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DESIGN CRITERIA AND TECHNIQUES FOR SIZING
MAJOR COMPONENTS OF FERRY AND RO/RO TERMINALS

By

B. Mark Podolak B.A.sc., M.B.A., P. Eng.

A Thesis Submitted
to the Faculty of Graduate Studies and Research
Carleton University
In Partial Fulfillment of the
Requirements for the Degree
of Master of Engineering

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The undersigned recommend to the Faculty of
Graduate Studies and Research acceptance of
the thesis,

"The Establishment of Design Criteria and
Techniques for the Determination of the Size
Parameters of Major Components of Ferry and
Ro/Ro Terminals"

submitted by B. Mark Podolak, B.A.Sc., M.B.A., P.Eng.
in partial fulfillment of the requirements
for the degree of Master of Engineering.

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ABTRACT

The planner/designer of a new or remodeled transportation facility must, as one of the most important of his tasks, determine the required size and number of that facility's elements or constituent parts. In the case of ferry and roll on/roll off (ro/ro) terminals he must, as part of this process, consider the special factor of vessel operations in addition to the usual civil engineering considerations. In the past, while some standard engineering techniques were applied to the design of some elements of ferry terminals, there has apparently been a large element of guesswork and inconsistency in the planning of other elements. This situation has arisen because there are few, if any, reference books that deal in a significant way with terminals of this type and because very little research or theoretical development work has been done on the topic.

This thesis is directed towards remedying the lack of reference materials and consistency of design for ferry and ro/ro facilities by means of a two pronged approach.

Firstly a comprehensive survey of the relevant technology is carried out. This consists of (1) a discussion of the advantages, disadvantages, definitions and operational problems of ferry and ro/ro services; (2) a discussion of vessel types according to classification by loading methodology and classification by cargo carried; (3) a discussion of the elements that constitute a terminal which includes the definition, use and characteristics of each element.

Secondly a two part design methodology is developed for ferry and ro/ro terminals. The first part consists of the establishment of the factors that should be considered when

setting the design criteria and parameters for the elements of a terminal design. Possible criteria for each factor or element are suggested.

The second part consists of the development of a number of practical mathematical techniques for determining the required sizes of the elements of ferry and ro/ro terminals.

The design methodology is then proven out by applying it to a terminal located in eastern Canada.

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1.1 Background

The number of ferry services, of all sizes, now operating in Canada, is in excess of 140. These vary in scope from the service which joins the Toronto Island Airport to the city using a single two automobile capacity vessel; to the service which joins Newfoundland to the mainland using a fleet of 1,200 passenger, 275 automobile capacity icebreakers.

In Europe, the number of services in operation is even more impressive. "The Motor Ship"⁽¹⁾ a well-known shipping publication lists 274 major ocean-going ferry services operating between or from European ports in 1976-77. The small services are not listed; nor are the inland services, but their number is significant and the total impressive.

It is evident, therefore, that the number of ferry terminals associated with and supporting these services must exceed the thousand mark, just in the Western World alone. It is also evident - although perhaps more so to those living in coastal areas than to those living inland - that the ferry services are of great economic importance. For example, in Prince Edward Island, more than 90% of all passenger and freight movements to or from the island are via this mode (see Table 1.1) while in Newfoundland, the ferry service is the second largest employer in the province.

The growth of this mode has come about for several reasons, the main ones being the ubiquity of the automobile combined with rising disposable incomes which allow more people than ever before to travel; the speed and flexibility provided by roll/on roll off services; and, perhaps most importantly, the convenience, speed and control afforded by using door-to-door truck services across short to medium length water gaps.

TABLE 1.1

TRAFFIC BY MODE AND ROUTE TO P.E.I. (1974)

	AIR	FERRIES		DIRECT SHIPPING
		Borden/ Tormentine	Wood Islands/ Caribou	
Passengers	62,000	804,900	226,000	
Autos	-	239,600	66,000	
Total Trucks	-	52,900	13,000	
Loaded Railcars	-	9,000	-	
Tons of Freight	-	-	-	660,848 Tons

Source: Reference 2, Volume 1

In spite of the large number of services, the larger number of terminals and the importance of this mode, there has been very little study done on the planning, development or design of ferry systems or terminals. As will be discussed in a later chapter, the published material is sparse and consists mainly of public relations type articles or at best discussions of the naval architecture aspects of a service.

It is the intention of this thesis to attempt to remedy, in part, this lack by considering certain aspects of ferry terminal development.

1.2 The Problem

The development of a new or remodeled marine transportation facility must, according to the American Association of Port Authorities⁽³⁾ go through four phases: Project definition; master planning and preliminary engineering; final design; and construction. As part of the first two of these phases, the planner/designer must carry out a "requirements analysis" and from that, develop a master plan. In order to do this, it is necessary to determine the size and number of facilities to be built. In the case of a ferry terminal, particularly a large one, this means that decisions must be made on such questions as: the number of berths to be built, the size and number of vehicle marshalling areas to be provided, the size of staff and visitor parking lots, the number of access and egress lanes required, the number of transfer roads required (i.e. roads from the marshalling areas to the berths), the size of container storage and handling areas (if containers are handled on a RO/RO* basis at that terminal), the facilities for drop trailers (i.e. truck trailers that are left at the terminal by a trucker

* Roll on/Roll off

for loading and shipping by the ferry operator with the trucker arranging to have the trailer picked up at the other side), and the passenger and administrative facilities required among others.

Typically, most of the terminals now in existence have been constructed piecemeal and rather than being laid out as part of a long-term development, have been added to from time to time to satisfy short-term needs or to ease an already congested situation. In many cases, the techniques used in planning these facilities have been a combination of on-site experience, basic traffic engineering and "gut feel". Oftentimes this has produced quite adequate terminals, but the problem with this methodology is that local experience is usually not transferable from person to person or from site to site, and is not standardized or documented. There is therefore no generally accepted approach to the particular problem of ferry terminal design.

The objective of this thesis is therefore to develop a methodology for determining the type, size and number of the components that make up a ferry terminal.

1.3 Thesis Organization

Before one can consider questions of terminal design, it is necessary to first understand the technology and operation of the transportation system of which the terminal is a part. The general approach will therefore be, to first study the hardware and operations of ferry services and then to develop the design methodology previously discussed.

The starting point will be a brief description of the main elements and flows of a ferry terminal to provide some perspective for the subsequent discussion. This will be followed

in turn by a critical look at the available literature to determine what others have found and, in Chapter III, by a detailed study of the hardware and operational problems of ferry and ro/ro systems. That will complete the first portion of the thesis.

The design methodology that will be developed in the second portion of the thesis consists of two parts: the establishment of criteria that should be considered during the planning process when decisions on type and size of components are being made; and the development of mathematical techniques for determining the sizes of the major components of ferry terminals. These topics will be the subjects of Chapters IV and V respectively.

The last portion of the thesis (Chapter VI) will be a sample application of the methodology to a terminal in the Canadian environment.

CHAPTER II

EXISTING PRACTICE AND AVAILABLE INFORMATION

2.1 Introduction

In this chapter an attempt will be made to place the subject of this research into perspective. This will be done in two ways: firstly by identifying and briefly describing the components of, and movements through a "typical" ferry terminal and secondly by reviewing the available published information relevant to the research topic.

It should be noted however that while the components of ferry terminals will be identified here, no detailed discussion will be held until Chapter III where the technology of ferry and ro/ro systems will be considered in some depth.

2.2 Flows and Components of a "Typical" Ferry Terminal

The reader is referred to Figure 2.1 which is a general arrangement drawing of the ferry terminal at Caribou, Nova Scotia. This terminal is the mainland terminus of the smaller of the two services to Prince Edward Island and handles about 100,000 auto equivalent units and a quarter of a million passengers per year. The service is domestic and there is no requirement for customs, duty-free shops or immigration facilities.

Let us trace the movements of arriving vehicles through the system.

The vehicles arrive via a four lane "access/egress road" which in this case is Nova Scotia Highway 106. Being a public highway, the access/egress road is not a sole use road but is also used by fishermen to reach the small craft harbour adjacent to the ferry berth, by the operators of the hotel and restaurant to the west of the terminal and by local land owners whose property abuts the highway.

FIGURE 2-1

There is a single "toll booth" at the entrance which processes all vehicle types. Trucks and buses are ticketed on the left (west side) and are channeled to the "truck marshalling area" near the berths where they are held until they board a vessel. All other vehicles are directed to "main marshalling area" to await passage.

Normally the area in front of the toll booth would be widened out slightly to form a "surge parking lot" to hold the random accumulations of arriving traffic and prevent these accumulations from obstructing non-ferry traffic. In this case however, the presence of the second inbound lane obviates this requirement and traffic surges are allowed to back up along the access road.

Once in the marshalling area, patrons are free to go to the "terminal building" where there is a waiting room, toilet facilities and a tourist information service. There are no restaurants in this terminal building since at the time of construction, as now, there were two restaurants within fifty metres of the marshalling area.

Just prior to a sailing, automobiles are moved from the "main" marshalling area to the "staging area" next to the truck marshalling area. The trucks are given some priority on this service and the number of non-trucks moved to this temporary staging area is only sufficient to fill the space remaining after the trucks have been loaded. The vehicles (trucks and all other vehicles) are then moved from the staging area to the vessel via the "transfer roads and transfer bridges".

The transfer roads are those internal roadways that connect the marshalling areas to the transfer bridges and the transfer bridges to the egress road.

The transfer bridges are moveable bridges that join the ship to the shore, and over which vehicles board the ship. They are connected at the shoreside end with a hinge and move up and down with the ship's motion at the seaward end. They are located at the shoreward end of the "berths" which are the docking locations for the vessels.

In addition to the facilities used by vehicles and passengers, the terminal also contains office facilities for the terminal manager and parking areas for the crews.

Conceptually this terminal is fairly simple. Vehicles arrive, are ticketed, wait for passage and are boarded. This is not always the case.

If the terminal were an international one rather than a domestic one, vehicles arriving on the ships would have to be additionally processed through a customs facility; if the terminal were located near a large city, provision would have to be made for dropping off passengers travelling without vehicles; if this terminal were connected to a rail line, provision would have to be made for marshalling, sorting and loading of railcars etc. It is apparent that ferry terminals can be significantly more complex than the one described above and in later chapters we shall consider some of these additional complexities.

2.3 Available Information - General

The planning and design of ferry and ro/ro terminals is not a field in which much theoretical work has been done as yet, and as a result little or no information is available that deals explicitly with the topic. Work has been done on related topics such as harbour development, wind and wave effects, offshore terminals etc, but this work is more relevant to oceanography or to structural engineering than it is to transportation engineering as related to ferry terminals.

In spite of the foregoing a number of books and articles that were considered to be of significant value were read and used as reference material for this research. These dealt with specific topics of a multi-disciplinary nature such as queuing theory, or simulation, or else dealt with analogous fields such as airport design. Many of the theories, ideas and design philosophies expressed in these readings are, in the opinion of the writer, able to be transferred to or applied to the field of ferry terminal design. For that reason we shall briefly discuss them in the next few sections.

2.3.1 On Planning and Planners

Transportation planning, in general, is of course a popular research field and the availability of copious articles and books reflects this fact. Given however that this thesis is intended to be oriented to design rather to pure planning, no attempt will be made to consider the totality of this wide body of knowledge, but rather few thoughts that relate to design will be extracted for discussion.

One matter of concern is the role of the planner. It is often difficult to distinguish a planner from a designer and that in many cases they are the same person. It has been the authors' observation that the main difference (if any) between the two is temporal. The planner tends to consider long range design horizons and implications, while the designer attempts to adopt the recommendations of the long-range plan into an acceptable layout for short-term implementation. With that distinction as background, it should be noted that Beinhaker and Elek* have defined the role of the planner thus:

"The role of the planner is to determine the relations between passenger convenience and

* Reference No. 4, Page 366

cost throughout the terminal's life and find for any level of convenience the plan that costs the least, or for any level of cost, the plan that provides the most convenience."

Beinhaker and Elek were considering airports when they wrote the above, but the principle holds true for ferry terminals as well. The two writers suggested that measures of convenience could include such factors as: feet of walking distance, minutes of waiting time, square feet of space per person etc., and we find that all of these are as applicable to ferry terminals as they are to air terminals.

As far as planning for marine facilities is concerned, the American Association of Port Authorities in its planning publication⁽³⁾ devotes some effort to a discussion of Conceptual Planning and establishes a four-phase development process of Port facilities. The four phases are:

- (1) Project definition
- (2) Master planning and preliminary engineering
- (3) Final design
- (4) Construction.

For each phase the major activities and outputs are discussed and factors to be considered are suggested.

The publication also deals with the role of the planner and states:

"It is the assignment of a Conceptual Engineering Planning group to take a basic statement of need, determine its validity and if valid determine what is needed functionally, what size and type of facility will best fulfil this need, and measure the economic feasibility of such a system."*

This of course is a general statement that applies to the planning of any facility including ferry and ro/ro terminals.

*Reference No. 3, Page 41

A final thought on planning as expressed by the International Air Transport Association** is that during the planning stages the Authorities should ensure early and continuous consultations with the airlines that will use the facility. This is analogous to the case of marine facilities where the port authority should ensure that the vessel operator has input regarding such matters as the depth of water, size of berth, quality of passenger amenities etc.

2.3.2. Criteria and Standards

Available information on criteria and standards is limited. Two publications discuss implicitly or explicitly the important task of setting criteria and standards.

The International Air Transport Association publication "Airport Buildings and Aprons"⁽⁵⁾ is almost entirely devoted to the establishment of standards but is of a qualitative nature rather than a quantitative nature, and contain such statements as "Consideration should be given to" and "Routings should be as short as possible." Clear statements of, for example, "how many feet constitute the longest acceptable routing are not given. Nevertheless the book does implicitly provide a checklist of all the factors that one might want to consider when designing a passenger terminal and the text is therefore considered a good reference book. It is of course necessary to ignore the parts that are relevant only to air terminals.

The other reading of interest is the previously mentioned article by Beinhaker and Elek contained in "Reading in Airport Planning"⁽⁴⁾

This article contains a large section on Criteria of Evaluation and without attempting to precis the article, we will note some of the points made in this paper.

** Reference No. 5, Page 3

The authors point out that the criteria of evaluation must follow directly from the purpose of the terminal, which they say is to provide as much convenience to the passengers as economically possible and to continue to do so throughout the life of the terminal. On this basis they establish three criteria for terminals: passenger convenience, economy, and flexibility to accommodate future change.

They later point out that there are no generally accepted units of measure or standards, either national or international against which passenger convenience can be measured. From reference number 6 and from discussions with staff members of the Canadian Department of Transport, the author has found that DOT is well advanced in the establishment of national standards of the sort which Beinhaker and Elek say need developing, but unfortunately as far as ferry services are concerned no similar progress has been made.

The authors suggest that a proper system must provide good service to most of the people and acceptable service to all and state that this can only be assured by setting standards that specify not only the required service levels, but also the percentage of passengers whose service should be equal to or better than the stated limit. They also suggest that the specification of an absolute maximum or minimum level of service is practically impossible due to extraordinary events such as strikes and storms which make it impossible to observe certain standards without exception at all times. They therefore consider it most reasonable to set a standard that will be attained by 90% or 95% of the people.

In a similar vein they also suggest that the peak hour volume should be used for planning purposes since annual or daily volumes are meaningless when trying to design for a given moment in time. They suggest that for air terminals the design "peak" hour should be the 15th highest annual hour.*

* Note that the approach used by the Canadian Department of Transport is to use forecasted airline schedules as a basis of design.

In a later section we will discuss the analogous situation for ferry terminals.

2.3.3 Queueing Theory and Simulation Approaches

As for transportation planning, much has been written on the subjects of queueing theory and on simulation and rather than attempting now to discuss the role of these subjects, we will wait till Chapter V and demonstrate their use. It would however be germane to consider some "philosophical" comments made by two different authors on the subject of required accuracy.

Dana Low in his article* says:

"To build a model to simulate all the details of a system to the same degree of fineness would not only be time consuming and expensive (and sometimes infeasible because of technical and financial limitations) but foolish and wasteful."

In a similar vein, Alec Lee says:**

"It is considered to be satisfactory to forecast monthly flows of passenger traffic through an air terminal, one year in advance, to an accuracy of 5% either way. Hourly flows are less accurate. How difficult then to do so, say 5 years ahead - the period needed to plan and put into operation a new terminal building. An error of 25% on a monthly flow - the annual figure would probably be more accurate - might then be very acceptable. In addition it may be quite difficult to foresee exactly what the mean service time at a facility will be, particularly if the activity which constitutes the service operation is in any way new or arranged in a new way -----

* Reference No. 7, Page 991

** Reference No. 8, Page 84

Under these circumstances a search for elegant precise queueing model is misguided ----.

Inevitably at the end of a long elaborate series of calculations of future requirements, made with as much accuracy as to volume forecasts and time studies and queueing analysis as one's professional conscience dictates, the consulting engineers or the architects, out of years of bitter experience will add at least 10% to everything. In other words from the purely practical viewpoint, there may be little to gain in being too conscious of the finer points of models when dealing with advance planning. It is always essential to answer the question: how accurate need we, or can we, be?----

A high fidelity model will often be complex, quite accurate and quite useless. A low fidelity model can be simple, not too accurate, but useful. The reader must decide which should be the choice of a conscientious operations research analyst."

From the comments of these two experienced planners we can see that it is often unnecessary to be overly concerned with third decimal precision. That is not to say that one should be sloppy, but rather the implication is that there is no point in being more precise than the probable accuracy of the traffic projections warrant.

2.4 Existing Ferry Terminal Design Methodologies

As previously indicated, little theoretical work has been done, and almost nothing published* on the topic of ferry and ro/ro terminal design. In addition, discussions

* In English. Some publication are apparently available in various European Languages

held by the author with staff members of the Canadian Departments of Transport and Public Works and with various ferry service operators both in Canada and abroad have not revealed the existence of any specific design methodologies:

Rather, the terminals seem to have been designed and built either on the basis of marginal increases in capacity when the facilities became overloaded or on the basis of providing capacity for "x" shiploads where "x" was a figure based on personal judgement and where the size of a shipload can vary over time, depending on fleet configuration. In addition to the above, the author knows of at least one case where a terminal size was determined almost solely on the basis of geographical constraints (cliffs, hills, and water boundaries).

Some elements of ferry terminals, such as roadways, are, of course, susceptible to design by standard techniques, or modifications of standard techniques and little study or development work needs to be given to such elements.

In summary then, no design methodologies specifically oriented to ferry and ro/ro terminals were found.

3.1 Introduction

Before a design methodology can be developed or a design actually carried out, it is first necessary to understand the operations and technology of the transportation system for which the design is being done. This entails understanding the objectives of the service, knowing the hardware that is used and how it is used, identifying the various elements that constitute the system and determining their purposes and inter-relationships. Finally and perhaps most importantly it entails understanding the operating problems and limitations of the service. This last is often overlooked, but it is evident that if the designer is not aware of the potential pitfalls, he will be less likely to avoid them in his designs.

In the case of ferries, it is a transport service that is composed of two subsystems: the terminal subsystem and the vessel subsystem, and in order to gain an understanding of how they function and interrelate, we shall first examine some general aspects of ferry operations, and will attempt to clearly establish their purpose, scope and location in the transportation universe. This will be followed by a detailed examination into those aspects of the vessels that affect terminal design and by an examination of the elements of ferry terminals themselves.

It should perhaps be pointed out that it is not the objective of this chapter to show how terminals are, or should be designed; rather it is to indicate what the end product is, how it operates, and what its constraints are.

3.2 General Aspects of Ferry and Ro/Ro Services

3.2.1 Definitions

In attempting to define the terms "ferry" and "ro/ro" the problem is immediately encountered that there is no fully accepted nomenclature and that not only are the two terms often used interchangeably, but they can sometimes be considered to be sub-sets of each other. With these problems in mind, a ferry service may be defined as:

"A water-borne transportation system in which passengers and vehicles which are driven on board, are transferred across a "short" water gap according to a fixed, fairly frequent schedule."

A ro/ro service is similar to the above except for two things - the term "ro/ro" is normally (but not always) applied to freight movements rather than to the movement of passengers, and the water gap is not necessarily short.

Some of the complications become evident when it is realized that most "ferry" services carry freight bearing trucks and can thus be considered to be of the ro/ro group, while most ro/ro vessels are allowed to carry up to 12 passengers. In addition, all vehicles carried on ferries are in fact "rolled" on and "rolled" off.

For purposes of this paper, and hopefully to help settle the terminology, a ro/ro service will be defined as:

"A water-borne transportation system in which freight bearing vehicles are transferred across a water gap."

This definition would by implication include not only trucks, but railcars and self-propelled freight such as bulldozers.

3.2.2 Advantages and Disadvantages of Ferry and Ro/Ro Modes

It would not be the norm for a ferry service to operate in complete isolation where it is the only mode available to the traveller or shipper. Usually there is a choice. Someone who wants to go to Charlottetown, P.E.I. for example, can fly there with either Air Canada or Eastern Provincial Airlines rather than take a ferry; a shipper can send his goods by freighter or, if the goods are of high value, he can send them by air freight.

