Hourly cost	1,020.22	1,074.42
Total cost/flt hr S	1,654.45	2,361.31
Utilization hrs/yr	2,200	2,200
Fixed cost/hr	509.13	954.13
Hourly cost	1,020.22	1,074.42
Total cost/flt hr S	1,529 35	2,028.55
Utilization hrs/yr	3,000	3,000
Fixed cost/hr	429.62	755.95
Hourly cost	1,020.22	1,074.42
Total cost/flt hr S	1,449.84	1,830.37

TABLE 6-36. Yarding Costs for Sikorsky S-64F Helicopters

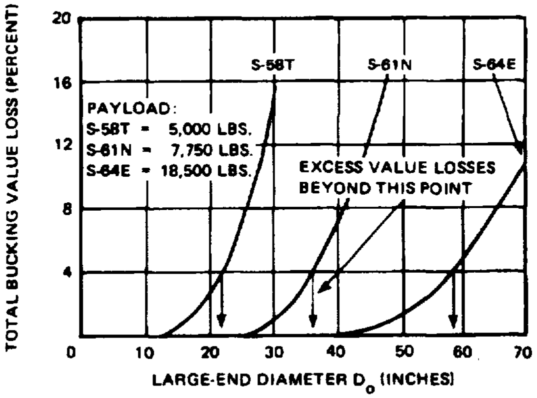
ITEM		S-64E	S-64F
Payload (2000 ft, ISA)		18,650	23,150
Load factor		70%	70%
Ave. Yarding dist. ft		4,000	4,000
Speed capability mph		110	120
Ave. cycle time min		2.9	2.9
Ave. flt. duration hrs.		0.5	0.5
Cycles/hr		19	19
Cunits/hr		41.3	51.3
<u>1500 hr Utilization</u>			
Cost/hr	$	1,654.45	2,361.31
Cost/cunit	$	40.06	46.03
<u>2200 hr Utilization</u>			
Cost/hr	$	1,529.35	2,028.55
Cost/cunit	$	37.03	39.54
<u>3000 hr Utilization</u>			
Cost/hr	$	1,449.84	1,830.37
Cost/cunit	$	35.11	35.68

FIGURE 6-7 Illustration of Bucking Value Loss of Medium-Size Tree — Douglas Fir (Density 50 Pounds Per Cubic Foot)



NOTE: P STANDS FOR PEELER AND S STANDS FOR SAWLOG IN ACCORDANCE WITH THE COLUMBIA RIVER LOG SCALING AND GRADING RULES.

FIGURE 6-8 Estimate of Bucking Value Losses for Different Helicopter Payload Capacities and Large-End Tree Diameters (Douglas Fir)



SOURCE: STEVE CONWAY LOGGING PRACTICES, PRINCIPLES OF TIMBER HARVESTING SYSTEMS, (MILLER FREEMAN PUBLISHING, SAN FRANCISCO) 1976, pp. 270-279.

heavy-lift free flying vehicle. The average yarding cost by the conventional methods were $8.89 per cunit.

- The loading costs differed from the yarding methods employed:

	Volume (cunits)	Cost $/Cunit (average)
Loading for conventional logging	139,200	2.95
Loading for free flying vehicle logging	268,800	1.57
	408,000	($2.04)

- The hauling costs differ also between conventional and free flying vehicle loading

System	Volume (cunits)	Delay Factor	Cost $/Cunit (average)
Conventional	139,200	1.8 hours	6.34
Free Flying Vehicles	268,800	1.2 hours	5.01
	408,000		($5.46)

In addition it is assumed that a total of three landing crews and three woods crews consisting of three men each are required for each full 8-hour day operation. The cost of these crews are presented as Table 6-37. The total crew cost is therefore $2,724 per 8-hour shift.

The total yarding cost using the helicopters can thus be summarized in Table 6-38.

The average yarding cost using the free flying concept assuming 2,200 hours of operation with an S-64E is therefore:

	Acres Yarded		Cost $/Cunit		
Conventional yarding	1,160	x	8.89	=	$ 10312.4
Helicopter	2,240	x	45.28	=	$101427.2
Total	3,400				$111739.6 Total

Average Cost/Cunit 111739.6/3,400 = 32.88

TABLE 6-37. Cost for Crews

Free Flying Vehicle Landing Crew:		
1 Front-end Loader	$58.47/hour (all found)	
1 Chokerman	9.00/hour	
1 Bucker	11.30/hour	
	$78.77/hour	$126,032/year
Overtime:		4,500/year
		$130,532/year
1 Crew sorts 250 cunits/shift		$ 81.58/hour
Woods Crews:		
3-Man Crew		
1 Rigging Slinger	$10.00/hour	
2 Chokermen	18.00/hour	
	$28.00/hour	$ 44,800/year
Overtime:		6,300/year
Total Cost, 3-Man Crew		$ 51,100/year
		$ 31.94/hour

TABLE 6-38 Total Yarding Cost

	S-64E			S-64F		
OPERATING HOURS/YEAR	1500	2200	3000	1500	2200	3000
Cost/hr - Helicopter	$1654.45	$1529.35	$1449.84	$2361.31	$2028.55	$1830.37
Manhour cost shift	$2724.48	$2724.48	$2724.48	$2724.48	$2724.48	$2724.48
Helicopters cost per cunit	$ 40.06	$ 37.03	$ 35.11	$ 46.03	$ 39.54	$ 35.68
Manhour cost per cunit[1]	$ 8.25	$ 8.25	$ 8.25	$ 8.25	$ 8.25	$ 8.25
Total cost per cunit	$ 48.31	$ 45.28	$ 43.36	$ 54.28	$ 47.79	$ 43.93

[1] An 8-hour operating day is assumed.

The cost for this system can therefore be summarized as follows:

Road access	$ 1.51/cunit
Falling	5.20/cunit
Yarding	32.88/cunit
Loading	2.04/cunit
Hauling	5.46/cunit
Total	$47.09/cunit

The total cost of the various existing systems can therefore be summarized as follows:

	Total cost/ Cunit	Proportion of logging performed by main System
Highlead	$29.85	68%
Running skyline with fixed spar	28.57	32
Running skyline with yarding crane	26.00	93
Balloon	33.13	41
Skycrane helicopter	47.09	66

As can be seen, helicopter logging is almost twice as expensive as existing systems.

6.12.2 Potential HLA Applications

The HLA has operating characteristics similar to that of a helicopter, although its payload is greater. There are limitations to the maximum payload that can be successfully utilized in a logging operation. The reason is the density of the forest, which will limit the availability of trees. If the HLA has to pick up logs from two different locations to fully utilize its payload capability, the efficiency gained with an increased payload will vanish. It is, however, possible that a small HLA with a payload between 15 and 30 tons may be successfully used in competition with the existing yarding systems.

6.12.2.1 Application 1: Logging Using HLA. The basic data for this analysis excluding the operating data on the Aerocrane were extracted from the study performed by FERIC. The logging operation has been evaluated for both high-speed (Heli-stat) and slow-speed (Aerocrane) types heavy-lift airships.

(1) Scenario

The scenario is identical to that described for the FERIC study previously mentioned.

(2) Assumptions

All operating assumptions are identical to those indicated for the helicopter yarding system described in the previous section, with the following exception:

- The maximum payload that can yield an efficient operation in the tract described in the FERIC study for the Aerocrane is estimated at 16 tons. As is indicated in Figure 6-7, an average Douglas Fir weighs approximately 14 tons. Using longer chokers and a larger load for the yarding, it is assumed that a reasonable load for the HLA will be the logs generated from two felled trees. This will amount to a payload of approximately 28 tons.

(3) Potential Cost Savings With HLA

There will be no savings in costs with the HLA beyond those already realized with the helicopter. The savings with the helicopter are lower access road costs, loading and hauling costs. These savings are reflected by the lower costs for these functions in the context of the complete logging systems.

(4) The HLA Threshold Cost

The threshold cost per cunit loaded will differ considerably for the various current systems. In general terms, it can be expressed as:

$$SC_{FF} + \left[\frac{(1{,}160 \text{ acres})\ \$8.89 + (2{,}240 \text{ acres})\ x}{3{,}400 \text{ acres}} \right] = TC_n$$

This can then be rearranged and expressed as:

$$x = \frac{3{,}400 \left(TC_n - SC_{FF} \right) - \$10{,}312}{2{,}240}$$

where:

X = HLAS threshold cost per cunit

SC_{FF} = System cost per cunit for heavy lift free flying system excluding yarding costs (i.e., \$14.21)

TC_n = Total cost per cunit of yarding system n

If we assume that the HLA will yard a total of 2,240 acres and that 1,160 acres will be yarded by conventional systems, we find that the HLA threshold cost per unit will have to be lower than the following values for the HLA to be competitive with existing systems:

		HLA Threshold Cost/Cunit
System 1:	Highlead	\$19.17
System 2:	Running skyline with fixed spars	17.19
System 3:	Running skyline with yarding crane	13.29
System 4:	Balloon	24.11
System 5:	Skycrane helicopter	45.28

These threshold costs include the cost of field and landing crews at \$340.50 per hour or \$2,724 for an 8-hour shift.

(5) Potential Operating Scenario with HLA

The operating scenarios of several different HLA configurations and payloads are outlined in Table 6-39. By combining these operating scenarios with the threshold cost per cunit we can easily compute the HLA threshold cost per hour.

As an example, the threshold cost for operating an HLA with a 25-ton payload and an average speed of 60 mph, in competition with the highlead system will be:

158 cunits per hour x \$19.17 cost/cunit	\$3,028.86
Field labor cost	340.50
HLA threshold cost per hour	\$2,688.36

TABLE 6-39. Potential Operating Scenarios With HLA

AVERAGE FLIGHT SPEED (MPH)			10 MPH	20 MPH	30 MPH	40 MPH
Average flying time per cycle		(min)	9.1	4.6	3.0	2.3
Average cycle time		(min)	11.1	6.6	5.0	4.3
Cycles per hour			5.0	8.9	10.9	12.9
Cunits per hour	Payload (tons)	15	30	50	66	78
		20	40	67	87	104
		25	50	84	109	129
		30	60	101	131	155

[1] Assumptions: The average yarding distance is 4000 feet
The average hook-up plus release time is 2 minutes
A total of 5 minutes every hour is required for refueling
Average density is 50 pounds per cubic foot

If the payload is dropped to 15 tons, the HLA threshold cost per hour will be:

92.4 cunits per hour x $19.17/cunit	$1,771.31
Field labor cost	340.50
HLA threshold cost	$1,430.81

6.12.3 Estimate of HLA Needed to Satisfy the Potential Market

This estimate assumes a range of potential HLA payload sizes, (15, 25, and 75 tons) to perform the work of the free-flying vehicle in this application.

6.12.3.1 The Annual Market. From Section 5, the annual logging market, worldwide, is approximately 80,000 million cubic feet. An average log density of 50 pounds per cubic feet results in an annual market of 2000 million tons, equivalent to roughly 140 to 160 million average fir logs. Assuming that the case study typifies the use of free flying vehicles in logging, 0.6 of the worldwide market is the potential market for HLA; that is

- 48,000 million cubic feet, or
- 1,200 million tons.

6.12.3.2 The Required HLA Capabilities. From the case studies, the yarding distance can vary from 2000 feet to around 6000 feet. From Table 6-5 in Section 6.3.5, it is evident that acceleration and deceleration will play an important part at these distances for speeds from 25 to 60 mph, and that these concise speeds cannot be reached at the shorter distances of interest. Table 6-40 gives the variation in operational time that would result from the case study conditions, to log the free-flying vehicle share of 3400 acres, a total of 26.88 million cubic feet (672,000 tons).

TABLE 6-40. Operational Time for Logging Applications

HLA CRUISE SPEED (MPH)					25			60		
YARDING DISTANCE (FEET)					2000	4000	6000	2000	4000	6000
ROUND TRIP TIME PER CYCLE (MINUTES)			ACCELERATION AND DECELERATION (g)	.075	2.32	3.64‡	5.45‡	1.92 / 47.4*	2.73	3.94
				.100	2.20			1.66 / 54.7*	2.43	3.64
				.125	2.12			1.56	2.75	3.46
TOTAL CYCLE TIME (MINS.)	LOAD AND UNLOAD TIME PER CYCLE (MINS.)	1		.075	3.32	4.64	6.45	2.92	3.73	4.94
				.100	3.20			2.66	3.43	4.64
				.125	3.12			2.56	3.25	4.46
		2			4.22	5.64	7.45	3.92	4.73	5.94
					4.20			3.66	4.43	5.64
					4.12			3.56	4.25	5.46
		3			5.32	6.64	8.45	4.92	5.73	6.94
					5.20			4.66	5.43	6.64
					5.12			4.56	5.25	6.46

6.12.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. The total number of vehicles to satisfy 100 percent of the market is given by:

$$\frac{\text{(Tons of timber per year)(Vehicle operating hours per ton)}}{\text{Annual Utilization}}$$

The "vehicle operating hours per ton" is the same as (vehicle operating hours per cycle)/tons per cycle), and the (tons per cycle) is equal to the paylod.

Therefore,

$$\bar{N}_{V_{NF}} = \frac{(\text{Tons Per year})(\text{Operating tons per cycle})}{(\text{Payload})(\text{Utilization})}$$

and is given in Table 6-41 for Utilization = 2000 hours.

TABLE 6-41. Number of No-Ferry Vehicles for 100% of the Logging Market

HLA CRUISE SPEED (MPH)					**25**			**60**		
YARDING DISTANCE (FEET)					**2000**	**4000**	**6000**	**2000**	**4000**	**6000**
$\bar{N}_{V_{NF}}$	**ALTERNATIVE PAYLOAD SIZE (TONS)**	**15**	**LOAD AND UNLOAD TIME PER CYCLE (MINS.)**	**1**	2130	3070	4330	1800	2330	3130
				2	2800	3730	5000	2470	3000	3800
				3	3470	4400	5670	3130	3670	4470
		25		**1**	1280	1840	2600	1080	1400	1880
				2	1680	2240	3000	1480	1800	2280
				3	2080	2640	3400	1880	2200	2680
		75		**1**	430	610	870	360	470	630
				2	560	750	1000	490	600	760
				3	690	880	1130	630	730	890

6.12.3.4 <u>"No-Ferry" Share of the Market</u>, M_{NF}. From the case study, the threshold cost is a function of several parameters, including the ground crew cost, which is in turn a function of vehicle operating time. Thus the threshold cost is also a function of vehicle cruise speed, acceleration*, payload, turnaround time and yarding distance, as follows:

Threshold cost per job =

(Threshold cost per cunit)(Cunits per job)

---

* Note that 1 cunit = 100 cubic feet of logged timber, which, at an average of 50 pounds per cubic foot, weighs 2.5 tons. Thus "cunits per cycle" = (payloads per cycle/2.5)

where

Threshold cost per cunit =

$$\left[\frac{\begin{pmatrix}\text{Conventional System}\\ \text{Cost Per cunit*}\end{pmatrix} - 14.21 - 8.89\,(1-Y)}{Y}\right] - \left[\begin{pmatrix}\text{Ground crew}\\ \text{Cost per Hour}\end{pmatrix}\left(\frac{\text{Operational hours per cycle}}{\text{Cunits per cycle*}}\right)\right]$$

However, the variation in threshold cost introduced by vehicle kinematics is within 10 percent, over the range of values of the kinematic parameters. Thus, threshold cost is assessed with average values of these parameters, resulting in Table 6-42. (An average operating time per cycle of 5.0 minutes was used.)

TABLE 6-42. Logging Application Threshold Costs

CONVENTIONAL SYSTEM COST ($/UNIT)			30				47			
PERCENT JOB YARDED BY HLA (%)			.6		.8		.6		.8	
FIELD AND LANDING CREW COST ($/HR.)			350	500	350	500	350	500	350	500
THRESHOLD COST ($/CUNIT)	PAYLOAD (TONS)	15	15.5	13.4	12.6	10.6	43.8	41.8	33.8	31.8
		25	17.5	16.2	14.6	13.4	45.8	44.6	35.8	34.6
		75	19.5	19.0	16.6	16.2	47.8	47.4	37.8	37.4

The average HLA job cost for this application is as shown in Table 6-43.

The market factors are A = 0, B = 32.5. These lead to the criterion that if HLA job cost is equal to or greater than the threshold cost, the market share is zero, while if the HLA job cost is less than .675 of the threshold cost, the share is 100 percent.

When competing with conventional surface logging systems, conventional system cost is on the order of 30 dollars per cunit, while the competitive helicopter system costs about 47 dollars per cunit. The corresponding market shares are given in Table 6-44 for average threshold costs.

