MODE SELECTION FOR LOG TRANSPORTATION ON THE COASTAL WATER OF B.C. : A TRANSPORT - INVENTORY COST MODEL APPROACH

by

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ABSTRACT

Logging and sawmilling are the activities identified with B.C. and are integral parts of its economy. Forestries direct employment is about 72,000 and involves more than 6 billion dollars in economic activity. The annual log production from the coastal forest is about 31 million cubic metres. The mountainous nature of B.C.'s coast line makes the construction of continuous roads and railways difficult, if not impossible. Thus, water transport of logs is most popular way of transporting coastal logs from the logging areas to the consuming mills.

There are three principal methods of moving logs on water along the coast: flat raft, bundle boom, and log barge or log ship. Each mode has its own advantages and disadvantages. Flat rafts and bundle booms do not need high initial capital investment, but because of slow speed of travel and dependency on weather condition, time taken to cover the distances are very high and sometimes unpredictable. Whereas, a log barge or a log ship requires a high capital investment, but its speed is high and is almost independent of adverse weather conditions, thus, time of travel is low.

This study considers a simple problem of economic transport of logs from a single source (sorting yard) to a single destination (mill). The problem is named as a 'transport - inventory selection problem', which means the selection of the mode of transport from the available modes in order to minimize the sum of the yearly transportation and inventory costs. Depending on the availability of suitable data and capacities, five different modes of transport have been considered in this study. They are: flat raft, bundle boom, log barge of capacity 15,000 tons, log ships of capacities

10,000 and 15,000 tons.

The study shows that different modes give minimum total costs depending on their capacities, the distance between the source and the destination, and the type of log being transported.

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CHAPTER 1

INTRODUCTION

1.1. Log transportation along the coast of British Columbia

Logging and sawmilling are the activities identified with British Columbia and are integral parts of its heritage and economy. The forest industry has developed on the coast over one hundred and twenty years. Forestries present direct employment is about 72,000 and involves 6.3 billion dollars in economic activity.

British Columbia's forests can be divided into two broad categories, coastal and interior. Coastal forests contain a greater proportion of high quality timber. The major species and volumes harvested in 1981 for both regions are outlined in Table-1.1.

The products from high quality timber include; lumber, plywood and shingles. Lower quality trees and wood waste are used to produce pulp and paper related products. Most of the finished materials are exported, primarily to the United States.

Truck and rail are the principal transport modes for logs harvested by interior timber companies. Interior lumber mills tend to be located for easy access to the harvesting areas. The finished materials from these interior mills are taken to market by rail.

Along the coast, most of the timber is accessible only by water. The mountainous nature of British Columbia's coast line makes the construction of continuous roads and railways difficult if not impossible.

TABLE - 1.1

Total Log Production in B.C.

	Coastal	Interior
Volume harvested in cubicmetre:	30,713,000	43,941,000
Major species harvested:	Hemlock(39%)	Spruce(34%)
	Cedar(21%)	Lodgepole-pine(33%)
	Balsam(18%)	Balsam(10%)
	Fir(15%)	Fir(10%)
	Others(7%)	Others(13%)

(SOURCE : B.C.Ministry of Forests Annual Report,1981)

Provincial highways only reach 2% of the total coastal timber sites. On the mainland between Vancouver and Prince Rupert there are only three points of access to the coast by road and rail. In the north, Prince Rupert and Kitimat are linked by road and rail, as are Vancouver and Squamish in the south. The only other link is a basic road into Bella Coola near the centre of the coast – this road is of little commercial importance, except to the local people. The processing plants of coastal timber are located in areas which have rail or port connections to the major domestic and foreign markets. Many of the mills are situated in Vancouver and Southeast Vancouver Island area.

Over the past ten years the coastal forest industry has become less cost competitive in comparison with other forest areas of the province. The situation is shown in Fig-1.1, of delivered log costs for the coastal versus the interior. Delivered coastal logs cost almost twice that of the interior logs per cubic metre. Of this delivered total cost, a certain percentage is allocated to direct marine transport. It is this transport cost and associated inventory costs that is the focus of this research.

1.2. Importance of transportation on the overall process

A breakdown of the steps used to move a log from the forest to a mill is given in Table-1.2. Transportation is an intermediate stage of the overall process. Its cost depends primarily on the distance between the cutting areas and the conversion sites as well as the number of intervening sorts. Additional factors include marine bore damage, salt water uptake, and sinkage to mention only a few.

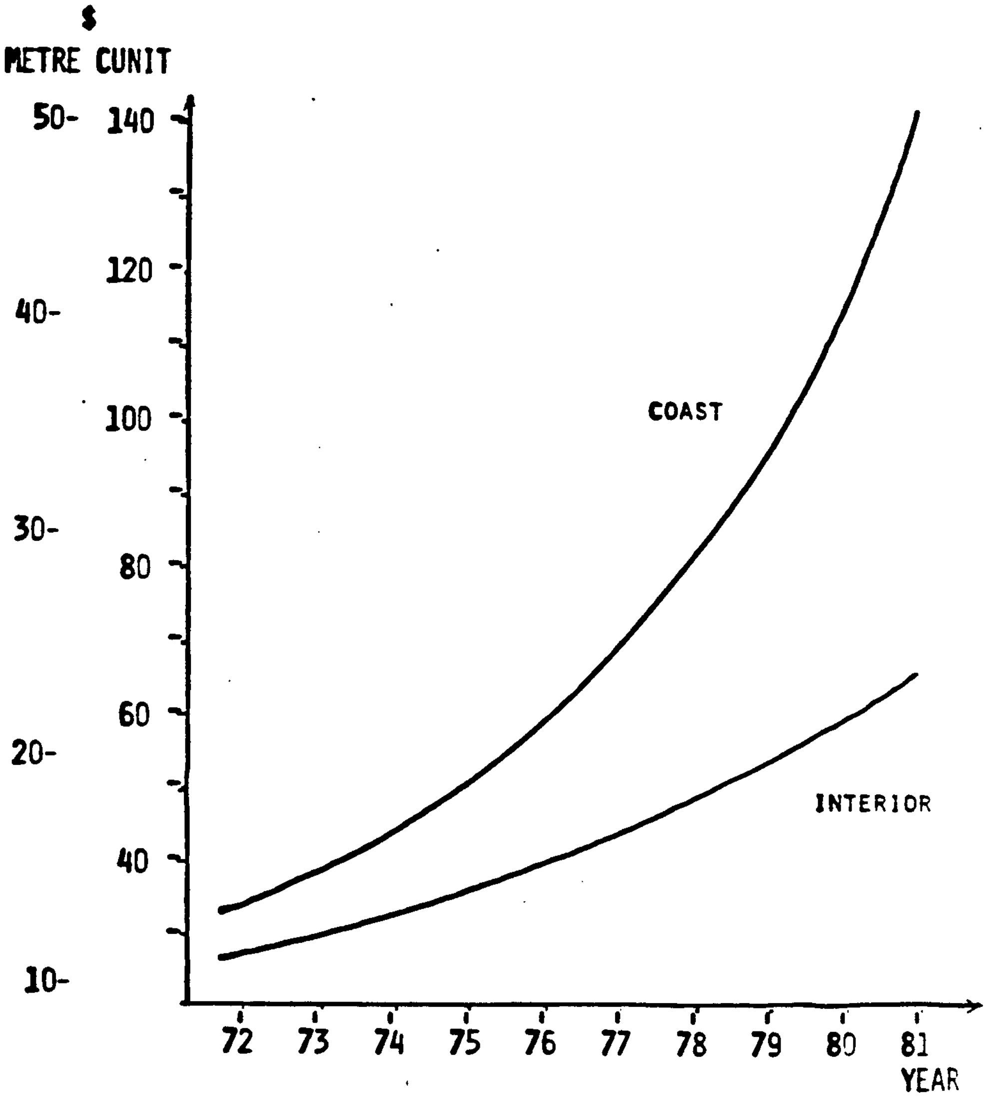

Fig 1.1

Delivered Log Cost for the Coast Vs. the Interior

Source: Research & Progress Report (1982).

TABLE - 1.2

Steps Involved in Moving a Log From the Forest to a Mill

Operation	*Description*
Forest Engineering	Construction of camps,logging roads etc.
Falling	Cutting down trees
Bucking	Removing branches & cutting the logs into proper lengths
Yarding	Gathering the logs to a central location
Loading	Loading logs onto logging trucks
Hauling	Trucking logs from the logging site to tide water
Dumping	Dumping the logs in water or land if there is dryland sort
Scaling	Measuring the volume of logs for company records and government stumpage appraisal
TRANSPORT	Movement of logs from the harvesting areas to the mills
Sorting	Separating logs by grade, species and size. This can occur before or after transport or at some intermediate point
Mill storing	Storing the logs in mill pond to be used later for conversion
Conversion	Production of finished forest products

(SOURCE: Adapted from Craig -1979)

A typical time-distance curve for a log from the time it is cut until processed is shown in Fig-1.2. The curve clearly indicates that a log's 'in-transit' time is very small when compared to the waiting time at the camp dump, central sort and mill pond.

1.3. Types of marine transportation modes

There are three principal methods of moving logs along the coast: flat raft, bundle boom, and log barges or log ships. Description of each mode is included in Chapter 2. Each mode has a resonably well defined role in the industry. For example, logs may be made into flat rafts or bundle booms to transport to nearby sorting grounds, or the sorted logs from the sorting grounds to the conversion plants. Bundle booms are generally constructed for tows of greater than 40 Km, while flat rafts are used for shorter distances in sheltered waters. The bundle boom has become the dominant method of transport for three reasons: first, tow volume may be doubled; second, they prevent logs from escaping or sinking; and third, they require less storage area. A log barge or log ship require major capital investments and are usually employed to haul large volumes of logs from isolated camps through unprotected waters. The logs are generally loaded by on-board cranes, either loose or in bundles. Bundles are preferred since they reduce loading time and also minimize log sinkage and breakage. Loading and unloading normally takes place in sheltered waters near storage sites.

Each type of mode has its own advantages and disadvantages. Flat raft and bundle booms do not need high initial capital investment, but because of slow speed of travel and dependency on weather conditions, time taken to cover the distances are high. On the other hand, a log

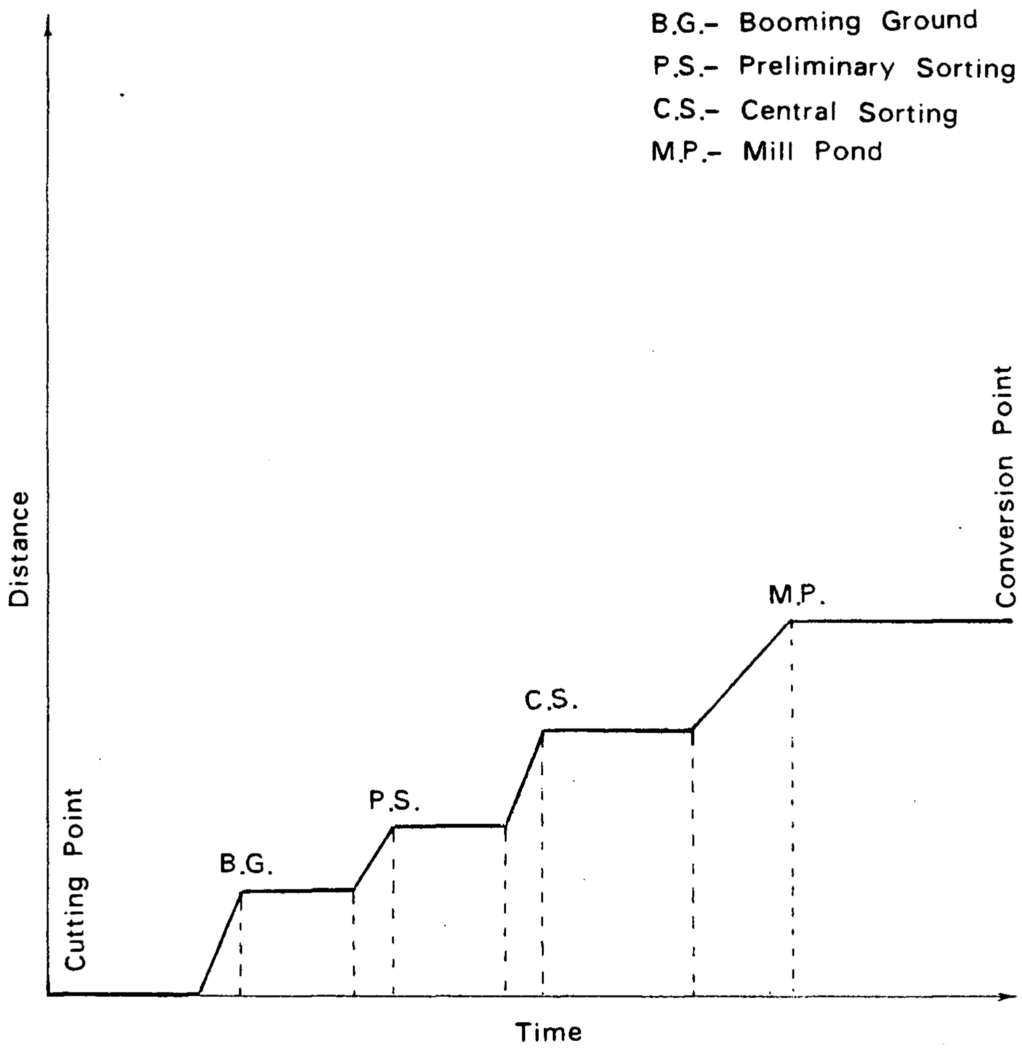

Fig 1.2
Typical Time-Distance Curve for A Log From Cutting to Conversion

barge or ship requires a high capital investment but their speed is high and almost independent of adverse weather conditions, thus, time of travel is low.

1.4. General Problem Development

The two major components of costs for transporting logs are inventory and transportation costs. This study focuses on the transportation of logs from the sorting yard to a mill for storage. The mill's demand· is assumed to be given. The general problem addressed in this study is: *which mode of marine transport minimizes the sum of the transportation and inventory costs for particular order quantities and times.*

The general problem is deceptively innocent as the following from Magee's(1960) discussion on the relationships and interactions between the inventory and transport decision:

> *Transportation costs are important indeed, but they are only part of the story. For example, think of the value of materials in transit :*
>
> *Data collected on sample shipments in various parts of the country indicate that material may spend one to two weeks in transit and that the capital value of assets tied up in the transportation system may, depending on the pressure for capital, add as much as 1% to the economic cost of the goods.*
>
> *Services, or reliability of the transport system, is also important. Goods must get to user promptly and reliably, to permit him to operate systematically with low inventories.*

The direct and indirect costs of damage in transport are another large item in the traffic bill that at times gets overlooked in the pressure for low cost per ton-mile. Clearly, transport time is one of the key determinants of the efficiency of the distribution system. Its impact is not vivid or dramatic and executives do not always appreciate what a difference it makes, but in a great many companies it is a significant factor in financing. To take a sample illustration :

Suppose that in a company doing an annual business of $100 million, time in transit is reduced from 14 days to 2. Time between reorders is 14 days, communication and processing time is 4 days, and field stocks average $12.5 million. In such a situation the reduction in transit time might well lead to a reduction in redistribution inventory investment of $6 million, made up of : (1) a reduction of $3.3 million in transit i.e, 12 days' sales; (2) a reduction of $2.7 million in inventories required to protect customer service resulting from a faster, flexible distribution system response.

Returning to our problem, the actual time a log spends in the water depends on many factors. In the present transport structure, the time the log is in the water before becoming a recorded boom and at the mill as inventory may be as much as four months. The time can easily be 14 months and in some cases 2 to 3 years. The industries at present, maintain a minimum 2 to 3 months log inventory at all times to offset possible interruptions from labour disputes, fire season, winter closures and adverse weather conditions. The scattered nature of the logging camps, slow and generally unresponsive transportation and location of the mills have conspired to create large log inventories. The large inventories consume considerable amounts of working capital. The log inventory on the coast varies by season, but generally averages about 9 million metre cubes. This represents an average direct cost of inventory of about $360 millions. Any significant decrease in inventory level would result in large savings. The object is to minimize the overall total cost - neither the transportation cost, nor the inventory carrying cost separately.

1.5. Research plan

The general problem area has been defined as the transport inventory selection problem which can be described as : the selection of the mode of transport in order to minimize the sum of the transportation and inventory costs, the determination of Economic Order Quantity (EOQ) . The objective of this study is to develop and to test the solution procedures for solving the transport-inventory selection for moving logs along British Columbia's coastal water.

The research plan is organized into five major sections. The first section summarizes the literature dealing with transport selection. The analyses of these articles form a basis for the model for the transport-inventory selection problem and also the formulation of the problem solution procedure.

The second section is the development of the transport inventory model that specifically deals with the unique characteristics and limitations of coastal marine transport.

The third part of the research plan is to gather sufficient data to be used to test the validity of the model. It is very important to collect the needed data for the model from available information. Sometimes, it might be necessary to modify the model itself because of non-availability of some data.

The fourth section of the research plan consists of applying the solution procedures to the data generated and evaluating the result.

The last section lists future research that is suggested by this particular project.

CHAPTER 2

THE TRANSPORT SYSTEM

2.1. Introduction

Towing has been the method of transport for the forest industry on the coast of British Columbia since the later part of eighteenth century. Even before that, the native Indians on the coast used water to transport their canoe, totem and house logs. Though towboats and barges are now used in the forest industry for all manner of services, such as delivering buildings, equipment and fuel, the prime industrial use of water transport is in the movement of logs, chips, logged fuels and finished products.

2.2. Causes of popularity of water transport

The physical geography of the B.C coast has encouraged the development of water transport. A few key features have made this possible. One is the well known 250 mile (400 Km) long inland passage, which provides protection from the full force of the Pacific ocean behind a string of islands, see Fig 2.1. This passage runs from Prince Rupert in the north almost to Vancouver Island. But the 60 mile (96 Km) stretch of open water between the passage and the shelter of Vancouver Island is very dangerous. Winter winds in this area of 90 - 100 mph (140-160 Km/h) are not uncommon and 50-60 mph (80-90 Km/h) are relatively commonplace. This gap between the inland passage and Vancouver Island is one of the reasons for the development of the log barges and log ships that move

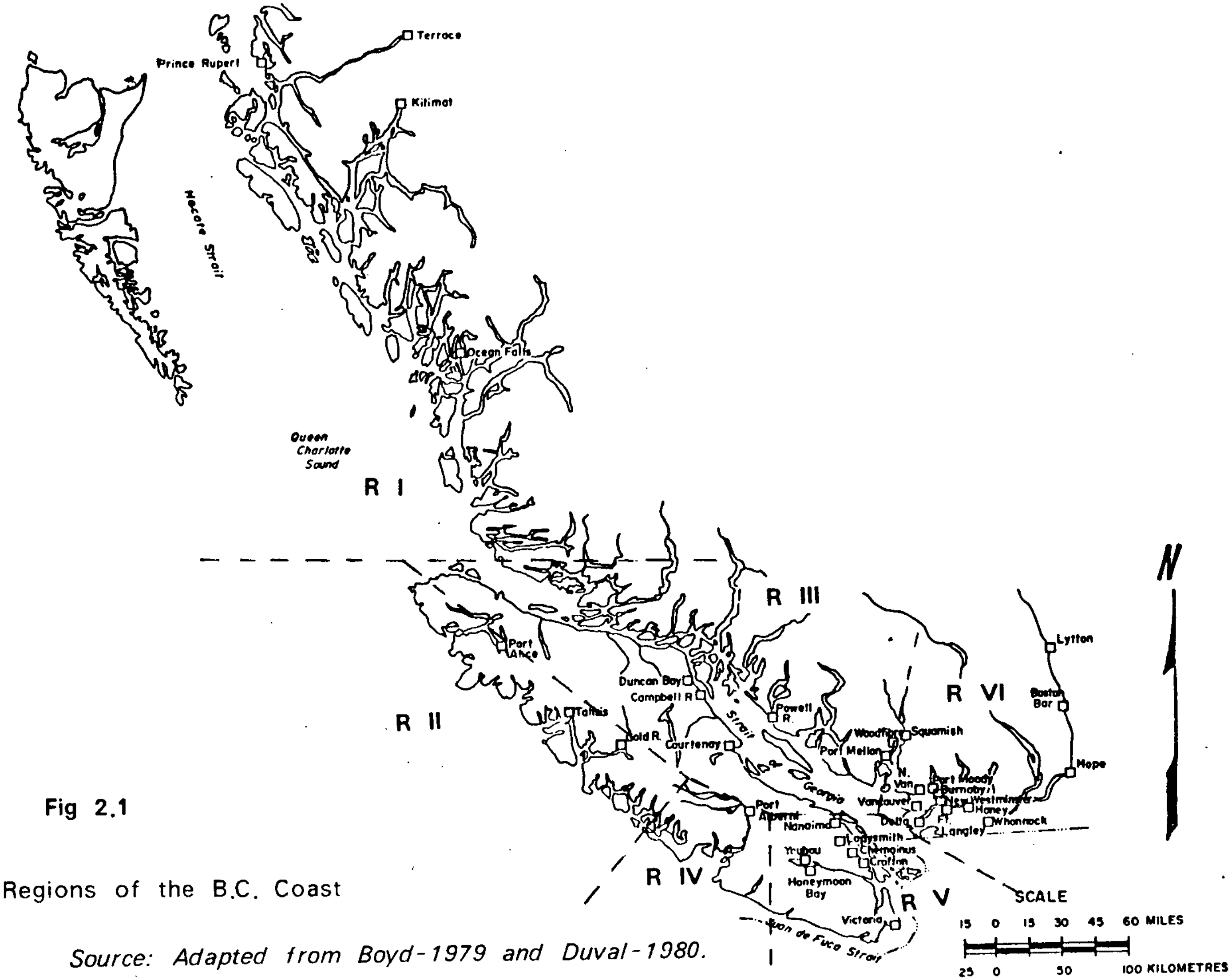

Fig 2.1

Log Source Regions of the B.C. Coast

Source: Adapted from Boyd-1979 and Duval-1980.

logs from the north coast and Queen Charlotte Islands to the mills in the southern part of Vancouver Island and the main land.