On what basis should a modal choice be made? Let us consider some of the factors that affect the choice.

The most obvious advantage to the traveller is the convenience that he gets by travelling with his automobile. This is a benefit that the traveller can't obtain with any other mode except by renting a car at his destination.

Along with the convenience there is a significant cost saving that accrues to him, with the added perk that this benefit increases disproportionately as the number of passengers per auto increases. For example, it costs almost the same amount for five people to travel by car from Halifax to Charlottetown as it does for one person. The four non-drivers would have to pay a fare for their passage, but all other costs would remain much the same (gas, drivers' fare, vehicles' fare, insurance etc.). This produces a low average cost per traveller compared to say, travel by air*. On the other hand, the total cost of transporting a car on a longer run, particularly one that includes a night portion can be considerable when one adds the cost of a berth to the tariff for car and driver.

* Actual cost comparisons are: \$150.00 for five air fares; versus \$29.80 for five passenger fares, one auto fare and 10¢ per mile operating cost. Average costs per person are \$30.00 vs \$5.96. (1977 fare levels)

In the case of ro/ro services and/or cargo transfer via ferries, the advantages and disadvantages are somewhat more definitive than they are for passenger movements. The advantages can be summed up in three words: convenience, control, and speed. The shipper of a consumable cargo to say, St. John's, Newfoundland from Montreal can expect a 3 to 4 week delivery time by rail**, and during that time he has only the vaguest idea of where his cargo is or when it will be delivered. By contrast, if the cargo is put on a truck and transported across the Gulf by ferry, the trip takes 48 hours and can be moved door-to-door without the inconvenience, cost, and damage incurred by having to pick up the cargo at the railway station; and with a high degree of control over the operation.

These advantages accrue most readily when the water gap is short and the vehicle does not have to waste a lot of time waiting on board a comparatively slow ship (even the fastest ferries only travel at about 22 knots (40 km/hr) as can be seen in Table 3.1). If the level of service is low and the driver and vehicle must wait in long line-ups to board, or if the schedule is bad, and the vehicle wastes time waiting for a departure, then the extent of the advantage decreases. These problems have been overcome in many instances by having the driver "drop" his trailer in a special area of the departure terminal. The ferry operator loads and unloads the dropped trailer onto and from the ship and a second driver picks up the trailer on the other side. The shipper is therefore able to increase his equipment utilization and does not have to pay a driver for idle and unproductive time. A list of ports using this system is given in Table 3.2.

** Note that the railcars must also cross to the island of Newfoundland by Ro/Ro vessel.

TABLE 3.1

TYPICAL SERVICE SPEEDS OF FERRIES IN CANADA

<u>Vessel</u>	<u>Service</u>	<u>Type</u>	<u>Year of Const</u>	<u>Speed</u>
"Ambrose Shea".	N. Sydney-Argentia	Auto/Truck	1967	17 kts
"Frederick Carter"	N. Sydney-PAB*	Railcars	1968	18 kts
"Marine Nautica"	N. Sydney-PAB	Auto/Trucks	1974	19 kts
"Seatrader"	N. Sydney-PAB	Trucks	1973	16 kts
"Abegweit"	Borden PEI-Tormentine, NB	Autos/Trucks/ Rail	1947	12 kts
"William Carson"	St. John's-Goose Bay	Autos	1955	15.5 kts
"Lord Selkirk"**	Caribou, NS- Wood Is PEI	Autos/Trucks	1958	11 kts

* Port-aux-Basques, Nfld.

** Sank off Labrador, 2 June 1977

Source: Vessel Operations Section
Water Transportation Assistance Directorate
Department of Transport

TERMINALS PROVIDING DROP TRAILER SERVICE

<u>Terminals</u>	<u>Service</u>
Digby, N.S.	Bay of Fundy
Saint John, N.B.	Bay of Fundy
North Sydney, N.S.	Gulf
Port-aux-Basques, Nfld.	Gulf
Argentia, Nfld.	Gulf
Port Borden, PEI	PEI
Cape Tormentine, N.B.	PEI

In addition to the abovenamed Canadian Ports, a similar service is provide by many European ports such as Felixtowe & Harwich in the U.K. and Esbjerg in Denmark.

Source: Terminal Operations Section
Water Transportation Assistance Directorate
Department of Transport
Ottawa

The main disadvantage of this mode for cargo, is that compared to rail or cargo freighter, it is a more expensive mode. In practice, however, this penalty has had only a minimal effect on the growth of shipping via ferries or ro/ro ships as can be seen in Fig. 3.1 which shows the growth of tractor-trailer movements to Prince Edward Island. These figures are typical for the mode.

One general disadvantage of the mode is that it is profligate in its use of space. Due to the varying heights of vehicles, it is necessary to set the deck heights to suit a high average and there is therefore a lot of wasted volume.

3.2.3 Traffic Demand

In terms of their relevance to the design of ferry systems, there are four aspects of the traffic demand (often referred to as "traffic offering") that are of some significance. They are: total volume, arrival patterns, traffic mix and traffic origins. Each of the four can have major effects on the size of the terminal elements or on their operations.

Volume of traffic can be measured in terms of passengers per year, automobiles per day, auto equivalent units* per hour or any convenient measurement that is useful for solving a given design or planning problem,

As one would expect, the total volume of traffic that offers itself for passage is one of the main determinants of the size and scope of the facilities that must be built, although the final size of the elements is not in fact linearly proportional to the total traffic volume. The reason for the lack of linear proportionality is the modifying effect of the traffic arrival pattern. We can perhaps illustrate this most clearly by using a numerical example.

* An "auto equivalent unit" is a loosely defined term that is used in Canada. It is equivalent to the space occupied by a full sized North American automobile - approx. 5.5m x 2.6m (18' x 8.5')

SOURCE: REF 2, VOL 1

FIG 3-1

It is known⁽²⁾ that the annual traffic from Cape Tormentine, New Brunswick, to Borden, Prince Edward Island in 1974 was 388,000 auto equivalent units (not counting railcars). This is equivalent to a mean flow of 1063 auto equivalents per day or 44 auto equivalents per hour. One could perhaps therefore assume that the terminal ought to be designed to handle 44 auto equivalents per hour, or more realistically 44 auto equivalents times a factor of safety. Any designer making such an assumption would be grossly in error. The service in question is highly tourist oriented with severe peaking of traffic. A full 54% of the passenger vehicles and 69% of the trucks are carried in the four summer months (June and September), with additional peaks occurring within each week and within the hours of the day. The extent of this peaking is shown graphically in Fig. 3.2 which gives the percentage of the annual flow that occurs each month, and in Fig. 3.3 which gives the percentage of traffic that occurs each quarter hour during an average summer day.

By combining the data from the two figures, we discover that the flow between 2 P.M. and 3 P.M. on an average summer day (not a peak summer day) is 266 auto equivalent units per hour, not the 44 auto equivalents obtained by using average annual figures - the difference being due entirely to application of arrival patterns.

In later chapters, we will examine the problem of determining what the design hour and/or day should be and how to design based on that hour or day.

The third aspect of traffic with which one must be cognizant is the traffic mix. Traffic mix is the percentage breakdown of the traffic into vehicle types (autos, tractor-trailers, straight trucks, etc.), and it

MONTHLY DISTRIBUTION OF PEI FERRY TRAFFIC - 1975

SOURCE: REF 2, VOL 1

FIG 3-2

PEI BOUND TRAFFIC ARRIVAL PATTERN - AVERAGE SUMMER DAY

<u>Time Interval</u>	<u>% of Traffic in Interval</u>	<u>Time Interval</u>	<u>% of Traffic in Interval</u>	<u>Time Interval</u>	<u>% of Traffic in Interval</u>
0401-0415	.04	0401-1100	1.7	0401-1745	1.4
0430	.05	1115	1.9	1800	1.4
0445	.1	1130	1.9	1815	1.3
0500	.1	1145	1.5	1830	1.3
0515	.15	1200	2.15	1845	1.2
0530	.15	1215	2.4	1900	1.2
0545	.25	1230	2.4	1915	1.1
0600	.25	1245	2.5	1930	1.1
0615	.4	1300	2.5	1945	1.0
0630	.4	1315	2.5	2000	1.0
0645	.5	1330	2.5	2015	.95
0700	.5	1345	2.65	2030	.95
0715	.65	1400	2.65	2045	.85
0730	.65	1415	2.5	2100	.85
0745	.8	1430	2.5	2115	.70
0800	.8	1445	2.5	2145	.60
0815	.9	1515	2.4	2200	.60
0845	1.0	1530	2.4	2215	.5
0900	1.0	1545	2.15	2230	.5
0915	1.2	1600	2.15	2245	.4
0930	1.2	1615	1.95	2300	.4
0945	1.35	1630	1.95	2315	.3
1000	1.35	1645	1.75	2330	.3
1015	1.5	1700	1.75	2345	.25
1030	1.5	1715	1.55	2400	.25
1045	1.7	1730	1.55		

FIGURE 3-3

Source: Reference 2, Volume 11B, Part 1

TRAFFIC MIX DATA FOR VARIOUS CANADIAN FERRY SERVICES

1976

A. GULF SERVICE

<u>Vehicle Type</u>	<u>Number of Vehicles (both directions)</u>
Railcars	29747
Containers	12558
New autos	7534
Passenger autos	62256
Auto trailers	6386
Campers	4702
Buses	193
Straight trucks	5459
Tractor trailers	28665
Mobile homes	191

B. YARMOUTH - BAR HARBOR SERVICE

Passenger autos	24263
Auto trailers	764
Campers	908
Buses	268
Straight trucks	643
Tractor trailers	196

C. BORDEN, PEI - TORMENTINE, NB

Railcars	25758
Passenger autos	432471
Auto trailers	34442
Campers	17640
Buses	2972
Straight trucks	66083
Tractor trailers	45920

Source: Statistical Records (unpublished)
 Water Transportation Assistance Directorate
 Department of Transport
 Ottawa

affects both the design of the terminals and the design of the ships. The terminals are affected by such things as the need to provide separate marshalling areas for different vehicle types (when the different vehicles require different or incompatible handling techniques or when the required strength of the pavement is different for different types of vehicles.

The vessel design is affected by the need to provide more or less high headroom space for trucks or other high vehicles, and by the need to account for different distributions of cargo weight when considering the stability of the vessel in the design stage.

For illustration purposes, Table 3.3 gives traffic mix data for selected Canadian ferry services.

The last aspect to be considered is the origin of the traffic carried, or more precisely, the average distance that a driver must travel to the terminal on the day that he wishes to take passage. The importance of this arises from the fact that the greater the distance a driver must travel, the greater is the difficulty he has in estimating his arrival time and therefore, the greater is his probability of missing a particular sailing. This problem is exacerbated when the driver is a tourist who does not know the road and who might want to stop along the way to visit points of interest. The effect of all this is to make reservation systems unpopular in countries such as Canada where the hinterland for a given service is relatively large, and where, to make a reservation system work, passengers are required to check in several hours before sailing time.

3.2.4. Effects of Climate on Ferry Operations

In a previous section, it was indicated that one of the definitive characteristics of a ferry service was its adherence to a fixed, repetitive schedule. It must be recognized however that a schedule is only as valid as external conditions allow it to be, and that the schedule will be modified by such uncontrollable factors as mechanical breakdown and weather.

For purposes of vessel operations, weather can be divided into two classes: random occurrences and predictable occurrences.

The first group includes events that are unpredictable such as summer storm, wind, rain or fog. When a vessel encounters conditions such as these, they may or may not be severe enough to disrupt the schedule and the master of the vessel can only deal with them as they occur, taking steps to maintain the schedule or not, as conditions develop.

Predictable occurrences, on the other hand are events that occur at certain periods of the year, in certain places, with great regularity.

While the operator can do nothing about these weather conditions per se, he can modify his operation and his hardware to minimize their effects. For example, it is known that the Northumberland Strait between New Brunswick and Prince Edward Island freezes every winter (see Fig. 3.4). This is a predictable event and the operator of the ferry service that crosses the Strait accounts for this freeze-up in his operating plan by allowing much more time in the schedule for each crossing and by employing only ice-breaking ferries equipped with bow and stern propellers during the winter months.

ANNUAL DURATION OF ICE COVER AT FERRY CROSSINGS

BORDEN - TORMENTINE

WOOD IS. - CARIBOU

SOURIS - GRINDSTONE

Source: Mr. Douglas Bradford
Dept. of Environment
Reference 2, Vol. 4

FIG. 3.4

Similar precautions can be taken in areas where fog is common or where there is little sunlight during the winter. In these areas, lighting of the dock areas, use of beacons and other navigation aids, and use of good quality radar sets and radar reflectors can minimize problems.

It can therefore be seen that while weather can be a disruptive force in ferry operations, its effects can be minimized at the expense of some planning time and some money.

3.2.5 Financial Aspects of Ferry Operations

A study of the finances of ferry services is beyond the scope of this thesis, but shipping in all its form is a business and the matter of how it fares financially cannot be ignored in any comprehensive considerations of a shipping operation. It must however be recognized that different services operate under quite different economic, cultural and political conditions and that the making of broad (international) generalizations is most difficult and probably somewhat invalid. This part of the discussion will therefore be confined to the Canadian situation.

The ferry service that runs between Borden, Prince Edward Island and Tormentine, New Brunswick carried over 1.5 million passengers, half a million cars and 18,000 railcars in both directions in 1974. During that year, it "lost" over \$1.5 million.*

The ferry service that runs between North Sydney, Nova Scotia and Port-aux-Basques, Newfoundland carried 300,000 passengers, 65,000 autos and 35,000 railcars in 1975. During that year, its loss* was almost \$50 million.**

* Source for loss figures is financial records of Water Transportation Assistance Directorate, Department of Transport

** Some of this loss is due to problems associated with the movement of standard gauge railcars to a province with narrow gauge tracks, really a rail problem and not a ferry problem.

The B.C. ferries lost about \$40 million on its operations in 1975.*

On the basis of the above statistics, one is tempted to ask whether ferries suffer from some technical or operational defect that precludes their operating at a profit or to question the administrative capability of Canadian ferry operators.

Certainly the costs of building and operating ferry boats in Canada is staggering. A recent "new building" cost the Department of Transport \$17 million and this was for a railcar carrier without any passenger amenities. A vessel with the capability of carrying 1200 passenger and 300 autos is estimated to cost over \$30 million. The cost of operating such a vessel is in excess of \$10,000 per day, not counting depreciation. We have then some idea of the costs. What of the revenues?

Quite simply, there is no major ferry service in Canada where the revenues equal the costs. Almost every service is subsidized by a government agency, usually the Department of Transport or the Government of British Columbia. (See Fig. 3.5 for historical data on subsidies to east coast ferries) This situation appears to have arisen as a result of the various government's unwillingness to offend segments of their populace who believe that ferries should be cheap, if not free.**

One could discuss at great lengths the correctness of this action and its positive and negative effects on the economy and on the competing transportation systems. That however is not within the scope of this thesis and the "facts" are presented without comment.

* Source for loss figures is financial records of Water Transportation Assistance Directorate, Department of Transport

** The author has, on several occasions, heard the opinion voiced that since the ferries join sections of the Trans-Canada Highway, and since the use of this highway is "free", therefore the ferries should be "free".

HISTORICAL SUBSIDIES TO MAJOR EAST COAST FERRY SERVICES*

- * Includes following ferry services:
- Borden P.E.I. - Tormentine N.B.
 - N. Sydney N.S. - Argentia Nfld.
 - N. Sydney N.S. - Port Aux Basques Nfld.
 - Newfoundland Coastal Service
 - Yarmouth N.S. - Bar Harbor Maine

FIGURE 3.5

Source: Statistical and Financial
Records (unpublished)
Water Transportation Assistance Directorate
Department of Transport
Ottawa

3.3 Vessels

3.3.1 Introductions and Definitions

The purpose of this section is to describe the different types of ferries in common use and to identify those aspects of them that affect the design of terminals. It is not however, intended that this be a treatise on vessel operations, naval architecture or shipbuilding.

In a previous section, ferry service and ro/ro service were defined. These definitions will now be extended to ferry and ro/ro vessels.

A ferry is a vessel that carries passengers and/or wheeled vehicles on "short" passages according to a fixed, repetitive, schedule. The vehicles are normally self propelled and are driven on board rather than being lifted on.

A ro/ro ship is a vessel that carries wheeled (freight) vehicles on passages that may be short or large, without necessarily following a fixed schedule.

The vehicles carried on a ro/ro ship can include railcars, tractorless trailers, straight trucks or self propelled construction equipment.

Having defined the vessels according to task, they will now be studied in somewhat greater depth from two different viewpoints - firstly according to loading methodology then according to cargo carried.

3.3.2 Vessel Types and Loading Methods

A. Side Loaders

As the name implies, side loaders are vessels in which the vehicles are loaded through doors cut into the side of the vessel at the level of the vehicle decks. As a generalization, it should be noted that few new ferries are being built as side loaders, although it is not uncommon for ro/ro vessels to be built that way.

The advantage of side loaders is that they can often use the readily available marginal wharves and piers without needing special facilities. This is not always possible however, since in many ports the tidal effects and dock heights are such that the side doors do not coincide with the elevations of the dock. In such cases, ramps or elevators must be used.

The disadvantages of side loaders are their long loading times, caused by the requirement for vehicles to turn and manoeuvre on entering the ship and the very long loading times and restrictions that arise if elevators are used to raise vehicles to the car decks. Their greatest disadvantage however arises from their inability to carry tractor trailers. This arises from the inability of tractor trailers to turn within the confines of the ship.

Figures 3.6 and 3.7 illustrate side loaders.

B. End Loaders

End loaders can be divided into two sub-groups: stern loaders and roll-through vessels.

Stern loaders are the more common of the two types (likely because they are less expensive to build) and are loaded through a large door at the stern of the vessel.

SIDE LOADING RO/RO VESSEL

FIGURE 3-6

SIDE LOADING FERRY VESSEL - ACCESS

FIGURE 3-7

(See Fig. 3.8) The advantage of stern loaders is that vehicles are loaded "straight in" without any turning movement. Thus, virtually any length of vehicle can be accommodated, and loading can be done quickly. As will be shown later, this can have a beneficial effect on the terminals since to some extent speedier handling implies smaller parking facilities. The disadvantage of stern loaders however are that they require special berthing facilities and, while they are easy to load, the requirement that vehicles be backed off means that unloading is rather slow - particularly if the cargo consists of tractor trailers.

Roll-through vessels have, in addition to a stern door, some form of bow door as well. This allows vehicles to be driven on from one end (say the stern) at the departure terminal and drive straight off from the other end at the destination terminal. The problem of backing off is therefore eliminated, while the advantages of driving straight on are maintained. The processes of unloading and loading are therefore very rapid and the vessel can be "turned around" within a short time - thus increasing its utilization. Note that when the vessel is "reloaded" at the destination terminal, the vehicles now enter from the bow and will drive out through the stern. This means that the vessel must back into the dock at the original terminal. This is a slower process than going in bow first and some time is therefore lost. For this reason, some ferries are so-called "double enders". That is, both ends are identical, with two bridges, two sets of propellers, two sets of controls and two rudders. Thus they can be sailed straight in at both terminals. When the time comes for departure, the captain just moves to the other bridge. The trade-offs of this system are that they

C

STERN LOADING RAIL CAR CARRIER

FIGURE 3-8

ROLL THROUGH VESSEL - SINGLE ENDER

FIGURE 3-9

are somewhat less efficient in the water due to the hull shape.

Figures 3.9 and 3.10 are photographs of typical examples of the above.

C. Quarter Loaders

These are vessels that load through doors that are located at the "quarters" of a vessel. The "quarters" are the areas that are equivalent to the "corners" of a rectangle. They are thus operationally somewhere between the side loaders and the end loaders. The tight angle of approach still tends to limit the size of vehicle that can be handled, and in practice quarter loading is usually only used for automobiles. The angle of approach does however allow vehicles to be loaded and stored in an oval arrangement on board so that the first vehicles drive almost all the way around an "oval track" and come to rest facing the door, from which position they can be driven out in forward direction.

The access ramp for quarter loading is normally mounted on shore, although there are a few vessels that carry very long (and expensive) shipborne ramps that can reach from the quarter point to a marginal wharf. This allows them some of the same flexibility as side loaders. This latter arrangement is not used for ferries on a fixed run, but is reserved for vessels that operate in many different ports where sophisticated shoreside facilities are not likely to be available.

ROLL THROUGH VESSEL - DOUBLE ENDER

FIGURE 3-10

DOUBLE ENDED PASSENGER FERRY

FIGURE 3-11

3.3.3 Characteristic Vessel Type - By Cargo Carried

A. Passenger Only

Vessels of this type are usually only found in circumstances where the service is "close" to its clientele. In this case, "close" means close in the sense of "convenient to" or "able to be reached in a short time". This of course follows from the fact that autos are not carried and the passengers must be able to reach the service by public transit, by walking or by being dropped off. The consequences of this are that passenger only ferries are normally only found in the vicinity of population centres, and most often are used to join two large population centres (such as the Thames service which joins central London to Greenwich). An exception to the above is the "Sprinter" service which joins the various small outports on the South Coast of Newfoundland to Port-aux-Basques, although one could argue that this a water-bus service rather than a ferry service.