TABLE 6-43. Average HLA Job Costs for Logging Applications

HLA CRUISE SPEED (MPH)						25			60		
YARDING DISTANCE (FEET)						2000	4000	6000	2000	4000	6000
M_{NF}	SURFACE	PAYLOAD (TONS)	15	LOAD AND UNLOAD	1	51	0	0	100	34	0
					2	0	0	0	34	0	0
					3	0	0	0	0	0	0
			25		1	100	25	0	100	100	60
					2	69	0	0	100	58	0
					3	11	0	0	56	0	0
			75		1	100	100	41	100	100	100
					2	100	70	0	100	100	93
					3	99	30	0	100	93	54
		THE MARKET SHARE IS 100% FOR ALL VARIATIONS									

TABLE 6-44. HLA Market Share for Logging Applications

HLA CRUISE SPEED (MPH)					25			60		
YARDING DISTANCE (FEET)					2000	4000	6000	2000	4000	6000
HLA JOB COST ($/UNIT)	PAYLOAD (TONS)	15	LOAD AND UNLOAD TIME PER CYCLE (MINS.)	1	10.9	16.9	22.9	8.2	11.5	14.8
				2	14.4	20.3	26.3	11.7	15.0	18.3
				3	17.8	23.8	29.7	15.1	18.4	21.7
		25		1	9.2	14.2	19.2	6.9	9.7	12.4
				2	12.0	17.0	22.0	9.8	12.5	15.3
				3	14.9	19.9	24.9	12.7	15.4	18.2
		75		1	7.4	11.4	15.5	5.6	7.8	10.0
				2	9.7	13.8	17.8	7.9	10.1	12.4
				3	12.1	16.1	20.2	10.2	12.5	14.7

6.12.3.5 "No-Ferry" Number of Vehicles to Satisfy the Market Share, $N_{V_{NF}}$. The market currently is satisfied mainly by conventional logging techniques, with a small proportion satisfied by helicopters. Assuming that the helicopter proportion is H, then the total number of HLA to satisfy the market, $N_{V_{NF}}$, is

$$\left[M_{NF}(1-H) + H\right]\bar{N}_{V_{NF}}$$

Combining Tables 6-41 and 6-44, and assuming H=.05, .10, provides the total number of vehicles required (assuming no ferry) against all competition. This is given in Table 6-45 for utilization of 2000 hours. Note that where $M_{NF}=0$, $N_{V_{NF}}$ is equal to $H\bar{N}_{V_{NF}}$, and where $M_{NF}=1.00$, $N_{V_{NF}} = \bar{N}_{V_{NF}}$.

TABLE 6-45. Number of HLA to Satisfy the HLA Share of the Logging Market

HLA CRUISE SPEED (MPH)					**25**			**60**		
YARDING DISTANCE (FEET)					**2000**	**4000**	**6000**	**2000**	**4000**	**6000**
$N_{V_{NF}}$ (*/)**	**ALTERNATIVE PAYLOAD SIZES (TONS)**	**15**	**LOAD AND UNLOAD TIME PER CYCLE (MINS.)**	**1**	1138/1190	153/307	216/433	1800/1800	869/946	156/313
				2	140/280	186/373	250/500	921/1003	150/300	190/380
				3	173/347	220/440	283/567	156/313	183/367	223/447
		25		**1**	1280/1280	529/598	130/260	1080/1080	1400/1400	1166/1203
				2	1185/1211	112/224	150/300	1480/1480	1082/1120	114/228
				3	321/414	132/264	170/340	1094/1136	110/220	134/268
		75		**1**	430/430	610/610	870/870	360/360	470/470	630/630
				2	560/560	536/548	50/100	490/490	600/600	709/712
				3	690/690	295/326	66/113	630/630	681/684	501/522

*5% of the conventional market taken by helicopter.
**10% of the conventional market taken by helicopter.

6.12.3.6 <u>The Effect of Ferry on the Number of Vehicles.</u> Using the expression and data derived in Section 6.3, the ratio $\frac{N_V}{N_{V_{NF}}}$ is as shown in Table 6-46, covering the range of yarding distance, acceleration, and load/unload times previously examined, and (annual ferry)/(utilization) values up to 0.6.

TABLE 6-46. Ratio of "Number of Vehicles With Ferry" to "No-Ferry Number of Vehicles," for Logging Applications

HLA CRUISE SPEED (MPH)						25	60
$\left(\frac{N_V}{N_{V_{NF}}}\right)$	CONVENTIONAL COMPETITION	HLA PAYLOAD (TONS)	15	ANNUAL UTILIZATION (HOURS)	1,000	0	0
					2,000	0	0
			25		1,000	0 → 0.4	0 → 0.55
					2,000	0 → 0.65	0 → 0.8
			75		1,000	0 → 0.8	0 → 0.9
					2,000	0 → 1	0 → 1.1
	HELICOPTER COMPETITION		15		1,000	0 → 0.8	0.1 → 0.9
					2,000	0.35 → 1.0	0.55 → 1.25
			25		1,000	0.35 → 1.0	0.55 → 1.25
					2,000	0.1 → 1.6	0.45 → 1.8
			75		1,000	0.3 → 1.6	0.6 → 1.8
					2,000	1.0 → 2.2	1.1 → 2.3

6.13 Case Study No. 10
Load and Discharge of Containers in Congested Ports

6.13.1 Current Operations

In the past 12 years since Sea-Land Service Incorporated inaugurated its first international container ship service on the North Atlantic between the U.S. east coast and Europe, a virtual revolution in liner cargo handling has taken place. By 1970, all major trade routes between developed nations were containerized and most major ports in developed nations were equipped with highly efficient container cranes and handling equipment. Simultaneously, with the development of container vessels, other cargo unitization concepts like roll-on/roll-off (Ro/Ro) ships and barge carrying vessels (LASH and SEABEE) were developed. At the present time, approximately 60 percent of U.S. flag liner capacity is accounted for by container/Ro-Ro/barge carrying vessels and it has been forecast that this proportion may increase to 85 percent by 1985.* (Reference 11)

By the early 1970's, containers were increasingly transported to ports in the developing nations. These containers were mainly carried on the decks or in the holds of conventional break-bulk vessels. The containerization of the trade to and from developing nations has been hampered primarily by the primitive port and transportation infrastructure that exists in many of the countries. This less developed infrastructure has frequently caused major pileups of cargoes in the ports because of inability to move the cargoes efficiently into and out of the port area.

The congestion problem reached catastrophic proportions in OPEC member nations following their sudden increase in oil income and wealth as a result of the 1974 ten-doubling of crude oil prices. The oil-nations in the Persian Gulf and Nigeria started a crash program to develop their nations with goods purchased from the industrial world. The ports and transportation infrastructure in these nations were far from prepared to handle the enormous increase in cargo load. The result was a massive congestion problem and ships had to wait at anchorage up to 180 days to be able to dock. To bypass this congestion, liner operators started to bring in highly efficient Ro/Ro vessels, which require minimal shore-based cargo handling equipment for loading and discharge. Congestion surcharges ranging from 30 percent up to 300 percent were imposed upon all cargoes to and from these ports.

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* Draft Report, Delex Control No. D76-6745-I, "The Potential of Air Systems in Short Haul, Heavy Lift Applications," Department of the Navy, October 19, 1976.

According to a study by UNCTAD*, (Reference 15) the average cost for loading and discharging unit load cargoes like containerized cargoes in inefficient, less developed ports are $5.45 per ton of cargo. The weight of a typical 40-foot container is 16 tons. Consequently, the costs of unloading a container at a port would be $87. The same UNCTAD study has estimated that the daily cost of a containerized vessel is $15,000, while the cost of a conventional break-bulk vessel is $4,000 per day. With such costs even minor delays caused by congestion or unavailability of a berth can be extremely costly to the ship operators and ultimately to the shippers and consignees who have to pay for these costs in higher freight rates.

In seriously congested ports, two solutions to the problem have been tested with good results:

- Unloading cargo and containers onto trucks or chassis placed in converted landing craft
- Unloading cargo and containers onto trucks or chassis placed on converted deck barges.

The first solution is currently operated by a joint-venture between Norwegian and Saudi Arabian interests in Saudi Arabian ports. The company bought several surplus American landing craft which were modified to enable the handling of containers and were equipped with Roll-on/Roll-off ramps. These landing crafts can normally accommodate four 40-foot chassis. A reasonable operating cost per day of these landing crafts is $1,000 to $1,500 per day.

The second solution is used in the port of Lagos, Nigeria, where Nigerian interests purchased four carfloats formerly used to transport railroad cars between New Jersey and Brooklyn. These carfloats have dimensions of approximately 360 feet by 38 feet. These carfloats were refurbished, equipped with Roll-on/ Roll-off ramps, and equipment to secure the chassis on deck. The total cost of the four carfloats delivered to Lagos, Nigeria was $1 million. Each carfloat requires the service of a harbor tugboat with 1,500 to 2,000 hp, which will cost between $1,500 to $2,000 per day to charter. This estimated charter cost is based on the tugboat industry's rule of thumb of $1/hp/day.

The operation of the converted landing craft and carfloat systems are very similar. The sequence is:

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* Technological Change and Its Effect on Ports: Cost Comparisons Between Break-Bulk and Various Types of Unit Load Berths, UNCTAD Study, Ref. TD/B/C.4/129/Supplement 2.

- Empty flatbed or container chassis are driven onboard and positioned on the vessel, while the barge/landing craft is at the landing site or port facility
- The deck barge/landing craft is sailed to the anchorage of the ship to be unloaded and moored alongside
- Cargo or containers are unloaded onto the flatbed or container chassis placed on the deck of the barge/landing craft
- When all the chassis are loaded, the barge/landing craft returns to the landing site where the chassis are driven off with trailer tractors
- Cargoes to be exported from the port which have been loaded onto chassis in the staging area are driven onto the barge/landing craft to be taken to the ship for loading with ship's gear.

The operation described above requires the following conditions to be fulfilled:

- The ship anchorage has to be within a protected harbor with calm seas
- A permanent or temporary Ro/Ro berth has to be available to load and discharge the barge/landing craft
- The ship to be loaded and discharged has to be geared and equipped with cargo handling equipment.

Most conventional break-bulk vessels are geared and equipped with cargo handling equipment for loading and unloading. Operators of containerships are reluctant to equip their vessels with gantry cranes because approximately 10 percent of the cargo carrying capacity is lost. In addition, the investment required for the cranes is high and the utilization is low.

The cost of this operation is expected to be at least equal and could possibly exceed the cost of cargo handling by conventional means because the number of handling operations, equipment, and manpower required will at least equal and in most cases exceed conventional operations. It is therefore estimated that the cost of these operations will be $5.45 per ton plus the cost of the vessels used.

Congestion caused by an overloaded port facility and an undeveloped infrastructure are often conditions that will exist for long period. Congestion alleviation can only result when cargo flows are reduced or the port and infrastructure is improved.

There are also congestions that occur due to natural catastrophe, sudden breakdown of equipment, strikes, or other completely unpredictable causes. Examples of such occurrences include:

- The hurricane that hit the containerports in Taiwan which destroyed the container cranes in the port. Containerships with cargoes for Taiwan had to be diverted to other Asian ports, transloaded to geared containervessels and shipped to Taiwan. Several floating cranes were brought to the port but their limited capacity caused severe back-up of ships and cargoes in the port. It was several months before the port was operating normally. In the meantime, the trade-oriented economy of Taiwan suffered and all major container operators serving Taiwan suffered great losses.

- In the port of Baltimore, Maryland, two of their four container cranes were made inoperable by strong gusts of wind. The result was a vast back-up of cargo and containerships in the port. This incident caused lost revenues and costs both to the Maryland Port Administration and shipowners.

- In the case of a strike in a port, it might be desirable for container operators to steam to a nearby neutral port to unload their cargoes to avoid incurring the tremendous financial burden of having a capital intensive containership idle for a long period. This possibility may be precluded either due to the lack of container unloading facilities at the nearby port or due to draft restrictions in the inner harbor.

Under such circumstances which are clearly temporary, more permanent solutions requiring long lead times to position the equipment in the port may not be feasible.

6.13.2 Potential HLA Applications

Port congestion due to limited port cargo handling facilities and transportation infrastructure, natural catastrophes or other circumstances decommissioning a port is a temporary condition. Long term solutions are always available, but these solutions often have long lead times. Thorough planning is required and vast inputs of manpower, equipment, and other resources are necessary.

Until these long term solutions become workable, temporary solutions that can be implemented fast and efficiently are required. The HLA presents one such temporary solution to the port congestion problem.

The HLA is a capital intensive operation which has to be operated efficiently. Efficient operation can be achieved with the HLA in congested ports, if its use is limited to containers or other large unitized loads. In such an operation, standardized containers or loads of relatively high weight (average 16 tons, maximum 30 tons) can be transported with a standard loading gear.

It is doubtful that the HLA can be utilized efficiently in the unloading of break-bulk cargoes. Break-bulk operation is normally a time-consuming procedure whereby small loads on pallets, in slings or nets, (generally not exceeding three to four tons) are lifted in each operation. It would be impractical if not impossible to attempt to lift break-bulk loads exceeding ten tons out of the hatch of a conventional vessel. This potential application is therefore disregarded in this analysis.

Two potential applications for the HLA in congested ports are considered:

- As a semipermanent solution to long term congestion problems in competition with alternate solutions
- As a solution to the congestion problem where no alternatives are available for a container vessel.

These are described below:

6.13.2.1 Application 1: Semipermanent Solution. The ports of several countries on the west coast of Africa have experienced a major congestion problem caused by a rapid increase in cargo flows. Cargoes are piled up in the warehouses and a number of ships are waiting for extended periods at anchorage before berthing. The situation is such that the liner operators serving the ports have imposed congestion surcharges on all cargoes going to the ports and countries. The port authorities in the various ports involved, ship operators and several entrepreneurial stevedoring companies are considering alternatives for lighterage of the ships at anchorage to ease the burden of the congestion. Three alternative lighterage options are investigated:

- Converted landing craft
- Ro/Ro deck barges/tug combinations
- High and low speed heavy-lift airships.

(1) Assumptions

The following assumptions are made:

- The total cost of a converted landing craft including amortization of the vessel is $1500 per day
- The cost of the barge/tug combination including all operating costs is $2000 per day
- The number of handling operations and manpower required with the landing craft and barge/tug options will equal or exceed a conventional loading and discharge operation. The cost of operation with these methods will therefore equal the cost for a conventional operation indicated by the UNCTAD study at $5.45 per ton plus the cost of the vessels
- The cost of $15,000 per day for an average containership indicated by the UNCTAD study is assumed to be a reasonable estimate
- No additional handling cost will be incurred with the HLA. The minimal stevedore work required on the ship can be accomplished by the ship's crew. On the shoreside staging area, the airship can position the containers on the ground
- The operating scenarios described in Table 6-47 are based on data obtained from the Navy and MarAd, and are assumed to be representative of ideal lighterage conditions for all modes evaluated
- The HLA can be equipped with spreaders to lift up to three containers out of the containership cell structure.

(2) Potential Savings with HLA

There are tremendous costs associated with port congestion. These costs are associated with costs of having cargoes sitting in warehouses and in ships for extended periods, spoilage and damage to cargoes due to extended storage and transit times and the costs of the vessels in which the cargo is held awaiting unloading. In this case there are several alternative solutions to bypass the congestion and each will have virtually the same potential cost saving. The HLA will therefore have no additional advantage over the other solutions in terms of potential savings.