Vancouver Island, in addition to providing 180 miles (280 Km) of protection, is itself a major reason for the emphasis on water transport. As it is separated from the main land, all its incoming supplies and outgoing production must move by either deep sea shipping or some form of local water transport.

Another important geogrphical feature is the rugged nature of the coast line. Roads or railroads along this coastline are virtually nonexistant. In addition to the lack of land transportation along the coast, there are few areas with links through the mountains to the interior.

2.3. Log production and transportation

The 20,000,000 acre (8,000,000 ha) coast forest is a 600 mile (965 Km) long strip bounded on the east by the coast range and on the west by the Pacific ocean. In addition to the large Vancouver and Queen Charlotte Islands, it includes hundreds of smaller islands as well. This forest produces about 11,000,000 cunits (31,100,000 cubic metres) of logs annually.

The coastal forest can be divided into six regions as shown in Fig-2.1 (Boyd, 1979), each of which has a distinctive mix of log production, transportation and conversion functions.

2.3.1 Region I, North Coast and Queen Charlotte Islands

This area produces about 1,600,000 cunits (4,500,000 cubic metres) or 15% of the coastal cut (Boyd, 1979). Western Hemlock represents 50% of this cut, with western red cedar, sitka spruce and balsam accounting for most of the remainder. Only 400,000 to 500,000 cunits (1,100,000 to 1,400,000 cubic metres) are converted within the region. The balance, about 1,100,000 cunits (3,100,000 cubicmetres), is transported to the market and mills on Vancouver Island and lower mainland. This volume includes virtually all the 800,000 cunits (2,250,000 cubicmetres) produced in the Queen Charlotte Islands, plus most of the western red cedar and the higher grades of Hemlock, spruce and balsam from the mainland operations.

These logs are transported by self dumping log barges, most of which are self loading. The newest additions are self propelled as well, while the others are towed. Weather would appear to be the most important reason for using log barges rather than towing booms of logs. Despite the inside passage, 75% of these logs come from the Queen Charlotte Island and would have to cross 60 miles (96 Km) of exposed water to reach the passage, and then face the gap between it and the protection of Vancouver Island. In addition some of the production is allocated to mills on the west coast of Vancouver Island, which is totally unprotected and subject to the same severe weather conditions as the northern waters.

The other reason for the choice of barging over towing seems to be the cost of inventory (Boyd, 1979). A minimum economic barge load is about 3,300 cunits (9300 cubicmetres) and can be reliably delivered in 5 to 7 days from this region, while an economic tow is about a quarter as large would have about 8000 cunits (22600 cubicmetres) and would require a minimum of 20 days for delivery and, if weather conditions were adverse, could take several months. As logs in water in this area are subject to heavy marine borer attack, time of exposure is an important inventory control factor.

2.3.2 Region II, west coast of Vancouver Island

This region, which is the Pacific ocean side of Vancouver Island north of the Alberni Inlet, contributes about 1,700,000 cunits (4,800,000 cubicmetres) or 15% of the total coastal cut. Two pulp mills and two sawmills in the region use about 50% of the volume produced. The imports of pulp logs from the other regions exceed 100,000 cunits (280,000 cubicmetres) annually, thus, there is a net log outflow of some 900,000 cunits(2,500,000 cubicmetres).

Sheltered inlets allow local towing of log booms, but logs destined for other areas or brought in to it must be barged. The reasons for barging instead of towing are the same as for the north coast and Queen Charlotte Island regions, with weather being even more important here, as there is no protection at all over long distances of the open ocean.

2.3.3 Region III, North Vancouver Island and mainland

This region contributes about 4,100,000 cunits(11,600,000 cubicmetres) or 35 - 40 % of the coast production. Log consumption of about 1,000,000 cunits (2,800,000 cubicmetres) is concentrated at the large lumber/pulp/newsprint complexes located within the region.

A limited volume of logs moves by truck on the Island Highway north of Nanaimo, but there are no roads on the mainland and most of the Vancouver Island logs also move by water.

Towing of flat or bundle booms within this area is the most common transportation system. Log barges are used extensively by some of the companies to meet their specific needs, and for shipments to the north or the west coast of Vancouver Island.

This region has numerous places where log tows can be safely held when weather conditions halt movement. The major weather deterrent to log towing in this area is a strong outflow wind from the interior. Tidal conditions in the narrow passages of the towing routes are violent at peak flows and also halt the tow.

In addition to the large production from this region, log barges from the north are dumped at several dumping grounds within it where tows are madeup for final delivery.

2.3.4 Region IV, Alberni

This small region, tributary to the Alberni inlet, produces about 10 % of the coastal cut, or 1,100,000 cunits (3,100,000 cubicmetres). All species are produced in the region and the range of conversion facilities at Port Alberni makes it the closest to being self - sustained of all regions.

Most of the logs produced are dry land or water sorted, bundle boomed and towed to the Port Alberni mills.

Some 150,000 cunits (420,000 cubicmetres) are barged out and up to 300,000 cunits (850,000 cubicmetres) barged in every year to balance the specific needs of the Port Alberni mills, and by other companies those log in the area and market or use them elsewhere. Most of the logs barged-in come from the adjacent west coast of Vancouver Island.

2.3.5 Region V, Southern Vancouver Island

This region contributes about 15 % of the coastal cut or 1,600,000 cunits (4,500,000 cubicmetres) annually.

Log consumption in this area is almost double the production and is increasing. Logs are transported within this area by truck, rail and water, but water remain the predominant mode. Bundle and flat booms are the usual system with special bundle booms being used from the more exposed south-west coast.

In addition to the 1,500,000 cunits (4,200,000 cubicmetres) which must be moved into the area to offset the deficit of production compared to consumption, another 600,000 to 700,000 cunits (1,700,000 to 1,900,000 cubicmetres) must be imported to replace the logs produced there but allocated to other regions. In this process, additional volume is brought in by barge and unsorted bundle booms, parts of which is subsequently re-allocated to mills elsewhere. As a result, some 35 % of the coastal cut, or 4,000,000 cunits (11,300,000 cubicmetres), move through the waters of this region.

2.3.6 Region VI, Howe Sound / Fraser River

This is essentially a consuming region. About 8 % of the coastal cut or 900,000 cunits (2,500,000 cubicmetres) is produced in the area. Some of the upriver mills receive all or part of their supply by truck from local logging operations, but the industry as a whole depends on logs towed or barged into the Fraser River from the other regions. In total, this region converts about 40 % of the total coastal log production.

Most of the logs produced in this region are boomed in flat rafts for the generally short and protected tow to consuming mills. Hemlock, which tends to sink and logs destined for other regions, are more commonly bundled before towing.

Howe sound and, to a much lesser extent, the Fraser River are the major recipients of barges from the north. The barges are dumped at booming grounds which are operated by the forest or towboat companies, where the logs are sorted and boomed for final towing to the mill storage areas.

2.4. Types of mode of transport

The two methods used to transport coastal logs are log booms and log barges.

2.4.1 Log booms

Most of the logs which originate on the protected coast in between Vancouver Island and the mainland are transported in log booms towed by tug boats. Log boom tows are the oldest and still the cheapest water transportation method available for short distances. The types of boom used are as follows :

1) FLAT RAFT

The simplest form of boom in major use is the flat raft. A flat raft consists of free floating logs kept in place by a perimeter of logs, known as boomsticks, held together by chains. Fig-2.2 is a isometric sketch of a flat raft showing a few construction details. The size of a raft is generally expressed in terms of sections. The figure is obviously referred to as a four section raft. The maximum loads hauled depends on the coastal location. The maximum horse power for tugs pulling a flat raft is about 1000 b.h.p. Travel time depends on the tow's susceptibility to weather conditions. As the towing time increases with increasing distance so does the probability of delay due to poor weather. The delay times are generally shorter during summer months than during winter months.

2) BUNDLE BOOMS

A bundle boom is similar in construction to a flat raft except that the logs are held together in bundles secured by wire rope or steel strapping. Fig-2.3 shows the details of bundle boom construction. The maximum horse power used for this mode is 2000 b.h.p. Total weight of each section is 200 tons.

Although the concept of transporting logs in bundles has been there for about 100 years, the use of this method has greatly accelerated in last few years. Table-2.1 shows that bundle boom is the most popular type of boom transportation on the coast to-day.

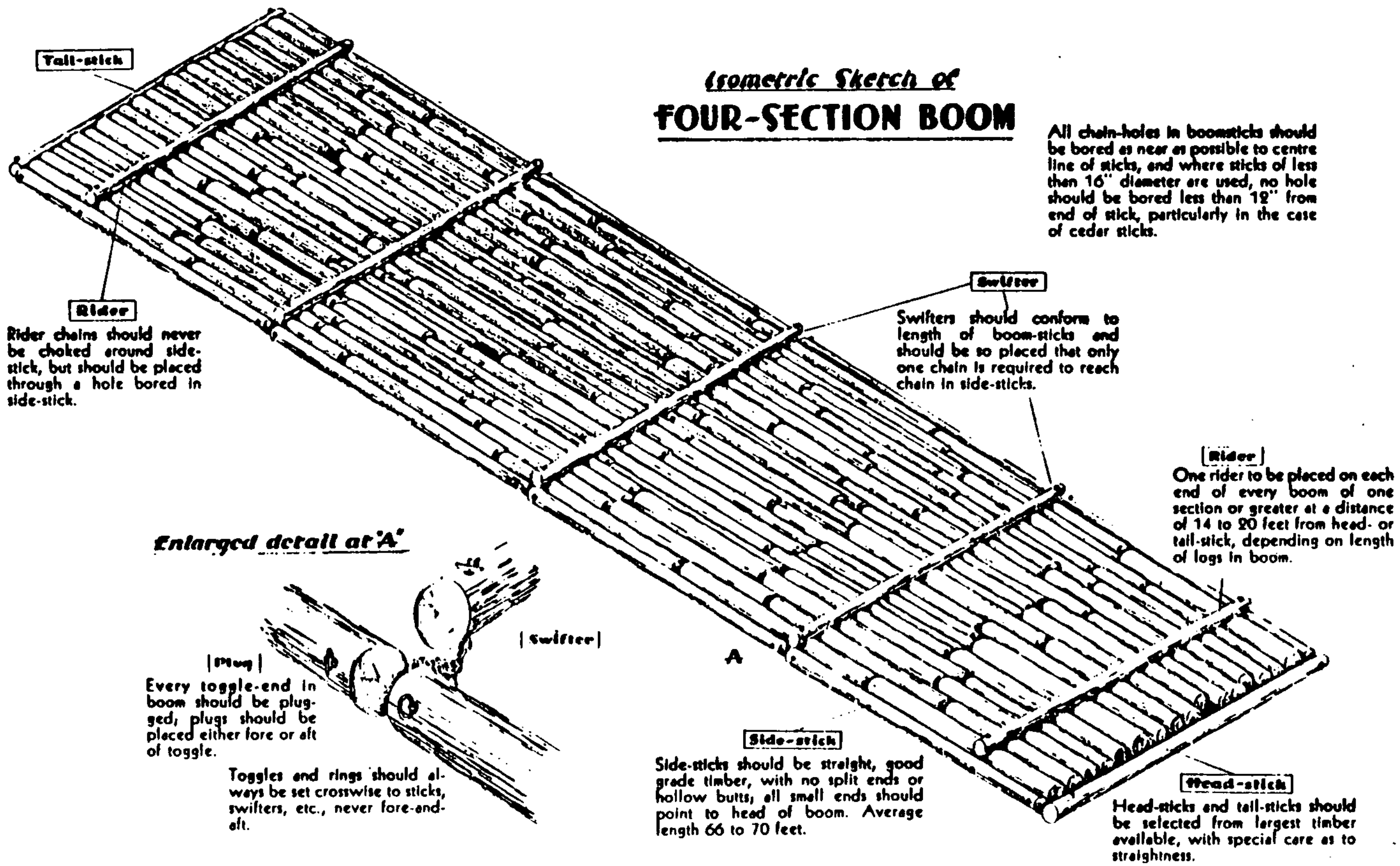

Fig 2.2

Details of Flat Raft Construction

Source: Duval-1980

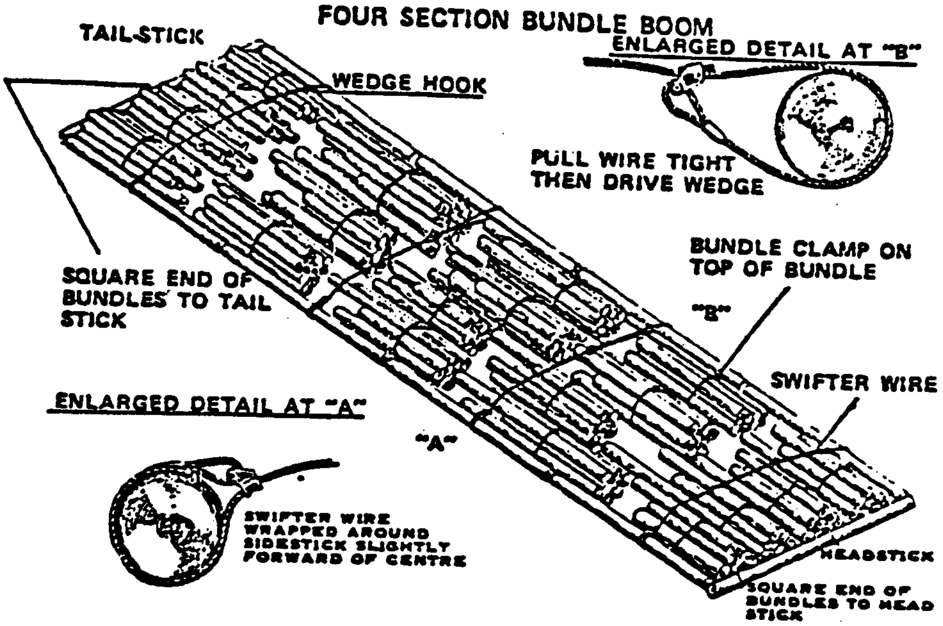

Fig 2.3

Details of Bundle Boom Construction

Source: Duval-1980

TABLE - 2.1

Log Booms Produced In Coastal B.C

Boom type	*% of total log volume*
Bundle boom	68.1
Flat raft	23.0
Bag boom (bundle)	6.6
Bag boom (flat)	2.3

(SOURCE : Duval - 1980)

There are several reasons for the increasing popularity of transporting logs in bundles :

(a) Faster towing : Because logs in bundle booms are more secure, same volume of log can be towed at higher speeds than flat rafts.

(b) Less log loss : If the water gets too rough when a flat raft is being towed, it is possible for loose logs to flip over the side of the boom. The average loss of this kind is about 6.1 % (Council of Forest Industries of B.C, 1974). Hemlock and small logs are the main sources of losses. Also, depending on the amount of time the logs are left in the water, a certain percentage sink. This problem is compounded when logs are towed from salt water to the less bouyant fresh water of rivers. (Poulton & Hughes, 1980). Table-2.2 shows the annual loss of logs in transit and storage off the coast of B.C.

It has been estimated that there is about 3 % loss by escapement and 5 % loss from sinkage when logs are handled loose during storage and transportation (Cottel, 1977). When logs are stored and transported in bundles, loss is minimal. It is difficult for a bundle to slip over the boomsticks and sinkage is unlikely because the bundles contain logs of varying densities.

Forestry companies have an incentive to increase bundle booming because the percentage of Hemlock in the coast harvest has been steadily rising as the higher quality stands of Douglas fir and cedar are being depleted. One major firm estimates that Hemlock will constitute 70 % of its logging production by 1987 (Oakley, 1979).

TABLE - 2.2

Annual Loss of Logs in Transit and Storage off The Coast of British Columbia

<u>*Total loss off B.C coast*</u>	
(Excluding Lower Georgia Strait & Lower Fraser River)	
Volume of logs lost	402,600 $metre^3$
Recovered by salvors	100,000 $metre^3$
Recovared as deadheads	8,600 $metre^3$
Sink	200,000 $metre^3$
Not recovered but float	94,000 $metre^3$
Loss in Lower Georgia Strait	
(Excluding lower Fraser river)	
Volume of logs lost	242,700 $metre^3$
Recovered by salvors	157,000 $metre^3$
Recovered as deadheads	37,000 $metre^3$
Sink	43,000 $metre^3$
Not recovered but float	5,700 $metre^3$
Loss in lower Fraser river only	
Volume of logs lost	68,900 $metre^3$
Recovered by salvors	43,000 $metre^3$
Recovered as deadheads	11,900 $metre^3$
Sink	14,000 $metre^3$
Not recovered but float	(negligible)

(SOURCE: Poulton & Hughes - 1980)

If all timber presently flat rafted were bundled, the saving from this source alone would amount to $ 396,000 per annum and if the 0.9 million cubicmetre of Hemlock presently flat rafted were hauled in bundles, the savings would be $ 110,000 (Poulton & Hughes, 1980).

(c) Less environmental effect : There has been considerable pressure from public interest groups to reduce the amount of escaped logs and log debris in B.C coastal waters. One study has shown that the annual cleanup cost of log debris on the lower coast and Fraser River is about $ 900,000. Yearly boat damage in the Vancouver area caused by floating logs and deadheads is estimated at $ 1,590,000 (Poulton & Hughes, 1980).

Although the government has not enacted specific regulations to force forest companies to reduce escape logs and debris, there is high possibility of the introduction of such laws in near future.

(d) Reduced log storage space : After logs have been transported to the mills, generally they are stored in water before processing. The availability of water storage space has been steadily shrinking. Bundling logs reduces this problem because a bundle boom contains 70 % more log volume than a flat raft with equivalent surface area (Sinclair, 1980). But this saving could be fully offset by the fact that they also require stronger anchorage piling and deeper water and hence would be stored in the outer portions of existing storage grounds (Poulton & Hughes, 1980).

(e) Dry land sorting : Before logs can be accepted by mills they must be sorted by grade, specis and size. Logs have been traditionally sorted in the water by small boom boats. Because it is difficult to see the specific charecteristics of a log in the water, a certain amount of mis-sorting occures. This combined with the problem of log sinkage has given companies an incentive to sort their logs on land (Sinclair, 1980).

On land it is easy to accurately sort the logs and stack different log types. This in turn has made it easier to bundle the sorted logs before they are dumped in water. The increase in dryland sorting has facilitated an increase in bundling (Sinclair, 1980).

3) BAG BOOMS

Bag booms constitute about 9 % of the booms used on the coast as seen from Table-2.1. They are groups of log bundles or loose logs pushed together randomly and surrounded by boomsticks chained end to end. They are very easy to make but because of their flimsy construction are only suitable for short hauls on very calm waters.

2.4.2 Log barges

The conventional self-loading, self dumping log barge first made its appearance on the B.C coast in 1960,when B.C Forest Products Company constructed the twin-crane, one million FBM carrier Forest Prince. The basic principle consists of loading logs onto a barge, which is then towed to its destination by a tug. Ballast tanks on one side of the barge are then opened to the water causing it to tilt over to an angle of about 33 degrees whereby the entire load of logs slides off at once. The water is then pumped out of the ballast tanks and the barge is towed to another loading site.

Log barging was introduced as a means for transporting logs through unprotected waters. This includes movements of logs originating on the mainland coast north of Vancouver Island, the Queen Charlotte Island, and the west coast of Vancouver Island.

In-order to realize economics of scale, forest companies replaced the early barges with ones having greater capacity. The second generation barges were fitted with twin cranes so that they had both a self dumping and self loading capability. Self loading barges have several advantages over simple flat deck barges (Henderson, 1977) :

1) Versatility : Flat deck barges can only load logs where there is a loading facility. Self loading barges can load at any location.

2) Loading speed : The twin cranes on a self loading barge can load logs faster, decreasing the barge turnaround time.

3) Non-dumpers : Occasionally a load of logs does not fully discharge when the barge is tipped over. If this happens on a flat deck barge, the remaining logs must be pulled off one by one with a tug. A self loading barge can easily unload with its cranes should a so called 'non-dumper' occur.

The next major innovation in log barging was self propulsion. MacMillan Bloedel introduced the first self propelled, self loading and self dumping barge in 1974. A self propelled barge has the following advantages over a tug barge combination :

1) A self propelled barge has a speed of about 12 knots versus 6 knots for a tug and barge.

2) It can handle rough weather better.

3) Risk of tow line breakage is eliminated.

4) Self propelled barges are more manoeverable.

The most recent advancement in log barging is the trend towards greater capacity loading cranes. Increase in crane strength has allowed forest companies to use larger log bundles. The maximum limit must, ofcourse, be kept within practical limits. Crown Zellerbach and MacMillan Bloedel have independently arrived at the same lift limit of 40 tons. These high capacity crane barges might be regarded as the fourth generation log barge which preserve both the quantity and quality of logs being transported. Table-2.3 gives a breakdown of the log barges currently operating on the coast.

The dominant factors affecting barging costs are the direct operating expenses of the vessels such as fuel, crew and the repair and maintenance of these units. Further cost of maintenance is the inventory of spare parts carried due to the specialized nature of its equipments. As an example, a Rotek gear for the Seaspan Forester valued at $38000 requires approximately 6 months delivery. To avoid a total shutdown of the barge, a spare gear is carried in inventory along with spare booms for each barge, exchange engines, wire rope and so on (Lusk, 1977).

2.5. Conclusions

The geography of B.C. coast has influenced the location of plants and made water transport of logs necessary, it has also influenced the methods of water transport. Two general methods have evolved, barging and boom towing. But within these two categories there is a range of systems which reflect the specific conditions and the industry's needs.

TABLE - 2.3

Log Barges Operating on the B.C. Coast

Barge type	*Year of Introduction*	*Name*	*Capacity(ton)*
Flat deck	1954	C.Z No.2	6,300
		C.Z No.3	4,700
		C.Z No.4	4,700
Self loading (10 ton cranes)	1960	Swiftsure Prince	8,000
		Forest Prince	5,000
		Rivtow carrier	10,300
		Straits logger	10,300
		Straits traveller	5,500
		Seaspan Forester	19,000
		Seaspan Yarder	11,300
		Haida Carrier	7,200
		C.Z No.1	10,500
Self loading (40 ton cranes)	1981	Seaspan Rigger	15,000
		Hercules	14,000
Self propelled (10 ton cranes)	1974	Haida Monarch	15,000
Self propelled (40 ton cranes)	1978	Haida Brave	10,000

(SOURCE: Adapted from Boyd -1979 and Henderson - 1977)

Log towing on the B.C. coast can be traced back 200 years or more. Bundling of logs is also not new. As log values have risen and more heavy Hemlock being logged, the economy of towing bundles with the newer tugs have been recognized. Log towing per ton mile is significantly less costly than barging, especially over the shorter distances where towing is possible.