The vessels used in passenger services tend to be small, light and relatively fast. The Newfoundland service, for example, uses 23 knot aluminum vessels while the Thames service and the Seattle service are using hydrofoils. There are exceptions, of course, such as the Toronto Island service, which uses a fleet of slow, heavy, large steel vessels able to move 50,000 passengers onto the island and back in one day.

The advantage of passenger only ferries are that they can move large numbers of people at low unit cost and with a minimum of investment in capital and minimum crew. The disadvantages are that the small vessels usually can't operate in winter conditions and in bad weather they can be somewhat uncomfortable.

The terminal requirements for vessels of this type vary considerably depending on the number of passengers carried and the speed with which they must be unloaded. The Newfoundland service, for example, carries small numbers of passengers using small vessels and can therefore utilize any dock on its route that has sufficient depth alongside. A new service which operates across the Burrard Inlet in Vancouver, however, connects two commuter bus lines, carries 400 passengers per trip (see Fig. 3.11) and must be unloaded as quickly as possible. In this case, the terminals have been designed to ensure fast docking, using U-shaped fitted berths and rapid unloading and loading of the vessel. The terminals are arranged so that all departing passengers are marshalled on one arm of the U and embark through doors spaced the full length of the vessels. Arriving passenger disembark through similar doors to the other arm of the U. The arriving and departing passengers do not meet or mix.

Other considerations for passenger only vessel facilities include provision of weather shelters for the passengers and provision of sanitary facilities.

B. Railcar Carriers

This kind of ship can be used to carry freight cars only (as do the ships operating on the Gulf of St. Lawrence) or they can carry passenger trains as well (as do the vessels owned by the Danish State Railway). In addition, they can be single purpose, carrying railcars only or they can be multipurpose, as are some of the vessels of the Borden-Tormentine run which carry autos,

passengers and trucks during the day and railcars at night. In this latter case, the vessels must be licenced to meet the more stringent safety regulations that this implies.

From a terminal design point of view, the presence of railcar carriers adds significantly to the cost and to the design problems. It is necessary that the transfer bridges be of type that provides a flush, continuous span from vessel to shore (to ensure continuity of the rail) and must always be able to move with the tide, something not always necessary when dealing with highway vehicles. In addition, the bridges must be strong enough to carry heavily loaded trains and rail marshalling yard must be provided to allow the trains to be broken up for loading aboard ship.

The advantage of railcar carriers is that they allow the movement of rail cargo across a water gap without the necessity of unloading and reloading the boxcars.*

C. Freight Only

This class of vessel is in fairly wide use in Europe, but has been used only occasionally in North America. It should be noted that the term "freight only" is a slight misnomer, since cargo vessels can normally carry up to 12 passengers (truck drivers in this case) without having to suffer the much more rigorous licencing requirements of a passenger vessel.

* Unless the tracks have different gauges on each side of the water gap, as is the case with Newfoundland bound traffic.

The advantages of this type of vessel are two: the comparatively low capital and operating costs that arise from eliminating the need to provide expensive accommodation, crewing and safety features for passengers; and the ability to be able to run "off shedule" if required, since large numbers of people are not inconvenienced by schedule changes.

The terminal implications of running this sort of vessel are not severe. The docks and transfer bridges are similar to those for ferries that carry passengers and vehicles. The one additional cost that can arise is the need for a segregated marshalling area for trucks and temporary storage space for vehicles that are carried without drivers, (and often without propulsion units). If the schedule is spread out, it is often possible to use the passenger vehicle marshalling area for both types of vessels - but usually segregated areas are necessary.

D. Passengers and Highway Vehicles

This is the most common type of ferry. Generally they can carry a mixture of cars and trucks, although the number of each vehicle type will vary with the size of vessel. A typical ferry of this configuration would have a single vehicle deck with sufficient clearance to enable it to carry 50 - 100 autos or 20 - 40 trucks. The vehicle deck might be equipped with drop down, light weight mezzanine decks that can convert a single deck of truck height into two decks of auto height. Another typical configuration would be to have two decks, one of which is high enough for trucks and one of which is high enough only for autos. The access to the higher deck can be through internal ramps on board (in which case no loading provision need be provided in the terminal) or can be by means of an external shore mounted ramp in which case the terminal designer must provide space for the ramps.

and must consider the more complicated traffic flows in his layout.

The size of passenger/vehicle ferries varies from a low of two autos and a dozen passengers to 300 autos and 1500 passengers.

The movement of this number of vehicles and people in the short periods required to ensure the rapid turnaround of multimillion dollar vessels obviously requires a highly organized approach to the marshalling and loading of passengers and vehicles. This will be dealt with in section 3.5, but the requirement should be noted. At a daily cost of \$10,000 for a ship of this type, a delay of minutes in loading the vessel will cost the operator \$69.00.

Figures 3.7, 3.9, 3.10 and 3.12 illustrate passenger/highway vehicle ferries.

3.4 Interface Requirements

In the previous sections, the vessels have been considered. In the next sections, the terminals will be considered. Some consideration should at this point be given to the elements that join the ships to the shore. These elements are called "interface details" or elements.

There are two main types of interface elements - cargo transfer mechanisms and service connections.

The service connections are similar to those required by all vessels, and these include fuel supply, water supply, shore power, telephone and (increasingly) sewage discharge facilities. Since these are more or less standard fittings, they will not be considered further except to note that during peak periods it might be necessary to turn the ship around faster than the ship can

PASSENGER/HIGHWAY VEHICLE FERRY

Figure 3.12

PASSENGER BRIDGE - GOTHENBURG, SWEDEN

Figure 3.13

be serviced using standard connections and some consideration may have to be given to using fittings with larger than normal discharge rates.

The cargo transfer mechanisms for ferries are of two types - passenger bridges and vehicle transfer bridges.

The passenger bridges are for the use of passengers who do not drive their cars on, but must walk from the terminal to the ship. Typically, they resemble the system used at airports. Figure 3.13 shows one in use in Gothenburg, Sweden.

The interface for vehicles can be any one of several different systems including a fixed shore ramp and a shipborne "flap" that drops on it (used for highway vehicles when there is little or no tide); a self-supported movable ramp that can be raised or lowered with the tide and a shipborne flap that drops on it (used for highway vehicles); a movable shore ramp that lands on the ship and is locked into a tight flush fit with the deck (used for rail transfer to ensure continuity of track). Figure 3.14 shows examples of the above.

In addition side loaders are sometimes served by elevators that lift the vehicles to the deck one at a time in a very slow process.

These topics will be considered again in the next section on terminal hardware and operations.

3.5 Terminals

3.5.1 Introduction

In previous sections ferry and ro/ro "services" and "vessels" have been defined and differentiated and these

A) SELF SUPPORTED MOVEABLE SHORE RAMP

B) SHIPBORNE FLAP LANDING ON FIXED SHORE RAMP

paired definitions can be continued by describing a ferry terminal as "a facility for receiving, processing, marshalling and loading passengers and vehicles onto ferry boats and for the carrying out of ancillary tasks required to support the operation of the service." A ro/ro terminal can be described as "a facility for receiving, processing, marshalling and loading wheeled cargo onto ro/ro vessels and for the carrying out of ancillary tasks required to support the operation of the service."

In fact, however, the functional differences between a ro/ro terminal and a ferry terminal are minor and relate for the most part to the provision of passenger related facilities. In practice, the same facility is often used for both types of traffic. In the following sections we will therefore not separate the discussion of the two terminal types, but will just bear in mind that the portions dealing with passengers do not apply to ro/ro terminals.

In Chapter II the main elements of a ferry terminal were identified and labelled on a drawing. The reader is therefore referred to Fig. 2.1 which indicates the relative location of each of the main terminal elements.

3.5.2 Terminal Elements

The purpose of this section is to identify and describe the purpose and characteristics of each of the elements that together constitute a ferry terminal. Not all of the elements described below are found in every terminal and the designer must determine the requirements and scope of the service (in conjunction with the operator) to decide which elements should be included in any particular

terminal. The next chapter will examine the criteria that the designer and operator should use in making these decisions and in determining the size of the elements.

A. Access/Egress Roads

These are roads that provide access to and egress from the terminal complex. They may be common use roads or may be dedicated solely to ferry traffic. The quality of these roads (i.e. number of lanes, geometrics, etc.) will normally vary with the importance of the service and the traffic flow as well as with other uses if any to which the road may be put.

B. Surge Parking

This is a fairly small "parking" area where vehicles arriving via the access road can queue up to purchase tickets at the ticket booths without backing up and causing congestion on the access roads.

C. Ticket Booths

These are booths normally located at the entrance to the terminal where drivers can pay their fares without leaving their vehicles. The configuration of the booths can be such that all types of vehicles can use every booth or there can be some booths dedicated to one type of vehicle only. In addition the ticketing system can be used to break the traffic up according to destination, if the particular terminal handles more than one service. In a very complex case there could be groups of booths for each destination of which each booth is dedicated to a particular type of vessel.

Ticketing facilities are also often located within the terminal building as well, to accommodate foot passengers who may not enter at the same location as the vehicles.

D. Marshalling Areas (also called Parking areas or Compounds)

These are the areas in which vehicles awaiting passage are held and sorted pending their being loaded aboard ship. They are essentially just a form of parking lot except that the self-propelled vehicles are parked "nose-to-tail" in parallel lines. This layout provides a compact arrangement and allows the operator to quickly move the vehicles to the ship in a controlled manner. The layout of the marshalling areas will vary depending on the number of destinations handled out of the one terminal; the ability of the ships to carry a random mix of automobiles and trucks without becoming unstable, the use of priority loading for certain traffic such as buses; and the carriage of non self-propelled vehicles. Each of the preceding could require the provision of a separate marshalling area.

The layout of marshalling areas designed for non self-propelled vehicles such as "drop trailers" or containers on wheeled flats is similar to the layout of a commercial parking lot with the vehicles parked parallel to each other (often angled) and facing an access aisle. This is to allow the yard tractors to easily back up to the trailer. Normally a facility of this sort is located as close as possible to the ship to keep the loading time to a minimum.

Very often the strength of the pavement in the different types of marshalling areas vary, with those areas designated for heavy vehicle use having a stronger structure.

E. Transfer Roads and Ramps

These are roadways that lead from the marshalling areas to the transfer bridge that joins the ship to the shore and from the transfer bridge to the egress road. They are usually one lane wide, but if the ship is designed for it, they may be two lanes wide. Ramps are only needed if the ship loads on two levels simultaneously, in which case the ramps serve to transfer the traffic to the higher level.

F. Transfer Bridges (also called Shore Ramps or Link Spans (UK))

These are the structures that join the ship to the shore. They may be fully fixed, but usually they are designed so that the shore end is a hinge and the seaward side is able to move up and down with the tide. This movement can be achieved by providing a hydraulic or mechanical lifting system near the seaward end or it can be achieved by building a floating structure on pontoons, that moves up and down with the tide at the seaward end. The length of the bridge must be such that even at extreme tides the gradient does not exceed the climbing capability of the vehicles that have to use it (5-6% for rail*, 6-8% for heavy trucks, 8-10% for autos).

For the case of rail bridges it is usual for the bridge to land on a recess in the fantail of the ship so that a "locked", flush and continuous deck system is created that allow the rails to be unbroken and level across the ship/shore transition. Normally, when this state is achieved the bridge mechanisms are put into neutral and all the weight is carried by the ship.

* This grade is only acceptable for the short length of the bridge, with the propulsion unit on level ground. The normal maximum grade for rail is much less (1-2%).

In the case of highway vehicle bridges, the above system may be used, but due to the flexibility of highway vehicles to handle changes in grade, a "flap" is usually used to connect the transfer bridge to the ship. The flap is most often the stern door of the ship, but it can also be mounted on the transfer bridge itself. The advantages of using the flap system are that the ship does not have to come into contact with the bridge so that there is much less possibility of damage being done to the bridge; the shipborne flap provides flexibility if the vessel has to go into a different dock (the flush systems are usually not interchangeable) and the flap acts as an extra means of taking up small height changes caused by tidal movements during loading.

G. Berths

The berth is the wharf or pier where the ferry docks. If the vessel is a side loader it will be a straight structure with no protrusions, but it will be "L" shaped if the vessel is an end loader (in which case the transfer bridge acts as the foot of the "L"). The end of the berth at the transfer bridge can be "square" or it can be "fitted". A fitted berth (see Figure 2.1) is sometimes called a ferry "slip" or a "bootjack" (in Canada). The advantages of a bootjack are that they allow the ships to dock much more quickly by "funnelling" or forcing the ship into position near the transfer bridge; also they provide much more lateral stability than can be achieved with rope lines - an important factor when loading railcars. The disadvantage of fitted berths are that they restrict the range of ships that can use the berth. A ship that is only a few feet beamier than the one for which the berth was designed will jam before it reaches a final docking position.

The fendering systems for ferry berths are normally much more sophisticated than for other vessels of the same size. Whereas other vessels can spend an hour on docking procedures a ferry usually can allot 5 minutes and must sometimes dock several times per day in the same berth. The fendering system must therefore be strong and be able to take the repeated impacts caused by fast dockings without damage to themselves or to the ship. They are therefore often built of hardwood timbers on steel on rubber energy absorption units on concrete. This obviously costs much more than a few truck tires hung over the side of a wharf.

H. Terminal Building

The terminal building for a ferry service provides many of the same facilities as does the terminal at an airport. It may contain any or all of the following services: waiting room for passengers, (both foot and auto); toilet facilities; eating facilities; ticketing facilities; offices for the ferry service operator; customs and immigration facilities; lunchroom for terminal or vessel staff; tourist information centre; gift shop; first aid station; repair shops, travel agency or other commercial enterprises; money exchange; duty free shop; etc.

The size of the terminal building and the number of the facilities contained in it will vary with the traffic (domestic or international), and the distance to similar services outside the terminal. It is up to the designer and the ferry operator to determine which of the possible services should be provided.

I. Intermodal Connections

These are facilities for connecting the ferry service to other modes. For the most part they concern only foot passengers and involve the provision of such facilities as bus stops, taxi stands, and passenger drop-off zones.

There are a few services, such as the Gulf of St. Lawrence service to Newfoundland where some cargo arrives on trains and is reloaded onto flatbed truck units for transport to Newfoundland. In this case a transit shed, similar to those in use at most marine terminals is required.

J. Staff Parking

This may or may not be provided depending on the remoteness of the terminal, availability of transit connections, union agreements or local practice. In many cases it is provided for senior staff only.

K. Visitor and Short-term Parking

A parking lot, of not too large proportions, is required to accommodate people who wish to obtain information about the ferry service; who must carry on business with persons involved with some aspect of the operation or who wish to drop passengers off, but stay with them until their departure.

The lot should be located close to the terminal building, if possible, in order to maximize convenience and must have an access route that bypasses the ticketing process.

L. Stevedoring Facility

This is not a common requirement of ferry services, but may be necessary if stevedores are used to "tie down" the ferry traffic. This is a process whereby vehicles are clamped to the deck of the vessel in order to decrease the possibility of their moving during heavy weather. The required facilities would normally be a lunchroom and a storage area for any equipment that the men need.

M. Maintenance Facility

The extent to which maintenance facilities are provided will vary with the policy of the operator to "make or buy" maintenance service. At a minimum, a maintenance facility could be just a janitor's store room. On the other hand, a recent study by the Canadian Department of Transport⁽⁹⁾ of one of its ferry service operators recommended the implementation of a policy whereby all maintenance except very major vessel repairs and repairs requiring the drydocking of vessels should be done "in house" and recommended the construction of a large maintenance facility to complement this policy. It was found that the conservatively estimated savings accruing from this policy would pay for the facility in under five years.

N. Customs and Immigration Facilities

This is a requirement for international services only and consists of a marshalling area in which vehicles leaving the ship can be lined up in several queues for

processing by customs and immigration officers. Depending on the locale, additional facilities could include a passport control office, secondary clearance office, lock-up, etc.

4.1 Introduction

In Chapter I, it was noted that the first phase of any major marine work is the project definition phase. It is at this time that the owner/operator of the ferry service and the designer establish the scope of the project and, at least in theory, explicitly determine the design criteria. The design criteria are a means of ensuring that the final product is designed not only to meet the needs of the users, but to do so at the level of service specified by the owner or operator.

Given the close relationship that exists between level of service and size of facilities required and between specified design criteria (such as vessel size etc.) and size of facilities required, it is evident that the design criteria established during the project definition phase act as a major determinant in the establishment of the sizes of the elements of the terminal during the design phase.

For the above reasons, the determination of the project design parameters constitutes the first part of the design methodology being developed in this thesis. The second part of the methodology consists of a series of mechanical techniques for determining the size of the major elements of ferry terminals and will be presented in Chapter V. The two parts of the methodology, when used together allow the designer to determine the size (or number) input required for producing a master development plan.

One problem that must be faced in establishing design criteria are that no two services or terminals are quite the same: almost always the traffic handled is different; the arrival patterns are different; the equipment is different, the operating environments are different and the policies are different.

It is thus impossible to establish definitive design criteria that will be universally valid. It is possible however to define the factors that must be considered when establishing design criteria and to suggest one or more criteria that could be used in "typical" situations. These "typical" criteria and the factors to be considered when setting them will generally reflect the policies, practices and experiences of those designing, operating and building ferry terminals in Eastern Canada but will also reflect the author's observations of foreign services.

Criteria could be established for virtually every minute aspect of design but it is felt that this is unnecessary and could prove constricting to the designer. Rather a list has been compiled (Table 4.1) of those aspects of a ferry terminal for which the establishment of criteria was considered relevant and from this list, the more important items were selected for further discussion.

The format that will be used will be to first define in the form of a question, a required criterion for a particular area of concern, then to discuss the factors that should be considered in the establishment of this criterion and finally to suggest one or more possible criteria for "typical" situations.

DESIGN CRITERIA AND POLICIES REQUIRED FOR FERRY AND RO/RDTERMINALS

<u>AREA OF INTEREST</u>	<u>REQUIRED CRITERION OR POLICY</u>
design vessel	What is size and capacity of design vessel?
design year	What year should be selected as the design year?
design day	What day of the design year should be the design day?
design hour	What hour of the design day should be the design hour?
Design vehicle	What size and type of vehicle should be the design vehicle?
Access/Egress Road	What level of service should be provided?
Access/Egress Road	What geometric standard and design speed to be used?
Access/Egress Road	What structural strength should be provided for road?
Access/Egress Road	What lighting should be provided?
Surge Parking Lot	How large should surge lot be?
Ticket Booths	How many ticketing channels should be provided (ie what is acceptable waiting time in queue)?
Marshalling Areas	How many separate marshalling areas to be provided?
Marshalling Areas	How large should the marshalling areas be?
Marshalling Areas	What structural strength should be provided?
Marshalling Areas	What lighting should be provided?
Transfer Roads	How many lanes wide should they be?
Transfer Roads	What geometric standards?
Berths	How many berths should be built?
Berths	What should be the dimensions of the berths?

Passenger Amenities

What passenger amenities should be provided?

Passenger Amenities

Size and number of amenities?

Staff Amenities

What amenities should be provided for staff?

Staff Amenities

What size should staff amenities be?

Maintenance facilities

What type and size of maintenance facilities to be provided?

Land Acquisition

What is policy re purchase or expropriation?

Environment

How much emphasis to be given to environmental protection?

Finance

What are the financial limitations?

Future growth and expand-
ibility

To what extent should future growth be considered in the design?

Socio-economic

What consideration should be given to effects on socio-economic fibre of surrounding area?

Level of Service

What is to be the general level of service of the ferry system - ie what average waiting time etc.?

Design life

What is to be the design life of the facility?

Quality of Construction

What is policy on capital expenditure vs maintenance expenditure?

Construction Staging

What are the requirements for staging of construction?

4.2 Design Year

4.2.1 Criterion Required

The traffic volumes and other conditions of what future year should be used as a basis for the design of the terminal facilities.

4.2.2 Factors to be Considered

- (a) The volume and rate of traffic growth.
- (b) The accuracy with which future traffic can be estimated.
- (c) Useful life span of terminal facilities. (Usually 25 - 30 years).
- (d) Useful life of the vessels. (20 - 20 years).
- (e) Potential for advances in technology. (Difficult to estimate this, but recent years have produced advances in propulsion, manoeuvrability, and loading techniques).
- (f) Estimated required life of facility. (Usually permanent, but sometimes much less).
- (g) Available funds. (The further in the future is the design year, the greater is the required size of the facility, generally).

4.2.3 Possible Criterion

A practical figure is 15 years from the decision to do a project, for a first phase horizon. Provision should be made for additional easy expansion after that time, depending on conditions. This figure has been used by the Canadian Department of Transport in much of its marine planning work and is approximately equal to the useful half-life of both the ships and terminals.

4.3 Design Day

4.3.1 Criterion Required

If the volumes of traffic offering (ie demand) for each day of the design year were listed in descending order, for which day should the facilities be designed?