TABLE 6-47. Operating Scenario-One-Way Container Traffic

	TYPE OF LIGHTERAGE	VESSEL COST/DAY (8 HRS)	CARGO BASELINE COST/TON	CONTAINER CAPACITY (40 FT)	SPEED (MPH)	VESSEL LOAD/ UNLOAD TIME	SHORE LOAD/UNLOAD TIME	TOTAL MOORING TIME	ROUND TRIP TRANSIT TIME (MINS)		
						PER CONTAINER			DISTANCE (MILES)		
									2	4	6
ONE WAY CONTAINER TRAFFIC	Landing Craft	$1500	$5.45	4	8	5 min	5 min	10 min	-	30	-
	Barge/Tug	$2000	$5.45	20	4	5 min	5 min	10 min	-	60	
	HLA, High Speed			1	60	3	2				
				2	60	2	1	NA	2	4	6
				3	60	1.33	.66				
	HLA, Low Speed			1	25	3	2				
				2	25	2	1	NA	4.8	9.6	14.4
				3	25	1.33	.66				
TWO WAY CONTAINER TRAFFIC	Landing Craft	$1500	$5.45	4	8	5 min	5 min	10 min	–	30	
	Barge/Tug	$2000	$5.45	20	4	5 min	5 min	10 min	–	60	–
	HLA, High Speed			1	60	3	2				
				2	60	2	1	NA	2	4	6
				3	60	1.33	.66				
	HLA, Low Speed			1	25	3	2				
				2	25	2	1	NA	4.8	9.6	14.4
				3	25	1.33	.66				

	TYPE OF LIGHTERAGE	TOTAL TIME PER TRIP (MINS)			TRIPS PER 8 HOUR DAY			TOTAL CONTAINERS PER 8 HOUR DAY			HANDLING COST PER CONTAINER	VESSEL COST/ CONTAINER	(TOTAL COST/ CONTAINER
		DISTANCE (MILES)			DISTANCE (MILES)			DISTANCE (MILES)					
		2	4	6	2	4	6	2	4	6			
ONE-WAY CONTAINER TRAFFIC	Landing Craft	-	80		–	6	–	-	24	–	$87.00	$62.50	$150.00
	Barge/Tug	–	270	–	–	2	-	–	40	–	$87.00	$50.00	$137.00
	HLA, High Speed							69	53	44	NONE		
		7	9	11	69	53	44	138	106	88	NONE		
								207	159	132	NONE		
	HLA, Low Speed							49	33	26	NONE		
		9.8	14.6	19.4	49	33	25	98	66	50	NONE		
								147	99	75			
TWO-WAY CONTAINER TRAFFIC	Landing Craft	-	120	–	–	4	–	-	32	–	$87.00	$47.00	$134.00
	Barge/Tug	–	470	-	–	1	–	–	40		$87.00	$50.00	$137.00
	HLA, High Speed							80	68	60			
		12	14	16	40	34	30	160	136	120			
								240	204	180			
	HLA, Low Speed							64	48	40			
		14.8	19.6	24.4	32	24	20	128	96	80			
								192	144	120			

(3) HLA Threshold Cost and Potential Operating Scenarios

The threshold cost of the HLA will equal the cost of the alternatives that are available. The threshold costs under the different operating scenarios and different types of operations are described in Table 6-47.

6.13.2.2 Application 2: HLA as a Solution to Congestion With No Alternative Available. There are situations or conditions where alternatives to the HLA are not feasible or available. Examples of such situations or conditions are:

- No temporary or permanent Ro/Ro landing facilities are or can be made available for Ro/Ro landing craft or barges
- The ships to be loaded and discharged have no cargo gear or cranes, and floating cranes are not available to load and discharge vessels at anchorage.

Under such circumstances, there are no alternatives to the HLA other than to wait for an available berth.

A typical scenario could be as follows:

> A new containerport in a developing nation is experiencing demand for its services beyond its capability by a sudden influx of new container liners operating to the port. This has at times caused delays with waiting times up to ten days for arriving containerships. All these containerships are not equipped with self-sustaining gantry cranes, and are therefore forced to wait their turn at the container berths to use the services of the crane. Container operators are considering using the services of the HLA to bypass these delays and to be able to maintain their schedules.

(1) Assumptions

All assumptions are the same as are described for the previous application. In addition, it is assumed that the only alternative to the HLA is to wait for a berth.

(2) Potential Savings with HLA

A container vessel is a highly capital intensive transportation mode with major investments tied up in both containers and vessels. The cost per day on a 24-hour day is estimated in the UNCTAD study to be \$15,000. Thus, for each day of idle waiting time that is eliminated through the use of the HLAs, the vessel operator will save \$15,000.

(3) HLA Threshold Cost

The HLA threshold cost will be equal to the cost of unloading the containers by conventional means which is \$5.45 per ton or \$87 for the typical 16-ton container plus the savings that can accrue due to reduction in the time the ship has to wait for a berth. The HLA threshold cost per container can be expressed as follows:

$$\text{HLA TC/cont} = 87 + \left[D + N(t_c - t_{HLA})/8 \right] (15000/N)$$

where:

N = No. of containers to be handled

D = No. of days delay in the absence of HLA support

t_c = Unloading time per container using conventional equipment (hours)

t_{HLA} = Unloading time per container using HLA (hours)

Thus, if 100 containers are to be unloaded, the vessel has to wait for three days to berth if the HLA was not available, then the HLA threshold cost per container would be \$680 to \$880 with the high speed HLA carrying one container each round trip. The threshold cost in the same situation, with HLA carrying three containers one way in each round trip, would be \$830 to \$1050 per container.

(4) HLA Operating Scenario

The operating scenario under different assumptions of carrying one or multiple containers was described in Table 6-47.

6.13.3 Estimate of HLA Needed to Satisfy the Potential Market

This estimate assumes that although 16-ton is considered to be an average container weight, a fully loaded container can have a maximum weight of 25-ton. Thus two sizes of HLA are considered; 25-ton payload for single containers, and 75-ton payload for three containers aggregated into a single load.

6.13.3.1 The Annual Market. From Section 5, the annual market is expressed as 325,000 to 575,000 16-ton average container lifts per year.

6.13.3.2 The Required HLA Capabilities. The typical operating times were given in the previous section in Table 6-46 for one-way and two-way container traffic.

6.13.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. The total number of vehicles to satisfy 100 percent of the market is given by

$$\frac{\left(\begin{array}{c}\text{Total Number of Containers}\\ \text{per Year}\end{array}\right)\left(\begin{array}{c}\text{Vehicle Operating Hours}\\ \text{per Container}\end{array}\right)}{(\text{Annual Utilization})}$$

This is given in Table 6-48 for one-way and two-way container traffic.

TABLE 6-48. No-Ferry Number of Vehicles to Satisfy 100% of the Congested Port Container Market

HLA SPEED (MPH)						25						60					
HLA CONTAINERS PER ROUND TRIP				ONE WAY TRAFFIC		1			3			1			3		
				TWO WAY TRAFFIC		2			6			2			6		
ROUND TRIP DISTANCE						2	4	6	2	4	6	2	4	6	2	4	6
OPERATING TIME PER ROUND TRIP (MINS.)				ONE WAY		9.8	14.6	19.4	9.8	14.6	19.4	7	9	11	7	9	11
				TWO WAY		14.8	19.6	24.4	14.8	19.6	24.4	12	14	16	12	14	16
$\bar{N}_{V_{NF}}$	ONE WAY	CONTAINERS PER YEAR	375,000	ANNUAL UTILIZATION (HOURS)	1,000	54	80	106	19	28	37	39	50	61	14	18	22
					2,000	27	40	53	10	14	18	20	25	30	7	9	11
			575,000		1,000	95	142	189	33	50	62	69	89	109	25	32	39
					2,000	48	71	94	16	25	31	35	45	54	12	16	20
	TWO WAY		325,000		1,000	47	62	77	15	20	25	39	45	51	13	15	17
					2,000	24	31	39	8	10	13	20	23	25	7	8	9
			575,000		1,000	83	110	137	27	36	45	70	82	94	25	29	33
					2,000	42	55	68	14	18	22	35	41	47	13	15	16

Note that the one-way analysis also applies to Application 2, "Without Competition," described in 6.13.2.2.

6.13.3.4 <u>"No-Ferry" Share of the Market</u>, M_{NF}. From the case study, the threshold costs for the two applications are as follows:

- Application 1: One-way traffic, \$137 to \$150 per container.

  Two-way traffic, \$134 to \$137 per container.

- Application 2: $\left\{87+15000\left(\frac{D}{N}\right)+1875(t_c-t_{HLA})\right\}$; this is given in Table 6-49, for $\frac{D}{N}$ values given in Table 6-50.

TABLE 6-49. Threshold Cost for Application 2 ($ per container)

HLA SPEED (MPH)				25						60					
HLA PAYLOAD (TONS)				25			75			25			75		
RD. TRIP DISTANCE (MILES)				2	4	6	2	4	6	2	4	6	2	4	6
HLA ROUND TRIP TIME PER CONTAINER (HOURS)				.163	.243	.323	.054	.081	.107	.117	.150	.183	.039	.050	.061
ONEWAY TRAFFIC	$\left(\frac{D}{N}\right)$	.0033	.33*	450	300	150	655	604	555	536	475	413	683	662	641
			.23**	253	171	-47	458	407	358	340	278	216	486	465	445
		.0066	.33	500	350	200	705	654	605	586	525	463	733	712	691
			.23	303	221	3	508	457	408	390	328	266	536	515	495
		.010	.33	550	400	250	755	704	655	636	575	513	783	762	741
			.23	353	271	53	558	507	458	440	378	316	586	565	545

* LANDING CRAFT ROUND TRIP TIME (HOURS)
** TUG/BARGE ROUND TRIP TIME (HOURS)

TABLE 6-50. In-Port Delay per Container (Days)

DAYS DELAY (D)			1	3	5
$\left(\frac{D}{N}\right)$	CONTAINERS PER SHIP (N)	500	.002	.006	.010
		1,000	.001	.003	.005
		1,500	.00067	.002	.0033
		2,000	.0005	.0015	.0025

The average HLA costs are given in Table 6-51.

TABLE 6-51. Average HLA Job Costs per Container ($)

HLA SPEED (MPH)				25			60		
ROUND TRIP DISTANCE (MILES)				2	4	6	2	4	6
AVERAGE HLA COST PER CONTAINER ($)	PAYLOAD (TONS) & CONTAINERS (EACH WAY)	25 & 1	ONE WAY	250	360	480	170	230	270
			TWO WAY	190	250	300	150	180	200
		75 & 3	ONE WAY	190	280	370	130	170	210
			TWO WAY	140	190	230	120	140	150

The market share parameters are A=20, B=50. Thus for

$$M_{NF} = 0, \quad \frac{HLAC}{TC} \geqslant 0.80$$

$$M_{NF} = 100\%, \quad \frac{HLAC}{TC} \leqslant 0.50$$

From this, by inspection, the market for Application 1 is zero, and the market for the 75-ton HLA is 100 percent. The market for the 25-ton HLA at 25 mph only exists at the shortest distances in competition against the more expensive conventional alternative, while at 60 mph it exists at all distances, but again in competition against the more expensive alternatives. Thus the vehicle numbers in Table 6-48 apply, except for the entries under 4 miles and 6 miles for the 25 mph, 25-ton HLA; these become zero.

6.13.3.5 <u>Effect of Ferry</u>. By inspection of the ferry ratio curves in Section 6.3.4, and the threshold cost data in Table 6-49 the effect of ferry is to reduce the number of vehicles somewhat for virtually all combinations of parameters, except possibly short-range operation of a 60 mph 75-ton HLA with 2000 hours annual utilization.

6.14 Case Study No. 11
Parametric Analysis of Transportation and Rigging of Heavy and Outsized Loads by Various Modes

6.14.1 Current Situation

In the following pages, a number of transportation and rigging jobs involving outsized and heavy components are described. This case study is divided into four sections:

- Heavy lift shipments originating in Europe
- Heavy lift shipments originating in the United States
- Parametric models of heavy lift transportation freight rates
- Complex transportation and rigging situations.

The first two sections describe the transportation and rigging of heavy lift shipments where no major complexity like limited clearances, bridge reinforcements, etc. were introduced. These sections are followed by a description of parametric heavy lift freight rate calculator models for rail, barge, and truck transportation developed by Lykes Bros. Steamship Company. Finally, several cases which presented major challenges to the expertise and ingenuity of both hauler/rigger and shipper/ consignee are presented.

6.14.1.1 Heavy Lift Shipments Originating in Europe. The following applications describe transportation of shipments originating in Europe by modal or intermodal transportation:

(1) Application 1: Electric Generators and Stators

A major manufacturer of electric generators and stators located in Switzerland is shipping his components worldwide either via the ports of Hamburg or Rotterdam. This manufacturer has estimated that transportation costs accounts for approximately 8 to 10 percent of the cost of his components and in exceptional cases the transportation may account for as much as 10 to 20 percent. A stator for an electric generating plant costs approximately 10 to 12 million Swiss Francs (U.S. $5-6 million).

In one specific case, this manufacturer had one 193-ton cylinder to be shipped to Ohio, USA. For this movement a 16-axle each with 8-wheels truck with a capacity of 410 tons was used to transport the cylinder from Birrfeld to Basel am Rhein. This move took a total of 6 days, of which 1 day was required to load, one day to secure the load and four days for the transport. Total cost was S. FR 60,000 (U.S. $30,000). At Basel, the load was transferred to a Lykes Seabee barge for transport to Rotterdam for loading onto a Seabee vessel for transportation to New Orleans. The transshipment cost in Basel am Rhein was S.FR. 20,000 ($10,000) and the transportation cost from Basel to New Orleans $42,000. Once in the United States, the shipment had to be transported further by barge to Ohio. Costs are not available for the United States land-based portion of the transportation.

(2) Application 2: Air Separation Plants for Steel Manufacture

A manufacturer near Munich, W. Germany, had two components each weighing 86 tons to be shipped to an export port, either to Bremen or Rotterdam. The alternative, shipping the components by barge via Nuremberg, was excluded, due to a lack of heavy lift cranes at Nuremberg. It was therefore decided to ship these components on special transporter trucks from the plant to the Port of Bremen. A rigger/transporter quoted a price of D.M. 25,000 (U.S. $12,000) for each component. Each component took three to four hours to load onto the transporter truck, and another four to five days to transport between Salchen and Bremen.

(3) Application 3: Package Boiler

A company in Hartlepool, England is constructing pressure vessels, package boilers and compressors ranging in weight from 100 to 380 tons. All these components have to be shipped fully assembled, and truck transportation is the only alternative available. Overseas shipments are normally shipped via the Port of Middlesbrough, where a 400-ton floating crane is available for transfer to ocean vessels.

A 200-ton package boiler was shipped from Hartlepool to Dammam, Saudi Arabia. It was loaded onto a truck trailer for transportation to Middlesbrough, where it was driven directly onboard a Ro/Ro vessel. Once onboard the vessel the boiler was jacked off the trailer and onto bearers sitting on the deck of the vessel. The trailer was an 800-ton capacity multi-axle trailer. It took one day to load at the factory and one-half day transit time to the port. The total cost of the overland transport was £8000 (U.S. $14,500). The cost of ship transportation to Dammam was not available.

(4) Application 4: Transformers and Generators

A manufacturer of transformers up to 400 tons and generators up to 900 tons with plants in Weiz and Vienna, Austria has two alternatives to ship its components to continental seaports. The company can ship by barge to Black Sea ports which costs $35,000 per shipment or by rail to Western European ports which cost $50,000. The latter alternative is used in most cases.

(5) Application 5: Transformers

A major manufacturer of transformers located in Hollinwood, Lancashire, England is shipping its components worldwide. Most of the shipments are made by trucks over the road to the Port of Manchester although at times barges are used.

One specific case described by the manufacturers involved the logistics of shipping two 290-ton transformers with dimensions of 28 feet x 12.5 feet x 15 feet from its plant to a nuclear electric generating station located on Lake Erie, Canada. These two transformers were shipped between Hartlespool and Manchester by truck and rolled onto a Ro/Ro vessel. The cost of transportation in England was £10,000 (U.S. $18,700). (1973)

In Canada, the shipments were transferred to railcars at Norfolk for transportation to the site. Rail cost was £50,000 (1973) (U.S. $93,500).

(6) Application 6: Transformers

A major Italian transformer manufacturer located in Lugano produce transformers weighing from 30 to 400 tons. The modes of transportation used are truck and rail. Over the road transportation by truck is limited by the Italian local dimension limitations, which are maximum 8 m long, maximum 4 m wide and maximum 4.7 m high including the truck.

The manufacturer received a contract for a 160-ton transformer for a power plant in the U.S. Pacific Northwest. This transformer was transported by a 200-ton low loader from Lugano to the Port of Genoa for transfer to an ocean vessel. The transformer was loaded at the factory in two hours using a gantry crane at the plant. The overland movement took five days. The cost of the transportation was 15,000,000 lira (U.S. $15,300). In Genoa, the transformer was loaded onto the vessel using two floating cranes with 100 and 150-ton capacity respectively. The cost of loading was not available.

(7) Application 7: Inlet Valves

A manufacturer of hydroelectric turbines and components for these turbines plus paper manufacturing machinery located in Zurich, Switzerland ships its components to all parts of the world via the Port of Rotterdam, the Netherlands. The mode of shipment is normally from Zurich to Basel am Rhein by truck and then onwards from Basel to Rotterdam by barge. The dimensions of the components are:

- Water turbines, 5.5 to 6 m diameter, 200 tons weight
- Pipe sections, 5 m diameter, 100 tons weight
- Inlet valves, 3.5 m diameter, 180 tons weight
- Paper machinery cylinders, 4.5 m diameter, 40 tons weight.