The first barge built specially for logs was put into service in 1954. After that the method of barging has undergone considerable technological advancement. The latest model of ships with their large bundle loading capabilities, will go a long way towards meeting the objective of preservation of quality and quantity of logs being transported.

There is controversy regarding the best way of transporting logs on B.C.'s coast. Some people in the industry feels that the flat raft and the bundle raft are cost beneficial for short distances and are the integral part of the system. Again, some are of the opinion that total barge system is the most efficient one if total cost/benefit relationship are taken into account. They feel, the high costs of large inventories, boomsticks, rafting, storage and many sundry items associated with conventional towing will make it unattractive when compared with barge transportation.

CHAPTER 3

SEARCH OF THE LITERATURE

3.1. Introduction

The management of the transport and storage of raw materials and finished goods to and from the production line is defined as business logistics. Two major components of logistics costs are transportation and inventory costs. There is interaction between the available transportation alternatives and the inventory parameters. This review must of necessity consider both transport and inventory, but the main emphasis is on the engineering aspects of marine transport.

The literature reviewed is generally concerned with transport selection that provide for a minimum total transportation and inventory costs. The purpose is two fold. First, the examination of current models and techniques will aid in the development of the transportation costs for the model. Second, the factors and characteristics of the transport alternatives considered important in making the transportation decisions can be determined. The analyses of these articles can also serve as a basis for the development of the model for the transport-inventory selection problem and aid in the formulation of the solution procedure for solving the problem. The literatures are discussed under different headings after the name of the authors.

3.2. Baumol, W.J and Vinod, H.D.

In developing the inventory theoretic model of freight transport demand, Baumol and Vinod have used unique concepts. First, they have the concept of an abstract mode. This technique describes any type of carrier not as railroad or a truck but as a vector of values specifing the relevant attributes which it offers to the shipper. Thus, since the type of fuel utilized is usually of little interest to the shipper, but the time for delivery matters a great deal, two carriers which are otherwise the same, but one of which is propelled by electricity and the other by a petroleum product, are considered to be the same mode in the analysis. A slower train service, however, is considered to constitute a mode different from a more rapid railroad train.

The set of attributes for a passenger transportation mode are different for goods transportation mode. For example, comfort is not a relevent consideration in goods transport, but likelyhood of piferage is of some importance. The authors considered the following four variables to be of most importance in goods transportation:

1. Shipping cost per unit (including freight rate, insurance etc.).
2. Mean shipping time.
3. Variance in shipping time.
4. Carrying cost per unit of time while in transit (interest on capital, pilferage, deterioration).

Some of the components of the variables are likely to to be the same for all carriers.

The authors felt the following attributes were the most important for the product as far as the transportation decision concerned:

1. The point to point transportation rates charged for that good by alternative carriers.
2. The rate of reduction in value per unit of time in transit.
3. The cost of storage of this commodity after it has been delivered.
4. The cost of delays in its delivery in terms of lost sales and other disadvantages.

Any two goods identical in all of these respects were considered to be the same abstract commodity in any analysis of decisions relating to their transportation.

To explain the choice of mode by which a commodity could be transported, is proceeded by attempting to specify the relevent indifference curves in modal space. To keep the diagrams to two dimensions, the authors characterized a mode entirely in terms of two variables, speed and economy, where speed was defined as the reciprocal of the avarage time required to transport the item, and economy as the reciprocal of the rate charged for transportation between the two points under consideration.

In Fig-3.1, any point, such as A,B,C or D, represents a mode of transportation since its coordinates constitute the vector of modal characteristics. Presumably mode E would not be utilized since it is both slower and more expensive than either C or D. With the help of shipper's indifference curves, the selection can easily be made. Point B is preferred to C if II' is taken as the shipper's indifference curve. Once shipper's indifference curves are located, it is possible to choose a mode not only from the presently available modes but also among modes, some of which have yet to be introduced.

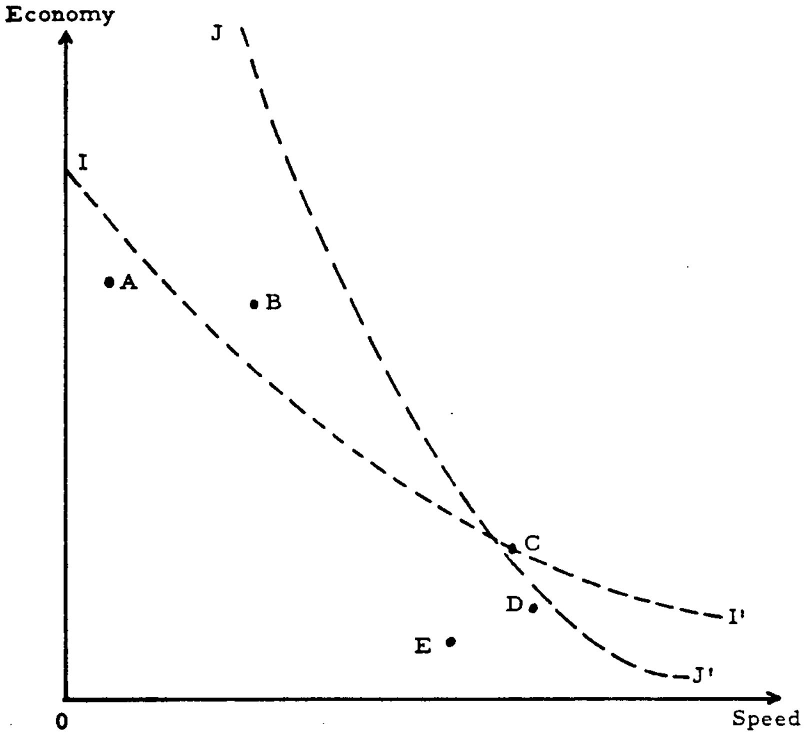

Fig 3.1

Indifference Curves in Modal Space

Source: Baumal and Vinod-1970.

To find how the equation of an indifferent curve can be determined, it is necessary to investigate the trade-off between speed and economy. Apparently a slow mode delays the recipient's acquisition of the commodity that is sent to him whereas speed offers real advantages to a shipper. But where shipments are made at relatively regular intervals, length of transit period does not affect receipt of the goods. Then what are the advantages of speed? It is where the authors introduced the concept of inventory theory. So, they have considered the freight in transit as an inventory on wheels. Hence, a slower mode is one which necessarily yields a larger in-transit inventory. Also, longer transit time causes trouble for the consignee if there is an unanticipated rise in demand, so that a special order takes a long time to arrive, or if there is some unexpected delay en route. That is why safety stocks are maintained against such contingencies. The longer and more uncertain the length of the transit period, the greater must be the level of safety stock. If the relationship between the transit time and the inventory level can be described, part of the indifferent relationship can be determined.

In developing the analysis the authors begin with a trivial case - the case of perfect certainty, in which transit time and final consumer demand for the products is clearly known. Safety stock in this case would be zero. The following notation is used to develop the equation:

C = expected total annual variable cost of handling.

T = total amount transported per year.

r = shipping cost per unit of commodity (e.g. tons,including freight rate, insurance, etc.).

t = average time required to complete a shipment in years.

s = average time between shipments in years (e.g., $s=1/12$

for monthly shipments).

u = carrying cost in transit per year (interest plus deterioration plus pilferage rate).

w = the warehouse inventory carrying cost per unit per year.

a = the cost of placing an order.

i = the average inventory level.

The total cost function, expressed in words is:

C = Direct shipping cost + In-transit inventory carrying cost + Ordering cost + Inventory carrying cost at the warehouse. ...(3.1)

If each term of 3.1 is considered separately, it can be further broken down and expressed as:

Direct shipping cost is:

(Unit shipping cost) x (Amount shipped) = rT ...(3.2)

In-transit inventory carrying cost is:

(Cost per unit time) x (Transit time) x (Amount shipped) = utT ...(3.3)

Ordering cost is:

(Cost per order) x (Time between orders) = a/s ...(3.4)

Recipient's inventory carrying cost is:

(Inventory carrying cost per unit) x (Average inventory) = $wsT/2$ ...(3.5)

Combining the four elements,

$$C = rT + utT + a/s + wsT/2 \qquad ...(3.6)$$

In the above equation 3.6, there are three mode characterizing elements, r,u and t and three exogenously given parameters, a,w and T.

The value of one variable, s, the frequency of reordering, is directly under the control of the shipper. The optimal value for s can be determined by taking the first derivative of 3.6 with respect to s, setting the derivative equal to zero, and solving for s. The second partial derivative can be taken to indicate if the value for s is a minimum or maximum value for 3.6. The expression the authors derived for s and minimum total cost are:

$$s = (2a/wT)^{0.5} \qquad ...(3.7)$$

$$C = rT + utT + (2a/wT)^{0.5} \qquad ...(3.8)$$

With a, w and T given, eq. 3.8 can be written as:

$$r + ut = k \qquad ...(3.9)$$

Now setting $e = 1/r$, $v = 1/t$, $p = 1/u$ as the variables: economy, speed and preservation of values in transit, eq. 3.9 becomes:

$$vp + e = kevp \qquad ...(3.10)$$

Thus, $$vp = e/(ke-1) \qquad ...(3.11)$$

The right hand side of 3.11 contains only e and k so that, for a fixed value of e, this expression can be treated as a constant, K . Thus, the cost indifference curves between v and p (speed and preservation of value in transit) are a family of rectangular hyperbolas. Similarly, taking p, rather than e as given, eq.3.10 could be solved for e in terms of v to obtain the cost indifference curves between economy and speed

$$e = vp/(Kvp-1) \qquad ...(3.12)$$

The corresponding indifference curves are shown in Fig.3.1.

The above discussion did not take into account a crucial element: uncertainty in demand forecasts and delivery time and their impact on the level of safety stock. Baumol and Vinod used Whitin's relationship which assumes that stochastic elements of the problem satisfy a poisson distribution and expressed the standard deviation of available inventory approximated by the expression for safety stock,

$$((s + t)T)^{0.5} \qquad ...(3.13)$$

The maximum possible shortage that can occur during the lead time is the maximum demand that can occur. The maximum demand is determined by the maximum delay in receiving an order times the demand rate. If the possion distribution is assumed, the probability of a shortage occuring can be determined by the following formula:

$$p(y>D) = \sum_{y=D+1}^{\infty} \bar{y}^{y} \cdot e^{-\bar{y}}/y \qquad ...(3.14)$$

where, $p(y>D)$ = the probability of shortage occuring.

D = reorder point.

y = units demanded during lead time.

$\bar{y}$ = mean lead time demand

The authors use a normal approximation to the poisson and specify the probability of a shortage occuring in order to determine the safety stock level. For a specified probability of a shortage occuring k standard deviations above the mean level, the safety stock is given as:

$$\text{Safety stock} = k((s + t)T)^{0.5} \qquad ...(3.15)$$

The safety stock can be multiplied by the inventory carrying cost and added to 3.6 to obtain the expression for total cost as:

$$C = rT + utT + a/s + wsT/2 + wk((s + t).T)^{0.5} \qquad ...(3.16)$$

The first partial derivative of 3.16 with respect to s is a quadratic equation which is not easily solvable. Therefore, Baumol and Vinod developed a different procedure involving the prediction of aggregate freight revenue. Estimating the aggregate revenue, requires an expression for estimating the demand and a relationship to be developed between the demand estimation expression and the total cost expression. The authors use the transport rate to estimate the aggregate demand and change the problem from cost minimization to profit maximization. The profit maximization equation becomes an econometric estimation equation when a stochastic component for demand is added. However, the solution process results in a nonlinear equation which can not be easily solved. When the total cost equation is generalized to the aggregate case, the transport rate becomes an average rate for the firm and not an actual rate charged for moving product from point A to point B.

Baumol and Vinod considered inventory carrying cost, in-transit inventory carrying cost and ordering cost in their model but excluded shortage cost and the transport rate as an investment cost in the product. The major drawbacks of the model are: (1) Shortage costs are not considered; (2) the lead time held constant and (3) there is no method presented for solving the more complex case of stochastic demand and lead time for making specific transport selections.

3.3. Constable II, G.K.

The model developed by Constable is based on the costs associated with the decisions concerning the determination of the quantity to order, the time to place an order, and the transport alternative by which the order should be shipped. The model is limited to intra-company movements and the objective criterion is the minimization of the expected total cost of inventory and transportation.

The cost elements employed in the model consists of the inventory carrying cost, the cost of placing an order, the transport rate for each transport alternative between the two points of interest, the cost of not being able to fill an order, and the in-transit inventory carrying cost. The costs of inventory (carrying cost, storage cost and ordering cost) are those normally associated with inventory models and contain similar components. The transport rate contains the basic movement rate charged plus any additional costs that can be apportioned on a per unit basis. These include items such as insurance costs and special packaging. The in-transit carrying cost contains items such as investment cost, pilferage cost, and damage or spoilage costs, among others. Although the in-transit inventory carrying rate might be different for each transport alternative, the author considered it to be the same for all alternatives but treated as a separate parameter. The inventory carrying cost and the in-transit inventory carrying cost is determined by multiplying the product's value times the inventory carrying rate and the in-transit inventory carrying rate respectively.

The inventory system considered by the author is the order quantity (q) - reorder point (r) system, commonly referred to as (q,r) system. The variables for the inventory portion of the model are q and r. The decision variable for the transportation portion of the model is the transport selection. A transport alternative is represented in the model by its measurements on three characteristics: the transport rate of the transport alternative to move a unit of product between its source and destination, the average lead time, and the standard deviation of the lead time.

The author has modified the Baumol and Vinod model to provide the basis for the inventory-transport selection model. The notion used in the model is as follows:

C = the expected annual total cost.

C_r = the inventory carrying rate per dollar per year.

v = the value or cost of the product prior to its shipment.

C_c = the inventory carrying cost per unit per year.

$= C_r.(v \ + C_t)$

C_r = the inventory carrying rate per dollar per year.

C_t = the transport rate per unit for shipping the product between the two points of interest.

C_s = the per unit storage cost.

C_{ti} = the per unit charge for moving the product from its source to its destination by transport i, j = 1,2,......,T.

C_i = the in-transit inventory carrying rate per dollar per period.

i_c = the in-transit inventory carrying cost per unit per period.

$=C_i.v$

q = the order quantity.

r = the reorder point.

$\bar{d}$ = the mean demand per period.

n = the number of periods in a year.

D = the mean annual demand $\bar{d}(\ .n)$

$\bar{t}_i$ = the mean lead time for transport i

$\bar{u}_i$ = the mean lead time demand when shipments are made using transport ix($\bar{d}\bar{t}$)

σ_d = the standard deviation of the demand distribution.

σ_{ti} = the standard deviation of the lean time distribution for transport i.

σ_{ui} = the standard deviation of the lead time demand distribution for transport i.

f(d) = the demand distribution density function.

$g_i(t)$ = the lead time distribution density function for transport i.

$h_i(u)$ = the lead time demand distribution density function for transport i.

C_0 = the cost of placing an order.

The total cost equation is given by:

$$C = C_r(v + C_{ti})(q/2 + r - \bar{d}.\bar{t_i}) + C_0.D/q + C_{ti}.D + C_i.v.\bar{t}.D + C_s.(D/q) \int_{u=r}^{\infty} (u-r)h_i(u)\, du \qquad \text{...(3.17)}$$

The author developed three solution procedures for determining the optimum q,r and transport alternative which minimize the expected total cost of the model. The first model called the enumerative approach considers each transport alternative individually, finding the minimum cost for 3.17 for each alternative. To implement this approach, the lead time demand distribution for each alternative must be specified. Depending on the form specified, the first partial derivative of 3.17 may still be nonlinear, but the enumerative procedure can accomodate that. A simulation procedure might be introduced, but it has several disadvantages. First, it is necessary to determine how long (how many periods) the simulation must be run to provide a good estimate of the average costs. Second, the number of possible combinations of the order quantity and the reorder point that must be considered in determining the minimum total cost combination can be large. In addition, the process has to be repeated for each transport alternative considered.

The second is a heuristic procedure for finding good solutions requiring considerably less computation time. There are three phases in using Heuristic I to find the q,r and transport alternative which define a solution. The first phase determines the q and r which results in the minimum expected total cost for one specific transport alternative. The second phase uses the q and r from this analysis to make an estimate of the minimum total cost for each transport alternative. The alternative with the lowest estimated total cost is selected as the transport alternative for the problem. The third phase is the determination of the q and r giving the minimum expected total cost for the transport alternative selected in the second phase. If the transport alternative with the minimum estimated total cost is the transport alternative evaluated in phase one, phase three is not implemented since the q and r values have already been determined.

In the third method known as Heuristic II, the parameters of the transport alternatives are considered to be continuous variables, and the reorder point is removed as a variable. The first partial derivatives of the total cost equation are taken with respect to the order quantity, the mean lead time and the standard deviation of the lead time. These are set equal to zero and solved to determine the optimum values of the three variables. The solution to the first partial derivatives is used to define an ideal transport. The ideal transport is hypothetical one which minimizes the total cost expression.

There are three major changes in the inventory-transport selection model for implementing Heuristic II. The first concerns the elimination of the reorder point as a variable. The second is the change in the calculation of the standard deviation of the lead time demand distribution. The third concerns the development of a relationship among the attributes of the transport alternatives.

3.4. Das, C.

The approach used by Das assumes that a consignee would always seek transportation service of such characteristics as will minimize the adverse effects of lead time fluctuations on the inventory. In actual fact the consignee's preference would usually imply improved performance of the shipper who should be compensated by the consignee either in the form of higher direct shipping cost or increased product price. Thus the problem of transport selection becomes an issue of balancing increased shipping costs against expected reduction in inventory costs. The author proposed a computational method of transport selection approprite for such situations. Since shipping costs are easily determined, a good method of comparing inventory costs for alternative sets of lead time characteristics becomes the crux of the problem. Costs of the inventory operation depends on several factors such as:

a) the nature of the inventory control policy in operation,

b) parameters of the control policy, and

c) the nature of demand.

Das has adapted the main concept of the model from Baumol and Vinod. The total cost equation is given by:

TC = total annual cost of handling

$$=C_s+C_t+C_I \qquad ...(3.18)$$

where, C_s = total annual direct shipping cost

= (unit shipping cost).(total amount shipped/year)

C_t = total annual in-transit carrying cost

= (carrying cost/day).(lead time in days).(total amount shipped/year)

C_I = total annual cost of the consignee's inventory operation

= ordering cost + inventory holding cost + cost of safety stock.

= (cost/order).(number of orders/year) + (holding cost/unit/year).(average inventory level) + (holding cost/unit/year).(size of safety stock).

The following symbols are then introduced to derive an expression for TC:

A = total annual demand

= total amount shipped annually.

M_d = mean demand/day

V_d = variance of demand/day.

M_t = mean lead time (days).

V_t = variance of lead time.

Q = order quantity.

S = safety stock.

Z_p = the value such that the area under the standard normal curve to the right of Z_p is p.

K = setup cost/order.

H = holding cost/unit/year.

r = shipping cost/unit.

u = carrying cost of in-transit inventory/unit/year.

The quantity which is crucial for the determination of the safety stock size is the standard deviation of available inventory during lead time. The author used Baumol and Vinod's approximation of the value of standard deviation of available inventory during lead times. This assumes that the stochastic elements of the problem satisfy the assumption of poisson distribution, and is given by:

$$B = (Q + (M_t + kV_t^{0.5})M_d)^{0.5} \qquad ...(3.19)$$

where Q is the order size to be determined and k is a constant multiplier to be chosen based on the desired protection against the unrealiability of lead time. Assuming that the normal approximation of a poisson distribution is satisfactory, the safety stock can be expressed as,

$$S = Z_p.B \qquad ...(3.20)$$

so that the cost of the safety stock becomes,

$$H.S = H.Z_p.B \qquad ...(3.21)$$

Hence,

$$C_I = (Ak/Q) + (HQ/2) + H.Z_p.B. \qquad ...(3.22)$$

Thus the resulting total cost expression of Baumol and Vinod then becomes:

$$TC = rA + uAM_t + (Ak/Q) + (HQ/2) + H.Z_p.B. \qquad ...(3.23)$$

To simplify the problem, Das assumed the operating inventory policy as a 'fixed-order-quantity, variable cycle' type and that demand is uncertain but the parameters of its probability distribution are known. He used the equation for standard deviation as derived by Hadley and Whitin, who considered that the lead time is independent of the quantity ordered and gave the expression for standard deviation as:

$$D=(M_t V_d + V_t M_d^2)^{0.5} \qquad ...(3.24)$$

where, $D^{\cdot}$ = standard deviation.

M_t = mean lead time (days).

V_d = Variance of demand/day.

V_t = variance of lead time.

M_D = mean demand/day.

The author also adapted the conclusion drawn by Constable that the normal approximation is satisfactory for realistic demand over lead time distribution, and set the safety stock at

$$S= Z_p.D \qquad ...(3.25)$$

where, S = safety stock.

$Z_{p\cdot}$ =the value such that the area under the standard normal curve to the right of Z_p is p.

Das gave the following steps for choosing a shipper:

Step 1: Compute D for each shipper by using eq. 3.18

Step 2: Compute the safety stock, $S = Z_p.D$, for each shipper.

Step 3: compute Q = EOQ (Economic Order Quantity)based on the given demand and other cost parameters.

Step 4: Compute C_I for each shipper as $C_I = (Ak/Q) + (HQ/2) + H.Z_p.D$.

Step 5: Compute TC for each shipper using the results of step 4.

Finally, the most desirable shipper can be selected on the basis of minimum TCC.

3.5. Constable, G.K and Whybark, D.C.

Constable and Whybark considered the relationship between the management of inventory and the determination of transportation policy. These areas interact, for example, when alternatives exist for transporting replacement inventory from a vendor or a plant, and each alternative necessitates different parameters for the management of inventories. Differences in the variability of transit time could lead to different reorder points, and/or differences in transportation costs could require different order quantities. This interaction between determining the inventory parameters and selecting a transportation alternative suggests that the decisions should be made simultaneously. The authors have presented an efficient method for making such a joint decision.