4.3.2 Factors to be Considered

- (a) Volumes of traffic per day.
- (b) Peaking effects. (How many and how high are the peaks?)
- (c) Do all vehicle types peak at the same time?
- (d) Does peaking by one type of vehicle cause more difficulty than peaking by another type?
- (e) Ability of the service to cope with the difficulties created by not having sufficient capacity at certain times of the year.
- (f) Relationship of design day in design year to traffic in years prior to the design year.
(The design day in the design year is likely to have much higher traffic volumes than any day in years preceding the design year.
Therefore, the number of days in the design life when capacity is insufficient may be very small).
- (g) Number of abnormal peaks.
- (h) Political repercussions of insufficient capacity.
- (i) Actions of competitors if service has insufficient capacity.
- (j) Available funds.

Note that in this thesis the general assumption has been made that on the design day, all facilities must be capable of handling 100% of the traffic demand.

4.3.3 Possible Criterion

For services with high summer peaking effects in locations where there would be significant embarrassment caused by insufficient capacity, the Canadian Department of Transport uses the 3rd peak day for autos and the 8th peak day for trucks.

For other services, the averages of the 6 highest days are used.

A graphical view of what these design days mean in terms of relative and absolute traffic volumes can be seen in Fig. 4.1 which shows the daily volumes through the Tormentine, N.B. Terminal during the peak (summer) season.

4.4 Design Hour

4.4.1 Criterion Required

Which hour of the year should be used as the design hour.

4.4.2 Factors to be Considered

- (a) Peaking effects
- (b) Desired level of service
- (c) Width of traffic peaks i.e. how long do the peaks last
- (d) Number of occurrences of traffic volumes similar in size to a proposed design hour volume
- (e) Effects of insufficient capacity

4.4.3 Possible Criterion

Most highways are designed on the basis of the 30th highest annual hourly volume and in the case of a multi-use road with minimal peaking effects this is considered satisfactory.

For services with marked seasonal peaks, the

DAILY PASSENGERS IN THOUSANDS

20

15

10

5

TRAFFIC VARIATIONS BY DAY

JULY 1976

BORDEN - TORMENTINE SERVICE

SOURCE: DOT STATISTICS (UNPUBLISHED)

FIG 4-1

T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S
DATE & DAY

Canadian Department of Transport uses the highest hour of the design day as a design volume. This is approximately equal to the 15th highest annual hour. This is considered necessary due to the large number of passengers who would be inconvenienced on the Department of Transport's tourist related services should the 30th hour be used.

4.5 Design Vehicle

4.5.1 Criterion Required

What size and type of vehicle should be used as a basis for the geometric and structural aspects of the design?

4.5.2 Factors to be Considered

- (a) Traffic Mix. (What percentage of the traffic is tractor/trailers, buses, trucks, autos?)
- (b) What is the future traffic mix likely to be?
- (c) Can different elements have different design vehicles? (For example, different marshalling areas could be designed to handle different vehicle types).
- (d) Limitations created by the topography.

4.5.3 Possible Criterion

Generally, the design vehicle should be the largest that can reasonably be used, in order to allow for future shifts in traffic mix. This is especially true when considering facilities that are difficult to change after they have been constructed, such as bridges. If possible then, the design should be a WB15^{*} vehicle, given the trend to the movement of goods by tractor/trailer.

Unless there is absolute certainty that trucks or buses will never use a service, passenger vehicles should not be used as a design vehicle.

* Roads and Transportation Association of Canada (Metric) Classification. See Reference 20.

4.6 Environmental Factors

4.6.1 Criterion Required

How much money and effort should be spent on trying to protect the local environment when designing and building a ferry or RO/RO terminal?

4.6.2 Factors to be Considered

- (a) Present and future laws and regulations.
- (b) Company policy re environmental protection.
- (c) Cost of environmental protection.
- (d) How fragile is the environment - ecologically and aesthetically?
- (e) Activity of public pressure groups.
- (f) Public relations considerations.
- (g) Existing condition of local environment.

4.6.3 Possible Criterion

The Canadian government follows a policy of trying to be an exemplary example in environmental matters and as a result expend as much money and effort as required to ensure the maximum protection of the environment during construction of all facilities.

Private operators generally follow a rule of providing only the minimum presently acceptable level of environmental protection for the jurisdiction in which the terminal is being built.

The author suggests that a reasonable approach is to design facilities to meet anticipated future laws and regulations to avoid the cost of retrofitting.

4.7 Design Ship

4.7.1 Criterion Required

What size of ships (dimensions and capacity) should be used as the design ship?

4.7.2 Factors to be Considered

- (a) Traffic projections for design year
- (b) Size limitations imposed by harbour topography
- (c) Size of vessels now in use
- (d) Technological change predictions
- (e) Level of service desired

4.7.3 Possible Criterion

The Department of Transport does its terminal layouts on the basis of the largest ship expected to be used in the design year.

4.8 Financial Matters

4.8.1 Criterion Required

How much money in excess of the bare minimum now required should be spent?

4.8.2 Factors to be Considered

- (a) Is it likely to be necessary to expand the terminal in the future? If so, some extra money spent now in preparation could save a lot of interference and costs in the future.
- (b) Is cash flow a problem? It is often possible to build cheaply now in exchange for higher maintenance costs in the future.
- (c) Is the builder planning to operate the facility himself for the long term or is he planning to sell it.
- (d) Is the facility being built to last a long time or is it a temporary facility?

- (e) Is it difficult to get the terminal maintained, or is vandalism a problem. In both cases, it may be better to spend extra to minimize maintenance.

4.8.3 Possible Criterion

A standard business approach would be to design to minimize the present value of the stream of capital and annual estimated maintenance costs.

4.9 Access/Egress Road

4.9.1 Criterion Required

What level of service* should be provided by the access/egress road? In effect this means "How many lanes should be provided?"

4.9.2 Factors to be Considered

- (a) Volume of traffic arriving to use the ferry
- (b) Volume of non-ferry traffic that uses the access road
- (c) Arrival pattern of traffic
- (d) Requirement to unload the ship quickly to maintain schedule or to get maximum use out of equipment

4.9.3 Possible Criterion

Level of service "C" provides a reasonably good flow and is generally considered acceptable. Therefore design for level of service "C" in the design year. Provide free access to non-ferry facilities at all times, even during peak periods.

* See Highway Capacity Manual for definitions of level of service - Reference 10.

4.9.4 Criterion Required

To what geometric standard should the access road be built?

4.9.5 Factors to be Considered

- (a) Access road alignment is almost always the same as the egress roads and the needs of the egress road must be considered.
- (b) Standard of roads into which the access road ties. The access road should be not too different in quality from the roads into which it joins.
- (c) Topography. Rough or hilly terrain adds to the cost for any given design standard.
- (d) Traffic volume and arrival pattern. Higher standards are required for higher volumes.

4.9.6 Possible Criterion

If the terminal is reached by a high level, high speed road, such as the Trans-Canada, then the access road should be RAU100* or RAU80 providing the access road is long enough to allow traffic to safely attain these speeds. This will provide a consistency of speed without entailing the costs of a divided highway.

If the terminal is in an urban environment, then the standards should be commensurate - probably RAU 30.

4.10 Surge Parking Lot

4.10.1 Criterion Required

How large should the surge parking lot be?

* Road and Transport Association of Canada Classification
RAU100 - Rural, arterial, undivided, 100 KM/HR (See Reference 20)

4.10.2 Factors to be Considered

- (a) What are the consequences if traffic backs up along the access road? If it is an isolated, sole use road, then there are no consequences, but if it is a common use road, then other users may be inconvenienced.
- (b) What are the delays at the toll booth caused by vehicles having to move from a line up on the access road to the toll booth? If there are only one or two booths, then the delay is minimal. If there is an array of 5 or 6 booths the delay would be considerable.
- (c) Can all vehicles use all toll booths? If some vehicles must go to specific booths, either because of segregation by vehicle type or because of segregation by destination, then a surge lot is required to allow these vehicles to quickly marshal themselves into the proper line-up.
- (d) Cost factors. The cost of a surge lot is not very high.

4.10. Possible Criterion

The surge lot should be big enough to hold the maximum queue formed in front of the ticket booths on the design day.

4.11 Ticket Booths

4.11.1 Criterion Required

How many ticketing channels should be provided?

4.11.2 Factors to be Considered

- (a) There is no advantage to being able to process more vehicles between vessel departures than the marshalling area can hold. Once the marshalling area is full, then the maximum number of vehicles that can be processed depends on the vessel schedule and the rate at which vehicles are loaded.
- (b) The greater the number of booths, the greater is the staffing development.
- (c) If all booths can handle all vehicles regardless of type or destination, then there will be less need for vehicles to jockey for position while being ticketed - but they will have to be sorted after the ticketing process.
- (d) Passengers tend to become angry at having to wait in line for tickets if they can see that the marshalling area is empty.
- (e) Slow ticketing can mean that people miss a sailing and that a ship that might have gone full, has sailed with unused capacity.
- (f) Even if there are a lot of ticket booths, it is not necessary to staff all booths at all times.

4.11.3 Possible Criterion

As a minimum, it is necessary to provide enough toll booths to ticket a full shipload (maximum sized ship in the fleet) between successive departure times.

If a desired level of service rule has been established, this can be used as a basis and the designer can provide sufficient toll booths, so that on the design day, nobody has to wait for more than "x" minutes to

purchase a ticket, where "x" reflects the acceptable level of service. The author suggests that "x" not exceed 10 minutes and if possible only five minutes. Note that in a single channel situation, a 10 minute wait can be translated into a line of cars 1,200' long.

4.12 Marshalling Areas

4.12.1 Criterion Required

How many separate marshalling areas should be provided?

4.12.2 Factors to be Considered

- (a) Is the pavement structure strong enough (or do you want to spend the money to make it so) in all areas to carry the weight of the heaviest vehicle to be carried. If the area is large and the number of heavy vehicles is small, it is cheaper to build only a portion of it to full strength.
- (b) Is it necessary to carefully place the heavy vehicles around the deck to ensure the stability of the vessel? If so, a separate area from which they can be loaded at will, is required.
- (c) Are some vehicles given loading priority. If so, it is convenient to marshal them separately.
- (d) Do different types of vehicles require different or special handling techniques? For example, drop-trailers require space for the tractor to manoeuvre.
- (e) How many vehicle types are handled at the terminal? If only one type of vehicle is handled, then one marshalling area may suffice.

- (f) How many destinations are handled from the terminal? It is usually more convenient to handle each destination from a separate marshalling area.

4.12.3 Possible Criterion

A separate marshalling area should be provided for each destination handled in the terminal.

A separate marshalling area should be provided for self-propelled trucks and buses.

A separate marshalling area, with wide aisles, should be provided for drop-trailers. Usually the same area can be used for both vehicles being loaded and those just unloaded.

4.12.4 Criterion Required

How large should the marshalling areas be?

4.12.5 Factors to be Considered

- (a) The marshalling area can be no smaller than the size of the shipload of the size of the largest ship in the fleet.
- (b) Traffic often arrives in larger numbers than the fleet can immediately transport, resulting in queues. The marshalling areas must be large enough to hold all these queues on the design day.
- (c) The process of vehicle accumulation in the marshalling area is "semi-dynamic", that is vehicles are constantly arriving in the queue, even when loading is going on - but loading is only done at specified times. The effect is that the queue is constantly changing its length but not at a uniform rate.

- (d) Loading is not an instant process. It can be as short a process as 7 minutes for 150 autos on the Borden-Tormentine service to PEI or as long as 1 hour for the same number of vehicles in a side loader reached by elevators.
- (e) The more frequent are the departures, the smaller is the number of vehicles that can accumulate between departures, and the smaller is the required marshalling area size.
- (f) It may be possible to use the access road as a backup marshalling area, but this may not be too popular with other users of the road or with passengers who are unable to leave their vehicles for long periods.

4.12.6 Possible Criterion

The marshalling areas must be large enough to hold the longest queue on the design day of the design years.

4.13 Transfer Roads

4.13.1 Criterion Required

How many lanes wide should the transfer roads be?

4.13.2 Factors to be Considered

- (a) How quickly must the vessel be loaded or unloaded in order to maintain its schedule or to maximize its utilization.
- (b) How wide are the access doors to the ship? Most ships' doors are 1 lane wide and there is no advantage to building the transfer roads wider than the doors since the door width is the limiting factor in the system.

- (c) How quickly can the egress road absorb the traffic? There is no point in unloading the ship faster than the traffic can be moved away from it.
- (d) Cost of construction. The transfer roads are usually a fairly minor portion of the total terminal development cost.
- (e) Can the vessel be loaded on more than one deck or at more than one location simultaneously? If so, more than one lane is likely needed.
- (f) How many vessels are to be loaded simultaneously?

4.13.3 Possible Criterion

The number of lanes of transfer road (in either direction) should not be greater than the number of lanes that can be simultaneously loaded on board ship or absorbed by the egress road.

4.14 Berths

4.14.1 Criterion Required

How many berths should be built?

4.14.2 Factors to be Considered

- (a) Ships with different loading methodologies require different types of berths so that if the fleet has a mix of vessel types, it might be necessary to build a different berth for each type of vessel. Often, however, one berth can be built to suit two different types of loading methodologies: i.e. side loading plus end loading or end loading plus quarter loading.
- (b) There is a limit to the number of vessels that can use a single berth. This limit is a function of the schedule (how many departures per ship per day) and the time in berth per departure.

The time in berth is the block of time for which a single departure monopolizes a berth, and includes docking time, unloading time, loading time, undocking time, and time in the harbour when the berth must be empty in preparation for the ship's arrival. There must also be a safety factor to allow for delays and miscellaneous problems.

- (c) If the service is the only way to cross the particular water gap, then it is desirable to have more than a single berth at each port just in case it is necessary to carry out repairs to the berth. This is often impossible due to high cost of the berth, especially in areas with high tides where the berths tend to be large.
- (d) The construction of a berth is very expensive.
- (e) Not all ships can fit into all berths. Fitted or bootjack berths are only able to accept a limited range of size and shape of vessel. Also, the available water depth at a given berth may preclude its use by vessels with deeper drafts.

4.14.3 Possible Criterion

The number of berths should be the minimum required to handle the expected fleet in the design year. If more than one berth is required in the design year, but only one berth is required for the first few years, then construction should be staged and the berths built one at a time as needed but according to a master development plan. This allows changes to the design to take advantage of new technology or different sizes of ship.

Given the very high cost of construction, spare docks should not be built unless the service is vital and no practical temporary alternatives exist.

4.14.4 Criterion Required

What should be the dimensions of the berth?

4.14.5 Factors to be Considered

- (a) The long arm of the berth should be longer than the ship to provide protection and resistance to lateral movement in bad weather.
- (b) The ships' lines at the bow and stern function best if they extend beyond the ends of the ship.
- (c) The tendency is for future vessels to be longer than past vessels.
- (d) Fitted berths can't take vessels that are beamier than the vessel for which they were designed.
- (e) The size of ship that can use a berth is limited by the depth of water alongside.

4.14.6 Possible Criterion

The berth should be designed at least 15m (50ft) longer and 60cm (2ft) wider than the vessel to use the berth.

The water depth alongside should be 2'-4' below the keel of the vessel at lower "low water" when the ship is fully loaded and badly trimmed. As an approximation the water under the keel should be 1% of the length of the ship.

4.15 Passenger Amenities

This includes restaurants, bars, loungers, toilets, waiting rooms, picnic areas, children's play areas, beaches snack bars, tourist information facilities, etc.

4.15.1 Criteria Required

To what extent should passenger amenities be provided?

4.15.2 Factors to be Considered

- (a) Average waiting time. The longer the average wait, the more the amenities required.
- (b) Presence of alternate facilities. If there are many nearby restaurants and bars, the ferry operator may not want or need to provide food service.
- (c) Financial opportunities. Can the amenities bring in revenue?
- (d) Goodwill and political pressure. Is the operator under social or political pressure to provide amenities?
- (e) Percentage of "foot" passengers. Passengers who are not driving will have to be provided with waiting rooms.

4.15.3 Possible Criterion

All terminals are to contain toilets, waiting rooms and coffee shops. The size of each is to be appropriate to the traffic volumes.

4.16 Staff Parking

4.16.1 Criterion Required

How much staff parking should be provided?

4.16.2 Factors to be Considered*

- (a) Size of Staff
- (b) Number of shifts. Note that extra parking is required at shift change time.
- (c) Extent of staggering of shift changes among the different groups of workers.
- (d) Percentage of employees who wish to drive to work.
- (e) Availability of public transit.
- (f) Distance of terminal from urban areas.
- (g) Availability of space for staff parking.
- (h) Requirements of union agreements.
- (i) Use and prevalence of car pools.

4.16.3 Possible Criterion

Provide the minimum number of staff parking spots that local conditions allow.

4.17 Maintenance Facilities

4.17.1 Criterion Required

To what extent should maintenance facilities be provided in the terminal?

4.17.2 Factors to be Considered

- (a) Availability of competent maintenance services from outside agencies.
- (b) Cost advantages or disadvantages of doing maintenance internally versus externally.
- (c) Size of facility and fleet and amount of maintenance required.
- (d) Sophistication of equipment on site.

* Reference 21 considers the parking design problems for the analogous field of airport design and attempts to establish methods for designing all of the types of parking lots required on airports. Some of the techniques established in Reference 21 may prove useful in ferry terminal design. These methods are however still under development.

4.17.3 Possible Criterion

If the terminal is large, it is usually justifiable economically to maintain a significant maintenance staff, and a facility containing a small machine shop, carpentry shop, mechanical shop and vehicle repair shop with a hoist should be built. The extent to which this is done depends on the size and amount of equipment to be maintained.

If the terminal is small, many operators have found it best to employ 1 or 2 handymen for general maintenance and to employ outside agencies for major repairs or rehabilitations.

CHAPTER V

TECHNIQUES FOR DETERMINING THE SIZE PARAMETERS
OF THE MAJOR ELEMENTS OF FERRY AND RO/RO TERMINALS5.1 Introduction

This chapter will present the second half of the terminal design methodology being developed in this thesis; this latter part consisting of a number of mathematical techniques for calculating the required size of the elements of the terminal.

Generally the techniques are dependent on the design criteria previously developed, either for evaluation and acceptance of the numerical results or for establishment of the base input data and in that sense the two parts of the methodology (criteria and techniques) form an integrated design system. It should however be noted that it is not necessary in all cases to employ a sophisticated calculation technique. For some elements such as the transfer roads the size of the element (number of lanes) can be evolved from the design criteria and criterion factors alone.

The techniques to be developed will have various bases: some will be modified applications of standard methodologies (in which case only the unique aspects will be presented), some will be developments and extensions of the work of other, in related or analogous fields and some techniques will be wholly original developments.

Unless otherwise stated, all techniques are intended to provide facilities to cope with the flow of traffic on the design hour of the design day. The establishment of traffic flows for that day and hour are in the realm of transportation planning and economics, and being beyond the scope of this thesis techniques for determining such traffic projections will not be dealt with here. For our purposes it will be assumed that the required traffic data is available for the specified day and hour.

2

5.2 Access/Egress Road

5.2.1 General Considerations

The access/egress road is the roadway which connects the ferry or ro/ro terminal to the highway network. It may vary in scope from the 50 km long "Trans Canada Highway" standard road which provides access to the ferry terminal at Argentia, Newfoundland; to the 300 m long road which leads to the terminal on the Magdalen Islands. In all cases however the main objective of the road is the same—to carry the randomly arriving traffic to the terminal and to carry the surge of traffic discharged by the vessel away from the terminal area and onto the highway network.

There may be other duties for the road as well, including the servicing of land and the provision of access to adjacent dockside facilities such as fishing wharves, general cargo wharves or container terminals. It is in fact fairly common for the access road to be a multi-use road, so much so, that in many cases the access road is virtually a part of the highway network itself rather than an autonomous connection.

It is evident however that the access/egress road is in essence just a highway much like any other highway and that for the most part it can be designed using standard methods. The one important area of difference lies in the determination of design volumes, which because of the nature of the ferry operation are somewhat different in character from the norm.

Once this design volume has been determined, however, the road may be designed using the methods outlined in the Highway Capacity Manual⁽¹⁰⁾.

5.2.2 Special Design Considerations

A. Design Day and Hour

The reader is referred to section 4.3 for information on the selection of the design day. Throughout this paper it has been assumed that the design hour is the busiest hour of the design day and all designs are set to handle this volume. Common "Highway" practice is to use the 30th highest annual hourly traffic volume in the design year as a basis for design and this figure may be acceptable if the traffic does not have extreme seasonal peaking. If there is such peaking then while the number of hours for which the road is under capacity is only 29 per year, it may also mean that the system will be overloaded for a very large percentage of the peak season. The implication is that a great many people will be inconvenienced and there could be localized economic problems.

B. Traffic Flows - Inbound

The inbound traffic flow is the sum of the design hour traffic flow for the ferry service (discussed above) plus the traffic generated by non-ferry users of the road plus the traffic generated by non passenger visitors to the ferry service.

The non-ferry traffic would include traffic to other shoreside facilities served by the access road such as fishermen, trucks to general cargo facilities etc. This traffic would have its own arrival pattern and an estimate of the amount of traffic that arrives during the design hour must be made and used in the summation.

The non passenger traffic to the ferry service includes traffic generated by staff, supply vehicles, taxis, sightseers and persons wanting information. As with the non ferry traffic an estimate of the amount of this traffic occurring during the design hour must be made and used in the summation.