Due to the large dimensions of their shipments, the truck transport between Zurich and Basel cannot use the most direct route of 90 km, due to heavy traffic on this route, bridges with limited load capacity and tunnels with limited dimensions. Instead the truck shipments have to follow a route of 200 km length avoiding these limitations.

One case involved the shipment of four inlet valves each weighing 150 to 170 tons plus accessory cargoes. For each valve, the following logistics plan was followed:

- Transportation by truck trailer from Zurich to Basel. The cost was S.F. 50,000 (U.S. $25,000) plus police escort S.F. 12,000 (U.S. $6,000).
- Loading by heavy lift crane onto barge in Basel. The cost of this operation was $10,000.
- Transportation by barge from Basel to Rotterdam. The cost was $3,000.
- Transfer from barge to ship in Rotterdam at a cost of $2000.

The transportation cost for each valve from the plant to the ship in Rotterdam was therefore $36,000 or a total of $144,000 for the four shipments.

(8) Application 8: Transformer

A West German manufacturer of electrical generating plant components is shipping worldwide from plants located in West Berlin and Nuremberg, W. Germany. Shipments are made either by barge or rail to continental seaports. The mode of shipment and seaport is selected based upon the final country of destination. Below the logistics of transporting a 150-ton, 9m long, 3.2 m wide and 4.4 m high transformer destined for Cabora Bassa, Mozambique is described.

The transformer was destined for a major hydroelectric power project sponsored by the government of Mozambique. Shipments for this project totaled 30,000 tons of which approximately 6000 tons were heavy lift shipments exceeding 100 tons.

From the plant in Nuremberg, the transformers were shipped by a 24-axle railcar owned by the Federal Railroad of Germany. It took 12 men four hours to load the transformer at origin, and another four days to transport it to the Port of Bremen. The negotiated rate obtained from the railroad was D.M. 35,000 (U.S. $16,000). It was loaded onto the vessel using a floating crane. The cost of loading is not available.

The cost of transportation in Mozambique is not available. The logistics of the operation is nevertheless interesting:

- The transformer was lifted off the ship onto wooden supports set up on the dock.
- It was then transferred to a railcar using hydraulic jacks and transported 600 km by rail.
- The transformer was transferred from the railcar to a 2 x 8 axle truck bogie that were interchangeable with the rail bogies. This trailer was pulled by a 2 x 450 ton tractor. It took 20 men one day to transfer the transformer from railcar to the truck. Once loaded and secured the shipment was transported 200 km to its destination. This final leg of the journey took eight days to complete.

(9) Application 9: Transformers

An Italian manufacturer located in Torino, Italy, makes transformers up to 200 tons in weight with dimensions of 9 m long, 3.5 m wide and 4.5 m high, and alternators weighing up to 150 tons with dimensions of 7 m long and 4.5 diameter. The components are generally shipped by rail. The case below describes the shipment of two transformers of 142 tons each to a power plant in South Africa. Both transformers were shipped from Torino to Genoa, Italy by rail. The rail cost was L 9.5 million ($14,400) for each transformer. The transformers were shipped from Genoa to Port Elizabeth, South Africa by ship.

In Port Elizabeth the transformers were transferred to rail for shipment to Hydra City, South Africa, a distance of 1200 km. From Hydra City, the transformers were transferred to truck and transported to the Hydra power station. The total cost for the rail and truck transportation plus the transfer was L 35 million ($53,200).

(10) Application 10: Refinery Reactor Vessel

The components for a major refinery in Sweden were ordered from a manufacturing company in Italy. These components were transported by truck to the Port of Venice for loading onto specialized heavy lift vessels for transportation to the Port of Lysekil in Sweden. From the port the components were loaded onto transporters for transportation to the refinery. A total of 15 or 20 voyages were required to transport all components between Italy and Sweden. The logistics and cost of transporting a reactor vessel of 220 tons are described below.

The reactor vessel was transported from the manufacturing plant to the Port of Venice, Italy by truck low loader. Several bridges had to be crossed which required careful maneuvering by the trucker. No strengthening of the bridges had to be performed. The 10-mile haul to the port required 48 hours. The ship was not scheduled to arrive for another four weeks and the reactor vessel had to be placed in storage. Once the ship was docked, the reactor vessel was moved 25 meters (82 feet) from the storage shed to the shipside with rollers moving on rails. The cost of inland transportation, the storage and the haul to the ship's side cost S. Kr. 60,000 (U.S. $13,000). The charter cost of the heavy lift vessel for the transportation between Italy and Sweden was S.Kr. 160,000 (U.S. $36,000).

6.14.1.2 Heavy Lift Shipments Originating in or Transported Within the United States. The cases described in the following pages involve shipments of heavy or outsized components by one or more modes of transportation.

(1) Application 1: Reactor Vessels for Refinery

Two reactor vessels of 200 tons, 59-foot length and 13 feet, 2 inches diameter each were manufactured in Japan and shipped to New Orleans for the account of a U.S.-based construction and engineering company. Once in the United States, the vessels were transported less than 100 miles by rail. The cost of the rail transportation for each vessel was $6000 plus $4000 to tie the vessels to the railcar.

(2) Application 2: Cryogenic Heat Exchangers

Two cryogenic heat exchangers of approximately 200 tons in weight with a length of 160 feet and 14 feet diameter were required to be moved from a plant in Wilkes Barre, Pennsylvania to Das Island in the United Arab Emirates. A total of 500 tons of spares and ancillary equipment followed the shipments.

The equipment was moved from Wilkes Barre to Jersey City, N.J. on a total of 10 railcars. Multiaxle, low bay cars were used. The total rail transportation cost was $150,000 for all the components.

In Jersey City the components were loaded onto a specialized heavy lift vessel for transportation to the Persian Gulf. Cost of ocean transportation was $526,000.

In the Persian Gulf, the cargoes were unloaded at Anchorage onto barges and transported by barge 100 miles to Das Island. At Das Island, the cargoes were unloaded with crawler cranes which were borrowed in an arrangement with an oil company with operations on the island. With the assistance of the barge crew, contractors and local labor, the unloading was accomplished in two days. Costs that may have been incurred in the Persian Gulf are not available.

(3) Application 3: Ammonia Converters

A major engineering company had contracted with a Japanese manufacturer to supply two 620-ton ammonia converters. Each converter was shipped from Japan to New Orleans at 60-day intervals. Final destination was Minititlan, Mexico.

A rigging company took responsibility for each converter in New Orleans. In New Orleans, the converter was transferred from the ship to a flat deck Ro/Ro barge using a large floating crane. The barge transported the converter to a shallow water river discharge point in Mexico. At this point the converter was transferred to two 400-ton low profile crawlers positioned on the deck, "walked" off the barge and transported 8 miles inland to the site. The cost for the total job from New Orleans to the construction site was $66,000 for each converter.

(4) Application 4: Petroleum Storage Vessels

A manufacturer of petroleum and petrochemical plant components shipped four 234-ton pressure vessels destined for a production platform in the United States gulf 100 miles offshore Louisiana. These vessels were loaded onto railcars in Paola, Kansas using one 150-ton crane and one 200-ton rubber tired crane in tandem. It took a team of 15 men (6 teamsters and 9 boilermakers) one full 8-hour day to load each vessel. The vessels were transported by rail to Houston, Texas. Rail transportation cost for each of the four vessels was $15,000 for a $60,000 total cost.

In Houston, the tanks were transferred to a deck barge equipped with 500-ton derrick, and transported to the offshore site. No costs are available on this portion of the move.

(5) Application 5: Heavy Lift Crane

A truck crane weighing 150 tons was shipped from Lorrain, Ohio to Philadelphia by rail. The crane was driven on the railcar, driven off the railcar in Philadelphia onto a Ro/Ro vessel for shipment to its final destination in the Persian Gulf. The rail transportation cost was $3 per cwt or $9000 total.

(6) Application 6: Metal Stamping Machinery

A metal stamping machine of 200 tons with dimensions of 25 feet length, 17 feet width and 17 feet height was shipped from Chicago to New York by rail. The cost of rail transportation was $13,000.

In New York the cargo was transferred to an ocean vessel for further transportation to Khomamshar, Iran. In Khomamshar the machine was transported by truck transporter 1000 km to the job site. The cost of truck transportation was DM 235,000 (U.S. $113,000).

(7) Application 7: Truck Crane

The truck crane was dismantled for shipment by rail and the largest component weighed 60 tons. Total weight was 350 tons. The cost of shipping these components from Lima, Ohio to Baltimore was $11,000.

(8) Application 8: Stators, Generators, and Rotors

A company was shipping stators/generators weighing 412 tons each with dimensions of 51 feet, 8 inches length, 21 feet, five inches width and 17 feet, 5 inches height, in addition to rotors of 67 feet length, 9 feet, 7 inches width and 10 feet height and a weight of 242 tons. These components were shipped from Schenectady, New York to ports in New Jersey by rail. The cost per component was $10,000.

(9) Application 9: Transformers

A company was shipping a 300-ton transformer from Chicago to Morris, Illinois by rail, a distance of approximately 70 miles. The cost was $4500 per shipment.

(10) Application 10: Components for Nuclear Power Generating Plant

The following components were transported from a barge landing on the Ohio River to the Dusqueue Light, Beaver Valley #1 generating plant:

- Neutron shield tank, 180-200 tons
- Steam generators, 350 tons

Total cost for the land transport with a crawler was $40,000.

6.14.1.3 <u>Parametric Models of Heavy Lift Transportation Freight Rates</u>. All of the above cases were derived from an extensive survey made by Lykes Bros. Steamship Company under contract to the Maritime Administration.

Based on the above cases and an extensive analysis of the tariffs published by regulated carriers and rates quoted by unregulated carriers, Lykes Bros. developed parametric heavy lift rate calculator models for rail, barge, and truck in the United States. These models are presented below.

(1) Rail, Freight Rate Calculator Model

The rate calculator model for U.S. rail freight rates is presented as Table 6-52. The model has been developed based on the rates for the following commodities:

- Machinery: Electrical generation equipment, gas turbines, metalworking machinery, construction machinery, material handling equipment, mining machinery, compressors, engines, dredges, boats

- Class 40: Reactor and petroleum refining vessels, boilers, transformers

- Commodity: Locomotives, earthmoving vehicles, road building equipment, mobile cranes, drill rigs.

The calculation of heavy lift freight rates are based on four components:

- The base distance rate
- Railcar use charges, including demurrage
- Special train service charges
- Extra car charges.

The base distance rate is the charge quoted in the tariff and is based upon the weight of the cargo, the type of commodity, the distance and origin and destinations of the cargo. The origins and destinations are important because railroads like other businesses price their services according to the competition for the cargoes. The Lykes study has characterized the rates by four different origins or destinations as follows:

- Origin or destination is a deepwater port. At these points low cost alternatives by barge and ship are available, and rates are consequently low.

- Origin or destination is on a navigable river and low cost alternative transportation by barge is available. The rates are therefore relatively low.

- Origin or destination is close to a navigable river and cargoes can be transshipped to barge after a short haul by overland modes of transportation. The rates are higher than the two alternatives above, but still low enough to discourage shippers from transhipment to barges.

TABLE 6-52. U.S. Railroad Heavy Lift Movement Costs

BASE CHARGE

(Sum of fixed cost per ton plus fixed cost per ton-mile)

Commodity Rate	(B) (C) or (D)	= $5/tonne	Rate x Weight = Setup Cost = $ ______
	(A)	= $0	
Class 40 Rate Machy Rate	(B) (C) or (D)	= $24/tonne	
	(A)	= $19/tonne	

Commodity Rate	A, B	@ 3.4¢/tonne-statute mile	Rate x Distance x Weight = Distance Cost = $ ______
	C	@ 3.8¢/t–s.m.	
	D	@ 4.35¢/t–s.m.	
Machy	B	@ 6.0¢/t–m.	
Machy Class 40	A Only A,B	@ 5.6¢/t–m.	
Class 40	C	@ 6.4¢/ · m.	
Machy Class 40	D	@ 7.3¢/t–m.	

TOTAL BASE CHARGE $ ______

RAIL CAR USE CHARGE

(2 free days load & 2 for discharge)

$6.70 per metric ton = $ ______

7¼c/stat. mile $ ______

Demurrage (over 2 days)		Loading	Emptying
1st & 2nd	@ $ 59 ea.	______	______
3rd & 4th	@ 118 ea.	______	______
5th & 6th	@ 177 ea.	______	______
7th & 8th	@ 236 ea.	______	______

Total Demurrage $ ______

TOTAL RAILCAR USE CHARGE $ ______

SPECIAL TRAIN SERVICE CHARGE

(for height add 2' for railcar to height of load)

If height +2' OR width greater than table, on map;

S.T.S. Charge = $18/mile - Southern
19/mile - Western (Minimum $118) $ ______
20/mile - Eastern

EXTRA CAR CHARGE

(split load or length) (add demurrage above)

Total number cars @ 60'/car = ______ (4 maximum)

Weight charge @ $73/extra car ______ (not 1st car)

Distance charge @ 75¢/mile/extra car ______ (not 1st car)

TOTAL EXTRA CAR CHARGE $ ______

TOTAL RAILROAD BILL $ ______

- Origin or destination is such that rail will be the only alternative except for truck. The rates are therefore relatively high.

The rail use charge refers to the cost of using the cars. The charges vary greatly depending upon the type and size of car. The charges presented in the model is an average cost based on the costs of a number of railroad-owned cars.

In cases where the dimensions of the cargo to be transported exceeds the clearances on the route, special trains often have to set up to transport the cargoes. A generalization of the clearances in the United States is presented as Figure 6-9 . The height clearance includes the car bed height. To estimate the height clearance of a cargo loaded on a depressed center flatcar approximately 2 feet has to be added to the height of the cargo.

When the length of the cargo exceeds 60 feet and cannot fit on one flatcar, one or more extra cars are frequently required at either end of the load or in the middle. As many as four extra cars may be required.

(2) Barge Freight Rate Calculator Model

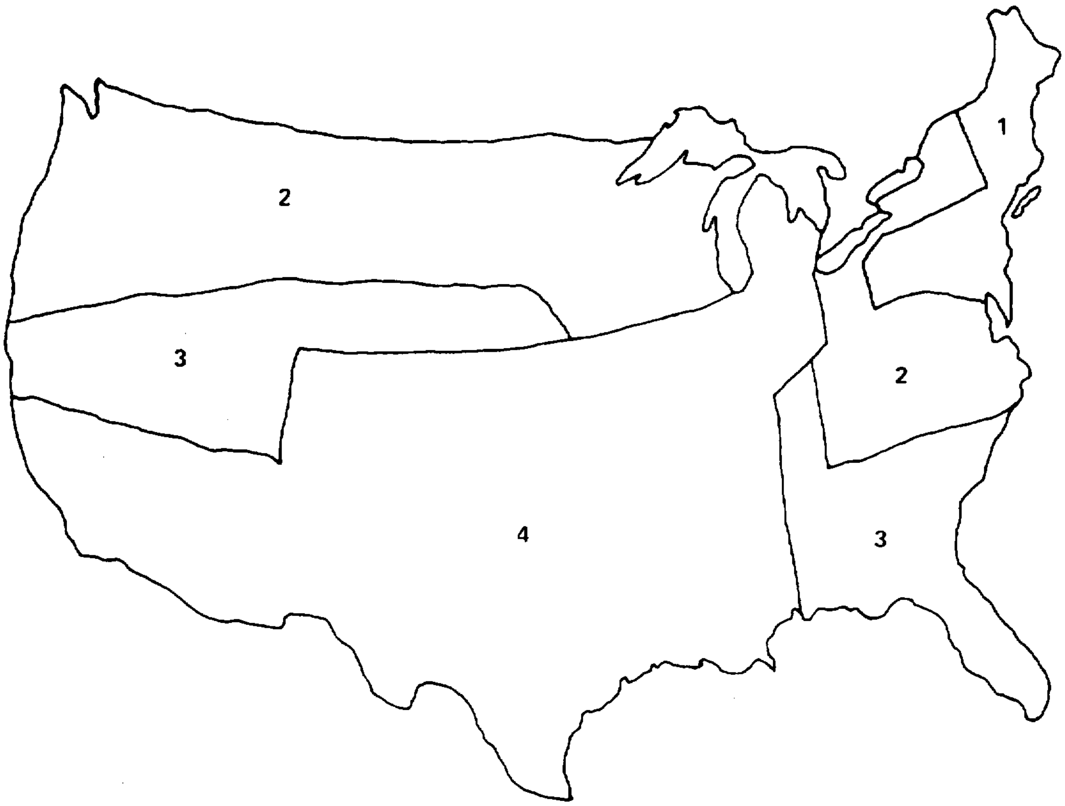
The barge freight rate calculator model is presented as Table 6-53. A graphical description is presented as Figure 6-10 . The barge freight rates are normally calculated based on the distance traveled plus the weight of the cargo subject to a minimum weight. The rates will differ depending upon the waterways on which the cargo is to be carried. The rates are lower on the main waterways than on the tributary rivers due to the fact that larger tows are possible on the main waterways.