The authors have considered a single product controlled by an order-point system i.e when the on-hand inventory reaches the reorder point, a replenishment order is placed for the order quantity. The transportation alternatives considered involve several different modes of transportation. Each distinct alternative is represented by a collection of attributes. The authors used three attributes to describe each transportation alternative for the product: the transportation cost, the expected time in transit, and the variability of transit time. A change in any of these attributes creates a new transportation alternative.

The problem is to jointly determine which transportation alternative and inventory parameters (reorder point and order quantity) lead to the lowest total inventory and transportation cost. The work of Baumol and Vinod provides the basis for the mathematical model. The annual cost for a specific transportation alternative and set of inventory parameters can be expressed as:

Annual cost = Transportation cost + In-transit inventory cost + Order cost + Expected inventory carrying cost + Expected backorder cost

Mathematically,

$$C = C_t D + C_i v \bar{t} \; D + C_0 D/q + C_r (r - \bar{u} + q/2)(v + C_t) + C_s D/q \sum_{u=r}^{umax} (u-r) P_r(u) \qquad \ldots(3.26)$$

where, C = the expected total annual cost.

D = the mean annual demand (d.n).

C_r = the inventory carrying cost rate per dollar of inventory investment per year.

v = the value or cost of the product prior to its shipment.

C_s = the per unit back order cost, which can contain direct costs and estimates of loss of goodwill.

C_0 = the cost of placing an order.

C_t = the transportation cost for moving a unit of product from its source to its destination, including loss and damage, packing, loading, unloading etc.

C_i = the in-transit inventory carrying rate per dollar per

t = the mean lead time (transit time).

u = the number of unit demanded during the lead time.

$\bar{u}$ = the mean lead time demand.

$P_r(u)$ = the lead time demand distribution density function (the probability of the units being demanded during the lead time).

q = the order quantity.

r =the reorder point.

Taking the derivative of eq. 3.19 with respect to q and setting equal to zero provides the following expression for q as a function of r and the transportation alternative:

$$q = \sqrt{\left(2(C_0D + C_sD \sum_{u=r}^{umax} (u-r)P_r(u))/C_r(v+C_t)\right)} \quad ...(3.27)$$

The exact solution of the problem involves the following steps. For any given r, the q can be determined from eq.3.27 and the total annual cost can be determined from eq. 3.26. A partial enumaration is used to determine the optimal q and r for a given transportation alternative. First a variable of r equal to u_{max} is used to find the first q and associated total cost. The value of r is reduced by one in subsequent steps, and the new q and and the associated cost are determined. The process is repeated until reductions in r begin to increase total cost. The q and r that produce the lowest total cost are optimal for that particular transportation alternative.

The process is repeated for each transportation alternative before making the final choice. When several alternatives exist, and the demand and lead time distributions are more complex, this process requires considerable computation time.

They have described another method to solve the problem, named as the heuristic procedure. This method makes use of the fact that each transportation alternative is associated with a total annual cost that is a function of the cost of transportation, expected lead time, and lead time variability for the product being considered. This procedure uses an estimation process to choose a transportation alternative that will either be associated with the lowest total cost or one quite close to it. Specifically, the heuristic procedure involves three phases. The first phase uses the exact procedure to determine the q and r values that provide the minimum expected total cost for one of the transportation alternatives. The second phase uses the q and r values, determined in the first phase, to estimate the annual total cost associated with each of the remaining transportation alternatives. The alternative with the lowest estimated total cost is the transportation alternative selected for the problem. The third phase is the determination of the q and r values that minimize expected total cost for the alternative selected in phase two, if different from that used in phase one. One additional simplification in the heuristic method is the use of the normal distribution in all phases to approximate the lead time demand distribution.

3.6. Summary

The variability of transit time may lead to different reorder points, and or different transportation costs could require different order quantities. The interaction between selecting a transportation alternative and determining the inventory parameters suggests that the decisions should be made simultaneously.

The model by Baumol and Vinod explains the choice of transport made by shippers, as well as their total demand for transportation services. The optimal choice of mode is shown to involve a trade-off among freight rates, speed, dependability (variance in speed) and en-route losses. It is shown that faster, more dependable service simply reduces the shipper's or receiver's inventories, including his safety stock and his inventory in transit. Hence inventory theory makes possible a direct comparison of the four attributes on which mode selection is based and leads to a model of rational choice in transport demand.

Research by Constable focuses on the relationships between the transportation and inventory decisions. The objective of that study was to develop and test solution procedure to solve the inventory transport selection problem. An expected total cost model is developed for the problem using an order-quantity (q), reorder-point (r) inventory model. Three solution procedures were developed to determine the optimum q, r and transport alternative which minimize the expected total cost. One procedure is an enumeration (Enumeration) which solves for the optimum q and r given the transport alternative. The second is a heuristic (Heuristic I) for finding good solutions and requires considerably less consumjtion time. The third procedure (Heuristic II) goes beyond the goals set for Heuristic I and tries to determine an 'ideal' transport mode.

The method proposed by Das is a modification of the Baumol and Vinod's model. He considers a general estimate of the variability of demand during lead time as the basis for determining the size of safety stock. To make the problem simple, the author assumed the operating inventory policy as 'fixed-order-quantity, variable cycle' and that demand is uncertain but the parameters of its probability distribution are known. He also considered that the normal approximation is satisfactory for realistic demand over lead time distributions as shown by Constable. The order quantity is chosen independently of the safety stock size in order to minimize the cost of ordering and inventory holding. For this Economic Order Quantity (EOQ) formula is used.

3.7. Conclusions

The paper by Constable and Whybark presents exact and heuristic procedures for jointly determining the inventory reorder points, order quantities, and transportation alternatives that provide minimum total transportation and inventory costs. They used three attributes to describe each transportation alternative: the transportation cost, the expected time in transit, and the variability of transit time. The assumption of the normal distribution as an approximation for the lead time demand distribution has the support of several authors.

Constable and Whybarks model will be used to develop the solution procedures for the coastal marine problem of transport-inventory selection for log transportation. The concept of minimizing the total cost for a specific lead time or transport alternative will be used in developing the solution procedure. The procedure of determining the safety stock level to meet the criterion of having the probability of a stockout during any lead time period equal to a certain value will also be used. Also, the Baumol and Vinod model will be modified to describe our problem of log transport and inventory along the British Columbia coast. inventory selection for log transportation.

CHAPTER 4

DEVELOPMENT OF THE MATHEMATICAL MODEL

4.1. Introduction

The physical situation that underlines the log transport - inventory model for B.C.'s coastal water requires that the traditional transport inventory models be revised. The unique parameters and the cost elements in the coastal log transport - inventory model are discussed and specified in this chapter.

4.2. Parameters of the model

The focus of this research is the transportation of logs from one source (sorting yard) to one destination (mill) using any of the three available water modes. in1128 Both the source and the destination are considered to be located by the side of the Georgia Strait, so that flat rafts do not have to encounter load limiting tidal currents, which is very common on the west side of Vancouver Island. The model is based on the costs associated with the decisions concerning the determination of economic order quantity (EOQ); time to place an order, which in turn depends on the determination of safety stock and the transport alternative by which the logs should be shipped.

The present system of cutting, sorting and transporting logs on the coastal water of B.C. is very complicated. There are many sources and destinations. Logs are generally sorted more than once before they reach the mills from the forests. B.C produces various types of logs and the value of each log varies widely. The requirement of the specified type of log in a mill depends on the kind of product it produces. To reduce these complexities, for this study the simpler problem of one source, one destination and one type of log at a time has been singled out.This simplified model should be adequate to determine whether the transport-inventory model that minimizes total cost can be applied successfuly to log transportation problem along British Columbia's coastal waters.

4.3. Costs incorporated in the model

The cost elements used in the model consists of: expected inventory carrying cost, safety stock carrying cost, transportation cost and in-transit inventory carrying cost. The cost of inventory (carrying cost, safety stock carrying cost) includes the components generally considered in inventory models. The transportation cost has been broken down into two parts, unavoidable and variable. The unavoidable cost is considered independent of the quantity carried e.g. fuel cost, wages, food cost for the crew etc.; whereas variable cost depends on the quantity of logs being shipped e.g loading cost and insurance cost, and is expressed in terms of cost per unit. The in-transit inventory carrying cost accounts for: interest on the capital invested on inventory, cost due to log losses, damage or spoilage. The in-transit inventory carrying rate is different for different modes of transport.

4.4. Variables considered in the model

Since transportation costs can be easily determined, a good method of comparing inventory costs for alternative sets of lead time characteristics becomes the crux of the problem. The costs of an inventory operation depend on several factors, for example, (a) the nature of the inventory control policy in operation, (b) parameters of the control policy, and (c) the nature of demand. In this study it has been assumed that the operating inventory policy is of the 'fixed-order quantity, variable cycle' type and that demand is constant throughout the year. It has also been considered that the lead time is independent of the quantity ordered.

4.5. Revision of Constable's model

The model developed by Constable is a modification of the original proposed by Baumol and Vinod. Baumal and Vinod's model was developed for the purpose of predicting demand for freight transport, but it contains all the essential elements of the transport mode selection decision. Constable modified the model to provide the basis for the inventory-transport selection model. The main limitation of the Conatable's model is it's consideration of transport rate. The rate for each mode is fixed irrespective of distance travelled and quantity carried. To remove this limitation the present study divides the transportation cost into two parts, fixed and variable.

This revised method considers a general estimate of the variability of demand during lead time as the basis for determining the size of the safety stock. Following Hadley and Whitin it can be shown that if lead time is independent of the quantity ordered then the standard deviation of demand during lead time can be given by:

$$\sigma_u = (\bar{t} . \sigma_d + \bar{d}^2 . \sigma_t{}^2)^{0.5} \qquad \ldots(4.1)$$

and mean lead time demand is given by:

$$\bar{u}=\bar{d}.\bar{t} \qquad \ldots(4.2)$$

where,

σ_u = lead time demand standard deviation.

$\bar{t}$ = mean lead time in days.

σ_d = variance of demand per day.

σ_t = lead time variance.

$\bar{d}$ = mean demand per day.

$\bar{u}$ = mean lead time demand.

Since daily demand of log at a mill is considered constant throughout the period (year), the expression for the standard deviation of demand during lead time becomes:

$$\sigma_u=(\bar{d}^2.\sigma^2{}_t)^{0.5} \qquad \ldots(4.3)$$

Also, Constable has shown that the normal approximation is satisfactory for realistic demand over lead time distributions. Thus, the amount of safety stock can be set at:

$$S=Z_p.\sigma_u \qquad \ldots(4.4)$$

where, Z_p = the value such that the area under the standard normal curve to the right of Z_p is p.

σ_u = lead time demand standard deviation.

S = safety stock quantity.

The notation that will be followed is:

C = the expected annual total cost.

C_{TF} = fixed transportation cost per day.

C_{TV} = variable transportation cost in dollars per ton.

C_i = in-transit inventory carrying rate per dollar per day.

v	=	value of product prior to shipment in dollars per ton.
$\bar{t}$	=	mean lead time in days.
D	=	mean annual demand ($\bar{d}.n$)
$\bar{d}$	=	mean daily demand.
n	=	number of days or periods in a year.
C_r	=	inventory carrying rate per dollar per year.
Z_p	=	value such that the area under the standard normal curve to the right of Z_p is p.
σ_u	=	standard deviation of lead time demand.
Q	=	economic order quantity.

The total cost is given by,

C = Transportation cost + In-transit inventory cost + Expected inventory carrying cost + Safety stock carrying cost.

$$= (C_{TF}\bar{t}D/Q + C_{TV}D) + (C_i v\bar{t}D) + C_r(Q/2)(v + C_{TF}\bar{t}/Q + C_{TV}) + C_r\sigma_u Z_p(v + C_{TF}\bar{t}/Q + C_{TV}) \qquad ...(4.5)$$

The approach to solve the transport-inventory selection problem is to determine the variable Q from equation 4.5. To obtain the minimum or the maximum value of Q, equation 4.5 is differentiated with respect to Q, set equal to zero and solved for Q.

Putting, $\frac{dC}{dQ} = 0$, and simplifying,

$$(C_{TF}\bar{t}D + C_r\sigma_u C_{TF}Z_p\bar{t})/Q^2 = (v + C_{TV})C_r/2$$

Therefore, the optimal Economic Order Quantity Q^* is,

$$Q^* = (2(C_{TF}\bar{t}D + C_r\sigma_u C_{TF}Z_p\bar{t}) / C_r(v + C_{TV}))^{0.5} \qquad ...(4.6)$$

To determine whether a solution to the first partial derivative is a maximum or minimum, the second partial derivatives can be investigated. If the second partials evaluated at the solution vector Q^*, where the first partials are equal to zero, meet the following condition, Q^* define a minimum,

$$\frac{d^2C}{dQ^2}(Q^*) < 0$$

$$\frac{d^2C}{dQ^2} = -2(C_{TF}\bar{t}D + C_r\sigma_u C_{TF}Z_p\bar{t})/Q^3$$
$$= -C_r(v + C_{TV})^{2/3}/(2(C_{TF}\bar{t}D + C_r\sigma_u C_{TF}Z_p\bar{t}))^{0.5} \quad ...(4.7)$$

Thus the total cost C is minimum when the value of Q^* is as in equation 4.5. In this procedure, solutions must be found for each transportation alternative separately before a final choice can be made.

4.6. Solution procedure

The computer program used in applying the above procedure to the available data is shown in Appendix A. A sample output is shown in Appendix B. The program calculates the cost components and the economic order quantity for a particular mode for a given distance. Thus the program is run several times for data of different modes of transport and different distances between the source and the destination. The most economical mode for any distance is obtained by comparing the outputs for different modes for that particular distance.

CHAPTER 5

DATA NEEDED AND AVAILABLE DATA

5.1. Assumptions for the problem

To reduce the problem to solvable proportions, simplifying assumptions are necessary. The complexity of the mathematical problem and difficulty in getting properly recorded data must both be considered. For this study the assumptions and numerical values chosen generally represent industrywide average estimates and are arrived at after discussions with professionals in the marine log transport industry.

1) The acquisition of the capital necessary to purchase equipments, tug boats, barges and ships is usually obtained in many ways, but it is assumed that these used in the problem are purchased outright.

2) The depreciation method is a straight line one for the capital cost and no interest is earned on the money set aside over the period.

3) The salvage value is considered to be zero. It is a fact that under some situations the salvage value may actually be more than the initial capital costs. These possibilities and uncertainties have been omitted.

4) Timber markets are sufficiently active to consume the quantities handled and resources are adequate to meet those demands.

5) The available methods used for log transportation are: flat raft, bundle boom and log barge or ship.

6) For this particular study it is considered that a log is transported to a certain mill from only one source (a central sort) and there are no other stoppages on the way.

7) Lead time for each mode of transport is independent of the quantity carried.

8) Normal approximation is satisfactory for realistic demand over lead time distribution.

9) Stochastic elements in the problem satisfy a poisson distribution.

5.2. Assumptions for transportation modes

The following is a detailed list and description of the assumptions made for each of the marine transportation modes:

5.2.1 Flat raft

The maximum horse power for tugs pulling a flat raft is about 1000 bhp, as large tugs can literally pull the rafts apart. The fuel consumption of .4 lbs per bhp-hour is considered in this case. Travel time variation is assumed as a minimum of 24 hours because of tow's susceptibility to weather delays. As the distance of the tow increases so does the chance of encountering poor weather. No further delay is assumed for distances of 125 miles or less while an one week delay is assumed for a 250 mile tow, and a 2 to 3 weeks delay for 500 miles tow. These delay times would in practicebe shorter during summer months and longer during winter months.

5.2.2 Bundle raft

The maximum horse power for this mode is 2000 bhp with the value of fuel consumption is .36 lbs per bhp-hour. Similar assumptions for variable travel time are used here as for flat raft.

5.2.3 Log barge/log ship

For barges, bhp ranges from 2000 to 3000 with fuel consumption rate of .35 lbs per bhp-hour. All barges are assumed to be self loading and self dumping. Horse power for two different ships is taken as 7,200 and 5,750 bhp. A consumption of .3 lbs per bhp-hour for 85-90% of the total power is assumed to be required under normal conditions. The reserve power is used only during severe storm conditions. The variation in travel time is negligible for both barge and ship and is considered to range between 3 to 6 hours depending on trip lengths. For distance, the variable time for barge has been considered 3% higher than variable time for ships (Talbot & Brown).

5.3. Cost assumptions

The values assumed for each mode are summerized in Table-5.1. Some other assumptions are made as follows:

Capital cost: represents the average costs to build each vessel in 1982 $ value.

Interest: is assumed at 15% per annum of the capital cost.

Depreciation: is assumed as a straight line depreciation over a 15 year period. No interest on the money set aside has been considered.

Useful life: is assumed as 15-20 years for all the vessels. It should be noted that some vessels last longer (up to 30 years) and high interest

Table 5.1

Characteristics of Different Modes of Transport

Trans. Mode	Cap. Cost (in million $)	Useful Life (years)	Max. Load Cap. (tons)	Engine B.H.P.	Fuel Cons. (lb/bhp-hr)	Maint. Cost in $ ($x10^3$) (per Year)	Crew size	Wages (av. /head /day in $)	Food Cost ($/head /day)	Av. Speed (Knots)	Load. Time (hrs.)	Dump. Time (hrs.)
Flat Raft	1-1.5	15-20	10,000	500-850	.34-40	30-40	5	95	20	1.5 Towing 10 Tug only	8 hours to make 60-80 sections	2
Bundle Boom	1-1.5	15-20	25,000	1000-1400	.36	60 plus $60 per running day	5	97	20	1.5 Towing 10 Tug only	8 hours to make 60-80 sections	2
Log Barge	6 for tug 18 for barge	15-20	8-19,000	2000-3000	.35	400	8-9	97	20	8-Ld'd. 10-Empt.	4-6 bundled 10-14 loose	3
Log Ship	25	15-20	15,000-1 10,000-2	7200-1 5750-2	.30	400-450	13	85	20	10.5 Ld'd. 12.5 Empt. 10.0 Ld'd. 12.0 Empt.	6 b'd'd-1 14 lse -1 4 b'd'd-2 10 lse -2	3

rates might favour retrofitting and repairs over the purchase of new equipment.

Maximum load capacity: is assumed as, 10,250 tons for flat rafts; 25,000 tons for bundle rafts; and the maximum designed capacity for barge or ship.

Engine: gives the range of sizes for each mode with the high and low values used to calculate the maximum and minimum costs for flat and bundle rafting.

Fuel consumption: is given as lbs per horse power-hour, which is an industry recognized measurement of engine efficiency. Smaller engines are generally less efficient than the larger ones.

Fuel cost: it is assumed that one Imperial gallon of S-M diesel weighs 9 lbs and the average price of one Imperial gallon is $1.65.

Maintenance cost: represents the costs of an average year in dollars.

Insurance cost: is assumed at an annual rate of 2% of the appraised value of the vessel.

Crew size: is given as required by law and or safe watch keeping practice while at sea.

Wages: are taken from CMSG and SIU Oct. 1981 - Sept. 1982 agreements and are charged out at the daily rate with no excess hours.

Food cost: is assumed as $20 per man per day.

Average speed: is shown in knots for both loaded and empty vessels.

Loading time: is the actual time required to either make a tow or load a barge with loose or bundled logs.

Dumping time: is the actual time required to either disconnect the tug from a tow or dump a barge.

In-transit inventory carrying cost: is the cost of having the logs while in

transit and is calculated assuming a log cost per ton and an interest rate.
Inventory carrying cost: is the combined cost of interest on inventory and the maintenance and obsolecence cost.
Cost due to log losses: is the cost incurred due to log losses by sinkage or escapage.
Bundling cost: The bundling cost per ton for Hemlock has been considered to be $1.35 and for 'Other than Hemlock' to be $1.80.

5.4. Cost data for this study

Since specific data for one barge and two ships having different costs and capacities are available, five modes of transport has been considered in this study. The modes are: (i) Flat raft having capacity of 12500 tons, (ii) Bundle boom with 25000 tons capacity, (iii) Log barge of capacity 15000 tons, (iv) Log ship of capacity 10000 tons, and (v) Log ship of capacity 15000 tons. The cost and other data for each mode are summerized in Table-5.2.

Log losses depend on many variables. They include species, size, source, time of year, handling method, distance transported, and time in storage. The handling method for logs has been considered as water bundled and mill pond broken. The value of log losses during handling as a percent of total log handled is taken from Table-5.3. Since the log ship with 15000 tons capacity loads the logs with cranes without bundling the logs, a loss of 4% during loading has been considered.

Total log losses during transportation in case of barges and ships are considered to be zero. In case of flat raft and bundle boom, log losses during transportation is considered as a function of the total travel

TABLE - 5.2

Characteristics Considered for Different Modes of Transport

Trans. Mode	Cap. Cost (in million $)	Useful Life (years)	Max. Load Cap. (tons)	Engine B.H.P.	Fuel Cons. (lb/bhp-hr)	Maint. Cost in $ $(\times 10^3)$ (per Year)	Crew size	Wages (av. /head /day in $)	Food Cost ($/head /day)	Av. Speed (Knots)	Load. Time (hrs.)	Dump. Time (hrs.)
Flat Raft	1.5	17	10,250	675	.37	35	5	95	20	1.5 Loaded 10 Empty	16	2
Bundle Boom	2.0	17	25,000	1200	.37	72	5	97	20	1.5 Loaded 10 Empty	24	2
Barge	21.5	17	15,000	4950	.35	400	9	97	20	9 Loaded 11 Empty	6	3
Ship (10,000t)	25.0	17	10,000	4600	.30	400	13	85	20	10 Loaded 12 Empty	6	3
Ship (15,000t)	20.5	17	15,000	5760	.30	400	13	85	20	10.5 Loaded 12.5 Empty	16	3

TABLE 5.3

Log Loss During Handling As a Percent of Total Log Handled

Handling Method	Hemlock	Other than Hemlock
Water Bundle/Mill Pond Break	4.2	.36

(SOURCE: Poulton & Hughes - 1980)

TABLE 5.4

Log Loss Per Day During Transportation As a Percent of Total Log Handled

Type of Log	Mode of Transport	
	Flat Raft	Bundle Boom
Hemlock	2.4	.7
Other than Hemlock	.92	.1

time. The values assumed are shown in Table-5.4.