C. Traffic Flow - Outbound

The outbound traffic flow is the sum of the non-ferry traffic which uses the road during the design hour plus the non-passenger traffic from the ferry terminal during the design hour plus the traffic discharged from the vessels during the design hour.

The non ferry traffic and the non passenger ferry traffic are similar to those same categories described above.

The traffic discharged from the ferries will in most cases provide the bulk of the outward bound traffic and in order to estimate this traffic volume it is necessary to have the following information:

- Size and number of vessels likely to be in operation in the design year. Size in this case means vehicle capacity.
- Percentage of vehicles that are likely to be buses or trucks. This is needed for calculation of bus and truck factors and auto equivalents as required for the techniques of the Highway Capacity Manual.
- A "Pro Forma" schedule of vessel operations. This is needed to determine the number of vessels that arrive and discharge vehicles during the peak hour of the design day. Note that for this purpose the peak hour will be determined by the vessel schedules and may be different from the peak hour for arriving traffic.

- The time required to unload each type of ship.
This is necessary to calculate the hourly discharge rate of vehicles from the ship.

D. Backups, Line-ups, and Auxiliary Lanes

In the next section (5.3) we shall discuss the need for a surge parking lot to absorb the arriving traffic that is waiting to be ticketed. If this surge lot is properly designed, then in the normal course of events there should not be many occasions when the traffic will back up along the access road. There will of course be some instances when this will happen but the frequency will depend on the design day chosen.

If however it is not possible to build a surge lot or if the main marshalling areas are too small then the traffic will be forced to back up along the road. In the case of a sole use road this is not a serious problem but if the road serves other users, severe inconvenience (and political repercussions) could result. In cases such as these it might be practical or necessary to build an auxiliary lane on the inbound side to provide local access. The length of this auxiliary lane should be at least as long as the expected queue length and should be clearly marked for use by non ferry traffic only. (Section 5.3 and 5.4 show methods of calculating the queue length).

5.2.3 Design Techniques

As previously indicated, once the design volume has been determined, the designer merely applies standard design techniques such as those described in the Highway Capacity Manual to determine the number of lanes required.

In summary the steps required to obtain the design volume are as follows:

- (a) Specify the design year, day and hour for the service.
- (b) Using projections of traffic for the design hour calculate the volume of inbound ferry traffic (by vehicle type), the volume of non ferry traffic using the road, and the volume of non passenger ferry traffic using the road.
Sum these figures to obtain the inbound volumes.
- (c) Set out a Pro-forma vessel schedule including capacities for each vessel. Determine the volume of non ferry traffic and non passenger ferry traffic existing on the road in the design hour.
Sum the above to obtain the outbound volumes (including the percentage of trucks and buses.)

5.3 Toll Booths and Surge Parking Lots - Method I
(By Hand Calculations)

5.3.1 General Considerations

It has previously been indicated that the surge parking lot is the area in front of the toll booths where vehicles waiting to buy tickets can be held without blocking the access road. It is evident that if all the vehicles could be processed instantly on their arrival, then no backups would occur and there would be no need for a surge parking lot. This of course could only happen if the number of ticketing channels were large enough to ensure that an empty channel was always available when a vehicle arrived.

This level of service could be provided but it would be both unnecessary and uneconomical to do so. The more common solution is to provide a smaller number of channels and allow the traffic to back up, knowing that the size of the backup will ebb and flow with the random arrivals of the traffic.

From the above, it can be seen that the required size of the surge parking lot is directly related to the number of ticketing channels as well as to the pattern and volume of arriving traffic.

On an annual, seasonal or even daily basis, traffic flows tend to follow a fairly predictable pattern. In Canada traffic typically increases during the summer and drops off in winter; it increases on weekends and is lightest in midweek; it peaks at midday and is almost non-existent at 3 a.m. (see Fig. 3.2 and 3.3) It is evident that in broad terms traffic follows a predictable cyclical pattern and over "long" time periods is not really a random flow.

A toll booth system however does not fail on the basis of long term patterns. Rather it functions or fails on its ability to cope with short bursts of traffic at specific times within the long term pattern. Over a short period, such as an hour, arrivals are random occurrences and frequency distributions used to describe random occurrences may be used to describe the arrival process.

For situations where traffic is random, not congested and not cyclic (due to the effects of traffic lights), it is possible* to use the Poisson distribution to describe the traffic counts and to use the related negative exponential distribution to describe the intervals between arrivals. If these conditions do not exist then

* Reference 11, Chapters 3 and 8

other distributions may be used including the binomial for congested traffic and the shifted exponential for situations where the exponential predicts too many short headways, such as on freeways.

The technique which will be described below is based on equations for exponential traffic patterns developed in "Traffic Flow Theory"* and since there are limits to the conditions under which these equations are valid, ~~some~~ consideration must be given to ensuring that the equations are valid here. Of the three requirements (randomness not congested, non-cyclic) it has already been suggested that arrivals over a short period are random. This follows from the fact that departure decisions are made independently by each individual driver and in the absence of constraints their actions are independent and random. The requirements for no congestion and no cyclical loading are slightly more difficult to be definitive about, but the congestion requirement can be met acceptably by noting that the facilities are all being designed to suit a specific design day and design year and that presumably the access road will be adequate as long as the rest of the system is adequate.

The presence or absence of a traffic signal will depend on the situation prevailing at an individual terminal. It is this writer's experience that the access roads to most ferry terminals (in Canada) do not have traffic signals. If a designer is dealing with a situation where signals do not exist he will have to decide if the lights are far enough from the terminal for the platooning thus created to work itself out; or if not, then he must decide if the lower level of service at the ticket booths, brought on by the mini-surges of platooned traffic is acceptable.

* Reference 11, Chapters 3 and 8

Finally, it is appropriate to consider the ticketing or servicing process.

In a typical operation, the time taken to sell a ticket will vary with the vehicle type, number of passengers, vehicle height, destination, ticketing policy, speed of the ticket salesman, etc., and since the vehicles arrive randomly as well, it can be inferred that the ticketing process is random.

The equations can thus be utilized on the basis that both the arrival rate and the service times are random events susceptible to description by the negative exponential distribution.

5.3.2 Design Technique

In general terms the technique which has been developed to determine the required number of toll booths and the required surge lot size is an iterative one in which the number of toll booths is set at one and the consequences of this decision are calculated and compared to some previously established criteria. If the criteria are met, then one toll booth is declared to be acceptable and the size of the surge lot is calculated accordingly. If the criteria are not met, then the number of toll booths is increased by one and the process repeated. The number of toll booths is continually increased until the criteria are met.

More particularly the technique is as follows:

STEP 1 Establish the "criterion of acceptance" for the toll booth system.

The suggested criterion is that the average time waiting in the queue should be no more than "x" minutes.

(Note that average time waiting in queue is only the time waiting to start the ticketing process and is less than the average time in the system, which is the sum of the time waiting to be ticketed and time it takes to buy a ticket.)

STEP 2 Establish the design criterion for the size of the surge parking lot.

The suggested parameter is that the surge parking lot should be large enough to hold the maximum queue length that forms during the design hour.

STEP 3 Using traffic projections, determine the traffic demand on the design day, according to destination and vehicle type.

At this point a decision must be made (or assumed for initial purposes) on whether every toll booth will be allowed to ticket any vehicle regardless of type or destination. If so, then the sum of all vehicles (i.e. all types and all destinations) should be used in determining the total traffic volumes.

If the ticketing is to be broken up by destination or by type, then the flows must also be broken up accordingly and separate iterations done for each such grouping.

It may be found that breaking traffic up into groups creates a need for more toll booths than would otherwise be required and that the utilization of each booth is excessively low. In such a case, it may be desired to recombine the ticketing process (hence the reference above to initial purposes).

From the ticketing point of view, the most flexible arrangement is to have every booth capable of handling any vehicle, but this can lead to criss-crossed traffic flows if the vehicles must move to separate marshalling areas.

It may be possible to have a mixed system in which some booths handle all of the trucks and buses as well as autos while other booths handle only autos. In this case the number of autos should be pro-rated between the separate types of booth and separate iterations done for each vehicle type.

STEP 4

Determine the mean traffic flow for the design hour.

It is suggested that the design hour should be the maximum hour on the design day, but the designer might wish to provide a different level of service such as the 30th highest annual hourly volume used in highway engineering.

A Canadian Department of Transport Study² showed that in a particular service, the highest continuous hour for traffic arriving to catch a ferry during the peak season, contained approximately 10.3% of the total days traffic flow. If no other data is available, it is suggested that the designer use 10% of the design day volume as the design hour volume.

STEP 5

Determine the average service time. This is the average time taken to sell a ticket to a customer. Rather than determine the pure service time it is more relevant to determine the average "block service

time" and apply it in the equations where service time is called for. The block service time includes the time for a vehicle to move from the surge lot to the booth, to buy a ticket and then to allow the next car in line to move into position. It is somewhat longer than the pure service time and is really the determining factor in the service rate.

STEP 6 Set the number of toll booths to one and using the equations below calculate the average time waiting in the queue.

$$E(w) = \frac{\lambda}{\mu(\mu - \lambda)} \quad \text{Ref. 11, Eqn 8.16}$$

WHERE

$E(w)$ = Average waiting time in queue

λ = Average arrival rate in vehicles/hour

μ = Average service rate in vehicles/hour

(Note that $\frac{1}{\mu - \lambda}$ gives the average waiting time in the system.)

STEP 7 If the average waiting time does not exceed the acceptable waiting time, the required number of booths is one and the required size of the surge parking lot may be calculated as described below. There is no equation which give the required size of the surge lot directly but the size can be calculated by determining the probability of a given number (or less) of vehicles being in the system during the design hour. If, for example it was determined that with a single toll booth, the probability was .99 that the number of vehicles in the system would always be 5 or less, during the design hour we could build a surge lot and toll booth system that held 1 car being ticketed and 4 cars in line behind him, and know that 99% of

the time the lot would be big enough. We could of course say that a .95 probability was good enough and accept that the lot would probably be overloaded for 5% of the design hour. The probabilities are calculated using the following two equations: *

$$P_0 = 1 - \rho \quad (\text{Ref 11, Eqn 8.12})$$

$$P_n = \rho^n P_0 \quad (\text{Ref 11, Eqn 8.11})$$

WHERE P_0 = Probability of zero vehicles in system

P_n = Probability of n vehicles in system

$$\rho = \lambda / \mu$$

λ = Average arrival rate

μ = Average service rate

The probability that n or less vehicles are in the system is the sum of the probabilities that zero to vehicles are in the system.

$$\text{WHERE } P_{x \leq n} = P_0 + P_1 + P_2 + \dots + P_n$$

The probabilities are added together until $P_{x \leq n}$ is equal to .99 (or to whatever the designer considers to be an acceptable level of service) and the surge lot is then designed and built to hold n vehicles.

STEP 8

If the average waiting time with 1 booth exceed the acceptable waiting time, then the number of toll booths is increased by one and a new average is calculated using the following equations* (which are only valid if the number of toll booths or channels is 2 or more).

$$E(w) = E(v) + 1/\mu \quad (\text{Ref 12, Eqn 8.29})$$

$$E(v) = E(n) / \lambda \quad (\text{Ref 12, Eqn 8.28})$$

$$E(n) = \rho + E(m) \quad (\text{Ref 12, Eqn 8.27})$$

$$E(m) = \frac{P_0 \rho^{N+1}}{N! N} \left[\frac{1}{(1 - \rho/N)^2} \right] \quad (\text{Ref 12, Eqn 8.25})$$

$$P_0 = \frac{1}{\sum_{n=0}^{N-1} \frac{\rho^n}{n!} + \frac{\rho^N}{N! (1 - \rho/N)}} \quad (\text{Ref 12, Eqn 8.24})$$

= probability of an empty booth

* These are steady state equations, valid only if $\rho < 1$ (for 1 booth)
 $\rho < N$ (for n booths)

$E(w)$ = expected wait,

$E(v)$ = average time spent in the system

μ = average service rate

$E(n)$ = average no. of units in the system,

λ = average arrival rate

$\rho = \lambda / \mu$

$E(m)$ = average queue length

N = no. of channels or booths

P_0 = probability of zero vehicles in the system

and

$$P_n = \left(\frac{\rho}{n} \right) P_{n-1} = \frac{\rho^n / n!}{\sum_{i=0}^N \rho^i / i!}$$

STEP 9

If the new average waiting time is acceptable, then the surge lot size is calculated as for the single channel case but using $P_n \frac{\rho^n}{n!} P_0$ for $n \leq N$ or $P_n \frac{\rho^n}{N!} P_0$ for $n \geq N$ to calculate the probability of n vehicles being in the system.

STEP 10

If the new average waiting time is not acceptable then the number of channels is increased by one and Steps 8 and 9 are repeated.

The number of channels is progressively increased until the waiting time is acceptable.

5.4 Toll Booths and Surge Parking Lot - Method 2

(By computer simulation)

5.4.1 General Considerations

The various design and traffic flow considerations have been discussed in section 5.3.1 and are the same for both design techniques.

5.4.2 The Computer Language GPSS*

The design technique to be discussed below consists of a simulation written in the computer language called

* Reference 12, Chapter 11 and Reference 13

"General Purpose Simulation System" (GPSS). This is the most commonly used simulation language and is an IBM package program available in several versions. The version used in this case is GPSS/360.

The system that is to be simulated is described in a block diagram in which the blocks represent the activities and the lines joining the blocks indicate the sequence in which the activities can be executed. This is similar in concept to the flow charts drawn in FORTRAN, except that in this method there are 43 specific block types, each of which represents a characteristic action of a system. The programmer is only allowed to describe the system in terms of these 43 block types.

Each block type has a name descriptive of the block action and is represented by a unique symbol.

For input to the computer, each block is translated to a single line of program consisting of a maximum of 8 fields. Field 1 holds an asterix to indicate a "comment" card. Field 2 is a location field to reference one block to another (if required). Field 3 is the operation field which states the name of the corresponding block type. The next 6 fields, labelled A to F have varying purposes according to the block type but contain such information as the number of the queue to be added to, a facility number, a priority number, etc. It is not always necessary to use every field.

The system automatically provides a base output with the programmer able to specify additional output if required. The base output consists of such data as a print out of the program, the status of each block at the end of the program, the utilization of each storage facility and the average and maximum length of each queue.

5.4.3 Design Techniques

The principles of this technique are similar to the principles of Method 1, described in Section 5.3. Essentially it consists of setting the number of toll booths to one, simulating the arrival of the design hour traffic on the computer, determining (by the computer) the effect of the arriving traffic on the facilities (i.e. determining the queue lengths and waiting times for the arriving traffic) and then comparing these effects to some previously established standards to see if one booth provides an acceptable level of service. If one booth does not provide an acceptable level of service, then two booths are tested, and so on for three booths etc. The size of queue (maximum or average depending on the preset criteria) associated with the selected number of toll booths determines the size of the required surge parking lot.

Note that one can set a level of service for the surge lot by specifying that the lot must be capable of holding 100% of the (average or maximum) queue length or 95% or even 50% of the queues, if so desired.

For simplicity of application the program is set up such that it will successively do calculations for one toll booth, then two toll booths then three etc., up to the number decided on by the designer. The sample run, carried out in the next chapter and shown in Appendix A, is programmed to test systems having from one to three booths. To make it test a system with say four booths it is necessary to insert the following three cards between statement number 31 and the END card:

CLEAR

STORAGE 4 (where the "4" is the number of booths)

START 250 (where 250 vehicles are simulated)

For 5 booths, repeat and change the 4 in the storage card to 5. After the program is run, the designer merely studies the results and chooses the system that most closely meets his criteria.

The program assumes that the traffic arrives in a random pattern that can be described by a Poisson distribution and whose inter-arrival time can be described as a negative exponential function.

Two inputs are required by the user. The first is the mean inter-arrival time in seconds and this is put into the program by changing the GENERATE card found at statement number 11. In the example shown in Appendix A the statement says GENERATE 17, FN1 where 17 is the mean inter-arrival time in seconds. This number is in field A of the card and starts in column 19. This should be changed to suit the time applicable to the designer's problem (using as many columns as necessary), followed by a comma, followed by the letters and number FN1 which refers the generate card to the previously defined negative exponential function. Note that no spaces are allowed after column 19, any characters following a space are interpreted as comments and are printed but not processed.

The second input required is the service time or time taken to sell a ticket to a waiting auto. This is put into the program by changing the ADVANCE card found at Statement number 16. The data required in this case is a mean service time in seconds which is placed in field A, and a modifier which is placed in field B. The modifier is the spread of service times around the mean.

In the example of Appendix A the service time is 20 seconds plus or minus 10 seconds. This is entered as ADVANCE 20,10. If the service time was always exactly 20 seconds then the entry could be ADVANCE 20,0 or just ADVANCE 20.

Note that the "Statement numbers" referred to above, are provided by the computer and not by the programmer.

5.5 Marshalling Areas - By Large Interval Simulation

5.5.1 General Considerations

The marshalling areas of a ferry or ro/ro terminal, are in a sense little more than a special type of parking lot. That they are called marshalling areas, arises from their purpose, which is not only to hold arriving vehicles in the manner of a parking lot, but also to segregate them by type and destination and to marshall them for efficient embarkation.

When developing techniques for the design of marshalling areas, one must be cognizant of their most relevant characteristic - that the system is (semi) dynamic. Vehicles are constantly, if randomly arriving, being ticketed and joining the end of the queue in the marshalling area. At the head of the queue, vehicles wait without moving until a ship arrives and unloads its cargo and then for a period of time (usually 10 to 30 minutes) the vehicles are loaded on board - but at the same time other vehicles are still joining the end of the queue. It is the fact that vehicles are always arriving but only occasionally moving that leads us to term the process semi-dynamic rather than dynamic.

It is evident that a process of this type is rather complex and does not lend itself to easy solution by evolved equations. It is however susceptible to analysis by simulation and this section presents a method of simulation

that is suitable for "hand" calculation rather than by computer. A later section will present a companion method for use with the computer.

5.5.2 Design Method

In general terms the design method will be to simulate the arrivals of vehicles and their departures aboard ship on the design day of the design year and to determine the length of the longest queue that forms in the marshalling area during that day. By definition the marshalling area should then be constructed to hold that queue since it is the "design day queue". Obviously however, one could set as a design parameter, that the marshalling area is to be large enough only to hold 90% or some other convenient percentage of the design day traffic, and in that case one need only build sufficient capacity to hold the specified percentage.

It has previously been indicated that there is frequently more than one marshalling area in a terminal, a common situation being to have a separate area for heavy vehicles such as trucks and buses and to have a separate set of marshalling areas for each destination handled through the terminal. The simulation method to be developed here provides a solution for only one marshalling area at a time so that if the terminal handles several destinations then a separate set of calculations must be carried out for the marshalling area allocated to each destination. It may however be possible to combine the calculations for different vehicle types that have the same destination providing that the arrival patterns of the different vehicle types are similar. In this case the non automobile vehicles are converted to auto equivalent units, and the calculations carried out in these units. At the end of the calculation a proportional amount of the

calculated marshalling area size is assigned to the non automobile vehicles. The conversion to auto-equivalents units is made on the basis of the conversion factors given in Table 5.1.

The method which has been developed for calculating the required marshalling area size is a form of simulation but not one of the Monte Carlo variety. In the Monte Carlo type of simulation, arrivals are artificially generated using a table of random numbers (or a pseudo random number generator on a computer) as input to an equation that produces a random inter-arrival time measured in small units such as minutes or seconds.

The method to be presented here however assumes that the daily arrival pattern is known (or can be assumed) usually in the form of the percentage of the total daily traffic that arrives in each $\frac{1}{4}$ or $\frac{1}{2}$ hour interval of the day. From this data and the projections of the total design day traffic, the number of vehicles arriving in each interval can be calculated. These arriving vehicles accumulate and queue up during successive intervals until a vessel is loaded and departs leaving either 0 or some vehicles behind in the queue. Vehicles continue to arrive through each interval until another ship departs, reducing the length of the queue once again. The queue length is calculated for each interval throughout the design day and the longest queue that forms is deemed to represent the required size of the marshalling area.

The data required in order to use this technique are as follows:

- Estimated daily traffic on design day of design year;
- Arrival pattern of traffic

TABLE 5.1

FACTORS FOR CONVERSION
TO AUTO EQUIVALENT UNITS

<u>VEHICLE TYPE</u>	<u>CONVERSION FACTOR</u>
Automobile	1
Small Truck (Pickup Van)	1
Straight Truck	2
Tractor Trailer	3
Bus	2
Auto with Camper Trailer	2
Auto with Large Trailer	2.5

Source: Water Transportation Assistance Directorate
Department of Transport
Ottawa, Ontario

- Pro-forma vessel schedule
- Sizes of ships expected to be in service during design year.

The technique can be most easily explained by the use of an illustrative example and the reader is referred to Figure 5.1 which contains a simplified example.

The terminal of the example operated 2 ships to one destination. The ships operate on a four hour cycle, taking 2 hours to make one way crossing. A vessel therefore departs every 2 hours on the odd numbered hours.