Two different rates are presented:

- Transportation in carrier-owned barges
- Transportation in shipper-owned barges.

When the cargo is transported in a barge owned by a barge line, the freight charge covers both the towing charges and the rental of the barge. In the case that the shipper owns barges, he will only have to pay the towage charges. Both these rates are included in the model.

The European barge costs are higher than those charged by companies operating on the U.S. waterways. Charges on various European waterways are presented as Figure 6-11. The charges presented in this figure include only the towage charges. A good



WIDTH	12'0"	12'10"	
AREA	HEIGHT (maximum)		SHIPPING AREAS
1	17'0"	–	New England
2	19'0"	19'0"	Upper Northwest & Southeast
3	19'3"	19'3"	Lower Northwest & Southeast
4	20'4"	20'4"	Mississippi Valley & Southwest

SOURCE: Combustion Engineering

FIGURE 6-9 Generalization of Clearances in the United States

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TABLE 6-53. U.S. River Barge Cost

Barge Size	Minimum Weight Carriage	Minimum Weight Towing
SeaBee Units of 2 @ 97' x 35'		800' S.T. in 1 or 2 barges
J = 200' x 35' or less	600 S.T.	1200 S.T.
SJ = 200' – 240' x 35' – 45'	1000 S.T.	1800 S.T.
S = 240' x 45' or more	1200 S.T.	2400 S.T.

CARGO WEIGHT ______________________ **/MINIMUM** ____________ **USE** __________

TOWAGE ______________________ **CARRIAGE** ________________

RIVER ROUTING =

		DESIGNATORS	BASE CARRIAGE/BARGE SET UP	BASE CARRIAGE/BARGE RATE	TOWAGE/BARGE SET UP	TOWAGE/BARGE RATE
M	=	Main Stream Mississippi and Ohio Rivers	$3,900 +	$6.80/Mile	–$800 +	$6.61/Mile
C	=	Combination M & One Tributary River or Gulf Intracoastal Waterway	$4,800 +	$7.35/Mile	0 +	$6.61/Mile
T	=	Two Tributary or Gulf I.C.W.W. Movements	$5,900 +	$8.90/Mile	+$700 +	$6.61/Mile

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BASE RATE = $__________/BARGE = 100% At 1,000 Metric Tonnes

MULTIPLIER = ________________ = _____% For Barge Size & Heavy Lift Weight

MULTIPLIER = ________________ = _____% Actual Weight or Minimum ÷ 1,000 M.T.

BARGING BILL = $__________________/BARGE

EXTRAS FOR CARRIERS BARGES

DECK

HL 200 S.T. OR J = 150%
HL 200 S.T. OR SJ = 200%
HL 200 S.T. OR S = 300%
MINIMUM = $4,184

HOPPER

HL 100 - 200 S.T. = 150%
HL 200 S.T. = 200%

MINIMUM = $4,184

EXTRAS FOR TOWING BARGES

ALL TYPES

J = 100%; MINIMUM $750
SJ = 150%; MINIMUM $750
S = 200%; MINIMUM $1,500
SEABEE UNIT = $700 Loaded;
MINIMUM = $600 Empty
EMPTY = NO CHARGE

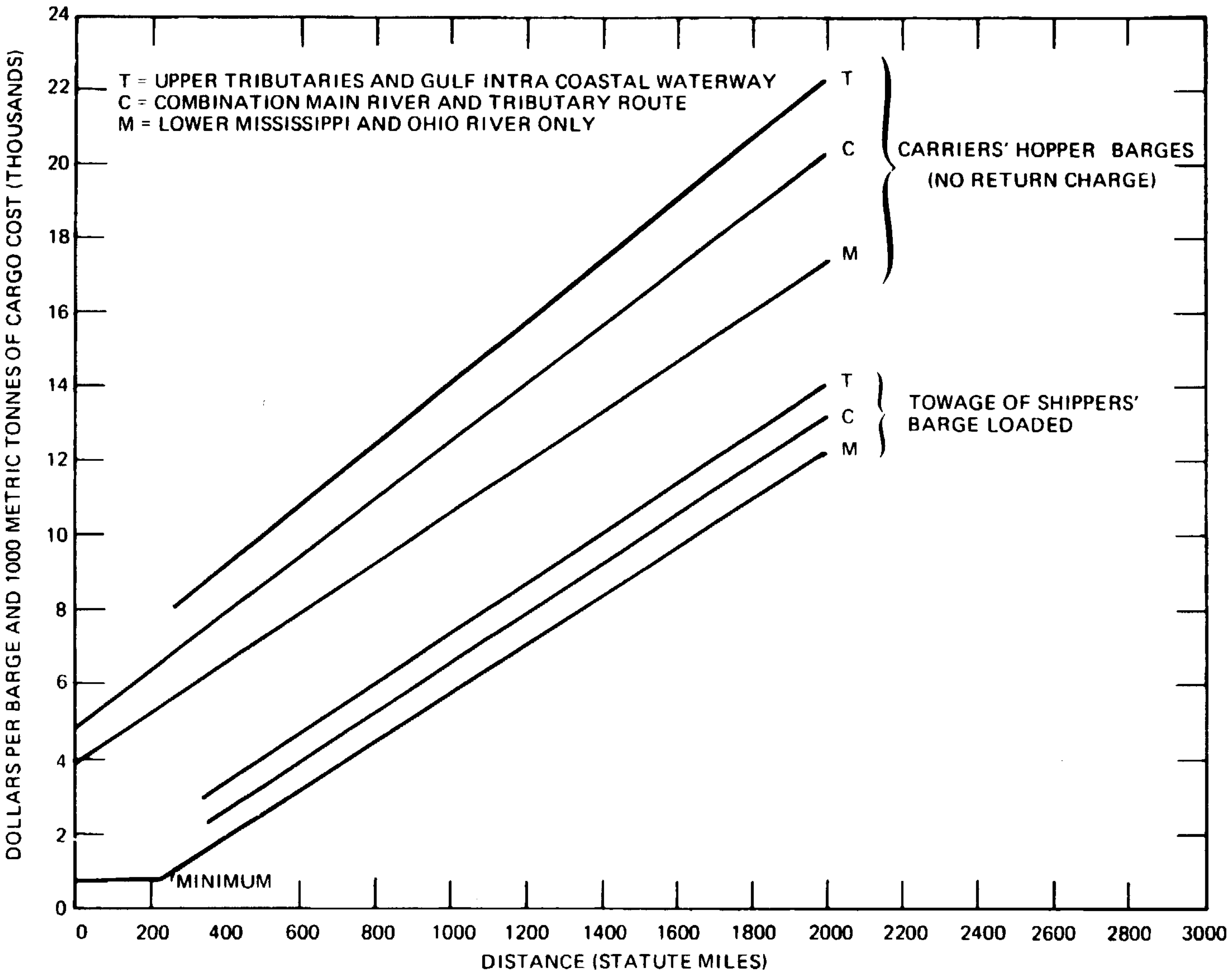
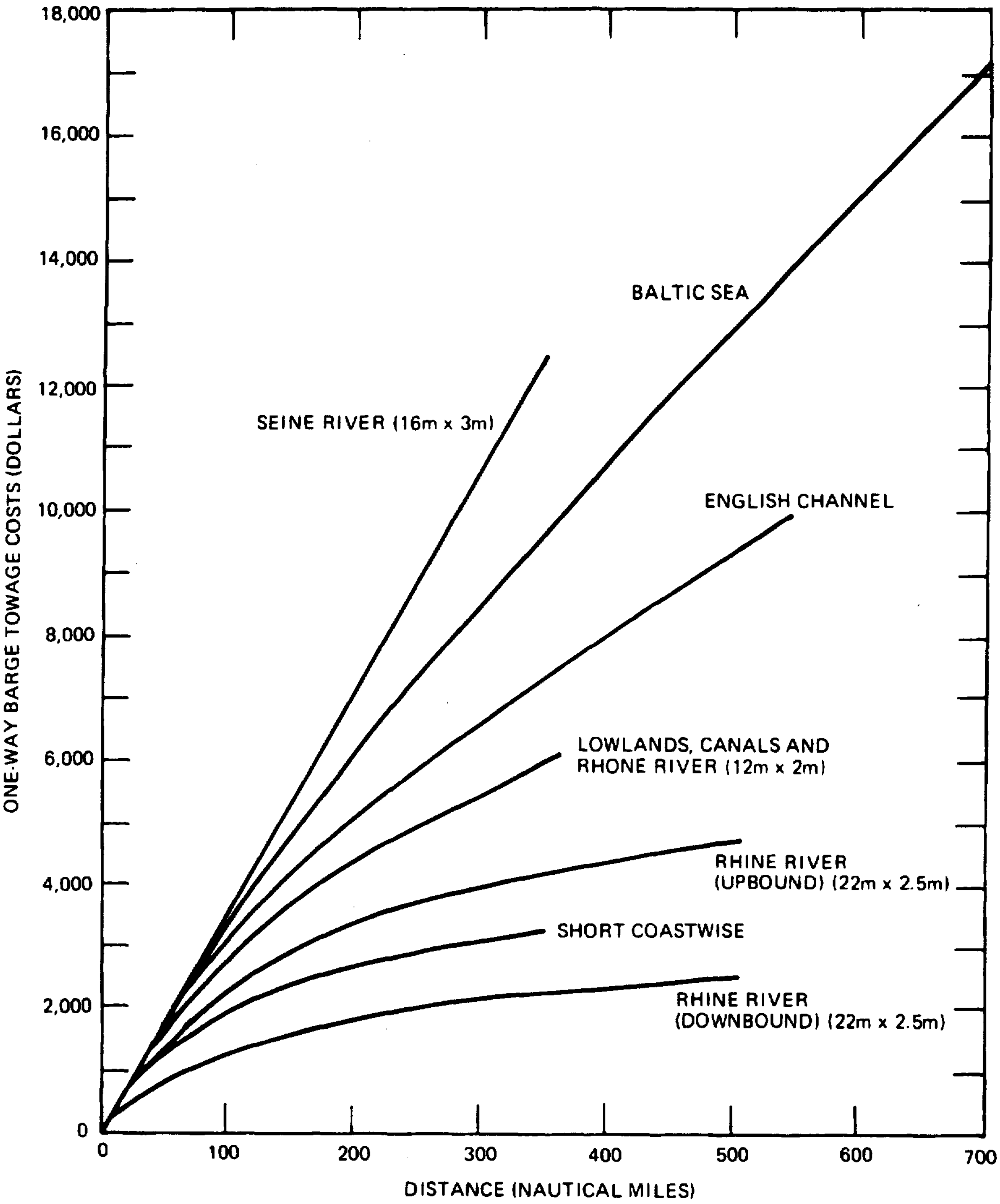


FIGURE 6-10 U.S. Inland and Coastal Barging Charges



SOURCE: Lykes Bros. Steamship Co., Inc.

FIGURE 6-11 European Barge Towing Charges by Navigation Channel estimate of the total barge costs (i.e., towage and barge charter) can be derived by adding the barge costs presented in Table 6-54 to the towage cost in Figure 6-11.

(3) Heavy Lift Truck Transport

A number of variables are used by hauler/riggers to calculate transportation charges. Each job is different, and it is bid as a total package with loading, unloading, road survey, special equipment and other charges included. Based on published tariffs and discussions with haulers/riggers, Lykes Bros. developed a parametric rate predictor model. This model is presented as Table 6-55.

It should be noted that charges for bypass roads, bridge strengthening and reconstruction, expansion of roads, construction of barge landings and other charges that are peculiar to each situation, will be additional to the charges presented in the parametric model.

In the next section, a number of cases which by their particular nature fall outside the scope of the parameters of the models are presented.

(4) Complex Transportation and Rigging Situations

The following application describe the transportation and rigging situations which in many ways are unique and require experience, expertise, and special equipment in the possession of only a few hauling and rigging companies.

(a) Application 1: Transportation of Nuclear Components by Heavy Lift Barges

The Union Mechling Corp. is one of the major barge and towing companies in the United States. This company has also invested in barges that can sustain deckloads of up to 1200 tons and can thus handle very large and heavy components required for among others nuclear power plants. Some typical components that the barges of Union Mechling transport for the nuclear power plant manufacturers are listed in Table 6-56.

TABLE 6-54. Flat Deck, Heavy Lift, Oceangoing Barges

	SEABEE	SPECIAL SEABEE	JUMBO	SUPER JUMBO	SHORT SUPER JUMBO	SUPER SHORT	SUPER LONG	OCEAN SHORT	OCEAN LONG
Length Overall	97′	115′	200′	239′	200′	200′	300′	200′	300′
Beam, Maximum	35′	35′	35′	45′	45′	50′	50′	70′	70′
Depth Hull	11′	15′	16.5′	15′	15′	15′	19′	15′	19′
Draft, Fresh Water	9.5′	9.5′	12.5′	13.75′	12.5′	12.5′	15.8′	12.5′	15.8′
Deadweight Tonnage	700	810	1900	3260	2460	2740	5320	3870	7500
Lightweight, Tonnes	196	210	430	680	540	590	1000	800	1350
Displacement, F.W.	896	1020	2330	3940	3000	3330	6320	4670	8850
Draft @ 1,000 Tonnes	N.A.	N.A.	7.8′	6.5′	7.2′	5.1′	4.9′	4.3′	4.2′
Total Daily Cost	$151	$163	$267	$381	$314	$335	$518	$421	$658
Capital Cost (Thousands $)	215	240	460	680	560	604	980	780	1250

SOURCE: Lykes Bros. Steamship Co., Inc.

TABLE 6-55. Rate Predictor Model (40 Tonnes)

BASE CHARGE

Setup Cost = $19.25 x weight (metric tonnes) = $__________

Transport Cost = $0.40 x weight x distance (S.M.) = $__________

Total Base Charge = $__________

SIZE EXTRAS - (use only the highest multiplier for oversize)

Length	Multiplier	Width	Multiplier	Ht. for Ground	Multiplier
45'-55'	1.05	8'-9'	1.05	12'-13'	1.05
55'-65'	1.10	9'-10'	1.10	13'-14'	1.10
65'-70'	1.20	10'-11'	1.15	14'-15'	1.15
70'-80'	1.30	11'-12'	1.20	15'-16'	1.20
80'-100'	1.40	12'-13'	1.25	16'-17'	1.25
100'	1.50	13'-14'	1.30	17'-18'	1.30
		14'-15'	1.35	18'-19'	1.40
		15'-16'	1.50	19'	1.50
		16'-17'	1.65		
		17'	2.00		

GEOGRAPHY EXTRAS

South of Tennessee = 1.00 Multiplier - Base

North East and Midwest = 1.05 Multiplier

Mountainous Areas = 1.10 Multiplier

South West = 0.95 Multiplier

COMMODITY EXTRAS

Steel Fabrications	1.00 Multiplier	Base
Metalworking Machinery	1.10 Multiplier	
Rotating Mechanical Machinery	1.20 Multiplier	
Rotating Electrical Machinery	1.30 Multiplier	

TOTAL BASE AND EXTRAS

$ Base charged x largest size Extra Multiplier x Geography Extra Multiplier x Commodity Extra Multiplier $__________

EQUIPMENT EXTRAS

Two-Way Radios @ $30/tractor $__________

Less than 100 tonnes Special Trailers 35"-40" @ 10¢/Mile ea $__________

Less than 100 tonnes Low-Boy Trailers 6"-35" @ 15¢/Mile ea $__________

If lennth over 100', or if weight over 150 tonnes, extra driver and tractor @ $12 75/hour loaded. $__________

Special heavy lift trailers @ $2.00/tonne/day $__________

Return of tractor and any trailer @ 74c/Mile empty $__________

Over 3 hours, demurrage for trailers @ $7.00/hour $__________

Over 3 hours, demurrage for tractors @ $13.00/hou $__________

(Dunnage for securing not included.)