Regarding loss due to teredo damage, it has been considered that if the logs remain in water for less than 16 weeks, damage is negligible. When time in water ranges between 16 to 24 weeks, the loss in percent of the log handled is considered to increase gradually according to straight line equation:

(.1339 x TTZ -15)

where, TTZ = Total time the log spends in water.

Similarly, when time in water is more than 24 weeks, the eqation for log losses in percent of log handled is given by:

(.0897 x TTZ - 7.6)

where, TTZ = Total time the log spends in water.

Regarding the number of trips a particular mode has to make to bring the logs from the source to the destination, the following way has been adapted in this study based on the economy of making the trip:

After making each trip, the remaining balance in the sorting yard to supply the economic order quantity to the mill is calculated. Then checking is done to find whether it would be economical to have another trip or to purchase the balance requirement from the local market. The value at the local market is considered twice the value of log at the sorting yard.

CHAPTER 6

ANALYSIS OF THE RESULTS

6.1. Introduction

Total transport - inventory cost for a mill per year for a particular mode of transport on the coastal water of B.C. depends on factors such as: distance between the source and the destination, average daily demand and the lead time demand variation of the mill, type of log being required, weather conditions, size of each shipment, time waiting for sort or sufficient volume to transport, etc. The objective of this study is to decide, which among the available modes of transport, would be the most economical.

The selection of the factors to be investigated is based on the potential effect of the factor on the overall decision process. The three factors selected are the mean daily demand, the distance between the source and the destination and the type of log.

Total amount of log to be transported to a particular mill depends on the average daily demand of the mill. Depending on the demand, the number of trips would be small or large and so would be the total cost.

Distance between the source and the destination is a factor which has a great influence on the total cost. With distance, the travel time and the variablity of travel time increases, which increases the total cost.

Different types of logs have different values in the market. Also, they have different densities and other physical characteristics, which determines their sinkability. Amount of log loss has a tremendous effect on the total cost and log loss depends on the type of log being handled.

The daily demand is chosen to range between 100 tons per day and 3000 tons per day with additional analysis at 1000 and 2000 tons per day. Distances between the source and the destination considered are: 50, 100, 200, 300, 400 and 500 nautical miles. Flat rafts are never used beyond a distance of about 200 n.miles. But, in this study it has been considered as a transport mode beyond that distance for purely academic interest.

Total costs for different modes are calculated for three conditions of travel time:

1. Without considering the variable time at all, which means that all the modes cover the distances without any delay.
2. Travel time is considered to consist of the usual travel time according to the speeds of the mode (basic time) and the mean variable time due to delays.
3. Travel time is considered to consist of the usual travel time according to the speeds of the modes (basic mode), the mean variable time due to delays, and twice the standard deviations of the variable time.

In the case of barge and ships, the variable time is very small even when the distance between the source and the destination is long. This is because these modes are almost independent of bad weather conditions. But, for modes such as flat raft and bundle boom, which are susceptible to bad weather conditions, variable times may be long. Given the weather conditions along B.C.'s coast, it would be improper not to take the variable times into consideration while calculating the total costs. Thus, even though total costs for all three cases have been calculated, results considering the variable time with two standard deviations have been analyzed in this study.

6.2. Analysis

The most economical mode of transport for a given distance is the one which gives minimum cost for that particular distance. Thus, after drawing the total cost - distance curves for different modes of transport, the minimum cost curve can be traced out by joining the lines showing the minimum costs as shown in the Fig. 6.1. It is possible that for different distances, different modes give the minimum cost. For example, Fig. 6.1 shows the cost - distance curve for three different modes of transport A, B, and C. From the figure, it is seen that the mode A gives the minimum cost for distance between O to D, mode B between D to E, and mode C beyond E. Thus, OLMN represents the minimum cost curve.

The variations of total cost with distance for different modes of transport when the type of log is Hemlock are shown in Figures 6.2 through 6.5, for average daily demands of 100, 1000, 2000 and 3000 tons respectively. It can be seen that in most of the cases, barge is the most economical mode of transport. In certain cases, e.g., when the demand is 100 tons per day (Fig. 6.2), log ship of capacity 15000 tons is cheaper than barge , but the difference is almost negligible.

The variations of total cost with distances for different modes of transport when the type of log is 'other than Hemlock' are shown in Figures 6.6 through 6.9, for average daily demands of 100, 1000, 2000, 3000 tons per day respectively. In all the cases it is seen that different modes

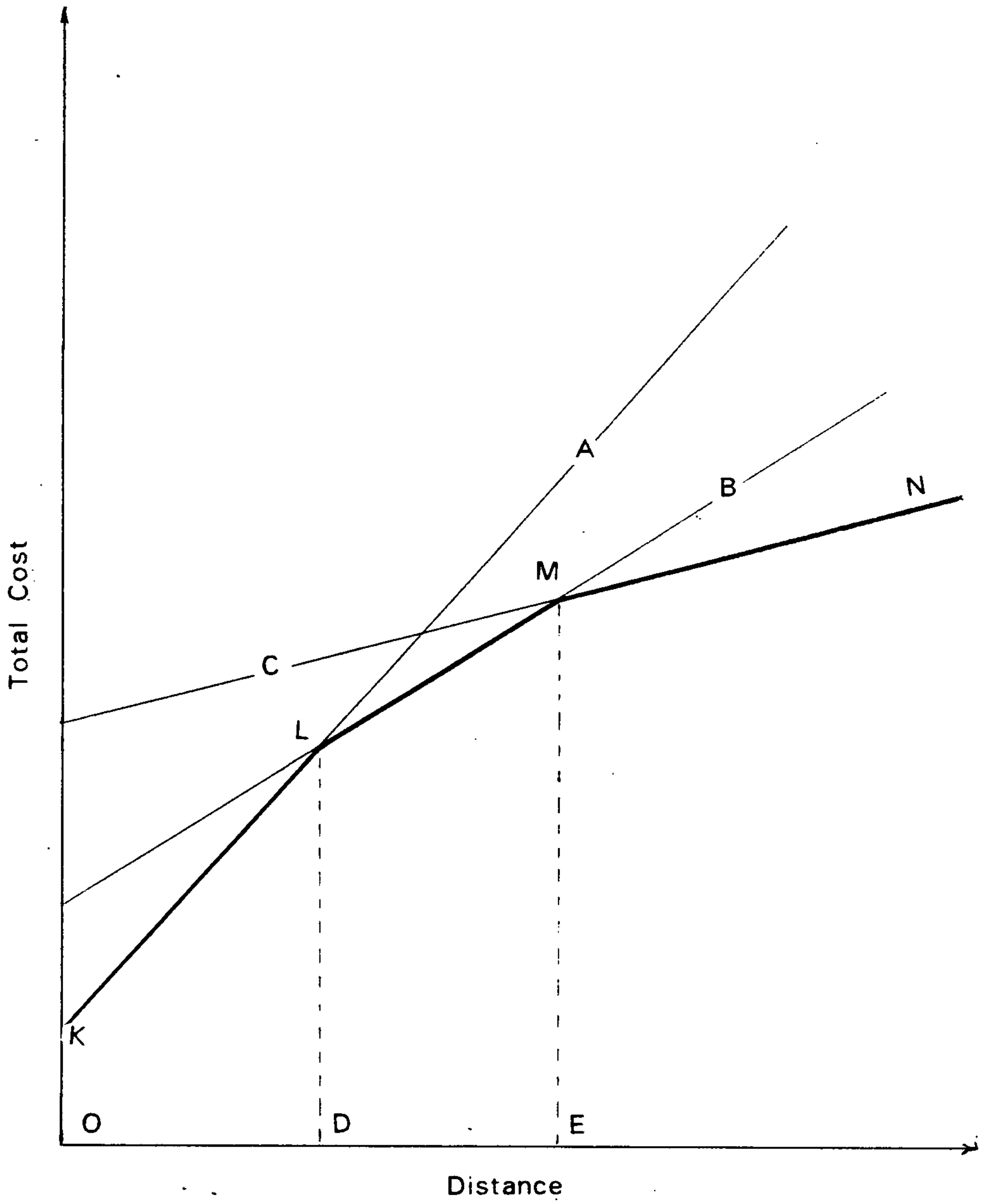

Fig 6.1

Minimum Cost Curve for different Modes of Transport

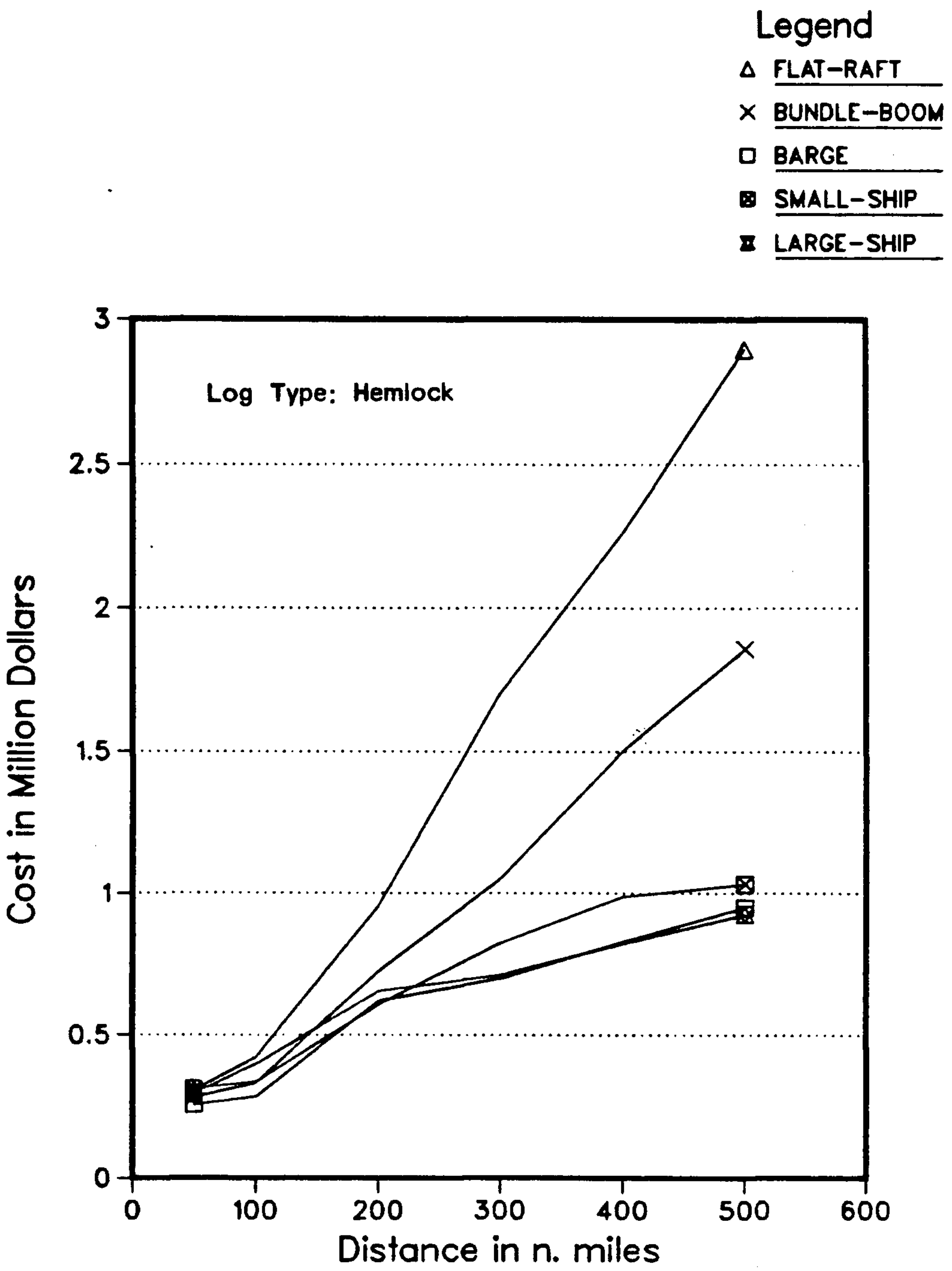

Fig 6.2

Cost Curves for Different Modes of Transport

When Average Daily Demand is 100 Tons.

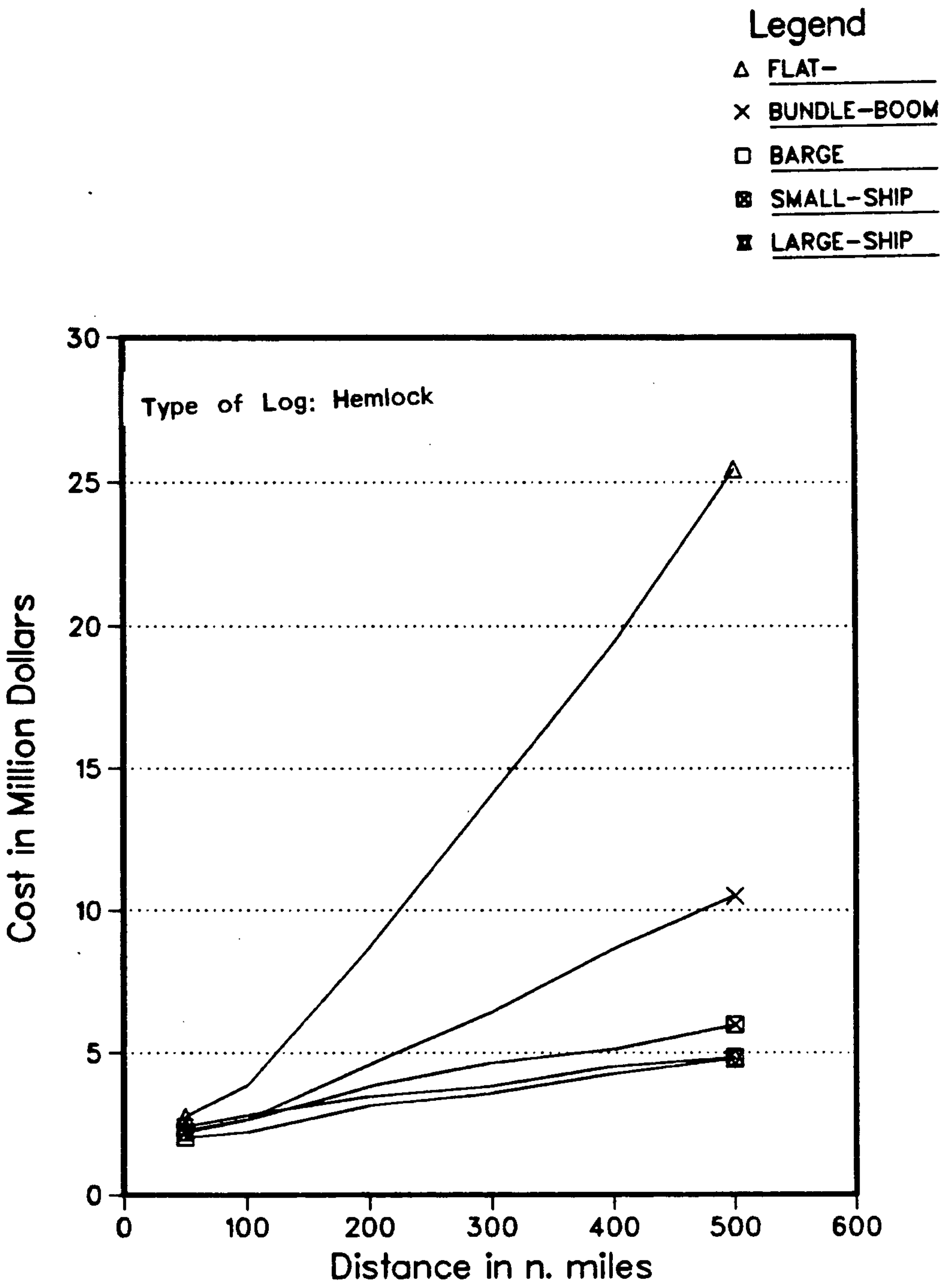

Fig 6.3

Cost Curves for Different Modes of Transport

When Average Daily Demand is 1000 Tons.

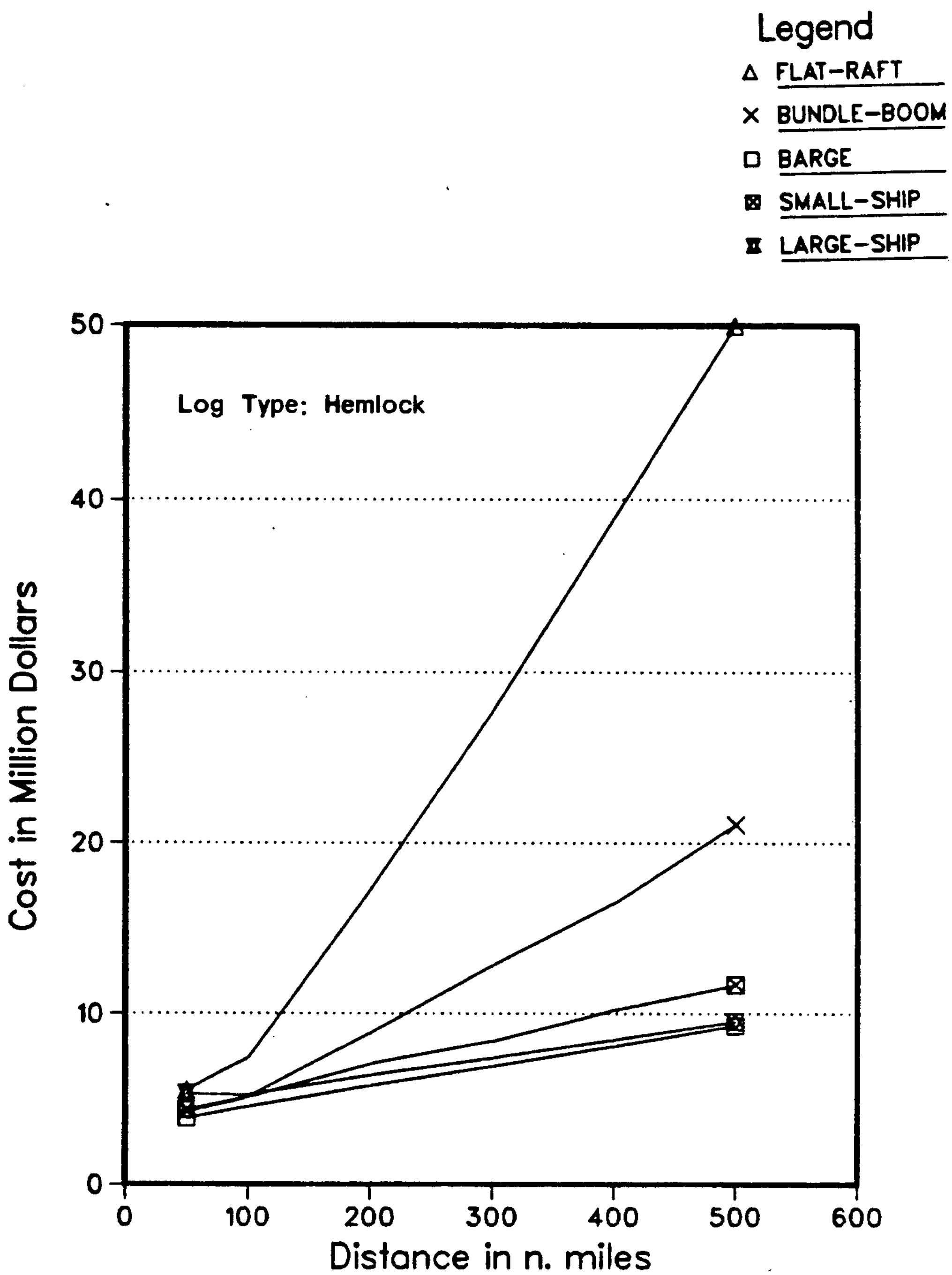

Fig 6.4

Cost Curves for Different Modes of Transport

When Average Daily Demand is 2000 Tons.

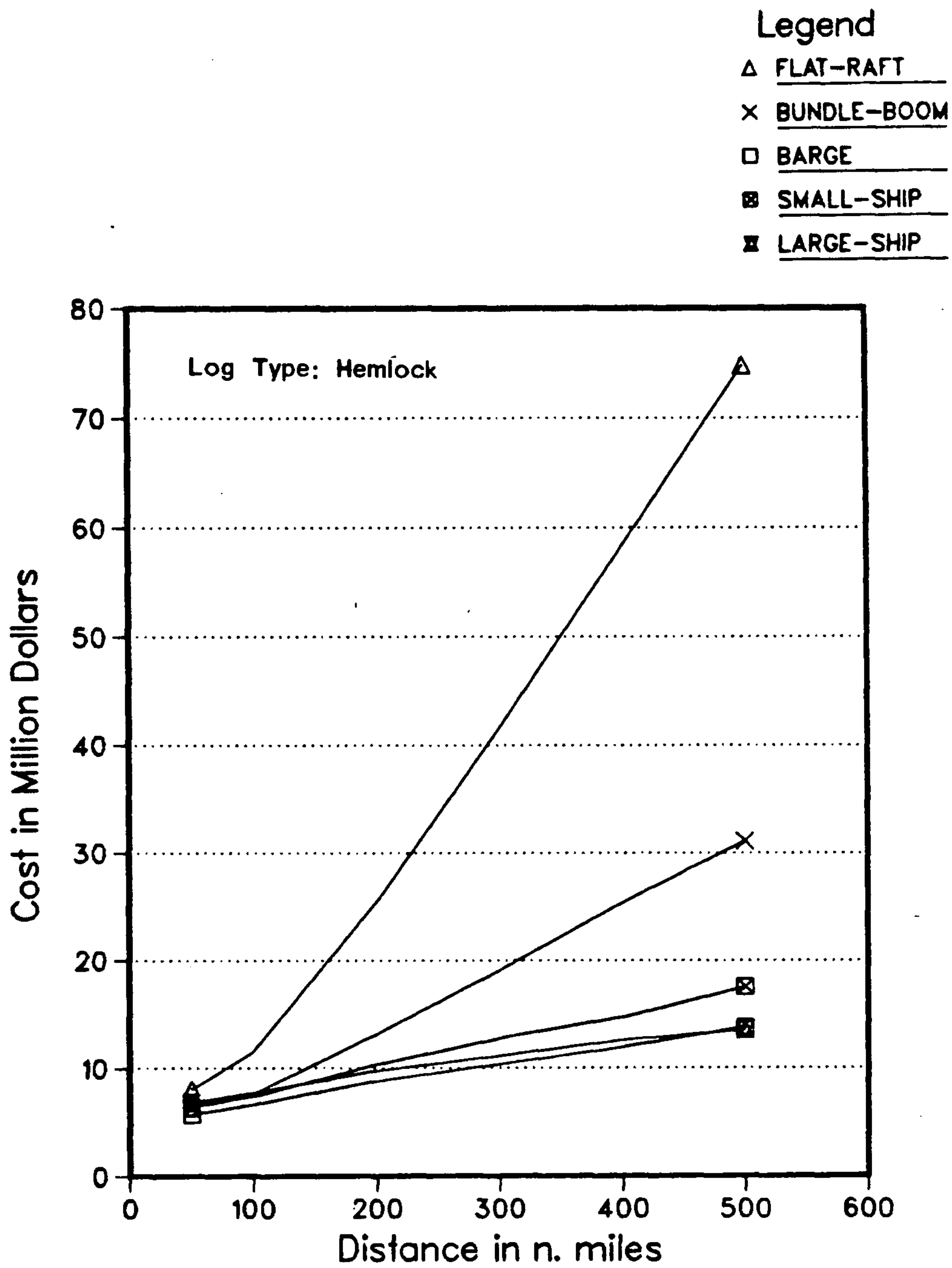

Fig 6.5

Cost Curves for Different Modes of Transport

When Average Daily Demand is 3000 Tons.