The daily traffic consists of 1,000 autos, 75 trucks, and 25 tractor trailers. This can be converted to 1,225 auto equivalent units using the conversion factors of Table 5.1.

The calculations are as follows:

- COLUMN 1 divides the day into intervals. In this simplified case 1 hour intervals have been used but intervals of $\frac{1}{2}$ hour should be used in practise to increase accuracy.
- COLUMN 2 describes the arrival pattern by listing the percentage of the day's traffic that arrives in each interval.
- COLUMN 3 converts the percentage of traffic arriving in each interval into the number of auto equivalents that arrives in each interval. This is done by multiplying the values of Column 2 by the daily traffic in auto equivalents (1225 in this case).
- COLUMN 4 is a running total of the queue length of vehicles waiting in the marshalling area. Generally it is the sum of the vehicles left behind after a departure plus the vehicles that have arrived since that last departure.

SAMPLE CALCULATION OF REQUIRED SIZE OF
MARSHALLING AREA BY LARGE INTERVAL SIMULATION

<u>INTERVAL ENDING AT</u>	<u>% OF ARRIVALS IN INTERVAL</u>	<u>NO OF VEHICLES IN INTERVAL</u>	<u>NO OF WAITING VEHICLES</u>	<u>MAXIMUM VEH. DEPARTING IN INTERVAL</u>	<u>VEHICLES LEFT BEHIND</u>
0630	1	12	12		
0730	2	24	36	150	0
0830	3	37	37		
0930	4	49	86	150	0
1030	5	61	61		
1130	7	86	147	150	0
1230	10	122	122		
1330	11	135	257	150	107
1430	12	147	254		
1530	11	135	389	150	239
1630	10	123	362		
1730	8	98	460**	150	310
1830	6	74	384		
1930	4	49	433	150	283
2030	3	37	320		
2130	2	24	344	150	194
2230	1	12	206		
2330	0	0	206	150	56
	<u>100%</u>	<u>1,225</u>			

Daily Traffic = 1000 autos 75 trucks 25 tractor trailers
 = 1000 (75 x 2) + (25 x 3)
 = 1,225 auto equivalents

Schedule - 2 ships operating on reciprocal 4 hour cycles
 (i.e. departure every 2 hours)
 - Capacity = 150 auto equivalents

** Maximum queue length is 460 vehicles

FIGURE 5.1

COLUMN 5 reflects the schedule and the ship capacity.

It is a statement of the maximum number of vehicles that can be carried on a given departure. There will of course be fewer than the maximum number carried, if the number of vehicles waiting to board is less than the capacity of the ship.

COLUMN 6 lists the vehicles left behind after a departure. This figure is added to Column 3 of the next interval to obtain Column 4 of the next interval.

The highest number in Column 4 represents the longest queue length formed during the design day and is the required size of the marshalling area.

In this example the longest queue length is 460 vehicles and occurs during the interval ending at 1730 hours.

It should be noted that in many cases it is desired to give priority to one type of vehicle or another for some or all departures. Common examples of this are night truck runs, priority to automobiles during tourist generated peaks etc. Priorities can be handled by the method described here if the different types of vehicles are not aggregated in the manner described in the example and the priority is inputted by modifying the vessel capacity available for specific departures. That is, if a vessel can actually carry, say, 140 auto equivalents in the form of an upper deck capable only of carrying cars and having a capacity of 65 autos plus a lower deck that can carry 75 autos or 25 tractor trailers, and it is decided to give priority to tractor trailers on a particular departure, then in the simulation for the auto marshalling area the ship is deemed to have a capacity of only 65 autos and in the tractor trailer marshalling area calculation the ship is deemed to have a capacity of only 25 tractor trailers. In fact of course the true capacity is greater than either deemed figure but only a portion of the true capacity is available due to the priority action.

Depending on the priority rules established it might be necessary to carry out two or more simulations. If these are done simultaneously by the designer (rather than in succession) the designer may act exactly in the manner of a terminal manager by changing priorities one way or another as the situation develops. He might for example have a vessel of 150 auto equivalent capacity about to depart and find that he had 300 cars and 30 tractor trailers waiting to leave. The designer/terminal manager could make a decision to allocate 90 spaces to tractor trailers and carry all of them or conversely he might decide that there were too many voters being delayed and move 150 cars and no tractor trailers.

5.5.3 Advantages and Disadvantages of Method

A. Advantages

- It is easy to understand.
- It is quick and easy to calculate.
- Most information required is usually available or can be easily obtained.
- It is fairly accurate. The accuracy can be increased by decreasing the interval length and prorating the departures over more than one interval depending on how long it actually takes to load.
- In practical applications the accuracy is probably at least as accurate as a traffic projection for 10-15 years hence.

B. Disadvantages

- It is an approximation method based on the assumption that all traffic arrives at the midpoint of the interval

and that all traffic is loaded and departs at the midpoint of a single interval. This last may not be too accurate for efficient ships. Some of the vessels travelling to P.E.I. load 150 autos in 6-7 minutes.

- Determination of the arrival pattern can be difficult if there is no historical or analogous data.
- It requires the prediction of ship sizes, numbers and schedules for a period fairly far in the future.

5.6 Marshalling Areas - Method 2 - Computer Simulation

5.6.1 Introduction

This section describes a computer program which calculates the maximum queue lengths of cars and trucks waiting in the marshalling area of a ferry terminal, thus providing the designer with the information needed to establish the required dimensions of the marshalling area.

The calculation is made by simulating the activity of the ferry terminal on the design day and keeping a count of the running total of vehicles waiting to board vessels, as well as the number that are actually loaded aboard for each sailing.

The vehicles are considered to arrive at the terminal according to a daily arrival pattern specified by the designer and to leave the terminal according to the vessel departure schedule but modified by a loading priority rule for each departure and limited by the capacities of the vessels.

The program is written in FORTRAN IV and with one minor modification can be run on any machine capable of

accepting a FORTRAN program. The modification entails changing the two lines in the program which specify the numbers of the input and output units for the user's computer system. The program was written using the variable IRD to indicate the input units and IWR to indicate the output unit and it is necessary to specify the numbers that these stand for. For example, if the program were to be read on cards and printed on paper and the card reader was unit 102 and the printer was unit no 103, it would be necessary to place the following two statements before the first read or write statement:

IRD = 102

IWR = 103

Appendix B contains details of the program including a flow chart of the logic, a printout of the program itself, sample output and the input coding forms.

5.6.2 Input Data Required

To simplify the provision of input data, coding forms have been provided (see Appendix B) which indicate the data required and the number of spaces available for the provision of the data, as well as the order in which the data must be submitted to the computer.

All numerical data that is of integer form (i.e. no decimals) must be right justified within the blocks of space allocated to that data on the coding form. Failure to do this will result in the computer interpreting the spaces to the right of the figures as zeros so that a number 7 written two spaces to the left of the right hand column would be interpreted as 700.

The data required is as follows:

- (a) The name of the terminal (maximum of 20 spaces) and the data set number which is any number of 3 or less digits that the user wants to use to identify the data;
- (b) The number of autos and trucks that are in the marshalling area at the start of the simulation. These could be vehicles left over from the previous day for example;
- (c) Daily volumes of autos and trucks. The number of autos and trucks that are expected to use the terminal on the design day;
- (d) The simulation interval in hours (maximum of 3 decimal places). The program simulates in short simulation intervals of a length of time specified by the user. The smaller the interval, the greater is the fineness of the computation. Sample calculations were done using a simulation interval of .01 hours.
- (e) End time of simulation. The hour (maximum 2400) at which the user wants the simulation to end. Note that the simulation starts at time 0.00 hours.
- (f) Conversion factor - number of autos that take up as much space as a truck aboard ship.
- (g) Number of ships in the fleet and for which data will be provided next (maximum 20).
- (h) Ship Data

Ship number - an identifying number for each ship

Ship name

Automobile Capacity - the number of autos that the particular ship can carry if all possible capacity is used to carry autos

Truck capacity - the number of trucks that the ship can carry if all areas of the ship that can carry trucks are indeed carrying trucks.

Note that these capacities are the theoretical maximums in each case. In practice on a particular sailing some of the truck capacity might be allocated to autos. Generally it is possible to convert truck capacity to auto capacity, but it is not always possible to convert auto capacity to truck capacity due to height or weight restrictions.

- (i) Number of points used to describe the daily traffic arrival patterns of autos and trucks (see (j) below)

- (j) Auto traffic arrival pattern data

This is submitted as a series of points on a cumulative volume/time graph. That is, for various times of the day, the decimal fraction of the total daily traffic that has arrived up till that time of day, is read in. For example if the simulation starts at midnight (time = 0) with no traffic having arrived at that time and if by 6 a.m. 10% of the daily traffic had arrived and if by 9 a.m. 24% of the daily traffic had arrived, then the first three points would be coded as follows:

<u>Volume</u>	<u>Time</u>
0.00	0.00
0.10	6.00
0.24	9.00
etc.	

A maximum of 100 points may be used to describe the daily traffic pattern. The computer will interpolate to obtain data for times between the points specified. Data should start at time 0.00 and end at 24.00.

Note that all times are in decimals of an hour.

(k) Truck traffic arrival pattern data

Similar to above. Allows the user to specify a different arrival pattern for trucks than that for cars.

- (l) Number of daily departures - the number of scheduled vessel departures per day for which data will be provided below. Maximum of 50 departures per day

(m) Schedule data

Departure number - an identification number

Vessel number - the identification number for the departing vessel as specified in (h) above.

Start loading time - the time at which the operator starts to load the vessel for departure.

Departure time

Priority - the loading priority rule for a given departure as specified by the user.

If priority = 1, then trucks are given first priority on that sailing;

If priority = 2, then cars are given priority;

If priority = 3, then vehicles are loaded on

a first come first served basis (within the truck or car capacity limits of the ship)

Truck spots allocated - If cars are given priority (priority = 2), then the user may reserve a specified minimum number of spots for trucks on a given sailing.

One special limitation should be noted:
The program is able to simulate the loading of only one ship at a time. If two ships have to be loaded simultaneously, then the simulated "start of loading time" for one of the ships must be moved backwards or forwards a few minutes to avoid the problem. This limitation is not felt to be too serious since in most cases only one ship can be loaded at a time due to congestion and road restriction problems.

5.6.3 Output Provided

A. "Summary of Simulated Traffic Volumes on Design Day"

A listing of the number of automobiles and trucks that are simulated to arrive at the terminal throughout the day. The output is presented for the sum of blocks of 20 "simulation intervals". The simulated daily traffic reflects the traffic pattern specified by the user.

B. "Summary of Queue Length in Marshalling Area on Design Day"

A status report on the number of autos and trucks waiting in the marshalling area at different times of the day.

C. "Summary of Vehicles Carried on Each Departure"

A listing of the number of autos and trucks that are carried on each sailing throughout the day.

D. "Maximum Queue Length Statements"

A statement of the maximum number of autos and trucks that wait in the marshalling areas on the design day, and the times at which this occurs.

5.7 Berths - By Block Time Method

5.7.1 General Considerations and Definitions

Reduced to basics, a ferry berth is little more than a "parking spot" occupied by a ship while it loads or unloads passengers and vehicles. As for the analogous case of a shopping centre, the number of parking spots required is dependent on the users arrival pattern and on the length of time each spot is occupied.

In the case of ferry operations the analogous criteria are "schedules", which describes the arrival pattern and "berth use block time" which will be defined as "that period of time during which a berth and its ancilliary facilities must be devoted to a particular berthing".

The berth use block time is the sum of the times taken for a vessel to: travel down the channel to the berth (if only 1 vessel at a time can use the channel); dock the ship; unload passengers and vehicles; load passengers and vehicles; undock the ship; move up the channel to open water.

In some cases a ship can occupy a berth for reasons other than the above, such as for fuelling, waiting for passenger etc. If any of these actions add to the required time in dock on the design day, then the berth use block time should be adjusted accordingly.

Related to the above, a "berthing" can be defined as "the action by a ferry boat of docking, unloading passengers and vehicles, loading passengers and vehicles and undocking". It should be noted that a single ship can make many berthings in a single day, and that unless overlaps occur, a given number of berthings has the same effect on the design facilities

whether they are made by one ship berthing often or by many ships, each of which only berths once. It is the total number of berthings per day which is important as is their distribution throughout the day. The distribution is important because it has an effect on the practical capacity of the berth. While the maximum possible capacity can be derived by dividing the number of hours in the (operating) day* by the weighted average of the berth use block times to obtain the maximum number of berthings that are possible in a day, this presumes that vessels will arrive in a closely spaced series and that as soon as one vessel leaves the harbour another vessel is just arriving to take its place. In practise this does not normally happen. Rather there will be gaps of varying size between the arrivals. These gaps occur because of such factors as the differences in speed of the various ships on the run; differences in distance and travel time between the port in question and the various destination ports; and the vagaries of scheduling. In many cases these gaps will be of too short a duration to be useable as a berth block time and the gap will thus represent wasted time. To some extent the gaps can be minimized by juggling the schedule but this depends on local circumstances. In general the effect is that the berth is used at less than its maximum possible capacity.

Cognizance must also be taken of the practical limitation that not all ferries can fit all berths due to differences in beam, shape or loading methodology. In cases where the fleet has a mix of incompatible ship types, then at least one berth of each type must be provided. It is however, often possible to build a single berth capable of accommodating several different

* A ferry service may not operate 24 hours/day. The operating day is the number of hours per day for which it does operate.

types of ships and in that case the number of berthings made by each type of ship going into the multi-use berth may be accumulated for purposes of the calculation of the number of berths required. The preceding does have one limitation and that is that the schedule must not call for two or more ships to use the same berth at the same time.

From the schedule, we can, for each vessel type, determine the number of berthings to be made at a particular terminal on the design day. By comparing the scheduled number of berthings and their distribution the required number of berths can be calculated. A more detailed description of this method is presented below.

5.7.2 Method of Calculating Number of Berths Required

- STEP 1 Determine the number of vessels of each type that will be in operation in the design year.
- STEP 2 Determine the schedule that the ships will be operating to in the design year.
- STEP 3 From Step 1 and 2 above, determine how many different types of dock are required. Note that (a) if two ships of different types arrive at the same time, it will not be possible to use the same berth for both types, even if it would be technically feasible; (b) generally one type of berth is required for each type of vessel unless a multi-use berth can be built.
- STEP 4 Determine the berth use block time required for each vessel type. This is the sum of: time to travel down the channel (if only 1 ship at a time

can use the channel), time to berth, times to unload and load vehicles and passengers, time to move down the channel, appropriate factor of safety.

STEP 5 From the schedule and the berth use block times calculate the maximum capacity of a berth in terms of berthings per (operating) day for each vessel type by dividing the number of hours per operating day by the weighted average of the berth use block times.

From the schedule determine the scheduled number of berthings per day for each vessel type.

A comparison of the above two calculations will indicate the number of berths required for each vessel type if the effect of gaps in the schedule is ignored. Because the schedule is normally less than ideal this figure gives the minimum number of berths that will be required. The ineffectiveness caused by gaps may require the construction of more berths than this minimum.

STEP 6 Check the berth utilization to see if the effect of the gaps increases the number of berths required. This is best done graphically as shown in Figure 5.2 on which the arrivals, berth use block times and gaps for each vessel are shown as horizontal bars plotted against the hours of the day. The overlaps, sizes of gap and block times are clearly shown and in this case it can be seen that 2 berths are required.

SAMPLE CALCULATION OF BERTH REQUIREMENTS

- 4 ships, 2 of which cross the water in 2 hours (4 hours round trip) and 2 of which cross in 3 hours (6 hours round trip)
- Service operates 24 hours per day
- All ships have a block time of 2 hours
- Therefore maximum capacity of a berth is 12 berthings per day
- Schedule calls for the 2 fast ships to operate "Back to Back" and for the 2 slow ships to operate "Back to Back" (i.e. they depart alternate terminals at the same time and pass each other at the mid point of the crossing)
- There are 16 berthings per day
 $\therefore$ number of berths required = $16/12 = 1\frac{1}{3} = 2$ (you can not have part of a berth)

2 berths maximum

... from the graph we see that on this schedule 2 berths are sufficient
 Vessels 1 and 2 share a berth
 Vessels 2 and 3 share a berth

FIGURE 5.2

5.8 Immigration and Customs Facilities

5.8.1 General Considerations

Not all ferry services require customs and immigration facilities, but for those that do the installations normally required are:

- Vehicle marshalling area
- Customs preliminary inspection booths
- Passport and immigration control booths (may sometimes be combined with customs booths)
- Offices (often with counter space)
- Secondary inspection facilities
- Secondary immigration examination facilities

The amount of office space and the amount of space for secondary inspection will depend on the number of supervisory and other staff employed at a particular station and on the historical percentage of travellers who undergo secondary inspection in a particular country. It is impossible to set any general rules for this. Local practise should prevail in this instance.

The number of booths of passport control will vary with local practise and with the percentage of travellers passing through a particular terminal who require passports. If only a small percentage require passports then it is efficient to ~~reserve~~ one or two channels for such traffic and only have passport control at those channels.

The size of the vehicle marshalling area for vehicles awaiting customs clearance will depend on the number of vessels arriving at one time, on the number of passengers and vehicles carried on each vessel, on the speed with which an arriving passenger is processed and on the number of processing channels.

As a minimum the size of the vehicle marshalling area must be large enough to hold all of the vehicles carried by the largest ferry on the service. If more than one vessel arrives at a time then the marshalling area must be large enough to accommodate the traffic from all of the ships with overlapping arrival times.

In addition to the above it is also sometimes necessary to provide space to hold vehicles in transit that are held in bond. This usually only applies to trucks.

It should also be noted that in addition to providing facilities for passengers carried in vehicles it is also necessary to provide customs facilities for "foot passengers". In North America this is usually a very small percentage of the passengers but in Europe foot passenger often account for up to half the number of passengers carried on a given route.

5.8.2 Design Technique

The situation for customs facilities is considered to be analogous to the situation for ticket purchase. Therefore either of the two methods developed for calculation of the number of toll booths and surge parking spots is applicable to the calculation of the number of customs channels required.

If the hand calculation method is used, the average arrival rate is the average rate at which vehicles depart the ship.

It is necessary to know the average service time and to know the average acceptable waiting time.

If the computer method is used, it is necessary to know the mean inter-arrival time as well as the service time.

Either method will produce the size of the queue and the number of ticketing channels required. Sufficient space must then be allocated to hold these facilities on the ground.

5.9 Terminal Building Space Allocation

5.9.1 General Considerations

A ferry terminal building, like its airport counterpart serves as the focal point for many of the passenger related and administrative functions of the terminal complex. Unlike an air terminal however, a ferry terminal building does not process all the passengers moving through the system. Rather, only those passengers who arrive "on foot" and those who arrive by auto but wish to use the amenities provided enter the terminal building itself. The remainder are processed in, and remain with their autos.

It is evident therefore that to some extent the size of the facilities provided in the terminal building will vary with the ratio of foot passengers to total passengers and on the number of auto passengers who use the terminal facilities. This in turn will depend on such factors as the average waiting time and on the isolation of the terminal complex from equivalent facilities (such as restaurants and bars) outside the terminal.

The determination of the number of users can thus be seen to be one of the designer's main tasks. Very little data is available on this utilization but one possible approach is to try to relate the usage of facilities to the waiting time. For ferry terminals this data is not available either at this time, but some direction can be found by considering the highly studied analogous field of air terminal design. The Canadian Department of Transport's "Design Guidelines for Space and Areas in Air Terminals"* contains some data on the characteristics of passengers by type of flight (domestic, international, charter, total)

including the distribution of their times of arrival before departure and the percentages of passengers that use various facilities. By calculating the average length of time before departure (i.e. waiting time) for each type of flight and plotting this against the facility utilization (see Fig. 5.3) an approximate relationship between waiting time and facility utilization can be derived. This relationship has not been field checked so that it cannot be assumed to be absolutely correct but it should serve on an interim basis as a rough guide.

More research specific to ferry terminals would be useful here.

In addition to the above relationship some "experience based" assumptions can be made. These are based on discussions held with various ferry service operators and on the authors own observations.

- most foot passengers stay in the terminal;
- foot passengers normally go on the next sailing since most ferries are limited by auto carrying capacity rather than by passenger carrying capacity;
- if the waiting time is short (under 15 minutes) and is known to be short then almost none of the auto passengers will use the terminal building. About 10-15% will use the washrooms;
- If the weather is bad and the waiting time is long, about 50% of the waiting passengers will prefer to wait in the terminal building rather than in or near their cars.
- If tour buses have priority and a short wait then most passengers will wait in the bus except for a small (say 10%) number who will use the washrooms. If the wait is over $\frac{1}{2}$ hour and the weather is bad then about $\frac{1}{2}$ to $\frac{2}{3}$ of the bus passengers will prefer to wait in the terminal building.

FIGURE 5-3

- The drivers of commercial vehicles can be assumed to behave in much the same pattern as non-commercial drivers.
- Incoming passengers do not normally use the waiting room facilities unless it contains a tourist bureau. Incoming foot passengers may pass through the building but will not normally use the waiting areas. They may use the passenger pick up zones.
- Those passengers who do use the building facilities do not use them for more than $\frac{1}{3}$ - $\frac{2}{3}$ of their waiting time.