LABOR EXTRAS

If over 10 hours, extra driver @ higher 15¢/loaded mile or $15.00/hour $__________

If over 12' wide, escort car @ higher 66¢/loaded mile or $10.75/hour (minimum $50) $__________

If over 16' wide, Flagmen @ $5.50/hour (loaded & empty) = $__________

SERVICE EXTRAS

If cargo L 55' or W 10' or H 15' above ground Special Permits @ $18/state = $__________

If call at marine terminal, charge @ $4.40/MT = $__________

If value $5,500 per metric tonne, insurance at 50¢/$1,000 over = $__________

If height or width 20', surveying route @ $1.70/mile = $__________

(Raising telephone & power lines not included)

TOTAL EQUIPMENT, LABOR, AND SERVICE EXTRAS = $__________

TOTAL UNIT TRANSPORT BILL = $__________

SOURCE: Lykes Bros. Steamship Company

TABLE 6-56. Components that Union Mechling Transport by Barge

	BABCOCK & WILCOX	WESTINGHOUSE	COMBUSTION ENGINEERING	GENERAL ELECTRIC (CHICAGO BRIDGE IRON)
Reactor pressure vessel	400 tons	400 tons	530 tons)	1100 tons
Steam generator	400	400	800)	
Stators	400	400	400	400
Transformers	400	400	400	400
Closure heads	100	100	100	100

At the present time, there are only five heavy lift barges with deck load capacities of 1200 tons operating on the inland waterways of the United States. This is due to the limited and specialized market opportunities for these barges and the large capital investment required to construct them. Due to these facts, the rates charged by the heavy lift barge operators are at a premium compared to conventional barge transportation. Some typical rates for a total load of maximum 1200 tons from Memphis, Tenn. (the location of several nuclear components manufacturers) to various destinations are listed in Table 6-57.

TABLE 6-57. Typical Rates for Load of 1200 Tons From Memphis, Tennessee

DESTINATION	DISTANCE	COST
Port Gibson, Miss.	300 miles	$ 30,000
St. Francisville, La. (Baton Rouge)	500 miles	35,000
Salem, N.J.	800 miles	110,000
Richmond, Wash.	6200 miles	430,000

The latter is a move via the Panama Canal, and up to Astoria, Washington and further up the river.

The above charges normally include one day free time for loading and discharge which is performed by the shippers and consignees or by a rigger for the account of the shipper and consignee. Beyond this one day free time, demurrage charges of $20 per hour for the barge and $120 per hour for the tug is assessed for each running hour, day, and night that the barge is retained.

The charter agreement between the barge operator and the shipper requires the shipper to provide a "safe harbor and berth" for the barge. Most manufacturers have good berths at their plants. In many cases, the shipper or consignee is required to construct a barge landing or berth to unload the components at the destination. The cost of such barge landings vary considerably by the conditions at each site. Typical costs range from $100,000 to $500,000 and average $250,000.

(b) Application 2: Components for Nuclear Power Station

A total of seven components for the North Anna Power Station, Units 1 and 2, a nuclear power station of Virginia Electric and Power Company at North Anna, Virginia had to be offloaded from a barge and transported 65 miles over the road to the site. The distribution and numbers of the weights of these components were:

- 3 components each 65 tons
- 2 components each 300 tons
- 2 components each 168 tons.

Each of these components had to be offloaded at a barge dock at Walkerton, Virginia designed and constructed by the hauler/rigger, Williams Crane & Rigging Company of Richmond, Virginia. Along the 65 mile route Williams had to build a 120 ft. bridge with a capacity of 600 tons, construct a half mile bypass around a railroad bridge and several facilities to be used as overnight stopping places. Each component required four days to transport with special transporters and a total manpower input of 15 men were required. Additional numerous hours were required for survey work, construction and loading and unloading. The contract cost for this project was $565,000.

(c) Application 3: Components for Nuclear Power Station

This project involved components for the North Anna Power Station, Units 3 and 4. A total of four components had to be shipped the 65 miles over the route described above. The weights of the four components were:

- 2 components each 344 tons
- 2 components each 140 tons.

Each component required a workforce of 17 men equipped with specialized transporters a total of 3 days to transport from the barge unloading to the power plant site. The total cost for the hauling job performed by Williams Crane and Rigging Company was $438,000.

(d) Application 4: LNG Deck Houses

As part of the construction of three LNG tankers at the Newport News Shipbuilding and Dry Dock Company, the construction of the deckhouses were subcontracted to an outside company. These deckhouses were constructed by Carteret Manufacturing Company of Carteret, North Carolina. The dimensions of the deckhouses were 135 ft. long, 56 ft. 3 inches wide and 62 ft. 11 inches high, and each weighed 760 tons. Williams Crane & Rigging Company moved these deckhouses from storage, loaded each on a barge and arranged for transportation and the unloading at Newport News. These deckhouses were transported complete with all fixtures and equipment in place. The total job cost was $320,000.

(e) Application 5: Relocation of Deck Crane

A large crane weighing 660 tons had to be relocated one-half mile within the Newport News Shipbuilding & Drydock Company yard. This job took 14 days to complete and required a workforce of 12 men. The total cost for the job, which was performed by Williams Crane and Rigging Company, was $93,000.

(f) Application 6: Nuclear Reactor Vessel Transportation in Europe

A manufacturer of nuclear generating plant components in France has a number of requirements for heavy lift transportation to European and overseas destinations every year. The logistics of moving a 310-ton pressure vessel from Le Creusot to Fessenheim is detailed below. The dimensions are 23 m long and 4.4 m in diameter.

At Le Creusot the reactor vessel was loaded onto a truck transporter to be moved 35 km to Chalon. This transporter had a load capacity of 600 tons, and it took one day to load and four days to transport. The cost of transportation to Chalon was FF 300,000 (U.S. $66,000).

At Chalon it was transferred to a barge for further transportation to Fos and loading onto ocean vessel. The total transfer time was one day and the transit time from Chalon to Fos was 14 days. Total cost of the barge transportation was FF 200,000 ($44,000).

In the port of Fos, the reactor vessel was again transferred to a ship which transported the reactor vessel from Fos through Rotterdam and up the Rhine to Ottmarsheim. At Ottmarsheim, hydraulic jacks were used to load the cargo onto the dock and from the dock to a truck trailer. This truck trailer transported the reactor vessel the 10 km to the plant in Fessenheim, where it was unloaded with a 400-ton gantry crane. Total transportation cost from Fos to Fessenheim was FF 1,000,000 (U.S. $220,000). The total transportation cost was therefore U.S. $320,000. It is estimated that the air distance between Le Creusot and Fessenheim is approximately 175 miles.

(g) Application 7: Refinery Vessel

A refinery component manufacturer is in the process of arranging for the transportation of a 370 ton refinery vessel from Minneapolis to a refinery located in Edmonton, Alberta. The manufacturer has been informed by the railroads serving the area that clearances prevent them from transporting the vessel.

The alternatives currently available to the manufacturer are to establish a plant in Alberta to manufacture the vessel or to contract a rigger/hauler to transport it over the highways. The first alternative requires major investments which the manufacturer is not willing to make at this time. The second alternative seems to be the alternative that will be selected.

The total highway distance between Minneapolis and Edmonton is 1500 miles and a number of obstacles in the form of narrow highways and bridges will have to be bypassed. It has been indicated by Williams Crane & Rigging that the total transportation job will cost close to $5 million for this one vessel. The route survey alone will cost in excess of $50,000.

6.14.2 Potential HLA Applications

It is apparent from the above cases the HLA cannot compete for the transportation of heavy and/or outsized cargoes in cases where sufficient waterway access is provided for ships or barges. Similarly, it is apparent that the HLA can only compete with rail and over the road transporters or trucks for the transportation of heavy and/or outsized components in cases where major obstacles or costly complications like strengthening or reconstruction of bridges, construction of bypass roads or rail lines, expansion or improvement of existing roads or rail lines, or even rearrangement of a town through which the load has to pass are necessary. In cases when railroads and over the road haulers are faced with such costly complicating factors which have to be calculated into the job cost, it is possible that an HLA can compete with the railroads and riggers/haulers.

6.14.2.1 Application 1: Transportation of Nuclear Components From Barge Landing. Nuclear power plants are encountering increasing regulatory constraints and opposition from environmentalists. For these reasons these plants often have to be located at sites away from easy access of existing raillines and waterways. The road infrastructure is frequently poor and require upgrading or bypasses for riggers/haulers to transport components from railheads or barge landings to the site often requiring costly upgrading, bypasses and bridge reconstruction to accomplish the task. The HLA can therefore possibly compete with conventional trailers or transporters to carry loads between railheads or barge landings and the construction site.

(1) Scenario

The scenario is identical to that described in Section 6.14.1.3,(4), Applications 2 and 3, above.

(2) Assumptions

It is assumed that all required rigging both at the origin and the destination will be performed by a rigging company or manpower provided by the construction company. The manpower required for the rigging job and the cost of this manpower is assumed to be 17 men for four full days at a cost of $200 per manday for each component to be hauled. The total cost for each component will therefore be $13,600. In addition, the following assumptions are made:

- All preparations and rigging for transportation of the components have been made both at the barge and at the construction site. The HLA will therefore experience minimal hovering time while loading and discharging the load.
- The HLA has received the approval of the nuclear regulatory agencies to transport components for nuclear power plants.

(3) Potential Cost Savings with HLA

No savings beyond those already included in the cost of current operations for bridge reconstruction and road upgrading are expected.

(4) HLA Threshold Cost

The threshold cost in this case will be the cost of the current operations minus the manpower cost required for the rigging. For units 1 and 2 of North Anna power station current cost of hauling 7 components is $565,000, while the cost of hauling 4 components for units 3 and 4 for the same power station complex is $438,000. The total cost for 11 components is therefore $1,003,000. To arrive at the threshold cost, however, we have to subtract the cost of the manpower for the rigging operation. This cost is estimated to be $13,600 per component or $149,600 for all 11 components. The threshold cost is therefore $853,400 or an average of $77,600 for each component.

(5) Potential HLA Operating Scenario

It is estimated that each component will require a total of two hours hovering time at the origin and destination to lift and emplace each component. Transportation time for the 130-mile round trip distance is expected to be 2 to 2.5 hours. Each component will therefore require 4 to 4.5 hours of the HLA time, in addition to the time required to ferry to and from the site. The number of individual trips will depend upon the scheduling of the arrival of the components by barge or rail.

6.14.2.2 Application 2: Rigging and Short Haul of Very Large and Oversized Components. The rigging, hauling, and emplacing of very large and heavy components under difficult circumstances is time consuming and costly. In such complicated situations it is possible that the HLA which can avoid obstructions faced by ground based systems, can be competitive.

(1) Scenario

The scenario is identical to those described in Section 6.14.1.3,(4), Applications 4 and 5.

(2) Assumptions

It is assumed that a total of 11 men will be required for four full days to rig each component to be lifted. The cost is assumed to be $200 per manday for a total of $8800 for each component.

It is further assumed that all rigging is performed prior to the arrival of the HLA so that the hovering time required for hook-up and emplacement will be minimal.

Finally it is assumed that the lifts of the four components, i.e., three deckhouses for LNG carriers each weighing 761 tons and one CMI Whirley crane, weighing 660 tons are to be performed at four different time intervals.

(3) Potential Cost Savings With HLA

It is expected that no cost savings can be derived from the use of the HLA.

(4) HLA Threshold Cost

The threshold cost in this case will be the cost of the current operation minus the cost of the rigging required prior to the arrival of the HLA. The cost of moving the three deckhouses is $320,000 for all three or an average of $107,000 for each. The expected rigging cost for each is $8800. The threshold cost for each deckhouse will therefore be $98,200.

The current cost of moving the crane is $93,000. The rigging cost for this crane is also estimated to be $8800. The HLA threshold cost for the crane is therefore $84,200.

(5) Potential HLA Operating Scenario

The distance between the hook-up and emplacement is minimal and the time required for hauling is expected to be small. The total time required for the HLA to lift each component is two hours. In addition ferry time to and from the site between the lifting of each component will be required.

6.14.2.3 Application 3: Hauling of Components That Require Long Deviations by Conventional Means of Transportation. In some cases heavy and outsized cargoes have to be transported over long and circuitous routes with several transshipments because of limitations on the transportation infrastructure or the modes of transportation serving the area. The cost of such circuitous transportation can be substantial. It is possible that an HLA which can bypass the obstructions facing overland modes and can transport cargoes on a direct air route, could be competitive in these situations. One such situation is presented with the logistics problem of transporting a 310-ton nuclear reactor vessel from Le Creusot to Fessenheim near the Swiss/German border in France.

(1) Scenario

The scenario is identical to that described in Section 6.14.1.3,(4), Application 6.

(2) Assumptions

Although this case describes the transportation of a nuclear component in France, it is assumed that the cost of French labor and the manpower requirements to perform the rigging will be similar to that experienced in the United States. All assumptions for this case will therefore be identical to those outlined in application 1: Transportation of nuclear components from barge landing.

(3) Potential Cost Savings with HLA

The primary cost saving that can potentially be obtained with the HLA results from reducing the time in transit of the component from more than three weeks to a few days. The cost of the component and the terms of its contract with respect to payment are not known. For these reasons no attempt has been made to calculate the financial cost savings to the project by enabling a shortening of the time in transit.

(4) HLA Threshold Cost

The total cost of existing modes of transportation was $320,000 delivered at the destination. The total cost of the manpower required to rig the nuclear reactor vessel both at the origin and destination is estimated at $13,800. The HLA threshold cost is therefore $306,200.

(5) Potential Operating Scenario of an HLA

The total hovering time required at the origin and destination is estimated to be 2 hours. The total air route distance between Le Creusot and Fessenheim is approximately 175 miles. The round trip transportation time for the HLA should be 4 hours and 22 minutes at an average cruising speed of 80 miles per hour, while at 40 mph, it should take 8 hours and 44 minutes.

6.14.2.4 Application 4: Transportation of Large Components Over Long Distances. In situations where neither rail nor barge transportation is available to transport large and outsize components over long distances, and where the overland route by truck is faced with major obstacles the HLA may present an alternate solution. One such situation is presented with the case of transporting a 370-ton refinery vessel from Minneapolis to Edmonton, Alberta, Canada.

(1) Scenario

The scenario is identical to that described in Section 6.14.1.3,(4), Application 7.

(2) Assumptions

It is assumed that it will require a crew of 12 men for the rigging to prepare for the HLA and to rig for the erection at the site. The crew will consist of:

- 10 ironworkers
- 1 crane/rig operator
- 1 oiler.

The average cost per man is $200 per day. The total job will require four full days of rigging at a total cost of $9600.

All work will be scheduled so that the HLA can pick up and erect the refinery reactor vessel without delay or waiting time at origin and destination.

It is finally assumed that refueling can be performed at regular intervals on the journey without major route deviations and delays.

(3) Potential Cost Savings with HLA

The major potential cost saving that can be achieved with the HLA is the reduction in transit time. This transit time saving may involve a substantial financial saving to the project. No attempt has been made to quantify these savings, since no cost data for the refinery vessel is available.

(4) HLA Threshold Cost

The cost of transporting the vessel on transporters over the road including costs of bridge strengthening, road improvements, permits, etc. has been estimated at $5 million. The rigging cost with the HLA will be $9800. The HLA threshold cost will therefore be slightly below the $5 million estimated cost of over the road transportation by truck transporter.

(5) Potential Operating Scenario with HLA

It is estimated that the hovering required at the origin for hook-up and at the destination for erection will not exceed 2 hours. In addition, the HLA will carry the load for 1500 miles and possibly have to deadhead back 1500 miles to the origin unless it will be possible to cluster other jobs close by the destination.

6.14.3 Estimate of HLA Needed to Satisfy the Potential Market

This estimate is divided among a variety of different transportation and rigging tasks (in addition to those already covered in the electric power generation, strip mining and refinery case studies). Two payload sizes, 500 ton and 800 ton, are selected to encompass the range of transport and rigging alternatives.

6.14.3.1 The Annual Market. From Section 5, the annual market is summarized as 900 to 1800 heavy lifts per year. This market is assumed to be divided equally among the 17 lifts in the 4 applications described in 6.14.2, involving payloads from 65 tons to 761 tons.