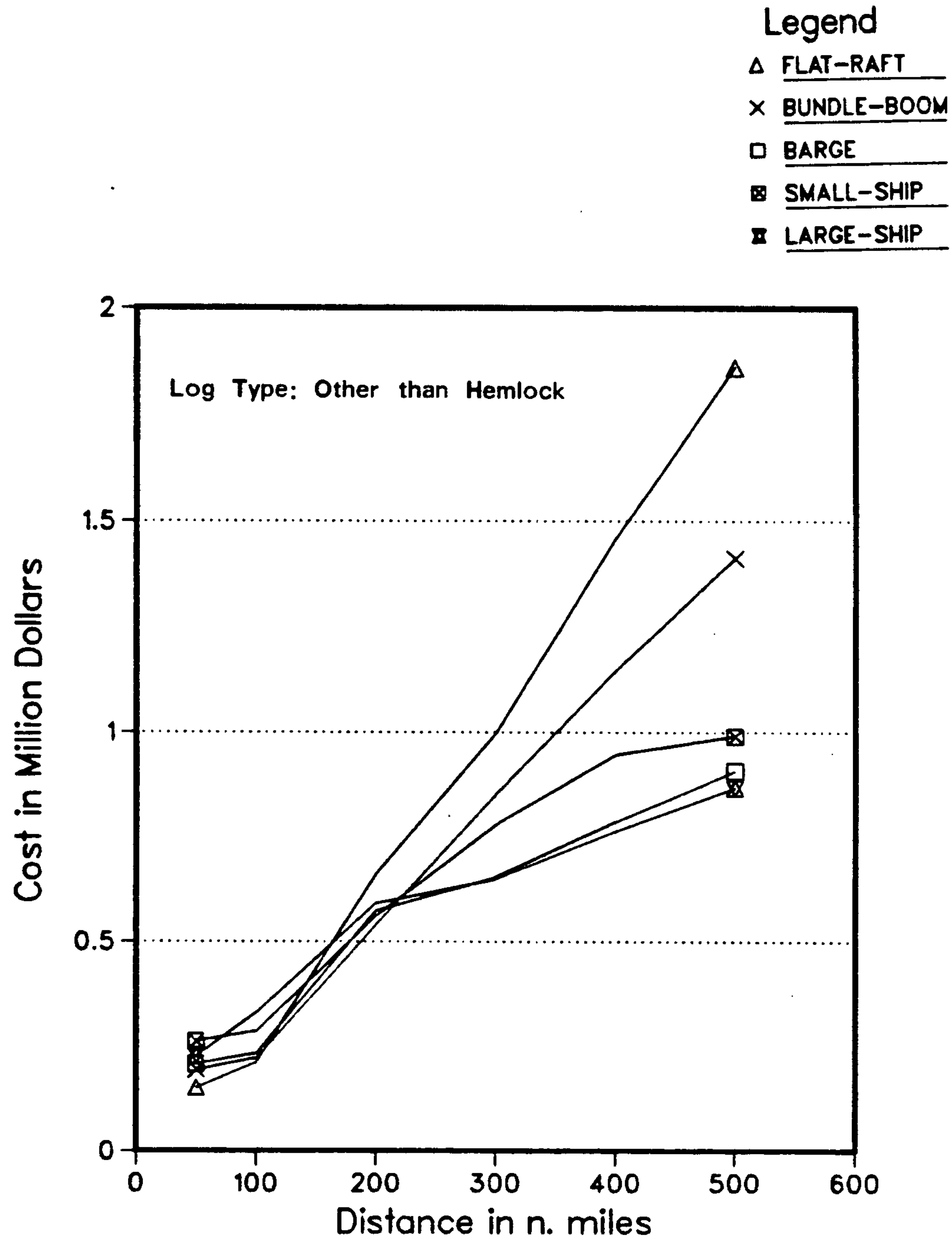

Fig 6.6

Cost Curves for Different Modes of Transport

When Average Daily Demand is 100 Tons.

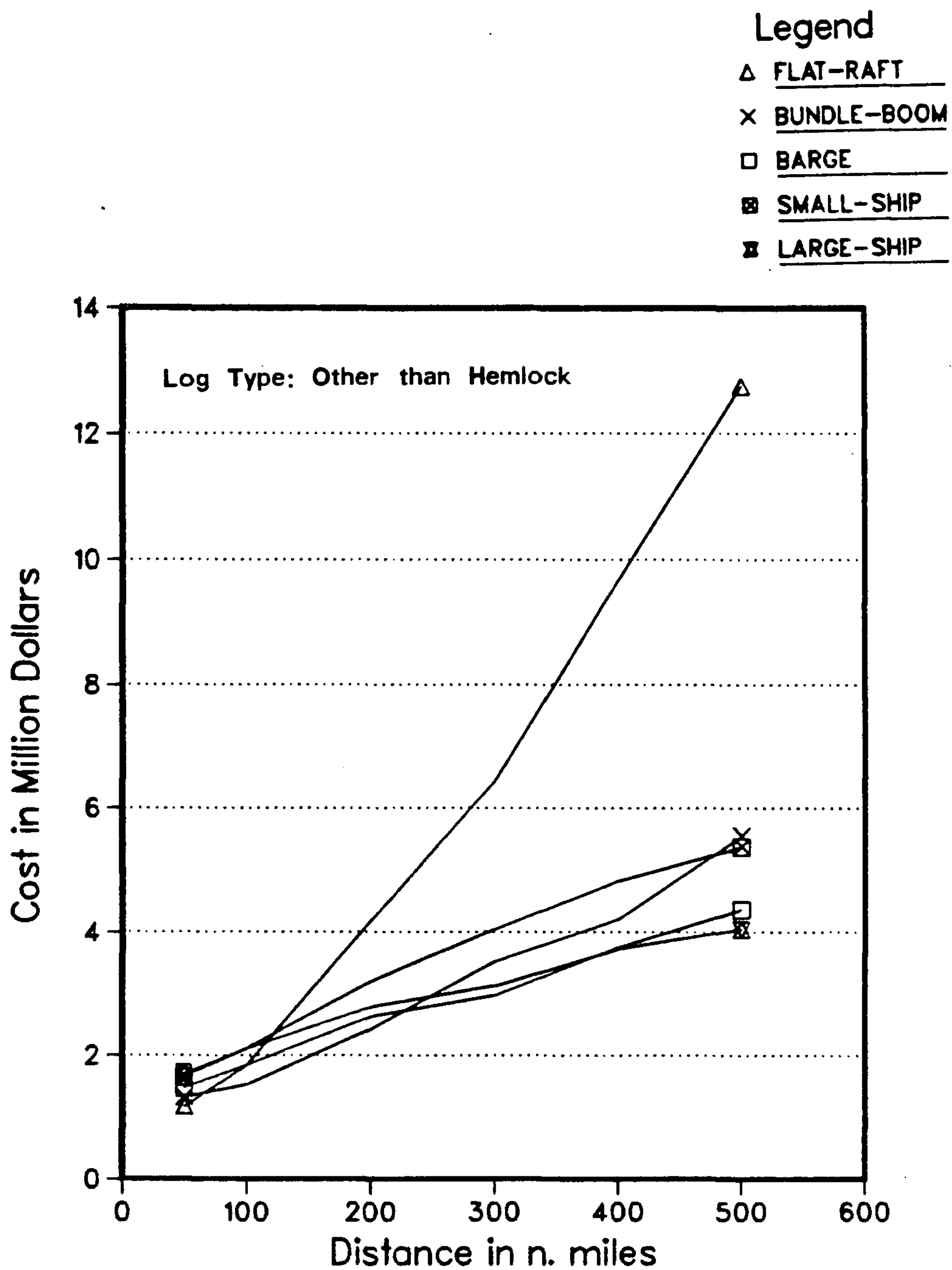

Fig 6.7

Cost Curves for Different Modes of Transport

When Average Daily Demand is 1000 Tons.

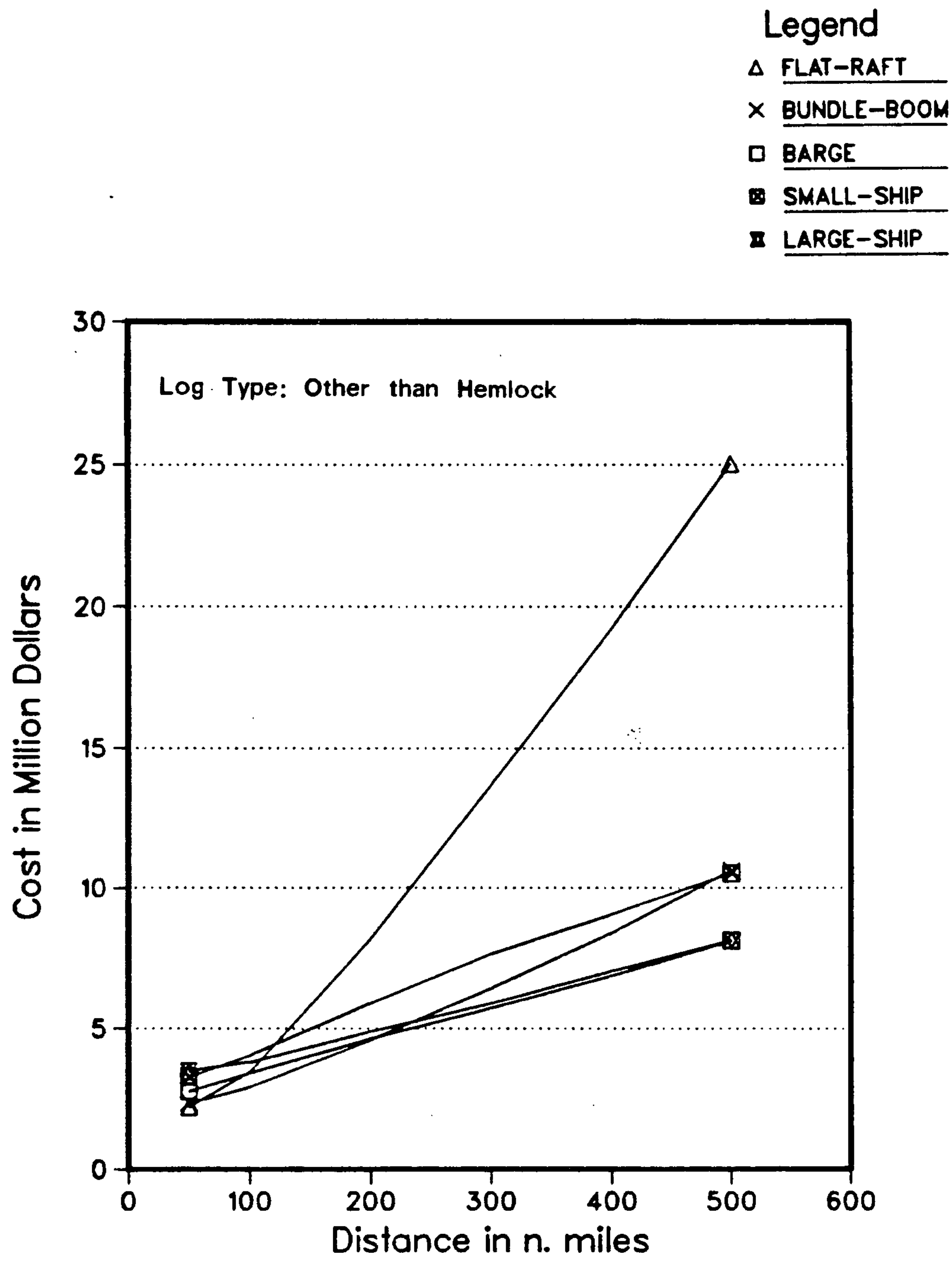

Fig 6.8

Cost Curves for Different Modes of Transport

When Average Daily Demand is 2000 Tons.

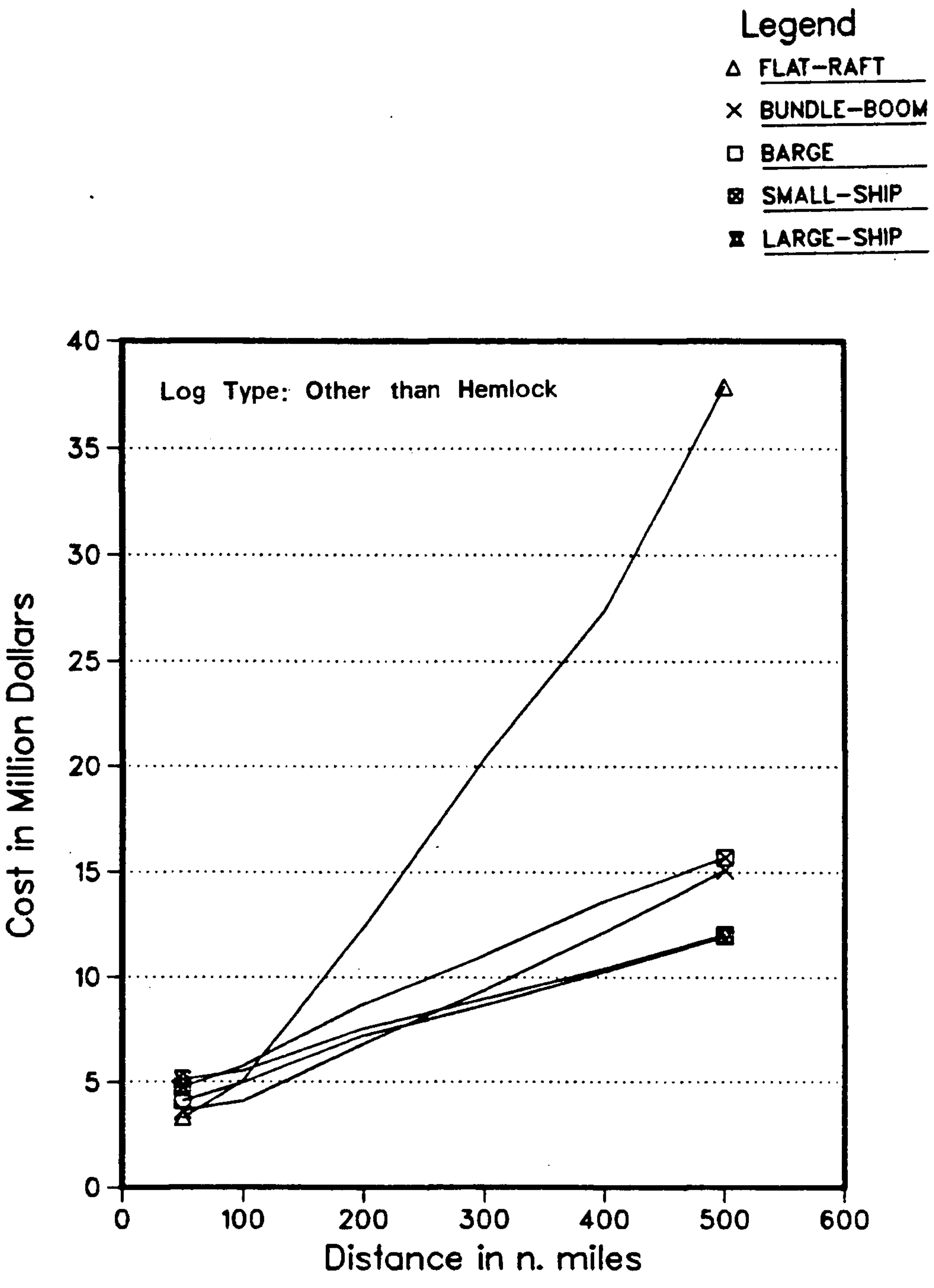

Fig 6.9

Cost Curves for Different Modes of Transport

When Average Daily Demand is 3000 Tons.

are economical for different distances between the source and the destination.

When daily demand is 100 tons per day, flat raft is the cheapest mode upto a distance of 100 n. miles, bundle boom between 100 to 220 n. miles, barge between 220 to 250 n. miles, both barge and ship (15000 tons) between 250 and 300 n. miles, and ship (15000 tons) beyond 300 n. miles(Fig 6.6). When daily demand is 1000 tons per day, flat raft gives the minimum total cost upto a distance of about 70 n. miles, bundle boom between 70 to about 225 n. miles, barge between 225 to about 385 n. miles and ship(15000 Tons) beyond 385 n. miles(Fig. 6.7). For daily demand of 2000 tons per day, a flat raft is the most economical from a total cost point of view up to a distance of about 65 n. miles, bundle boom between 65 and 215 n. miles, barge between 215 and 500 n. miles(Fig. 6.8). When the daily demand is 3000 tons per day, flat rafts give the minimum total cost up to a distance of about 60 n. miles, bundle boom from 60 to about 235 n. miles, and barge beyond 235 n. miles.

The cost difference between the barge and the ship(15000 tons) is small because: (a) both have the same capacity, (b) bundling cost of the logs in the case of a barge is almost balanced by the cost during loading because of log losses and high loading time in case of a 15000 ton ship.

It can be seen from all the figures that when the distance is small, the variations of total cost among the modes of transport are not very much. Costs for flat raft and bundle boom increase at a high rate with increase in distance. Because, greater the distance, greater is the variation of travel time, and thus higher the loss.

Total operating costs per day varies with the type of mode being considered. The values for flat raft, bundle boom, barge, logship(10000 tons) and logship(15000 tons) are respectively $2745.00, $3980.00, $23715.00, $24745.00 and $23360.00. Thus, flat raft and bundle boom are very cheap in operating cost per day compared to barge and logships. But, for most of the cases barge or logships give minimum total costs because: (a) speed of the loaded barge or ship (between 10.5 to 12 n. miles per hour) is very high compared to flat raft and bundle boom(about 1.5 n. miles per hour); (b) barge or ships are not susceptible to bad weather conditions, whereas flat raft and bundle booms may have to wait for months because of unfavourable weather conditions when crusing; (c) log losses during transportation is almost zero in case of barge and logships, whereas losses are most in flat rafting, and quite high in case of bundle booms, depending on the type of log being transported.

The daily operating cost for ship(10000 tons) is the highest among all the modes because of its high capital cost. Since this is the most recent one among the ships and barges considered in this study, it is equipped with all the modern facilities including the on-board cranes having lift capacity of 40 tons each. So the capital cost of the ship(10000 tons) is high.

It is seen from the results that for each mode, with the increase in distance, the ratio of the transportation cost to the total cost increases. In case of flat raft the increase is not very much. For example, considering demand of 'Hemlock' of 3000 tons per day, transportation cost conatitutes 14% of the total cost when the distance is 50 n. miles; whereas for distance of 500 n. miles the value is 17.5%. For the same demand and same distances, the values for bundle boom are 13% and 26%, for barge are 28% and 66%, for ship(10000 tons) are 34% and 73%, and for ship(15000 tons) are 29% and 62%. Similar variations are also seen for other demands. Thus for barges and ships, transportation cost is the major cost when the distance is high, whereas inventory cost is the most predominant in case of flat raft and bundle boom. The value for ship(10000 tons) is the maximum for both the distances because of its high operating cost and comparatively low capacity. For the same demand and same distance the ship(10000 tons) must make more trips when compared with barge or ship having capacities of 15000 tons, and the daily operating cost of ship(10000 tons) is higher than for barge or ship (15000 tons) in this particular case.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1. Introduction

Economical transport of logs on the coastal water is a key factor in the growth of the coastal wood industries of British Columbia. Transportation is an intermediate stage in the overall process consisting of cutting, sorting, scaling, and conversion. This study focusses on the transportation component of the overall system.

7.2. Log Transportation on the Coastal Water

Because of the rugged nature of the coastal line, roads and railroads parallel to B.C's coastline are virtually nonexistant. This geographical feature historically encouraged the development of water transport of logs. The modes of log transport used along the B.C coastal waters include: tug pulling logs loose with a boom called a flat raft, bundles of logs held together by wire rope and grouped together as loose bundles within a boom known as bundle raft, tug–barge which may be self loading and self dumping, and log ships.

7.3. Objective of the Study

The particular problem chosen in this study is a transport -inventory selection problem, which means the selection of the mode of transport from the available modes in order to minimize the sum of the transportation and inventory costs.

7.4. Transport-inventory selection Model

The mathematical model developed determines the various costs, including the total cost per year for a particular mode of transport at a time for different demands per day and different distances between the source and the destination. The output shows the results for two types of logs: (a) Hemlock, and (b) Other than Hemlock. Also, the costs are calculated for three types of travel times, i) travel time without considering variable time, ii) travel time with mean variable time, and iii) travel time with mean variable time and twice the standard deviation of the variable time.