5.9.2 Space Allocations

It has been noted that little or no data is available for ferry terminals. Much work has however been done on air terminal design and, on the assumption that a given function has a fixed unit space requirement regardless of the mode with which it is associated, air terminal standards will be modified and/or adapted to ferry terminals.

The source documents for this are the previously mentioned "Design Guidelines and Criteria for Space and Areas in Air Terminal Buildings"* and "The National Building Code"**.

The recommended space allocations are given in Table 5.2.

The reader should note that most ferry services would not require all of the facilities for which unit space allocations are given. It is up to the operator and the designer to decide which facilities are needed to satisfy local needs.

* Reference No. 5

** Reference No. 14

RECOMMENDED UNIT SPACE ALLOCATION
FOR FERRY TERMINALS

<u>FACILITY</u>	<u>RECOMMENDED SPACE</u>
General Applications	25SF (2.3m ²) per design passenger
Passenger Drop Off:	
(a) Taxis & Passenger Cars	25LF (7.6m) of curb per space
(b) Buses	40LF (12.2m) of curb per space
Public Telephones:	
(a) Booth	9SF (.8m ²)
(b) Open Stall	7SF (.7m ²)
(c) Wall Hung	3SF (.5m ²)
Ticket Lobby & Lobbies Generally	25SF (2.3m ²) per occupant
Ticket Concourse	12.5SF (1.1m ²) per passenger
Queuing	2.5LF (.7m) per passenger in line
Information Counter	5' width of counter per clerk 25SF
Washrooms	Per National Building Code Section 3.6
Waiting Areas	Assume 50% seated, 50% standing Seated 25SF (2.3m ²) per occupant Standing 15SF (1.4m ²) per occupant
Corridors	Per National Building Code
Concourses	25 SF (2.3m ²) per occupant
Customs:	
(a) For automobiles	covered 25' x 10' module per inspector plus marshalling lanes for waiting vehicles
(b) For buses	40' x 12' module per inspector plus marshalling
(c) For trucks	55' x 12' module per inspector plus marshalling
	<u>NOTE:</u> Trucks & Buses could be combined
(d) For foot passengers	15 SF (1.4m ²) per passenger

FACILITY

RECOMMENDED SPACE

Secondary Customs

(a) Vehicle Holding Areas

Truck Modules (12 x 55) plus
auto modules (20 x 10)

(b) Baggage Examination Counter

3' x 7' (1m x 2.1m)

(c) Cashier Counter

80SF (7.4m²)

(d) Seizure Room

120SF (11.1m²)

(e) Personnel Search Room

80SF (7.4m²)

Immigration - for vehicles

same as Customs

Secondary Immigration

(a) Waiting Areas

12.5SF (1.1m²) per passenger

(b) Interview Rooms

80SF (7.4m²) per immigration officer

(c) Supervisor Examination

80SF (7.4m²) per supervisor

(d) Detainee Waiting Area

25SF (2.3m²) per person

First Aid Facility

100SF (9.3m²)

Currency Exchange

100SF (9.3m²)

Barber Shop

90SF (8.4m²) for first chair and
50SF (4.7m²) for additional chair

Beauty Salon

50SF per booth plus 20% for
waiting area

Shoe Shine Stand

36SF (3.3m²)

News Stand

50SF (4.7m²)

Duty Free Shop

12.5SF (1.2m²) per customer for
waiting area
16SF (1.5m²) per customer for
employee work station

Offices

80-100SF per office worker

Building Service

Varies with electrical and
mechanical design

Security Facilities

(a) General Office

200-400SF (18.6-37.2m²)

(b) Guard Station

40SF (3.7m²)

(c) Chief's Office

120SF (11.2m²)

Lunch Rooms (Staff)

26SF (2.4m²) per occupant

Lounge (Staff)

5SF (.5m²) per employee

<u>FACILITY</u>	<u>RECOMMENDED SPACE</u>
Cafeteria (Staff)	13SF (1.2m ²) per occupant
Janitor Closets	180SF (16.7m ²) for every 28,000SF of public space
Maintenance Facilities	Varies with policy on maintenance
Restaurant	13SF per customer
Bar	10SF per customer

In addition to the above guidelines, a general standard used for many years by the Department of Transport for "small terminals where all passenger activities such as baggage claim take place around the waiting area"* may prove useful for many ferry terminals. This standard called for 25 square feet of terminal per design hour passenger, and should be applicable providing the number of passengers is the number using the terminal building rather than the number moving through the system.

5.9.3 Design Technique

1. Establish a level of service standard for the design. It is suggested that a reasonable standard would be to design to suit the average volume during the peak 12 hours of the design day. Another possible standard is to design to suit that portion of the minimum (or maximum, or average) queue length that must wait for at least "x" hours.
2. Establish the number of passengers corresponding to the above standard.
3. Determine, if possible the number of the above passengers who will use the terminal facilities and estimate the length of time they will use them. If no local historical data is available apply the assumptions of section 5.9.1 to obtain an estimated figure. Determine the types of facilities required in the building.
4. Determine the sizes of these facilities by applying the design passenger volume figure of Step 3 to Table 5.2. Alternately, apply the 25 sq.ft./passenger rule to the design volume.

* Reference No. 6, Section 1.02

6.1 Introduction

Previous chapters have described the technology and operations of ferry and ro/ro systems and have developed a two part methodology for determining the sizes of the elements of ferry and ro/ro terminals.

This chapter will demonstrate the design methodology by applying it to a real terminal operating in the Canadian environment. Furthermore to demonstrate its practical applicability the only data that will be used in the sample calculations will be the data that was (and is) available to the Department of Transport designers. No artificial data will be generated for demonstration purposes.

The layout to be used will be to first describe the terminal in question and the available data, then to establish the design criteria (Part 1 of the methodology) and finally to apply the techniques of Chapter V to the problem of determining the required size of the facilities.

6.2 Data Presentation

The terminal to be considered is the previously described terminal at Caribou, Nova Scotia (see section 2.2).

The Department of Transport's planners have carried out a study* which has predicted significant growth in traffic. It is therefore necessary to develop a master plan that will describe the facilities needed to handle this predicted traffic.

The design year chosen for vessel development purposes was 1990 (15 years from the start of the study) and the predicted traffic volumes for the design day are

* Reference 2

1,992 passenger related vehicles (PRV) and 94 tractor-trailer equivalents of freight. The PRV figure includes an estimated 18 buses which were converted to PRV's using the conversion factors of Table 5.1. The cargo figure was developed on the basis of tons and then converted to tractor trailer equivalents.

The planners have recommended a fleet consisting of two 150 auto equivalent capacity ferries similar to the "Holiday Island" class now operated by CN Marine on the nearby Borden, P.E.I.-Tormentine, N.B. run and two 97 auto equivalent capacity ferries to be obtained by lengthening two existing 60 car ferries. The 150 car ferry is a double ended roll through vessel with two vehicle decks (see Fig. 3.10) of which the upper can carry autos only and the lower can carry autos and trucks. The existing vessels of this class, operated by CN Marine are loaded two lanes at a time on each of the two decks, and can be loaded in 7 minutes. The smaller vessels will be single decked and will load but 1 lane at a time. It is estimated that loading or unloading will take 11 minutes.

The daily traffic arrival pattern in the design year is expected to be similar to the pattern now experienced by CN at the nearby Tormentine terminal. The data describing this pattern is available and is shown in Figure 3.3.

The service is expected to operate on the same vessel schedule as at present but with two old 60 car ferries replaced by 150 car type of vessel.

A small office facility has recently been built near the berths and no further offices are required since the service has its main office in Charlottetown.

There are two privately operated restaurants adjacent to the terminal and unless these go out of business the service operator is prepared to let them serve the needs of the passengers.

6.3 Establishment of Design Criteria

The first step in the design methodology is the establishment of design criteria. This is done below:

1. Design Year: 1990

This is the year used by the planning staff in the establishment of the fleet configuration.

2. Design Day: 3rd highest annual day for automobiles
8th highest annual day for trucks

These are the same design days used by the planning staff in the establishment of the fleet configuration and reflect an attempt to cope with the problem of very high peaking of automobile traffic in the summer.

3. Design Hour: Highest hour of the design day

This is a higher level of service than is used by most highway departments and reflects the need to cope with the effects of severe summer peaking and the large number of people who would be inconvenienced by a lower level of service.

4. Design Vehicle: WB 15 tractor trailer

This is the type of truck commonly carried.

5. Design Ship(s):

(a) "Holiday Island" Class - 150 car capacity, loads simultaneously on two decks, lower deck carries cars and trucks, upper deck carried cars only, 600 passenger capacity, length 99m overall, beam 20.7m (325'x68') over the rubbing strake.

(b) Stretched "Prince" Class - 97 car capacity, single deck, 1 lane loading, carries cars or trucks, 300 passenger capacity, length 75.9m overall, beam 16.2m over the rubbing strake (249'x53').

6. Environmental Matters: Meet expected and present regulations of Department of Fisheries and Environment

This means that a sewage reception facility for shipborne sewage is required.

7. Financial: Design for minimum capital outlay now
This reflects government spending policy and implies no excess capacity or facilities.
8. Access/Egress Road: Level of service B in design year
9. Geometric Standards of Access/Egress Road: RAU 100*
10. Surge Lot: To be capable of holding maximum queue length on design day
11. Toll Booths: Average wait in line not to exceed 5 minutes
12. Marshalling Areas: A single marshalling area capable of holding queue length that forms on the design day
13. Number of Berths: Separate berth required for each class of vessel since beams are incompatible
14. Berth Dimensions: Beam to suit design ships length to be length of ship plus 15m (50 ft..) if possible
15. Passenger Amenities: No restaurant since passengers now served adequately by 2 restaurants adjacent to terminal.
Provide a playground, tourist booth. Waiting room to suit design day traffic.
16. Staff Parking: Sufficient for 2 ships crews, assuming 2/3 drive.

* Rural, arterial, undivided 100km/hr

17. Maintenance Facilities: Only janitorial facilities are required.

6.4 Sample Design Calculations

The second part of the design methodology proposed in this thesis is the application of the design techniques of Chapter V. These calculations are carried out below for Caribou Ferry Terminal.

6.4.1 Access/Egress Road

The existing access egress road is the end portion of Nova Scotia Highway 106 and is a straight road with four 3.35m* wide lanes, good shoulders and a 2% grade for the last quarter mile down to the terminal. The road serves as access to the fishing harbour adjacent to the ferry terminal and provides service to a few farms and houses along its length. The speed limit is 60 mph.

Figure 6.1 below is an example of the calculations for determining the inbound traffic volumes for each quarter hour of the design day. From the figure (column 3) it can be seen that the peak hour occurs between 1330 hours and 1430 hours and that in this hour 234 vehicles arrive at the terminal. Locally generated traffic is insignificant.

The maximum outbound traffic flow occurs when a 150 vehicle ferry unloads, which it does in 7 minutes. This is equivalent to an hourly volume of 1,285 vehicles. (Assumption is made from schedule that only 1 vessel unloads at a time).

The fishing traffic peaks in the early morning ((inbound)) and in the early evening (outbound) and consists of about 50 vehicles over a one hour period. This traffic consists mainly of autos or light trucks.

* 11 feet

Since ferries arrive full in the early evening the outbound fisheries volume should be added to the outbound ferry volume to obtain the peak outbound volume of 1,335 vehicles. The ferry traffic consists of approximately 5% trucks and 1% buses.

Strictly speaking the following calculation which is an application of techniques in the Highway Capacity Manual is not a part of this thesis but is included for completeness:

Determine the level of service provided in the design year to confirm that it meets the design criterion:

$$SV = 2,000 \ N^{V/c} \ W \ T_L$$

where

SV = Service Volume

N = Number of lanes in 1 direction

v/c = Service volume/capacity ratio from Table 10.1 of Reference 10

W = Adjustment for lane width and lateral clearance = .95 (from Table 10.2 of Ref. 10 for 11' lanes with no obstructions for 6')

= .85 (from Tables 9.4 and 9.6 of Ref. 10 for 2% grade for $\frac{1}{4}$ mile, 6% trucks (1% buses counted as trucks))

$$SV = 2,000 \times 2 \times .5 \times .95 \times .85$$

$$= 1,615 \text{ for level of service B}$$

The service volume at level of service B is higher than the projected volume in the larger direction. The existing 4 lane road width therefore provide an acceptable level of service in the design year.

6.4.2 Toll Booths and Surge Parking Lot - Method I
(By Equations)

STEP 1 Criterion of Acceptance: Average waiting time in queue should not exceed 5 minutes.

STEP 2 Criterion for surge lot: Surge lot must be capable of holding 100% of the traffic on the peak hour of the design day, 95% of the time.

STEP 3 Traffic offering by destination and vehicle type: There is only 1 destination.
From planners it is known that the daily traffic is (see Fig. 6.1):

Passenger related vehicle equivalents	
(including 1% buses)	1,992
Buses (1% of 1992)	20
Passenger related vehicles (excluding buses)	1,972
Tractor Trailers	94

It has been decided that all booths will be capable of ticketing automobiles and other small vehicles but that the left hand booth will handle all trucks and buses as well as autos since the left side of the marshalling area will be devoted to heavy vehicles.

STEP 4 Design hour traffic flows:
The design hour will be the peak hour of the design day. From data given in Fig. 6.1, it can be seen that this represents 10.3% of the daily volume.

Buses: 20 x 10.3%	2
Passenger related vehicles 1972 x 10.3%	203
Tractor Trailers 94 x 10.3%	<u>10</u>
Total vehicles/hour	215

Due to small number of trucks and buses, all vehicles will be combined for the calculations.

STEP 5 Average Service Time = 20 sec/customer/booth
(from experience with existing installation)
= 180 vehicles/hour

STEP 6 Try one (1) booth

$\lambda = 215$ = average arrival rate/hr
 $\mu = 180$ = average service rate/hr

Arrival rate exceed service rate. Queue would grow uncontrollably. One booth is insufficient.

STEP 7 Try two (2) booths

$N = 2$ booths, $\lambda = 215$ arrivals/hr
 $\mu = 280$ = service rate/channel
 $\rho = \lambda/\mu = 215/180 = 1.19$, utilization factor $\rho/N = .59$

(a) P_0 = Probability of an empty booth

$$P_0 = \frac{1}{\sum_{n=0}^{N-1} \frac{\rho^n}{n!} + \frac{\rho^N}{N!(1-\rho/N)}} = \frac{1}{\frac{1.19^0}{0!} + \frac{1.19}{1!} + \frac{1.19^2}{2!(1-\frac{1.19}{2})}} = \frac{1}{3.94} = .2539$$

$$(b) E(m) = \frac{P_0 \rho}{N! N} \left[\frac{1}{(1-\rho/N)^2} \right] = \frac{(.2539)(1.19)^3}{2 \times 1 \times 2} \left[\frac{1}{(1-\frac{1.19}{2})^2} \right]$$

$$= .1069 \left[\frac{1}{(.405)^2} \right] = .651 \quad \text{Average queue length}$$

$$(c) \quad E(n) = \rho + E(m) = 1.19 + .65 = 1.84$$

= Average number of units in the system.

$$E(v) = E(n) / \lambda = 1.84 / 180 = .0102 \text{ hours}$$

= 36.8 seconds

$$E(w) = E(v) - \frac{1}{\lambda} = .0102 - \frac{1}{180} = .0046445 \text{ hours}$$

= 16.7 seconds
= expected wait

Expected wait is less than minimum acceptable time. Therefore a two channel system is acceptable.

STEP 8

Calculate Size of Surge Parking Area

Probability of vehicles in the System is:

			<u>Px = n</u>	<u>Px ≤ n</u>
USE	Po = .2539		.2539	.2539
Pn = $\frac{\rho^n}{n!}$ Po for n ≤ N	*P ₁ = (1.19/1) (.2539)		.3021	.5060
	P ₂ = (1.19/2) (.2539)		.1511	.7071
	P ₃ = (1.19 ³ /2 x 2!) (.2539)		.1070	.8141
	P ₄ = (1.19 ⁴ /2 ² x 2!) (.2539)		.0636	.8777
USE Pn = $\frac{n}{N^{n-N} N!}$ Po for n > N	P ₅ = (1.19 ⁵ /2 ³ x 2!) (.2539)		.0379	.9156
	P ₆ = (1.19 ⁶ /2 ⁴ x 2!) (.2539)		.0225	.9381
	P ₇ = (1.19 ⁷ /2 ⁵ x 2!) (.2539)		.0134	.9515

It is 95.15% certain that the number of vehicles in the system is 7 or less. Therefore with 2 of the 7 vehicles being serviced by the toll booths there are still five vehicles that must be held in the surge lot. Since there are two booths, space for 2½ (say 3) vehicles, additional to the vehicle being ticketed, must be provided in front of each toll booth.

* Computation up to Pn = N can be simplified by observing that Pn = $\binom{\rho}{N}$ P.

Note that 5% of the time during the peak hour, this surge lot will probably be overloaded.

6.4.3 Toll Booths and Surge Parking Lot - Method 2
(by computer simulation)

The computer printout for this calculation is presented as Appendix A3 and the reader is referred to that Appendix.

The criterion of acceptance is that the average wait should not exceed 5 minutes in the queue.

Two inputs are required: the inter-arrival time in seconds and the mean service time. From the previous section it is known that the number of vehicles per hour is 215. This is equivalent to an inter-arrival time of $3600/215 = 16.7$ seconds (say 17 seconds). This is placed in the GENERATE statement.

From the previous section it is also known that the mean service time is 20 seconds. This is placed in the ADVANCE card. A spread of 10 seconds (plus or minus) has been assumed in the service time and this has also been indicated in the ADVANCE card.

From the printout it can be seen that with 1 toll booth the average time in the queue is 771 seconds and the average queue length is 54 vehicles, being a lineup over 1,000' long. This does not meet the acceptance criterion.

With two booths the average time in line is 18.868 seconds. This is acceptable and a two booth system is selected. With two booths the maximum number of vehicles in the system is 8, two of which are being processed, and six of which are in line. Space must therefore be provided in the surge lot for 3 vehicles in front of each booth.

6.4.4 Marshalling Areas by Large Interval Simulation

The calculations for determining marshalling area size by large interval simulation are given in Fig. 6.1

Since only one marshalling area will be built and since the percentage of trucks is not too large, all vehicles have been converted into auto equivalent units and only a single set of calculations has been done.

The arrival pattern shown in columns 1 and 2 was available from a study of the nearby Borden-Tormentine service. It was felt by the planners that this pattern was more likely to be representative of the design year traffic pattern at Caribou than would be the existing traffic pattern. This is because the existing system at Caribou is overloaded and the traffic arrivals are considered "forced"; i.e. traffic arrives very early to ensure a place on the boat. This does not happen at Tormentine and should not happen at Caribou with the proposed fleet. Hence the use of the Tormentine traffic pattern at Caribou.

From the calculations it can be seen that the maximum queue length is 460 auto equivalents and occurs at 1700 hours. Of this number of certain percentage must be allocated to trucks and buses. If it is presumed that the arrival rate is consistent throughout the day, then the average daily percentage of trucks and buses can be applied to the peak period to determine the number of auto equivalent spaces that must be allocated to trucks and buses in the marshalling area.