6.14.3.2 The Required HLA Capabilities. Typical operating times for the four applications are as shown in Table 6-58.

TABLE 6-58. Typical Operating Times for Transportation Applications

APPLICATION	NO. OF LIFTS	PAYLOAD (TONS)	AV. HLA SPEED (MPH)	25			60		
1	7*	500	TOTAL TRANSPORT DISTANCE (ELEVEN ROUND TRIPS) (MILES)	250	500	750	250	500	750
			OPERATING TIME (INCL. 2 HRS HOVER PER ROUND TRIP) (HOURS)	24	34	44	18.2		
2	4	800	HOVER TIME (FOUR ROUND TRIPS) (HOURS)	8			8		
3	1	500	TOTAL TRANSPORT DISTANCE (MILES)	90	180	270	90	180	270
			OPERATING TIME (INCL. 2 HRS HOVER PER ROUND TRIP) (HOURS)	6.6	9.2	12.8	3.5	5	6.5
4	1	500	TOTAL TRANSPORT DISTANCE (MILES)	750	1600	2250	750	1500	2250
			OPERATING TIME (INCL. 2 HRS HOVER PER ROUND TRIP) (HOURS)	32	62	92	14.6	27	39.5

* THE 11 LIFTS OF APPLICATION 1 ARE AGGREGATED TO 7 LIFTS TO TAKE ADVANTAGE OF THE ASSUMED 500T PAYLOAD CAPACITY.

6.14.3.3 "No-Ferry" Number of Vehicles, $\bar{N}_{V_{NF}}$. The total number of vehicles to satisfy 100 percent of the market in each application is given by

$$\frac{(\text{Annual Lifts})(\text{Operating Hours per Lift})}{(\text{Annual Utilization})}$$

This is given in Table 6-59 for each payload size.

TABLE 6-59. No-Ferry Number of Vehicles to Satisfy 100% of the Transportation Market

AVERAGE HLA SPEED (MPH)								25			25		
						*DISTANCE (%)		50	100	150	50	100	150
$\bar{N}_{VNF}$	APPLICATION	1 + 3 + 4	PAYLOAD (TONS)	500	UTILIZATION (HOURS)	1000	MIN.	5	8	11	3	4	5
							MAX.	9	15	21	5	8	10
						2000	MIN.	3	4	6	2	2	3
							MAX.	5	8	11	3	4	5
		2		800		1000	MIN.	1			1		
							MAX.	1			1		
						2000	MIN.	1			1		
							MAX.	1			1		

* % Of Distance in Previous Table

6.14.3.4 <u>"No-Ferry" Share of the Market</u>, M_{NF}. From the case study, the threshold costs for these applications are:

- Application 1: $853,400 for eleven components (seven 500 ton HLA lifts)
- Application 2: $378,800 for four components (four 800 ton HLA lifts)
- Application 3: $306,200 for one component (a 500 ton HLA lift)
- Application 4: $5M for one component (a 500 ton HLA lift)

The average HLA costs for these lifts are given in Table 6-60.

The market share parameters for this case are A=27.5, B=55. This means that for no market capture

$$\frac{\text{HLA cost}}{\text{Threshold cost}} \geqslant .725,$$ while for 100% market capture,

$$\frac{\text{HLA cost}}{\text{Threshold cost}} \leqslant .45.$$ Thus the market share is as given in Table 6-61.

TABLE 6-60. Average HLA Job Costs for Transportation Applications

APPLICATION	NO. OF LIFTS	PAYLOAD (TONS)	AV. HLA SPEED (MPH)	25			60		
1	7	500	TOTAL TRANSPORT TIME (HOURS TOTAL HOVER TIME (HOURS)	10 14	20 14	30 14	4.17 14	8.33 14	12.5 14
			HLA JOB COST ($M)	.52	.73	.94	41	.49	58
2	4	800	TOTAL HOVER TIME (HOURS)	8			8		
			HLA JOB COST ($M)	.35			.35		
3	1	500	TOTAL TRANSPORT TIME (HOURS)	3.6	7.2	10.8	1.5	3.0	4.5
			TOTAL HOVER TIME (HOURS)	2	2	2	2	2	2
			HLA JOB COST ($M)	.12	.19	.27	.07	11	.14
4	1	500	TOTAL TRANSPORT TIME (HOURS)	30	60	90	12.5	25	37.5
			TOTAL HOVER TIME (HOURS)	2	2	2	2	2	2
			HLA JOB COST ($M)	.67	1.29	1.91	31	.56	.82

TABLE 6-61. "No-Ferry" HLA Share of Transportation Market

APPLICATION	PAYLOAD (TONS)		25			60		
1	500	M_{NF} %	42	0	0	89	55	16
2	800		0			0		
3	500		100	38	0	100	100	100
4	500		100	100	100	100	100	100

6.14.3.5 "No-Ferry" Number of Vehicles to Satisfy the Market Share, $N_{V_{NF}}$. From Tables 6-59 and 6-61, the total number of vehicles required to satisfy the market share is given in Table 6-62

TABLE 6-62. "No-Ferry" Number of Vehicles to Satisfy the Market Share

AVERAGE HLA SPEED (MPH)								25			60		
$N_{V_{NF}}$	APPLICATION	1 + 3 + 4	PAYLOAD (HOURS)	500	UTILIZATION (HOURS)	DISTANCE (%)		50	100	150	50	100	150
						1000	MIN.	4	5	7	3	4	5
							MAX.	7	10	13	5	7	10
						2000	MIN.	3	3	4	2	2	3
							MAX.	4	5	7	3	4	5
		2		800				0					

6.14.3.6 Effect of Ferry on the Number of Vehicles. By inspection of the operating times, the threshold costs, the ferry costs, and the relationship in Section 6.3.3, it is evident that in all applications except Application 4, the number of vehicles will be somewhat less than the "no-ferry" estimate, while in Application 4 there would be a slight increase. Thus overall there should be no significant change from the results in Table 6-62.

From the cases just developed, median values of the number of HLA required, assuming "no-ferry", are given in Tables 6-63 and 6-64 for speeds of 25 and 60 mph, respectively, and annual utilizations of 1000 to 2000 hours.

TABLE 6-63. Number of 25 mph HLA That Would Satisfy the Worldwide Heavy Lift Market

NUMBER OF VEHICLES ~ UTILIZATION (HOURS)

1000
2000

CASE STUDY \ PAYLOAD (TONS)		7 TO 15	25 TO 30	75	150	200 TO 300	500	800	NA%
1. Refinery & Petro Chemical Plants									20
2. Offshore Oil/Gas Drill Rigs							0 2		50
3. Strip Mining Power Shovels						1			50
4. Power Transmission Lines			22 12						30
5. Power Generating Plants					1	19 10		1	45
6. Gas or Oil Pipelines				3					40
7. High Rise Construction		1	2						100
8. Remote Drilling Sites			11 6						35
9. Logging		7460 3730 or	4480 2240 or	1500 750					10
10. Port Congestion			75 37 or	26 13					0
11. Transportation							10 5		30
TOTALS Utilization (hours)	1000	7461 or	4590 or	1529	1	20	10	1	
	2000	3731 or	2295 or	766	1	11	7	1	

TABLE 6-64. Number of 60 mph HLA That Would Satisfy the Worldwide Heavy Lift Market

NUMBER OF VEHICLES ~ UTILIZATION (HOURS)

1000
2000

CASE STUDY \ PAYLOAD (TONS)	7 TO 15	25 TO 30	75	150	200 TO 300	500	800	NA%
1. Refinery & Petro Chemical Plants								20
2. Offshore Oil/Gas Drill Rigs						3 2		50
3. Strip Mining Power Shovels					1			50
4. Power Transmission Lines		17 9						30
5. Power Generating Plants				1	9 5		1	45
6. Gas or Oil Pipelines			4					40
7. High Rise Construction	1	2						100
8. Remote Drilling Sites		6 3						35
9. Logging	6000 3000	or 3600 or 1800	or 1200 or 600					10
10. Port Congestion		54 27	or 20 or 10					0
11. Transportation						7 4		30
TOTALS Utilization (hours) 1000	6001	or 3679	or 1224	1	10	10	1	–
TOTALS Utilization (hours) 2000	3001	or 1841	or 614	1	6	6	1	

6.15 Summary of the Number of HLA Required to Satisfy the Worldwide Heavy Lift Market

6.15.1 The Effect of Utilization. Note that decreasing annual utilization per vehicle brings about an increase in the HLA job cost of roughly 40 percent (due to a direct increase in the prorated annual fixed cost), which causes the market share to decrease for those applications in which the threshold cost is too close to the HLA job cost. Thus, for these applications, the tendency for an increase in HLAs needed as a result of the reduction in operating hours per vehicle, is offset by the reduction in the HLA share of the market.

6.15.2 The Effect of Annual Ferry Time. Where the calculations indicated that only a small number of vehicles was involved, the effect of ferry time was not calculated because its effect would not significantly alter the overall result.

On the other hand, where the numbers are significant, the effect was calculated, as reported in sections 6.7.3.5, 6.8.3.6, 6.11.3.5, 6.12.3.6, 6.13.3.5, and 6.14.3.6. Study of these results and Figures 6-1 and 6-2 shows that the effect of ferry can vary widely from application to application, but generally falls between 0.5 and 1.5 times the "no-ferry" value, with the greater likelihood being for an increase in number of vehicles.

REVIEW OF OTHER INFLUENCES ON HLA SELECTION

CHAPTER 7

7. REVIEW OF OTHER INFLUENCES ON HLA SELECTION

LIST OF TABLES

7. REVIEW OF OTHER INFLUENCES ON HLA SELECTION

7.1 Introduction

In the previous sections, operational and cost characteristics have been developed to describe the use of HLAs in a wide range of potential markets, and to develop estimates of the size and number of HLAs that could satisfy each market in the face of current and potential competition.

In this section, the following influences on the desirable characteristics of HLA for these markets are discussed:

- A set of operational requirements for acceptable use of any free-flying vehicle
- Characteristics that can enable the HLA to be more profitable
- Aspects of HLA design that can be chosen to improve its profitability in each application
- Military compatibility with civil market selection
- Point design changes to improve HLA utility
- An approach to entry into service.

This section concludes with a summary of pertinent study results for each application.

7.1.1 Operational Requirements Derived for Each Application

Implicit in the definition of each market application are a set of operational requirements that should be satisfied for acceptable use of any free-flying vehicle. Briefly, the more significant requirements deal with

- The need to emplace some very large components with considerable precision, and/or very low relative velocities to avoid damage
- The need for operations at altitude is a second serious consideration for some application
- The need to reach currently inaccessible forests, and heavy lift needs in exploring for other resources such

as gas, oil and minerals, may require occasional HLA operations at altitudes up to 12,000 feet

- The need to maintain high productivity for repetitive tasks in particular, and to keep HLA job time to a minimum on many tasks, means that the effects of weather, terrain, or darkness must be minimized.

The variation of such operational requirements across the study applications are described below with particularly important features emphasized:

Altitude. From sea level to 5,000 feet will satisfy more than 80 percent of the logging opportunities in the U.S., although some treelines are as high as 7,000 feet in Oregon to 12,000 feet in California. This range applies essentially to all other applications, with extensions of 6,000 to 7,000 feet for construction and transportation in industrial areas.

Temperature. Below freezing (winter logging provides improved power plant performance at lower temperatures) to above 120° F.

Elevation Change per Cycle. The most severe case is likely to be logging with slopes up to 1:1, probably on the order of 1:3 to 1:5. The elevation change may be up to 3,000 to 4,000 feet per turn.

Wind Conditions. Horizontal and vertical gusts, and steady winds up to about 30 mph, occasional horizontal gusts and winds up to 70 mph to 100 mph, particularly in coastal and mid-plains areas.

Safety Considerations. From applications in logging, tower erection, remote drill rig construction, pipeline construction, strip mining, refining construction and transportation, the major safety considerations involve:

- Static changes in the tagline
- Load gyrations at lift-off
- Multiple engine operations
- Load release system
- Cable snapback
- Pilot fatigue
- Ground crew clearance
- Rotor hp clearance on hills.

In congested port activities, the following is added

- Limited room on ship or deck to avoid swinging load.

In high rise construction, generator plant construction, and offshore oil and gas, add further,

- Rigging crew safety on top of structures.

Load Pickup Precision. Applications including logging, transmission towers, remote drill rigs, high rise construction, pipeline construction, require

- Control of the pickup assembly to within about ±5 feet
- Time for the "hooker" or loader to clear the area after hookup.

In congested port operations, communication between the HLA operator and the cargo handlers on the moving ship is essential to prevent impact between the cargo and the ship structure; special fittings or cable winches may be required to provide some guidance and restraint as the cargo is lifted from the hatches or decks. This task is simplified if the HLA can be held virtually stationary through precision hover techniques.

For operations involving transportation, lifting and positioning of very large, very costly components, whose inertia and weight are such that even low impact velosities can cause unacceptable damage (power plant, ship mining, refinery component, and offshore oil and gas components), continuous control of position to within a very few inches may be necessary to prevent development of a swinging load. In some cases, it may be important while erecting a large component to raise one end slightly and support it off the ground with conventional rigging techniques, while the HLA raises the other end to the vertical position, so that the concentrated ground contact load cannot cause component damage.

Unload/Placement Considerations. For logging, remote drilling components, and unloading onto congested port docks,

- Positioning to within about 5 feet for logs, less for fabricated components and cargoes
- Descent rate not more than about 5 feet per second for logs, less for fabricated components and cargoes
- Altitude hold to within about 5 feet
- Ground handlers are needed (part of the user's work force).

For transmission towers, high rise construction, pipeline construction, and transportation of non-damage sensitive components

- Positioning to within about 1 foot
- Altitude hold to within about 1 foot
- Ground handlers (riggers) will guide the components into position, to line up attachments in direct coordination with the pilot
- The final position and altitude accuracy requirements can be eased with the use of guide rail attachments.

For heavy components requiring extreme care and precision (power plant, ship mining, refinery, offshore oil and gas and others involving damage-sensitive components)

- Positioning to within a few inches to line up attachments and minimize possible inertia effects
- Descent rate accurately controlled at a few inches per second to minimize impact damages
- Ultimate control should be by the rigging crew on the ground using lines and winches.

Logistics Considerations. In general, the HLA should be at the site when needed, otherwise costly delays can be incurred, reducing the HLAs attractiveness to the user.

Load Considerations. For situations involving relatively small lifts, frequently or regularly repeated (logging, congested port containers, remote drilling components, high rise construction and pipeline construction), development of load aggregations will permit use of larger HLAs with greater fuel economy, less total time spent on the job, and probably lower overall job costs. The larger HLA can also be ferried longer distances without refueling.

All heavy lifts present a problem of bulk as well as weight and inertia, which adds considerable drag to the basic vehicle, and drives the optimum operating speed down from that of the clean vehicle to that of the vehicle with external or faired payload stowage.

Other Environmental Considerations. In most heavy lift applications, delays in completing the jobs to the schedule required by the user can be very detrimental to the profitability of the operation. Thus a basic set of operational requirements relates to being able to perform better than the competition in bad weather conditions, on or over rough terrain or water, and in bad visibility, day or night. Typical difficulties faced by the competition are as follows:

- Helicopters are very sensitive to temperature-altitude variations, icing conditions, gusty weather and poor visibility
- Ground transport is heavily affected by rain, snow and ice on the ground, and the nature and condition of the surface
- Water transport is heavily affected by ice, rough water, and winds
- All forms suffer from heavy precipitation of any kind.

7.1.2 Factors that Enhance HLA Chances for Success

In each application, there are scenarios which favor the employment of HLAs, and which result in a greater savings relative to its competition, thus increasing its chances for success. Similarly, in some applications, where threshold costs and HLA cost appear to be close or overlapping, there are clear reasons to reduce HLA job cost, through selection of favorable design and operational characteristics.

The scenario features that enhance HLA chances for success are peculiar to each application, with some commonality, as outlined below:

Logging. To enhance HLA success, it is desirable to

- Compete for jobs normally involving either the most costly conventional ground systems, or the helicopter
- Reduce the cost of the ground crew as much as possible
- Compete for jobs where the operating time can be minimized (the lowest aggregate yarding distance and turnaround time)

- Carry the largest payload per cycle compatible with field aggregation capacity
- Optimize the portion logged by the HLA in each job
- Minimize the time spent in refueling, services and resupplying the HLA.

Port Congestion. Enhanced HLA chances for success result from:

- Competition for the most costly container ship
- Competition against the most costly conventional system with the slowest transit speed and turnaround time, the smallest number of containers per round trip, over the longest ship-to-shore distance.