The total cost in a year in this model has been considered to be the sum of: transportation cost, inventory cost, in-transit inventory cost, and safety stock carrying cost. Five different modes of transport are considered baseing on the load capacity and the availability of suitable data. The modes considered are: flat raft, bundle boom, barge of capacity 15000 tons, log sships of capacities 10000 tons and 15000 tons. The model does not consider a combination of different modes to get the minimum total cost, but considers a single mode at a time.

7.5. Conclusions

The following conclusions can be drawn from this specific study:

(1) Of the total cost in a year, transportation cost constitutes the major cost in case of barge and log ships, whereas total inventory cost is in case of flat raft and bundle boom, it is the total inventory cost.

(2) Bad weather is the major factor causing an increase in total cost for flat rafts and bundle booms.

(3) Total cost in a year depends not only on the mode of transport, but also on the capacity of the mode. When daily demand is high, it is economical to use large capacity vessels.

(4) Depending on the type of log being transported, and daily demand of log at the mill, the modes of transport to be selected varies with the distance between the source and the destination.

CHAPTER 8

SCOPE FOR FURTHER RESEARCH

8.1. Introduction

The suggestions for additional study are divided into three parts. The first part concerns the modification of the input data for testing the validity of the model for different conditions. The second part concerns modifications to the model used in this study. The third part is concerned with the development of alternative models incorporating changes in the basic assumptions.

8.2. Modification of Input Data

The area of applicability of the method can be examined by testing additional data. The data tested should be of two types. First, various theoritical distributions may be used for the demand and lead time distributions to observe if the performance is affected by the form of the demand and lead time distribution for each transport alternative within the field of this study. A second set of data could be gathered describing actual situations for a different case. Thus the performance of the model can be checked for different operating situations.

8.3. Modification of the Model

The second suggestion is concerned with the modification of the transport-inventory selection model to broaden its usefulness to the practitioner. These include introducing the exact cost of possible lost sales.

Another modification could be to see if, for a particular distance, a combination of different modes give lesser total cost than a single mode.

8.4. Alternative Models

The third part of the suggestions concern the major modifications that would change the model radically. The model can be modified to include several sources and destinations instead of one source and one destination as has been considered in this study. Also, it might be possible to find the effect of introducing some intervening sorting yards with delay times in this model. This particular model has been developed considering mean of the seasonal variable times. Also, overall mean of some other values like loss due to teredo damage has been considered. It would be more realistic to vary the delays and losses according to seasonal variations.

BIBLIOGRAPHY

1. Ash, L.L. and Yager, S. (1977), *A Design Methodology for Improving An Existing Commodity Collection or Distribution System,* **Logistics and Transportation Review**, Vol. 13, No. 12.

2. Baumol, W.J. and Vinod, H.D. (1970), *An Inventory Theoritic Model of Freight Transport Demand,* **Management Science**, Vol. 16, No. 7, March, pp. 413-421.

3. Beil Kenneth E. (1974), *The Economics of Rafting Vs. Barging As Means of Transporting Logs in Southeast Alaska Waters,* A Study1 by International Forestry Consultants, Ins, Seattle, for the **Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service, Portland** , Contract No. 19-200.

4. Boyd, Kenneth G. (1979), *Water Transport of Wood: B.C. Coast,* **Pulp and Paper Canada**, Vol. 80, No. 11, November, pp. 28-34.

5. Constable II, Gordan K. (1972), *Formulation and Solution of the Inventory - Transport Selection Problem,* thesis submitted to the **Faculty of Purdue University** in Partial Fulfillment of the Requirement for the Degree of Doctor of Phylosophy.

6. Constable, Gordon K. and Whybark D. Clay, (1978), *The Interaction of Transportation and Inventory Decisions,* **Decision Sciences**, Vol. 9, No. 4, October, pp. 688-699.

7. Cottel, Philip (1977), *Introduction,* Proceedings of **Coastal Log Handling and Transportation**, December 8 & 9, Parksville, B.C..

8. Crawford, S. (1981), *MB Log Bundling Costs and Techniques,* **B.C. Lumberman**, March, pp. 24-25.

9. Das, C (1974), *Choice of Transport Service: An Inventory Theoritic Approach,* **The Logistic and Transportation Review**, Vol. 10, No. 2, pp.

181-187.

10. Duval, W.S. (1980), *A Review of the Impacts of Log Handling on Coastal Marine Environment and Resources,* Prepared for the **Environmental Review Panel of the COFI/Government Estuary, Foreshore and Water Log Handling and Transportation Study.**

11. Duggleby, J. (1980), *Dryland Sorting in the Chuck ....CZ's Goliath Bay,* **B.C. Lumberman**, November, pp. 13-14.

12. Erdle, T.A. et al. (1981), *Optimizing Pulpwood Inventories at Roadside, Millyards and Concentration Yards: A Case Study,*Proceedings of the **XVII IUFRO World Congress**, Kyoto, Japan, (September 6 to 17).

13. Glosten, Lawrence R. and Heyrman, Jacques S. (1965), *Offshore Barge Transportation on the Pacific Coast,* Paper Presented for the Conference of **Society of Naval Architecture & Marine Engineering**, November 11-12, Paper No. 10.

14. Heathway, D. (1975), *Water Carriers Cautious as Financial Woes Ease,* **B.C. Lumberman**, November, pp. 31-32.

15. Henderson, R.D. (1977), *Alternative Methods and Equipment for Log Barge Operation,* Proceedings of the Seminar on, **Coastal Log Handling & Transportation**, December 8 & 9, Parksville, B.C.

16. Johnson, L..W. (1981), *A New Log Barge for Riv Tow,* **B.C. Lumberman** , March, pp. 20-25.

17. Johnson, L.W. (1982), *Flagship of the Riv Tow Fleet,* **B.C. Lumberman**, March, pp. 20-25.

18. Julseth, C.P. (1977), *Factors Affecting Productivity and Cost of Log Towing,* Proceeding of the Seminar on, **Coastal Log Handling & Transportation**, December 8 & 9, Parksville, B.C.

19. Karau, John (1975), *Water Transport of Wood: The Current Situation,*

Water Pollution Control Directorate, Environment Protection Service, **Environment Canada**, Report No. EPS 3-WP-75-3.

20. Lusk, W.D. (1977), *Factors Affecting Productivity and Cost of Barging Logs,* Proceedings of the Seminar on, **Coastal Log Handling & Transportation**, December 8 & 9, Parksville, B.C.

21. Martin, B. (1977), *The Future is a Question Mark,* **B.C. Lumberman**, March, pp. 14–17.

22. Martin, B. (1978), *The Costs Just Keep Going Up?,* **B.C. Lumberman** , February, pp. 14.

23. Martin, B. (1979), *Towboaters Enjoy Buoyant Economy,* **B.C. Lumberman**, February, pp. 16 & 19.

24. Martin, B. (1979), *Gulf Log Salvage Fading Enterprise?,* **B.C. Lumberman**, February, pp. 14–15.

25. Ministry of Forests (1982), *Ministry of Forests Annual Report 1981-82,* Province of British Columbia.

26. Ministry of Forests (1983), *Ministry of Forests Annual Report 1982-83,* Province of British Columbia.

27. Murray, A. et al. ------, *Losses in Pulp Yield and Quality Resulting from 'Teredo' Attack on Logs Stored in Sea Water,* **B.C. Research Council** , Report No. 314.

28. Navin, F.P.D. and McNabb, M. (1982), *Log Transport Along B.C. Coast Waters,* Unpublished Draft Report, **Department of Civil Engineering, University of British Columbia**, Vancouver,B.C.

29. Oakley, P. (1977), *The Future of Coastal Log Handling and Transportation,* Proceeding of the Seminar on, **Coastal Log Handling & Transportation** , December 8 & 9, Parksville, B.C.

30. Poulton, M.C. and Hughes, J.R. (1980) *Minimizing the Costs Associated*

with Sawlog Transportation to the Lower Fraser River, **Centre for Transportation Studies, University of British Columbia**, Vancouver, B.C.

31. Sinclair, A.W.J. (1980), *Evaluation and Economic Analysis of TwentySix Log-sorting Operations on the Coast of B.C.,* Report to the Council of Forest Industries Subcommittee on **Foreshore & Estuary Use, The Forest Engineering Research Institute of Canada, Western Division**, (May 30).

32. Sorensen, J. (1975), *Bundling Plus Barging Yields Profits Boost,* **B.C. Lumberman**, April, pp. 64-65.

33. Talbot, W.E.G. and Brown, P.M. ------, *Log Ships: Their Design and Experience in Service,* **Talbot, Jackson & Associates Ltd.**

34. Urton, K.G. (1977), *Trends in Log Towing Methods and Equipments,* Proceedings of the seminar on, **Coastal Log Handling & Transportation** , December 8 & 9, Parksville, B.C.

35. Waugh, P. (1981), *The Haida Brave - Fast, Efficient, Manoeuverable,* **B.C. Lumberman**, March, pp. 19 & 34.

36. Young, B. (1975), *MB Muscle Machine Largest Ship Built Here,* **B.C. Lumberman**, March, pp. 22-23.

37. Young, B. (1975), *Log Bundling Spells Big Money,* **B.C. Lumberman**, September, pp. 64.

38. Young, B. (1976), *Financial Snags Imperil Tow Boats,* **B.C. Lumberman**, March, pp. 18-20.

39. Young, B. (1978), *Water Sorting - 1978 Fashion,* **B.C. Lumberman**, February, pp. 20-21.

APPENDICES

APPENDIX A

Computer Program Used

```
C       TRANSPORT - INVENTORY COST MODEL FOR LOG TRANSPORTATION
C       ***************************************************
C       ON THE COASTAL WATER OF BRITISH COLUMBIA.
C       *****************************************
C
C
C       DEFINITIONS OF THE TERMS USED :-
C       ----------------------------
C       CC - CAPITAL COST OF THE SHIP IN $
C       AINT - INTEREST ON CAPITAL IN % PER YEAR
C       YR - PROBABLE LIFE OF THE SHIP
C       BHP - ENGINE POWER IN BHP
C       CONF - FUEL CONSUMPTION RATE IN LBS/BHP-HOUR
C       FC - FUEL COST PER GALLON IN $
C       AMAINT - MAINTENANCE COST IN $ PER YEAR
C       AINSU - INSURANCE RATE IN %
C       CR - NUMBER OF CREW MEMBERS
C       WAGE - AVERAGE WAGE PER HEAD PER DAY
C       FOOD - FOOD COST PER HEAD PER DAY
C       HR - HOUR OF OPERATION PER DAY
C       DIS - DISTANCE BETWEEN SOURCE & DESTINATION
C       DHT - DEADHEAD TIME IN HOURS
C       ALDT - LOADING TIME IN HOURS
C       DDT - DUMPING TIME IN HOURS
C       VT - VARIABLE TIME IN DAYS
C       SPEED - AV. SPEED IN N.MILES/HR. WHEN LOADED
700     FORMAT('-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.--.-.')
C       ESPEED - AV. SPEED IN N.MILES/HR. WHEN EMPTY
C       ALOG - COST OF LOG PER TON
C       BINT - INTEREST RATE ON LOG
C       TON - INVENTORY CARRYING RATE EXCLUDING INTEREST ON LOG
C       +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C
C
        DIMENSION D(370)
        DIMENSION T(80)
        READ(5,400)IMODE
        READ(5,221)CC,AINT,YR,DIS,BHP,BHP1
        READ(5,220)HR,CONF,FC,AMAINT,AINSU
        READ(5,220)CR,WAGE,FOOD,ALDT,DDT
        READ(5,251)SPEED,ESPEED,ALOG,BINT
        READ(5,291)ZP
        WRITE(6,700)
        GO TO(41,42,43,44,45),IMODE
41      QM=10250.
        WRITE(6,57)
        GO TO 46
```

```
 42     QM=25000.
        WRITE(6,58)
        GO TO 46
 43     QM=15000.
        WRITE(6,53)
        GO TO 46
 44     QM=10000.
        WRITE(6,54)
        GO TO 46
 45     QM=15000.
        WRITE(6,55)
        GO TO 46
 46     CONTINUE
C
C       CALCULATION OF DAILY INTEREST & DEPRECIATION
C
        DINT=AINT*CC/100./365.
        DEP=CC/15./365.
C       CALCULATION OF DAILY FUEL COST
        DFC=BHP*HR*CONF*FC/9.
        DFC1=BHP1*ALDT*CONF*FC/9.
C       CALCULATION OF DAILY MAINTENANCE COST
        DMAINT=AMAINT/365.
C       CALCULATION OF DAILY INSURANCE COST
        DINSU=AINSU*CC/100./365.
C       CALCULATION OF DAILY TOTAL WAGE
        DWAGE=CR*WAGE
C       CALCULATION OF DAILY TOTAL FOOD COST
        DFOOD=CR*FOOD
C       TOTAL OPERATING COST PER DAY WHEN MOVING
        TOC=DINT+DEP+DMAINT+DINSU+DWAGE+DFOOD+DFC
        WRITE(6,111)
 111    FORMAT(2X,/,'TOTAL OPERATING COST / DAY IN $',/)
        WRITE(6,300)TOC
C       CALCULATION OF TRAVEL TIME
C
        DHT=DIS/ESPEED
        TT=DIS/SPEED
C       TOTAL TRAVEL TIME
        TTT1=(TT+DHT+ALDT+DDT)/24.
        TTT2=(TT+ALDT+DDT)/24.
        READ(5,230)N
        READ (5,235)(T(I),I=1,N)
        SUM=0.0
        SUM1=0.0
        DO 21 I=1,N
        SUM=SUM+T(I)
 21     CONTINUE
```

```
      AN=N
      VT=SUM/AN
      DO 22 I=1,N
      SUM1=SUM1+(T(I)-VT)**2
 22   CONTINUE
      ST=SQRT(SUM1/(AN-1.))
      TTT=TTT1+VT
      TTS=TTT1+VT+(2.*ST)
      TT3=TTT2+VT
      TT4=TTT2+VT+(2.*ST)
C
      WRITE(6,200)
      WRITE(6,300)DIS
      DO 841 I=1,2
      ISPE=I
      IF(ISPE-2) 742,743,743
742   WRITE(6,744)
744   FORMAT(3X,/,'TYPE OF LOG IS HEMLOCK',/)
      GO TO 746
743   WRITE(6,745)
745   FORMAT(3X,/,'TYPE OF LOG IS OTHER THAN HEMLOCK',/)
746   CONTINUE
      WRITE(6,120)
120   FORMAT(3X,/,'COSTS CONSIDERING MEAN VARIABLE TIME',/)
      WRITE(6,121)
121   FORMAT(1X,/,'DEMAND',2X,'TRANSPORT',4X,'INT INV',6X,'INV'
     1,4X,'SAF STOCK',5X,'BUND',8X,'TOTAL',10X,'ECO. ORD',/)
C     AD IS CONSIDERED AS 365 TIMES THE DAILY DEMAND
C----CALL VTIME TO DO THE CALCULATION-----
      CALL VTIME(TTT,TOC,ZP,ALOG,QM,ST,ALDT,BHP,
     1  CONF,FC,IMODE,DFC1,BINT,ISPE)
C
C
C     CALCULATION WITHOUT CONSIDERING VT
      WRITE(6,151)
151   FORMAT(3X,/,'COSTS WITHOUT CONSIDERING VARIABLE TIME',/)
      IF(ISPE-2) 842,843,843
842   WRITE(6,844)
844   FORMAT(3X,/,'TYPE OF LOG IS HEMLOCK',/)
      GO TO 846
843   WRITE(6,845)
845   FORMAT(3X,/,'TYPE OF LOG IS OTHER THAN HEMLOCK',/)
846   CONTINUE
      WRITE(6,121)
      CALL VTIME(TTT1,TOC,ZP,ALOG,QM,ST,ALDT,BHP,
     1  CONF,FC,IMODE,DFC1,BINT,ISPE)
C
C     CALCULATION CONSIDERING 2 STD. DEV. + MEAN VT
```

```
C
      WRITE(6,181)
181   FORMAT(3X,/,'COSTS CONSIDERING 2 STD. DEV. VARIABLE TIME',/)
      IF(ISPE-2) 942,943,943
942   WRITE(6,944)
944   FORMAT(3X,/,'TYPE OF LOG IS HEMLOCK',/)
      GO TO 946
943   WRITE(6,945)
945   FORMAT(3X,/,'TYPE OF LOG IS OTHER THAN HEMLOCK',/)
946   CONTINUE
      WRITE(6,121)
      CALL VTIME(TTS,TOC,ZP,ALOG,QM,ST,ALDT,BHP,
     1  CONF,FC,IMODE,DFC1,BINT,ISPE)
300   FORMAT(10X,F20.2)
301   FORMAT(16X,F20.2)
200   FORMAT(3X,/,'DIST BETWEEN SOURCE AND DESTINATION IN N.MILES',/)
220   FORMAT(5F12.2)
221   FORMAT(6F12.2)
291   FORMAT(F12.2)
251   FORMAT(4F12.2)
400   FORMAT(2I2)
230   FORMAT(I4)
235   FORMAT(5F10.4)
57    FORMAT(3X,/,'MODE OF TRANSPORT IS FLAT-RAFT',/)
58    FORMAT(3X,/,'MODE OF TRANSPORT IS BUNDLE-BOOM',/)
54    FORMAT(3X,/,'MODE OF TRANSPORT IS LOG SHIP(10000 TONS)',/)
53    FORMAT(3X,/,'MODE OF TRANSPORT IS BARG',/)
55    FORMAT(3X,/,'MODE OF TRANSPORT IS LOGSHIP(15000 TONS)',/)
841   CONTINUE
      STOP
      END
      SUBROUTINE VTIME(TTT,TOC,ZP,ALOG,QM,ST,ALDT,BHP,
     1  CONF,FC,IMODE,DFC1,BINT,ISPE)
      DD=0.
31    DD=DD+100.
      AD=DD*365.
C     TOTAL TRAVEL FIXED COST WITHOUT VT
      TTC1=TTT1*TOC
C     TOTAL TRAVEL FIXED COST WITH VT
      TTC2=TTT1*TOC+VT*TOC
C     IN-TRANSIT INVENTORY RATE PER DAY
      DINV=BINT/100./365.
C     INVENTORY CARRYING RATE PER DOLLAR PER YEAR
C     IT INCLUDES INTEREST,MAINTENANCE & OBSOLECENCE COST
      CINV=BINT/100.
C     IN-TRANSIT INVENTORY COST WITHOUT CONSIDERING VT
      DINVC1=DINV*ALOG*((TT+ALDT+DDT)/24.)
C     IN-TRANSIT INVENTORY COST WITH VT
```

```
      DINVC2=ALOG*DINV*((TT+ALDT+DDT)/24.+VT)
C
C     CALCULATION CONSIDERING MEAN VARIABLE TIME
C     STANDARD DEVIATION OF DEMAND DURING LEAD TIME
      SU=SQRT(DD*DD*ST)
C     TOTAL TRAVEL VARIABLE COST
C     ECONOMIC ORDER QUANTITY
      IF(IMODE-2) 86,87,88
 86   IF(ISPE-2) 74,75,75
 74   TTC4=4.2*ALOG/100.+2.4*TTT*ALOG/100.
      GO TO 89
 75   TTC4=.36*ALOG/100.+.92*TTT*ALOG/100.
      GO TO 89
 87   IF(ISPE-2) 14,15,15
 14   TTC4=4.2*ALOG/100.+.7*TTT*ALOG/100.
      GO TO 89
 15   TTC4=.36*ALOG/100.+.1*TTT*ALOG/100.
      GO TO 89
 88   IF(ISPE-2) 16,17,17
 16   TTC4=4.2*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=(4.2+4.)*ALOG/100.
      GO TO 89
 17   TTC4=.36*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=(.36+4.)*ALOG/100.
      GO TO 89
 89   CONTINUE
      AB=TOC*TTT*AD+CINV*SU*ZP*TOC*TTT
      BA=CINV*(ALOG+TTC4)
      Q=SQRT(2*AB/BA)
C     TOTAL COST IN A YEAR
      QMM=Q/QM
      ITRIP=IFIX(QMM)
      ADB1=AD/Q
      IADB1=IFIX(ADB1)
      TRS1=AD-(Q*IADB1)
      TRIP6=TRS1/QM
      ITRIP6=IFIX(TRIP6)
      ITRIP6=ITRIP6+1
      ADB9=365./ADB1
      IADB9=IFIX(ADB9)
      IADB9=IADB9+1
      TTZ=TTT+IADB9
      TTY=IADB9
      IF(IMODE-2) 341,342,343
 341  IF(ISPE-2) 121,122,122
 121  TTC6=2.4*TTT*ALOG/100.
      IF(TTZ .LE. 112.) GO TO 123
      IF(TTZ .LT. 112. .AND. TTZ .GE. 168.) GO TO 124
```

```
      IF(TTZ .GT. 168.) GO TO 125
 123  TTC4=4.2*ALOG/100.
      GO TO 991
 124  TTC4=4.2*ALOG/100.+((15./112.)*TTZ-15.)
     1*ALOG/100.
      GO TO 991
 125  TTC4=4.2*ALOG/100.+(.0897*TTZ-7.6)*ALOG/100.
      GO TO 991
 122  TTC6=.92*TTT*ALOG/100.
      IF(TTZ .LE. 112.) GO TO 126
      IF(TTZ .LT. 112. .AND. TTZ .GE. 168.) GO TO 127
      IF(TTZ .GT. 168.) GO TO 128
 126  TTC4=.36*ALOG/100.
      GO TO 991
 127  TTC4=.36*ALOG/100.+((15./112.)*TTZ-15.)
     1*ALOG/100.
      GO TO 991
 128  TTC4=.36*ALOG/100.+.92*TTT*ALOG/100.+(.0897*TTZ-7.6)*ALOG/100.
      GO TO 991
 342  IF(ISPE-2) 131,132,132
 131  BUN=1.35
      TTC6=.7*TTT*ALOG/100.
      IF(TTZ .LE. 112.) GO TO 133
      IF(TTZ .LT. 112. .AND. TTZ .GE. 168.) GO TO 134
      IF(TTZ .GT. 168.) GO TO 135
 133  TTC4=4.2*ALOG/100.
      GO TO 991
 134  TTC4=4.2*ALOG/100.+((15./112.)*TTZ-15.)
     1*ALOG/100.
      GO TO 991
 135  TTC4=4.2*ALOG/100.+(.0897*TTZ-7.6)*ALOG/100.
      GO TO 991
 132  BUN=1.8
      TTC6=.1*TTT*ALOG/100.
      IF(TTZ .LE. 112.) GO TO 136
      IF(TTZ .LT. 112. .AND. TTZ .GE. 168.) GO TO 137
      IF(TTZ .GT. 168.) GO TO 138
 136  TTC4=.36*ALOG/100.
      GO TO 991
 137  TTC4=.36*ALOG/100.+((15./112.)*TTZ-15.)
     1*ALOG/100.
      GO TO 991
 138  TTC4=.36*ALOG/100.+(.0897*TTZ-7.6)*ALOG/100.
      GO TO 991
 343  IF(ISPE-2) 151,152,152
 151  BUN=1.35
      IF(TTY .LE. 112.) GO TO 153
      IF(TTY .LT. 112. .AND. TTY .GE. 168.) GO TO 154
```

```
      IF(TTY .GT. 168.) GO TO 155
153   TTC4=4.2*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=(4.2+4.)*ALOG/100.
      GO TO 991
154   TTC4=4.2*ALOG/100.+((15./112.)*TTY-15.)
     1*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=TTC4+4.*ALOG/100.
      GO TO 991
155   TTC4=4.2*ALOG/100.+(.0897*TTY-7.6)*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=TTC4+4.*ALOG/100.
      GO TO 991
152   BUN=1.8
      IF(TTY .LE. 112.) GO TO 156
      IF(TTY .LT. 112. .AND. TTY .GE. 168.) GO TO 157
      IF(TTY .GT. 168.) GO TO 158
156   TTC4=.36*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=TTC4+4.*ALOG/100.
      GO TO 991
157   TTC4=.36*ALOG/100.+((15./112.)*TTY-15.)*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=TTC4+4.*ALOG/100.
      GO TO 991
158   TTC4=.36*ALOG/100.+(.0897*TTY-7.6)*ALOG/100.
      IF(IMODE .EQ. 5) TTC4=TTC4+4.*ALOG/100.
      GO TO 991
991   CONTINUE
      IF(ITRIP-0)1,1,2
1     ITRIP=ITRIP+1
      IADB1=IADB1+1
      IF(IMODE-2) 103,103,104
103   TC11=ITRIP*(TOC*TTT*IADB1)+ITRIP*(ALDT*80.-ALDT*BHP*CONF
     1*FC/9.)
      TC15=AD*BUN
      TC12=(DINV*ALOG*TTT*AD)+TTC6*AD
      TC13=(DINV*Q/2.*ALOG*IADB9*ADB1)+TTC4*AD
      IF(IMODE .EQ. 1) TC15=0.
      GO TO 999
104   TC11=ITRIP*(TOC*TTT*IADB1)+ITRIP*(DFC1-(ALDT*BHP*CONF*
     1FC/9.))
      TC15=AD*BUN
      TC12=(DINV*ALOG*TTT*AD)+TTC6*AD
      TC13=(DINV*Q/2.*ALOG*IADB9*ADB1)+TTC4*AD
      IF(IMODE .EQ. 5) TC15=0.0
      GO TO 999
2     RES2=Q-(ITRIP*QM)
      RES21=RES2*2.*ALOG
      COS=TOC*TTT
      IF(RES21-COS)3,3,4
3     IF(IMODE-2)261,262,262
```

```
 261  TC11=ITRIP*(TOC*TTT*IADB1)+RES2*IADB1+
     1(ITRIP+ITRIP6)*(ALDT*80.-ALDT*BHP*CONF*FC/9.)
      TC12=(DINV*ALOG*TTT*AD)+TTC6*(AD-(RES2*IADB1))
      TC12=(DINV*ALOG*TTT*AD)+TTC4*(AD-(RES2*IADB1))
      TC15=(AD-(RES2*IADB1))*BUN
      IF(IMODE .EQ. 1) TC15=0.
      GO TO 999
 262  TC11=ITRIP*(TOC*TTT*IADB1)+TTC4*(AD-(RES2*IADB1))+RES21*IADB1+
     1ITRIP6*(TOC*TTT)+(DFC1-ALDT*BHP*CONF*FC/9.)*(ITRIP+ITRIP6)
      TC15=(AD-(RES2*IADB1))*BUN
      IF(IMODE .EQ. 5) TC15=0.
      GO TO 999
 4    IF(IMODE-2)263,263,264
 263  TC11=ITRIP*(TOC*TTT*IADB1)+TOC*TTT*IADB1+ITRIP6*(TOC*TTT)
      TC12=(DINV*ALOG*TTT*AD)+TTC6*AD
      TC13=(DINV*Q/2.*ALOG*IADB9*ADB1)+TTC4*AD
     1+(ITRIP+ITRIP6)*(ALDT*80.-ALDT*BHP*CONF*FC/9.)
      TC15=AD*BUN
      IF(IMODE .EQ. 1) TC15=0.
      GO TO 999
 264  TC11=ITRIP*(TOC*TTT*IADB1)+TOC*TTT*IADB1+ITRIP6*(TOC*TTT)
     1+(ITRIP+ITRIP6)*(DFC1-ALDT*BHP*CONF*FC/9.)
      TC15=AD*BUN
      TC12=(DINV*ALOG*TTT*AD)+TTC6*AD
      TC13=(DINV*Q/2.*ALOG*IADB9*ADB1)+TTC4*AD
      IF(IMODE .EQ. 5) TC15=0.
      GO TO 999
 999  CONTINUE
      TC14=DINV*SU*ZP*ALOG*ADB1*IADB9
      TC11=TC11/1000000.
      TC12=TC12/1000000.
      TC13=TC13/1000000.
      TC14=TC14/1000000.
      TC15=TC15/1000000.
      TC=TC11+TC12+TC13+TC14+TC15
      WRITE(6,192)DD,TC11,TC12,TC13,TC14,TC15,TC,Q
 192  FORMAT(1X,F6.0,6(3X,F8.5),3X,F14.2)
      IF(DD .LE. 2900.)GO TO 31
      GO TO 32
 32   CONTINUE
      RETURN
      END
```