Transmission Towers. The HLA chances are already radically improved compared to conventional ground-borne systems; success against current helicopters (including the S64 series) is assured if the HLA payload permits carrying each tower in a single trip.

Remote Drill Rigs. A significant success potential exists from direct substitution, and is enhanced by increasing the payload per round trip and the distance per round trip.

High Rise Construction. In this market there are situations where the units to be emplaced are small enough to be handled efficiently by current helicopters. However, since lifting capacity, rather than speed, is important over the short distances involved, the HLA should become successful in the right size even though somewhat slower. For crane dismantling, an optimum HLA size may be reached from trading off hover time per segment with payload size per segment.

Pipeline Construction. Virtually all opportunities that arise in this activity offer assured HLA success against either conventional or helicopter operations.

Power Generation Plant Construction. HLA success depends largely on the balance between threshold and job costs, and both increase with plant size. This balance can be altered to favor the HLA through varying HLA characteristics and techniques of employment. For example, reduction of module hookup time, and use of fewer, larger modules fully utilizing the HLA payload.

Strip Mining. Conventional techniques in this case are extremely low cost to begin with, offering the best HLA opportunities at short transit distances; thus a base situated near a strip mining area might be a worthwhile strategy.

Refinery Construction. This application is similar to the power generation plant case, but the conventional costs are lower; thus the HLA has less opportunity to share in the market.

Offshore Oil and Gas Rigs. The greatest chance of HLA success comes from situations where HLA use permits the largest reduction in lifting equipment costs.

General Heavy Lift Transportation. In all except the long distance situation, where much roadbuilding cost and time was saved by the HLA, generalized opportunities for enhanced HLA success are not possible to assess.

The operational design features of the HLA that enhance its chances for success also depend significantly on applications, and are outlined below:

Logging. Design for maximum practical payload, probably about 75 tons; design for the most economical combination of cruise speed and acceleration to reduce cycle time; design for efficient ferry.

Port Congestion. This is similar to logging except that a different size might be optimum. However, 75 tons appears to be a very practical choice.

Transmission Towers. The HLA payload capacity must be sufficient to carry a complete tower. If not, then its operational costs must be less than those of the helicopter, to offset the probable higher helicopter productivity.

Remote Drill Rig. In this application there is some indication that maximum productivity is achieved around 50 tons to 100 tons payload, as increasing payload size and decreasing project time offset each other. The HLA may not match the helicopter speed, but its payload capacity substantially compensates for any lack.

High Rise Construction. To rapidly take advantage of opportunities as they arise, payload size, efficient hover and efficient ferry are the most critical considerations.

Pipeline Construction. The characteristics defined in the case study analysis appear to be satisfactory.

Power Generation Plant Construction. Onsite transport and placement of structural modules is the only critical activity; success depends on reducing hover costs by closely matching module size and vehicle capacity.

Strip Mining. Design for low first costs through simplicity, with economy in hover and forward flight.

Refinery Construction. Design for optimum economy in lifting and ferry; this may result through reduced hover time if positioning accuracy is achieved.

Offshore Oil and Gas Rigs. Design for reliable operation in windy weather, so as to operate when sea states would prevent large operation; design for efficient ferry.

General Heavy Lift Transportation. Design simplicity, and economy in hover and ferry, are necessary features for this application, but need less emphasis for the long range transport opportunity.

The following non-operational HLA design features can enhance HLA chances for success in all applications:

- Design for austere support facilities
- Design for minimum fuel cost per hour
- Reduction of development and production costs
- Reduction of maintenance requirements per flying hour
- Selection of most favorable financing terms
- Development of a market position maximizing the production quality of any given size, and maximizing the interchangeability of components or subsystems between sizes
- Marketing to develop the fullest annual utilization for each HLA in service.

7.1.3 Institutional Implications

Successful operation of HLAs in real life situations requires that the interests and concerns of many institutional parties, in addition to the user, operator and manufacturer, be recognized in the design and development process. These institutional influences are summarized in Table 7-1.

7.1.4 Military Compatibility

The potential for military applications exists whenever heavy lifts have to take place. There are two general areas of application—peacetime equivalents to the civil applications already discussed; and wartime lifts of weapons and equipment over short distances as in amphibious operations. A study by Delex* (Reference 11) of Navy ship-to-shore container transfer identified and compared the characteristics of current or projected surface transfer systems; HLA capabilities would compete satisfactorily with any of the surface systems as shown in Table 7-2. The Delex study reflects tentative requirements defined in a Navy Development Concept Paper for Container Offloading and Transfer System (COTS). The current status of these requirements is open to question; they do not, in general, appear to present a difficult design problem for HLAs, except for the requirement to operate in winds, precipitation, and temperatures likely to be experienced in stormy weather. The payload size requirements are compatible with several of the market candidates reviewed earlier, and provided the HLA can achieve an average one-way, two-mile trip time of better than seven minutes, it will be competitive with the best current capabilities. To do this, an aggregate payload of at least three containers appears necessary, driving a Navy HLA to at least 75 ton payload size.

7.1.5 Design Point Changes

The overall marketability of the currently proposed Goodyear HLAs could possibly be improved by changes to the design conditions. A proposed set of such changes is outlined and explained in Table 7-3.

7.1.6 HLA Entry into Service

A possible approach to introducing the HLA into service is outlined in Table 7-4, which would expose the HLAs to as wide a range of potential applications as possible, while developing an operational data base in the most promising area of application. Selection of a demonstration logging locale is desirable near other potential applications. Two demonstration vehicles may be required, one to acquire an operational data base in logging, while the other operates part time in logging applications and

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* The Potential of Air Systems in Short Haul, Heavy Lift Applications, Delex Control No. D76-6745-I, 19 October 1976.

TABLE 7-1. Institutional Influences on the HLA

IMPLICATIONS OF	RESTRICTIVE MEASURES	INSTITUTIONAL INVOLVEMENT	
		NON-FED	FED
DESIGN CRITERIA	Application of a body of conservative design rules		FAA
MISSION REQUIREMENTS	Application of a multitude of operational requirements	• User Industries	FAA
CERTIFICATION	Development, test, and flight certification		FAA
SAFETY	Vehicle safety, flight corridors, Ground personnel safety } initially severe	• Citizen Groups	FAA NTSB OSHA
ENVIRONMENTAL REQUIREMENTS	Noise, Pollution standards for aircraft, applied to HLA	• Citizen Groups • State/Local Govt.	EPA OSHA
RATE STRUCTURES	Regulations to limit monopoly	• Competitive System Operators	CAB ICC
INSURANCE	Conservative rates for an unproven technology	• State/Local Govt. • Insur. Ind.	
MODAL INTERFACES	Labor agreements in handling cargo	• Union	
	Non-compatible rate regulations and/or interchange agreements		FMC
FINANCING	Conservative conditions, capital hard to acquire	• Financial Institutions	SEC

TABLE 7-2. Military Compatibility

- Task: Navy Container Offloading and Transfer
- HLA Matches These Requirements and is Competitive with the Best Current Conventional Systems
- If
  - HLA Carries Aggregate Payload or at Least 3 Full Containers
  - Makes an Average one-way, Two-Mile Trip in Less Than 7 Minutes
- A 75T Payload with a Cruise Speed of 25 to 30 MPH will Satisfy this Requirement
- But HLA Must Operate During
  - 30 KT Winds
  - Night, Day, Rain, Sleet, Snow
  - −28°C to +65°C

  And Must Survive
  - In 75 KT Winds
  - A Hurricane with 24 Hours Warning, Resume 48 Hours Later.

part time in the exploration of nearby additional market applications. Logging opportunities in the Pacific Northwest suggests the potential of a cooperative development effort on the part of the U.S. and Canadian Governments. Intra U.S. Government user interest could stem from NASA, the Departments of Defense, State, Interior, Transportation, and Commerce, the EPA and several other agencies. The alternative to Government sponsorship is, of course, the private venture; the responsiveness of the aerospace industry typically ensures a much more rapid entry into service. In either case the same general program features outlined should be applicable.

TABLE 7-3. Summary of Point Design Changes that Might Enhance the Next Generation HLA

	CURRENT	SUGGESTED CHANGE	REASON
MAXIMUM PAYLOAD -	75T (S.L., STD. Day, 100 Ft/Min ROC)	75T (8000 Ft, Hot day (100 Ft/Min ROC))	Logging, Other Lifts, in Remote Inland Regions
SPEED - MAX	60 KTS	> 75 KTS	Survival (Naval Requirement)
- CRUISE	–	> 50-60 KTS	Maintain Operation in Headwinds
RANGE - MAX. (W/MAX. P.L.)	> 100 Miles	–	–
PRECISION HOVER CAPABILITY -	Adequate to Perform Current Helicopter Vertical Lift Missions	Equal to Capability Offered by a Heavy Lift Crane of Same Capacity in Winds up to 30 KTS	Must Perform as Well as a Rigging Crane (with Rigging Crew Support in Both Cases)
ALTITUDE - BALLONET CEILING	8200 Feet	–	–
CROSSWINDS - MAX	30 KTS	–	–
AMBIENT TEMPERATURE -	–	– 28°C to 65°C	Military Application Requirement

TABLE 7-4. An Approach to Entry Into Service

START DATE*	PHASE
	DEVELOPMENT
0	– Determine Detailed Requirements of Military and Civilian Users (G)
6 to 9	– Develop Preliminary Design (G)
12 to 15	– Identify and Develop Long Lead Time High Risk Items (G)
Approx. 18	– Initiate Prototype Design and Development (G)
6 to 9	– Establish Dialogue between Fabricators and Users (I)
Approx. 42	– Test and Evaluate Prototype (G)
48 to 54	– Conduct Demonstrations (G and I)
	PROCUREMENT
18	– Develop Support Specifications (I)
18	– Establish Specifications for Production Vehicle ( )
Approx. 24	– Design (I)
30 to 33	– Manufacture (I)
42 to 45	– Production Test (I)
Approx. 33	– Establish Support Facilities (I)
45 to 50	– Deliver Production Vehicles (I)

* – Months from start of activity; G - Government Activity
I - Industry Activity

7.1.7 Discussion of Study Results

The validity of the approach used depends heavily on the accuracy of:

- The worldwide market assessment
- The share of each market that might accrue to the HLA (in turn depending on the "threshold" job cost and the HLA job cost)
- The rate of work achieved by each HLA size in a given application.

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The accuracy of the worldwide market assessment varies widely from application to application. It reflects in each case:

- Current experience and trends
- Uncertainties in areas where high growth potential exists but where ideology and environment offer restraints.

The assessment of the share of the market that might accrue to the HLA is an area of substantial uncertainty, because:

- It reflects the varying influence of economic and competitive forces
- It does not simulate a real life operator's decisions with respect to investment in current equipment
- It assumes all opportunities will be seized, and is therefore an over-estimate.

The HLA threshold cost estimates are uncertain, because:

- They vary from situation to situation, even though the case studies represent the best judgment of major users (thus, situations can be sought that enhance the HLA competitive ability through increased threshold costs).

HLA job cost estimates are, of course, just as critical as estimated threshold costs and at this stage of HLA development, probably just as uncertain because

- Variations in potential concepts will vary costs
- The potential for future refinement and optimization will change costs appreciably
- All the conventional aeronautical cost-reducing approaches apply to the HLA as it is developed
- In larger markets, HLA must succeed in direct competition on price
- The influence of basing and consequent ferry can markedly change the number of vehicles required, and consequently job cost.

Given that there is a market and that the HLA has the potential to share in it substantially, another very important element is the number of HLAs needed to absorb that share in the course of a year. This in turn is very dependent on the time that has to be spent traveling between jobs, which in turn depends on the concept adopted for providing permanent or temporary bases for HLAs. The subject is one that requires considerable examination since it impacts all major influences on potential HLA success, in addition to the number of HLAs, i.e.,

- The markets in which HLAs can compete
- The market share they can acquire
- The annual costs that must be prorated to each job
- The tradeoff between maintenance philosophy and operational costs.

The influence of varying utilization and vehicle quantities are identical to those for any other aeronautical system. Maximum production quantities and utilization are the goals to strive for. The estimates show that in several cases it is going to be difficult to operate a vehicle for the assumed utilization of 2000 hours. This is true mostly for the very large sizes; except for the largest sizes (750T - 900T) there is another application for each size that requires more than 2000 hours utilization, so that the same vehicle can be put to multiple uses. With respect to production quantities, the smaller sizes up through 150 tons require production quantities well in excess of the nominal 25 assumed in the cost analyses. Bigger sizes, however, require less than 25, with the consequence that their correspondingly increased job costs may drive them into a less competitive position, making sales harder, utilization more difficult to achieve, and possibly driving them out of the market.

One factor that has the potential for increasing production quantities is the extent to which the total market is distributed throughout the world. If individual segments of the market (each capable of supporting HLA operation) are separated by distances which preclude ferrying from one segment to another, the total number of vehicles required could be larger than if the entire market were located within a viable ferry range. Such isolated market segments may grow noticeably in areas of the world where an economical aerial vehicle is the only practical means of access particularly for applications such as mineral resource exploration, and even oil and gas exploration. These may become economic at altitudes and in terrain that had previously discouraged such attempts.

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DATA SOURCES

APPENDIX A

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DATA SOURCES

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DATA SOURCES

LITERATURE SURVEY

- Bibliographies from NTIS and Predicast
- LTA Symposia and Workshop Documents
- Documentation of HLA Studies by:
    - Aerocrane
    - Aerospatiale
    - All-American Engineering
    - Bell Aerospace
    - Boeing Vertol
    - Canadair
    - Goodyear Aerospace
    - Grumman Aerospace
    - Piasecki Aircraft
- Other Data Sources
    - Maritime Administration
    - Lykes Bros. Steamship Company
    - United States Navy
    - Miscellaneous Papers and Brochures

TRADE ASSOCIATIONS CONTACTED

- Aerospace Industries Association of America
- American Boiler Manufacturers Association
- American Petroleum Institute
- American Textile Machinery Association
- American Trucking Association
- American Waterways Operators
- Association of American Railroads
- Edison Institute
- Manufacturer Housing Institute
- Motor Vehicle Manufacturers Association
- National Association of Home Builders
- National Industrial Traffic League
- Rail Industry Clearance Association

GOVERNMENT AGENCIES CONTACTED

- National Aeronautics and Space Administration (NASA)
- United States Forest Service
- Federal Highway Administration
- Forest Engineering Research Institute of Canada
- Interstate Commerce Commission
- Bureau of Census
- Highway Research Board
- United States Navy
- American Railroad Association
- Maritime Administration
- Agency for International Development (AID)
- Alberta Ministry of Transportation
- Federal Railroad Administration
- Military Sea Lift Command

COMPANIES CONTACTED

- Potential HLA Manufacturers/Developers:
  - Aerocrane, Inc.
  - Bell Aerospace
  - Boeing Vertol
  - Canadair
  - Goodyear Aerospace
  - Grumman Aerospace
  - Piasecki Aircraft
  - Sikorsky Aircraft
- Heavy Lift Users:
  - American Metal Climax (AMAX)
  - Armco Steel Corp.
  - ASEA
  - Bechtel Corp., Power Division
  - Bechtel Corp., Refinery and Petrochemical Division
  - Brown & Root, Inc.
  - Combustion Engineering
  - Consolidated Gold Fields, Inc.
  - Fluor Corporation
  - Fluor Ocean Services
  - Gibraltar Industries, Inc.
  - Hanna Mining Company
  - Hoosier Engineering Company
  - Midland Constructors, Inc.

  - Parker Drilling Company
  - Tennessee Valley Authority
  - Wausau Homes, Inc.
  - Westinghouse

- Heavy Lift Operators:

  - Consolidated Rail Corporation
  - Evergreen Helicopters
  - Frank W. Hake, Inc.
  - Illinois Central Gulf Railroad
  - Lykes Bros. Steamship Company
  - Norton, Lilly & Co. (U.S. Agents for Jumbo Shipping)
  - Southern Railway
  - Williams Crane & Rigging
  - Union Mechling Corporation

SOURCES OF INTERNATIONAL MARKET INFORMATION CONTACTED

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- OECD Publications Office
- World Bank
- Experts in Foreign Market Area

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  - Dr. Peter Frank
  - Dr. Joseph Kaplan
  - Dr. Ira Sohn, NYU

CONSULTANTS CONTACTED

- Marketing Control, Inc.
- Commonwealth Associates
- Roy Jorgenson Associates, Inc.
- R. J. Hansen Associated, Inc.
- Development Alternatives, Inc.

EMBASSIES CONTACTED

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- German
- British

RAILROADS CONTACTED

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- Southern Railroad
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