APPENDIX B

A Sample Output

-.--.-.

MODE OF TRANSPORT IS BARG

TOTAL OPERATING COST / DAY IN $

23712.51

DIST BETWEEN SOURCE AND DESTINATION IN N.MILES

300.00

TYPE OF LOG IS HEMLOCK

COSTS CONSIDERING MEAN VARIABLE TIME

DEMAND	TRANSPORT	INT INV	INV	SAF STOCK	BUND	TOTAL
100.	0.21332	0.00304	0.41878	0.00055	0.04927	0.68497
200.	0.50035	0.00609	0.31230	0.00109	0.09855	0.91838
300.	0.64153	0.00913	0.42495	0.00164	0.14782	1.22507
400.	0.71679	0.01217	0.53260	0.00219	0.19710	1.46085
500.	1.07285	0.01521	0.63575	0.00274	0.24637	1.97292
600.	1.14344	0.01826	0.73590	0.00328	0.29565	2.19652
700.	1.29085	0.02130	0.83405	0.00382	0.34492	2.49494
800.	1.64847	0.02434	0.93320	0.00439	0.39420	3.00460
900.	1.71906	0.02738	1.02735	0.00491	0.44347	3.22217
1000.	1.86803	0.03043	1.12650	0.00552	0.49275	3.52322
1100.	1.93862	0.03347	1.21715	0.00601	0.54202	3.73727
1200.	2.43897	0.03651	1.30980	0.00655	0.59130	4.38313
1300.	2.50956	0.03955	1.40595	0.00716	0.64057	4.60279
1400.	2.66009	0.04260	1.50010	0.00775	0.68985	4.90038
1500.	2.73068	0.04564	1.59225	0.00831	0.73912	5.11600
1600.	2.80127	0.04868	1.68240	0.00884	0.78840	5.32959
1700.	3.37377	0.05172	1.77055	0.00935	0.83767	6.04306
1800.	3.44436	0.05477	1.85670	0.00981	0.88695	6.25258
1900.	3.59645	0.05781	1.95035	0.01044	0.93622	6.55126
2000.	3.66703	0.06085	2.04300	0.01106	0.98550	6.76744
2100.	3.80821	0.06389	2.13465	0.01166	1.03477	7.05319
2200.	5.88306	0.00000	0.00000	0.01201	1.07964	6.97471
2300.	4.45286	0.06998	2.30345	0.01257	1.13332	7.97217
2400.	4.52344	0.07302	2.39160	0.01311	1.18260	8.18377
2500.	4.67710	0.07606	2.47875	0.01364	1.23187	8.47742
2600.	4.81827	0.07911	2.57790	0.01446	1.28115	8.77089

2700.	4.88886	0.08215	2.66355	0.01496	1.33042	8.97995
2800.	4.95945	0.08519	2.74820	0.01544	1.37970	9.18798
2900.	5.60565	0.08823	2.83185	0.01590	1.42897	9.97061
3000.	5.74683	0.09128	2.92950	0.01673	1.47825	10.26258

COSTS WITHOUT CONSIDERING VARIABLE TIME

TYPE OF LOG IS HEMLOCK

DEMAND	TRANSPORT	INT INV	INV	SAF STOCK	BUND	TOTAL
100.	0.20320	0.00290	0.40809	0.00055	0.04927	0.66401
200.	0.47673	0.00580	0.30930	0.00110	0.09855	0.89147
300.	0.61115	0.00870	0.42045	0.00164	0.14782	1.18977
400.	0.68304	0.01160	0.52660	0.00218	0.19710	1.42053
500.	1.02223	0.01450	0.63075	0.00275	0.24637	1.91660
600.	1.16289	0.01740	0.72990	0.00328	0.29565	2.20912
700.	1.23010	0.02030	0.82705	0.00382	0.34492	2.42619
800.	1.57084	0.02320	0.92520	0.00438	0.39420	2.91783
900.	1.70527	0.02610	1.02285	0.00496	0.44347	3.20265
1000.	1.84749	0.02900	1.11650	0.00550	0.49275	3.49124
1100.	1.91470	0.03190	1.21165	0.00607	0.54202	3.70635
1200.	2.32422	0.03480	1.30380	0.00661	0.59130	4.26072
1300.	2.45864	0.03770	1.39295	0.00710	0.64057	4.53697
1400.	2.60243	0.04060	1.48610	0.00767	0.68985	4.82665
1500.	2.66964	0.04350	1.57725	0.00822	0.73912	5.03774
1600.	2.73685	0.04640	1.66640	0.00874	0.78840	5.24679
1700.	4.47561	0.00000	0.00000	0.00940	0.83350	5.31851
1800.	3.42769	0.05220	1.84770	0.00986	0.88695	6.22440
1900.	3.49491	0.05510	1.94085	0.01049	0.93622	6.43757
2000.	3.56212	0.05800	2.03300	0.01110	0.98550	6.64972
2100.	3.69654	0.06091	2.11365	0.01147	1.03477	6.91734
2200.	3.76376	0.06381	2.20330	0.01204	1.08405	7.12695
2300.	5.78703	0.00000	0.00000	0.01260	1.13064	6.93027
2400.	4.52493	0.06961	2.37960	0.01314	1.18260	8.16987
2500.	4.59214	0.07251	2.46625	0.01366	1.23187	8.37642
2600.	4.65935	0.07541	2.56490	0.01448	1.28115	8.59529
2700.	4.72657	0.07831	2.65005	0.01498	1.33042	8.80032
2800.	4.86099	0.08121	2.73420	0.01545	1.37970	9.07155
2900.	4.92821	0.08411	2.81735	0.01590	1.42897	9.27453
3000.	7.51983	0.00000	0.00000	0.01673	1.47530	9.01186

COSTS CONSIDERING 2 STD. DEV. VARIABLE TIME

TYPE OF LOG IS HEMLOCK

DEMAND	TRANSPORT	INT INV	INV	SAF STOCK	BUND	TOTAL
100.	0.21969	0.00313	0.42733	0.00055	0.04927	0.69998
200.	0.51522	0.00626	0.31530	0.00109	0.09855	0.93642
300.	0.66064	0.00940	0.42795	0.00164	0.14782	1.24745
400.	1.22749	0.00000	0.00000	0.00220	0.19456	1.42425
500.	1.03199	0.01566	0.64075	0.00275	0.24637	1.93753
600.	1.17741	0.01879	0.74190	0.00330	0.29565	2.23706
700.	1.93237	0.00000	0.00000	0.00385	0.34298	2.27919
800.	1.69731	0.02506	0.93720	0.00438	0.39420	3.05814
900.	1.77002	0.02819	1.03635	0.00497	0.44347	3.28300
1000.	1.92324	0.03132	1.13150	0.00552	0.49275	3.58432
1100.	3.16324	0.00000	0.00000	0.00601	0.53753	3.70679
1200.	2.43845	0.03759	1.31580	0.00656	0.59130	4.38969
1300.	2.58388	0.04072	1.41245	0.00717	0.64057	4.68478
1400.	2.65659	0.04385	1.50010	0.00763	0.68985	4.89802
1500.	2.81137	0.04698	1.59225	0.00819	0.73912	5.19791
1600.	3.32814	0.05011	1.69040	0.00887	0.78840	5.86592
1700.	3.40085	0.05325	1.77905	0.00938	0.83767	6.08020
1800.	3.54628	0.05638	1.86570	0.00985	0.88695	6.36515
1900.	3.61899	0.05951	1.95985	0.01049	0.93622	6.58506
2000.	3.77533	0.06264	2.05300	0.01111	0.98550	6.88758
2100.	3.84804	0.06577	2.13465	0.01150	1.03477	7.09473
2200.	4.43908	0.06891	2.22530	0.01208	1.08405	7.82942
2300.	4.51180	0.07204	2.31495	0.01265	1.13332	8.04475
2400.	4.65722	0.07517	2.40360	0.01320	1.18260	8.33179
2500.	4.72993	0.07830	2.49125	0.01374	1.23187	8.54509
2600.	4.88783	0.08144	2.57790	0.01425	1.28115	8.84256
2700.	4.96054	0.08457	2.66355	0.01475	1.33042	9.05382
2800.	7.74189	0.00000	0.00000	0.01558	1.37192	9.12939
2900.	5.77128	0.09083	2.84635	0.01604	1.42897	10.15347
3000.	5.84399	0.09396	2.92950	0.01649	1.47825	10.36219

TYPE OF LOG IS OTHER THAN HEMLOCK

COSTS CONSIDERING MEAN VARIABLE TIME

DEMAND	TRANSPORT	INT INV	INV	SAF STOCK	BUND	TOTAL
100.	0.21332	0.00304	0.35939	0.00055	0.06570	0.64200
200.	0.50035	0.00609	0.17614	0.00110	0.13140	0.81507
300.	0.64153	0.00913	0.21921	0.00164	0.19710	1.06861
400.	0.93168	0.01217	0.25628	0.00219	0.26280	1.46511
500.	1.00226	0.01521	0.29035	0.00274	0.32850	1.63906

600.	1.14344	0.01826	0.32142	0.00329	0.39420	1.88060
700.	1.51163	0.00000	0.00000	0.00383	0.45545	1.97091
800.	1.64847	0.02434	0.38056	0.00441	0.52560	2.58338
900.	1.71906	0.02738	0.40563	0.00495	0.59130	2.74832
1000.	1.86803	0.03043	0.43070	0.00549	0.65700	2.99164
1100.	2.29780	0.03347	0.45727	0.00608	0.72270	3.51731
1200.	2.36838	0.03651	0.48084	0.00663	0.78840	3.68076
1300.	2.50956	0.03955	0.50141	0.00714	0.85410	3.91176
1400.	2.58015	0.04260	0.52598	0.00773	0.91980	4.07625
1500.	2.73068	0.04564	0.54855	0.00829	0.98550	4.31866
1600.	3.23259	0.04868	0.56912	0.00883	1.05120	4.91042
1700.	3.30318	0.05172	0.58769	0.00934	1.11690	5.06883
1800.	3.37377	0.05477	0.61326	0.00999	1.18260	5.23438
1900.	3.51494	0.05781	0.62833	0.01044	1.24830	5.45982
2000.	3.59645	0.06085	0.65140	0.01106	1.31400	5.63376
2100.	3.73762	0.06389	0.66297	0.01145	1.37970	5.85563
2200.	4.31168	0.06694	0.68354	0.01203	1.44540	6.51958
2300.	4.38227	0.06998	0.70311	0.01260	1.51110	6.67905
2400.	4.52344	0.07302	0.72168	0.01315	1.57680	6.90809
2500.	4.59403	0.07606	0.73925	0.01368	1.64250	7.06552
2600.	4.67710	0.07911	0.75582	0.01419	1.70820	7.23441
2700.	4.81827	0.08215	0.78489	0.01502	1.77390	7.47423
2800.	5.46448	0.08519	0.79996	0.01551	1.83960	8.20474
2900.	5.53507	0.08823	0.81403	0.01598	1.90530	8.35860
3000.	5.67624	0.09128	0.82710	0.01642	1.97100	8.58204

COSTS WITHOUT CONSIDERING VARIABLE TIME

TYPE OF LOG IS OTHER THAN HEMLOCK

DEMAND	TRANSPORT	INT INV	INV	SAF STOCK	BUND	TOTAL
100.	0.20320	0.00290	0.34656	0.00055	0.06570	0.61891
200.	0.47673	0.00580	0.17214	0.00110	0.13140	0.78716
300.	0.61115	0.00870	0.21471	0.00165	0.19710	1.03331
400.	0.68304	0.01160	0.25028	0.00218	0.26280	1.20991
500.	1.02223	0.01450	0.28535	0.00275	0.32850	1.65333
600.	1.08944	0.01740	0.31542	0.00329	0.39420	1.81975
700.	1.23010	0.02030	0.34349	0.00384	0.45990	2.05763
800.	1.57084	0.02320	0.37256	0.00441	0.52560	2.49661
900.	1.70527	0.02610	0.39663	0.00493	0.59130	2.72423
1000.	1.78028	0.02900	0.42070	0.00547	0.65700	2.89245
1100.	1.91470	0.03190	0.44627	0.00605	0.72270	3.12162
1200.	2.32422	0.03480	0.46884	0.00658	0.78840	3.62284
1300.	2.39143	0.03770	0.49491	0.00720	0.85410	3.78534
1400.	2.53521	0.04060	0.51198	0.00766	0.91980	4.01525

1500.	2.60243	0.04350	0.53355	0.00821	0.98550	4.17319
1600.	2.73685	0.04640	0.55312	0.00873	1.05120	4.39631
1700.	3.21514	0.04930	0.57919	0.00939	1.11690	4.96992
1800.	3.28235	0.05220	0.59526	0.00986	1.18260	5.12228
1900.	3.42769	0.05510	0.61883	0.01049	1.24830	5.36042
2000.	3.49491	0.05800	0.64140	0.01112	1.31400	5.51942
2100.	3.62933	0.06091	0.65247	0.01149	1.37970	5.73389
2200.	3.69654	0.06381	0.67254	0.01207	1.44540	5.89035
2300.	4.24360	0.06671	0.69161	0.01263	1.51110	6.52565
2400.	4.37803	0.06961	0.70968	0.01318	1.57680	6.74729
2500.	4.52493	0.07251	0.72675	0.01371	1.64250	6.98039
2600.	4.59214	0.07541	0.74282	0.01421	1.70820	7.13278
2700.	4.65935	0.07831	0.77139	0.01504	1.77390	7.29799
2800.	4.79378	0.08121	0.78596	0.01552	1.83960	7.51607
2900.	5.41915	0.00000	0.00000	0.01598	1.89864	7.33377
3000.	5.47683	0.08701	0.81210	0.01642	1.97100	8.36335

COSTS CONSIDERING 2 STD. DEV. VARIABLE TIME

TYPE OF LOG IS OTHER THAN HEMLOCK

DEMAND	TRANSPORT	INT INV	INV	SAF STOCK	BUND	TOTAL
100.	0.21969	0.00313	0.36580	0.00055	0.06570	0.65487
200.	0.51522	0.00626	0.17814	0.00109	0.13140	0.83211
300.	0.58793	0.00940	0.22221	0.00164	0.19710	1.01828
400.	0.95928	0.01253	0.26028	0.00219	0.26280	1.49708
500.	1.03199	0.01566	0.29285	0.00273	0.32850	1.67173
600.	1.17741	0.01879	0.32442	0.00327	0.39420	1.91810
700.	1.55188	0.02192	0.35399	0.00382	0.45990	2.39152
800.	1.62460	0.02506	0.38456	0.00440	0.52560	2.56421
900.	1.77002	0.02819	0.41013	0.00494	0.59130	2.80457
1000.	1.84273	0.03132	0.43570	0.00549	0.65700	2.97224
1100.	2.36574	0.03445	0.46277	0.00607	0.72270	3.59174
1200.	2.43845	0.03759	0.48684	0.00663	0.78840	3.75790
1300.	2.51117	0.04072	0.50791	0.00714	0.85410	3.92103
1400.	2.65659	0.04385	0.53298	0.00774	0.91980	4.16095
1500.	2.85522	0.00000	0.00000	0.00831	0.98515	3.84868
1600.	3.25543	0.05011	0.57712	0.00885	1.05120	4.94272
1700.	3.40085	0.05325	0.59619	0.00937	1.11690	5.17655
1800.	3.47357	0.05638	0.61326	0.00985	1.18260	5.33565
1900.	3.54628	0.05951	0.63783	0.01049	1.24830	5.50240
2000.	3.70261	0.06264	0.65140	0.01091	1.31400	5.74156
2100.	4.29366	0.06577	0.67347	0.01151	1.37970	6.42411
2200.	4.36637	0.06891	0.69454	0.01210	1.44540	6.58731
2300.	4.43908	0.07204	0.71461	0.01267	1.51110	6.74950

240	2400.	4.58451	0.07517	0.73368	0.01323	1.57680	6.98339
241	2500.	4.65722	0.07830	0.75175	0.01378	1.64250	7.14354
242	2600.	4.81512	0.08144	0.76882	0.01430	1.70820	7.38787
243	2700.	5.48043	0.08457	0.78489	0.01480	1.77390	8.13859
244	2800.	5.55314	0.08770	0.79996	0.01529	1.83960	8.29568
245	2900.	5.62586	0.09083	0.82853	0.01611	1.90530	8.46662
246	3000.	5.77128	0.09396	0.84210	0.01657	1.97100	8.69491