Of the 2274 auto equivalent units 282 are tractor trailers and 18 of 1992 $\approx$ 20 are buses. Ratio
 $= (282 + 20) / 2274 = .1328.$

CARIBOU FERRY TERMINAL

CALCULATION OF REQUIRED SIZE OF MARSHALLING
AREA BY LARGE INTERVAL SIMULATION

1990 Design Day Traffic:

Passenger Related Vehicles
(including 18 buses)

1992 (in auto equivalents)

Freight
(94 tractor trailers)

282 (in auto equivalents
at 3:1 conversion)

TOTAL

2274 auto equivalents

FIGURE 6.1

<u>TIME</u> <u>INTERVAL</u>	<u>% OF ARRIVALS</u> <u>IN TIME INTERVAL</u>	<u>NO. OF ARRIVALS</u> <u>IN TIME INTERVAL</u>	<u>NO. OF</u> <u>WAITING</u> <u>VEHICLES</u>	<u>VEHICLES DEP.</u> <u>IN INTERVAL</u>	<u>VEHICLES</u> <u>LEFT</u> <u>BEHIND</u>
0401-0415	.05	1	1		
0430	.05	1	2		
0445	.1	2	4		
0500	.1	2	6		
0515	.15	3.4	9		
0530	.15	3.4	13		
0545	.25	5.7	18		
0600	.25	5.7	24	97	
0615	.4	9.1	9		
0630	.4	9.1	18	150	
0645	.5	11.4	11		
0700	.5	11.4	23		
0715	.65	14.8	38		
0730	.65	14.8	52	97	
0745	.8	18.2	18		
0800	.8	18.2	36	150	
0815	.9	20.5	21		
0830	.9	20.5	41		
0845	1.0	22.7	64		
0900	1.0	22.7	86	97	
0915	1.2	27.3	27		
0930	1.2	27.3	55		
0945	1.35	30.7	85	150	
1000	1.35	30.7	31		
1015	1.5	34.1	65		
1030	1.5	34.1	99		
1045	1.7	38.6	138	97	40.5
1100	1.7	38.6	79		
1115	1.9	43.2	122	150	
1130	1.9	43.2	43		
1145	2.15	48.9	92		
1200	2.15	48.9	141		
1215	2.4	54.6	196	97	98.6
1230	2.4	54.6	153		
1245	2.5	56.8	210		
1300	2.5	56.8	267	150	116.8
1315	2.5	56.8	174		
1330	2.5	56.8	230		
1345	2.65	60.3	291		
1400	2.65	60.3	351	97	254
1415	2.5	56.8	311		
1430	2.5	56.8	368	150	217.6
1445	2.5	56.8	274		

FIGURE 6.1 (con't)

<u>TIME INTERVAL</u>	<u>% OF ARRIVALS IN TIME INTERVAL</u>	<u>NO OF ARRIVALS IN TIME INTERVAL</u>	<u>NO. OF WAITING VEHICLES</u>	<u>VEHICLES DEP. IN INTERVAL</u>	<u>VEHICLES LEFT BEHIND</u>
1500	2.5	56.8	331		
1515	2.4	54.6	386		
1530	2.4	54.6	441	97	343.6
1545	2.15	48.9	393		
1600	2.15	48.9	441	150	291.4*
1615	1.95	44.3	336		
1630	1.95	44.3	380		
1645	1.75	39.8	420		
1700	1.75	39.8	460*	97	362.6
1715	1.55	35.2	398		
1730	1.55	35.2	433		
1745	1.4	31.8	456	150	314.8
1800	1.4	31.8	347		
1815	1.3	29.6	376		
1830	1.3	29.6	406	97	308.8
1845	1.2	27.3	336		
1900	1.2	27.3	363		
1915	1.1	25	388	150	238.4
1930	1.1	25	263		
1945	1.0	22.7	286		
2000	1.0	22.7	309		
2015	.95	21.6	330	97	233.4
2030	.95	21.6	255		
2045	.85	19.3	274		
2100	.85	19.3	294	150	143.6
2115	.70	15.9	160		
2130	.70	15.9	175		
2145	.60	13.6	189	97	92
2200	.60	13.6	106		
2215	.5	11.4	117		
2230	.5	11.4	128	150	0
2245	.4	9.1	9		
2300	.4	9.1	18		
2315	.3	6.8	26		
2330	.3	6.8	33	97	0
2345	.25	5.7	6		
2400	.25	5.7	11		11.4

* Maximum queue

FIGURE 6.1 (con't)

Therefore of the 460 auto equivalent spaces, $.1328 \times 460 = 61$ auto equivalent spaces must be allocated to trucks and buses.

6.4.5 Marshalling Areas by Computer Simulation

The printout of the computer simulation is shown in Appendix B.

The input data used in this example is shown in Fig. 6.2.

Much of the input data such as the traffic pattern is similar to that used in Fig. 6.1 but as can be seen the computer program required somewhat more detailed data in such areas as ship characteristics, where both auto and truck capacity is needed and in the realm of vessel scheduling where the program user must simulate the service management's action in assigning priorities and truck space allocations.

In the case of the sample calculation, the input data reflects an extrapolation from present practise as much as possible.

From Appendix B it can be seen that according to the computer simulation, the required size of the marshalling area is 452 auto spots and 10 truck spots.

6.4.6 Transfer Roads

There are no techniques for the determination of the number of lanes of transfer road required. Rather, the designer must consider and apply the factors discussed in Section 4.11.

It should be noted that the vessels being proposed will be capable of loading two lanes of traffic on each of two decks simultaneously while the existing vessels (that will be lengthened) will load 1 lane of vehicles on one deck, it must also be noted that it is desired to turn the vessels around as quickly as possible during

1	2	3	4	5	6	7	8	9	10	11	12
NO OF POINTS						NO OF POINTS					
AUTO PATTERN						TRUCK PATTERN					
			4	1						4	2
AUTO TRAFFIC PATTERN											
VOL AS A						TIME					
DECIMAL											
			0	0	0				0	0	0
			0	0	1				4	5	0
			0	0	3				5	0	0
			0	0	6				5	5	0
			0	1	1				6	0	0
			0	1	9				6	5	0
			0	2	9				7	0	0
			0	4	2				7	5	0
			0	5	8				8	0	0
			0	7	6				8	5	0
			0	9	6				9	0	0
			1	2	0				9	5	0
			1	4	7				10	0	0
			1	7	7				10	5	0
			2	1	1				11	0	0
			2	4	9				11	5	0
			2	9	2				12	0	0
			3	4	0				12	5	0
			3	9	0				13	0	0
			4	4	0				13	5	0
			4	9	3				14	0	0
			5	4	3				14	5	0
			5	9	3				15	0	0
			6	4	1				15	5	0
			6	8	4				16	0	0
			7	2	3				16	5	0
			7	5	8				17	0	0
			7	8	4				17	5	0
			8	1	7				18	0	0
			8	4	3				18	5	0
			8	6	2				19	0	0
			8	8	9				19	5	0
			9	0	0				20	0	0
			9	2	9				20	5	0

1	2	3	4	5	6	7	8	9	10	11	12
TRUCK TRAFFIC PATTERN											
VOL AS A DECIMAL						TIME					
	.	0	0	0				0	.	0	0
	.	0	0	0				4	.	0	0
	.	0	0	1				4	.	5	0
	.	0	0	3				5	.	0	0
	.	0	0	6				5	.	5	0
	.	0	1	1				6	.	0	0
	.	0	1	9				6	.	5	0
	.	0	2	9				7	.	0	0
	.	0	4	2				7	.	5	0
	.	0	5	8				8	.	0	0
	.	0	7	6				8	.	5	0
	.	0	9	6				9	.	0	0
	.	1	2	0				9	.	5	0
	.	1	4	7				10	.	0	0
	.	1	7	7				10	.	5	0
	.	2	1	1				11	.	0	0
	.	2	4	9				11	.	5	0
	.	2	9	2				12	.	0	0
	.	3	4	0				12	.	5	0
	.	3	9	0				13	.	0	0
	.	4	4	0				13	.	5	0
	.	4	9	3				14	.	0	0
	.	5	4	3				14	.	5	0
	.	5	9	3				15	.	0	0
	.	6	4	1				15	.	5	0
	.	6	8	4				16	.	0	0
	.	7	2	3				16	.	5	0
	.	7	5	8				17	.	0	0
	.	7	8	9				17	.	5	0
	.	8	1	7				18	.	0	0
	.	8	4	3				18	.	5	0
	.	8	6	7				19	.	0	0
	.	8	8	9				19	.	5	0
	.	9	0	9				20	.	0	0
	.	9	2	8				20	.	5	0
	.	9	4	5				21	.	0	0

[illegible]

the peak periods and that the existing roadway is capable of handling the flow from a vessel of this size unloading in seven minutes (see Section 6.2 for these calculations), although it would be necessary to step the number of lanes down to the two possessed by the egress road.

From the above it is evident that provision must be made for moving 4 lanes of traffic from the marshalling area to the dock area and from the dock area to the egress road but note also that it is possible it is useful to have the 4 lane portion long enough to hold a full shipload of traffic so that even if there is difficulty merging down to two lanes, the ship can be emptied and another shipload loaded without delay.

6.4.7 Berths by Block Time Method

STEP 1 From data in Fig. 6.1 there will be two vessels of 150 auto capacity loading on 2 decks and requiring a double decked transfer bridge. There will also be two vessels of 97 car capacity which load on one deck.

If required the single decked vessel can load in a double decked berth but double decked vessels cannot load in a single decked berth.

STEP 2 The schedule is shown in Fig. 6.1 under the column marked "Vehicles departing in interval". This gives the time of departure and the capacity of the departing ship. Operating day is from 0545 (15 minutes before first departure) to 2345 (15 minutes after last departure).

STEP 3 Two types of dock are needed. One type with two level loading and capable of taking vessels of 68 foot beam and one with single level loading capable of taking vessel of 53 foot beam.

STEP 4 It takes 2 minutes to dock or undock and 5 minutes to clear the channel.

The 150 car ferries load or unload in 7 minutes.

The 97 car ferries load or unload in 11 minutes.

Factor of safety required is 10 minutes.

Therefore the block times are:

150 car ferries: $5 + 2 + 7 + 7 + 2 + 5 + 10 = 38$ minutes

97 car ferries: $5 + 2 + 11 + 11 + 2 + 5 + 10 = 46$ minutes

STEP 5 Operating day (0545 - 2345) is 18 hours long which equals 1080 minutes.

For double decked type of berth, maximum possible number of dockings is $1080/38 = 28$ dockings per berth.

For single decked type of berth, maximum possible number of dockings is $1080/46 = 23$ dockings per berth.

The actual number of berthings is 12 for the 97 car ferries and 11 for the 150 car ferries.

The berthings are spaced fairly uniformly at about 90 minutes apart for each type of vessel so that the probabilities of needing more than 1 berth of each type are very slim if not non-existent since the time between departures is two to three times as long as the block times.

There is therefore no need to check this graphically.

In summary one berth of each type is both sufficient and necessary.

6.4.8 Terminal Building

As previously mentioned the terminal complex contains a terminal building which has a waiting room, washrooms and a tourist bureau but not a restaurant since that service is now provided by 2 private restaurants adjacent to the terminal.

The tourist bureau is considered to be of adequate size for the future as are the washrooms.

It is required to determine if the waiting room which is approximately 35' x 30' is of sufficient size for future needs.

It is felt that the standard should be that the facilities be acceptable to the average traffic during the 12 busiest hours of the design day.

From Fig. 6.1 the total number of auto equivalents in the queue during the peak 12 hours (1030 hours - 2230 hours) is 3516. The average queue length is 270 auto equivalents of which 1% are buses (at a 2:1 conversion) rate and 12% are trucks (at a 3:1 conversion).

$$\begin{aligned}\text{No. of buses} &= .01 \times 270 = 2.7 \text{ auto equivalents} \\ &= 1.23 \text{ buses}\end{aligned}$$

Assume 30 passengers/bus

$$\text{No. of Bus Passengers} = \underline{41}$$

$$\begin{aligned}\text{No. of Trucks} &= .12 \times 270 = 32.4 \text{ auto equivalents} \\ &= 10.8 \text{ trucks (say 11)}\end{aligned}$$

$$\text{No. of truck drivers} = \underline{11}$$

$$\text{No. of automobiles} = \underline{270} - 2.7 - 32.4 = 235$$

Assume 2.5 passengers per auto

$$\text{No. of passengers in autos} = 2.5 \times 235 = \underline{587.5}$$

The number of foot passengers varies but historically there are usually about 10 foot passengers waiting at any given time.

The vessels have been designed such that the average wait will be two hours or less. On the design day the wait is likely to be at least two hours.

The design day occurs in midsummer and it will be assumed that there is no weather related reason to force everybody to wait in the terminal.

No other historical data is available so it is necessary to apply the "observations" mentioned in Section 5.9.1 and the recommended unit space allocations of Fig. 5.2.

1. Foot passenger always take the next vessel since ferries are space restricted or weight restricted but almost never passenger capacity restricted (in Canada).

Average time between sailings = $3/4$ hour

Average wait for foot passengers = $3/8$ hour

Assume all time spent in terminal

No. of passenger hours = $3/8 \times 10 = 4$

2. Bus passengers:

Assume 50% wait in the terminal for 50% of their average waiting time

$41 \text{ passengers} \times .5 \times 1 \text{ hour} = 20.5 \text{ passenger hours}$

3. Truck drivers and auto passengers

Assume 50% wait in the terminal for 50% of their average waiting time

$599 \text{ passengers} \times .5 \times 1 \text{ hour} = 300 \text{ passenger hours}$

total number of passenger hours = 325

Assume 50% seated and 50% standing

Seated passengers require $\frac{325}{2} \times 25 \text{ sq.ft.} = 4062.5$

Standing passenger require $\frac{325}{2} \times 15 \text{ sq.ft.} = \underline{2437.5}$

Waiting area = 6500.0 sq.ft.

NOTE: Some of this area could be outside in the form of patios, etc.

7.1 Summary

This thesis has been directed to filling a perceived void in the field of transportation engineering as related to the design of ferry and ro/ro terminals. Up till the present very little theoretical research or development work has been carried out on the design aspects of such terminals and as a result, there has been inconsistency in their design inconsistency in terminology employed and lack of appreciation of the interactions between the shoreside and shipside elements of ferry systems.

The objective of this thesis has therefore been to develop a "design package" that would enable the engineer to possess in one reference all the technology background and design methodologies necessary to carry out that portion of design related to the establishment of the sizes of the elements that constitute a ferry or ro/ro terminal.

This has been done in two stages. Firstly a comprehensive survey of the relevant technology was carried out. This was done in three parts: (1) a discussion of advantages, disadvantages, definitions and problems of ferry and ro/ro systems was presented; (2) a discussion of the relevant vessel technology was presented; (3) a discussion of the use and characteristics of each of the elements that constitute a terminal was presented.

Secondly a two part design methodology was developed. The first part of the methodology consists of the establishment of the factors that should be considered when setting the design criteria and parameters for the terminal design. The second part of the methodology that was developed consists of a number of practical mathematical techniques for determining the required sizes of the terminal elements.

Finally the methodology so developed was applied to a real ferry terminal in Eastern Canada.

7.2 Conclusions

This thesis has achieved two things. Firstly it has gathered together in one place background and operating information relating to all of shipside,* interface and shoreside elements* that together constitute a ferry or a roll on/roll off system.

For the terminals it has described each of the constituent elements; it has described the role played by each in the system; it has described how they relate to other elements both physically and operationally; it has defined them and it has illustrated them.

For the vessels it has classified and described them according to loading methodology and according to cargo carried; it has described the advantages and disadvantages of each vessel type and has indicated the effects and implications of each type to the terminal design problem.

For the interface aspects, it has described the main types of ship/shore interfaces now in use and has illustrated several of these.

In general then the thesis has presented, in concise form, a summary of the current technology and operations of all aspects of ferry and ro/ro systems.

The second thing which this thesis has achieved is to develop a design methodology for determining the size of the constituent elements of a ferry or ro/ro terminal. This has been done in two* parts. Firstly by discussing the factors that must be considered when establishing the design criteria for each element of a terminal and secondly by developing a number of mathematical and other techniques for actually calculating the size of each element.

* But not harbour elements which were considered to be beyond the scope of the thesis.

As important as the fact that these design techniques can be developed in theory, are the two practical considerations that the techniques are not too difficult to apply and that the answers provided by the techniques appear reasonable.

The validity of these two statements was shown by the applied demonstration of Chapter VI where a calculation for each element was carried out. The data used in the example was the data available within the Department of Transport and perhaps can be considered to be representative of the data that would normally be available to the designer. No simplifying assumptions were made and no data fabricated for the example. The question of the reasonableness of the results is perhaps a little more difficult to support, but in the two cases where two techniques were available for one element, both techniques gave very similar results. In the case of the other elements, it was the opinion of the Department of Transport's staff that the results were reasonable.

It is felt that the application of these techniques together with the proper selection of design criteria (as outlined in Chapter IV) constitutes a viable and practical framework for consistent and accurate designing of ferry and ro/ro terminals. It is also felt that the background information provided in the earlier sections will be sufficient to allow the practising engineer to apply the techniques with some confidence that they are being applied correctly.

7.3 Recommendations for Further Research

As indicated in the text very little work has been done in this field and a number of topics related just to the sizes of the terminal elements are in need of further study. These are:

- (a) Study of ways of modifying passenger arrival patterns and behavior to increase the utilization of facilities (The Department of Transport has done some work on this.)

- (b) Study of relationships between waiting times, time of day or year and the use of terminal facilities.
- (c) Study of facilities that the passengers feel are necessary for the improved enjoyment of their passage and the cost and benefits of such facilities.
- (d) Study of the required sizes of the facilities within the terminal building (i.e. specific to the ferry environment rather than adaptations from the air mode.)
- (e) Study of means and ways of optimizing traffic flow within ferry and ro/ro terminals.

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OLCK NUMBER	OPERATION SIMULATE	A.B.C.D.E.F.G.H.I	COMMENTS	STATEMENT NUMBER
1	FUNCTION	RNI.C24	FUNCTION FOR INTER ARRIVAL INTERVAL	1
2	0.9	0.1	0.252 0.1 0.355 0.4 0.505 0.5 0.60	2
3	0.6	0.915 0.7	1.35 0.8 1.6 0.84 1.83 0.25 2.12	3
4	0.9	2.3 0.92	2.52 0.64 2.81 0.95 2.99 0.96 3.2 0.97 3.5	4
5	0.98	3.5 0.99	4.5 0.995 5.3 0.998 6.2 0.999 7 0.99978	5
6	GENERATE	17.FN1	CREATE ARRIVING VEHICLES MEAN RATE IS	6
7	0.9	0.1	ONE VEHICLE EVERY 17 SECONDS	7
8	0.6	0.915 0.7	ADD TRANSACTIONS TO QUEUE NO 1	8
9	0.9	2.3 0.92	MOVE A VEH TO AN EMPTY BOOTH (STORAGE 1)	9
10	0.98	3.5 0.99	REMOVE TRANSACTIONS FROM QUEUE NO 1	10
11	GENERATE	17.FN1	PURCHASE A TICKET (20 SEC + OR - 10 SEC)	11
12	0.9	0.1	LEAVE TICKET BOOTH (STORAGE NO1)	12
13	0.6	0.915 0.7	MEASURE TIME AUTOS ARE IN THE SYSTEM	13
14	0.9	2.3 0.92	REMOVE TRANSACTION FROM SYSTEM	14
15	0.98	3.5 0.99	NO OF TOLL BOOTHS = 1 FOR THIS RUN	15
16	GENERATE	17.FN1	INITIALIZE WITH 50 VEHICLES	16
17	0.9	0.1	CLEAR STATISTICAL TABLES	17
18	0.6	0.915 0.7	RUN 250 VEHICLES	18
19	0.9	2.3 0.92	CLEAR SYSTEM FOR NEW RUN	19
20	0.98	3.5 0.99	NO OF TOLL BOOTHS = 2 FOR THIS RUN	20
21	GENERATE	17.FN1	RUN 250 VEHICLES	21
22	0.9	0.1	CLEAR SYSTEM FOR NEW RUN	22
23	0.6	0.915 0.7	NO OF TOLL BOOTHS = 3 FOR THIS RUN	23
24	0.9	2.3 0.92	RUN 250 VEHICLES	24
25	0.98	3.5 0.99	CLEAR SYSTEM FOR NEW RUN	25
26	GENERATE	17.FN1	NO OF TOLL BOOTHS = 3 FOR THIS RUN	26
27	0.9	0.1	INITIALIZE WITH 50 VEHICLES	27
28	0.6	0.915 0.7	CLEAR STATISTICAL TABLES	28
29	0.9	2.3 0.92	RUN 250 VEHICLES	29
30	0.98	3.5 0.99	CLEAR SYSTEM FOR NEW RUN	30
31	GENERATE	17.FN1	NO OF TOLL BOOTHS = 3 FOR THIS RUN	31
32	0.9	0.1	RUN 250 VEHICLES	32

*** ASSEMBLY TIME = .01 MINUTES ***

BLOCK DIAGRAM FOR GPSS
SIMULATION OF TOLL BOOTHS
AND SURGE LOT

*** C P S S V - O S V E R S I O N ***
*** IBM PROGRAM PRODUCT 5734-XS2 (VIM3) ***

BLOCK NUMBER	OPERATION	A.B.C.D.E.F.G.H.I	COMMENTS	STATEMENT NUMBER
1	START		INITIALIZE WITH 50 VEHICLES	1
2	START		CLEAR STATISTICAL TABLES	2
3	START		RUN 250 VEHICLES	3
4	START		CLEAR SYSTEM FOR NEW RUN	4
5	START		NO OF TOLL BOOTHS = 2 FOR THIS RUN	5
6	START		RUN 250 VEHICLES	6
7	START		CLEAR SYSTEM FOR NEW RUN	7
8	START		NO OF TOLL BOOTHS = 3 FOR THIS RUN	8
9	START		RUN 250 VEHICLES	9
10	START		END	10
11	START		END	11
12	START		END	12
13	START		END	13
14	START		END	14
15	START		END	15
16	START		END	16
17	START		END	17
18	START		END	18
19	START		END	19
20	START		END	20
21	START		END	21
22	START		END	22
23	START		END	23
24	START		END	24
25	START		END	25
26	START		END	26
27	START		END	27
28	START		END	28
29	START		END	29
30	START		END	30
31	START		END	31
32	START		END	32

*** ASSEMBLY TIME = .01 MINUTES ***

NOTES

1. STATEMENT NUMBERS ARE PROVIDED BY THE COMPUTER AS ARE BLOCK NUMBERS

SIMULATE		SIMULATION OF SURGE PARKING LOT AND TOLL BOOTHS FOR FERRY TERMINALS									
1	FUNCTION	EN1.C24									
0.0	C.0	C.1	1.2	0.75	0.222	0.3	0.355	0.4	0.509	0.5	0.69
0.6	C.015	C.7	1.2	0.75	1.38	0.8	1.6	0.84	1.83	0.89	2.12
0.9	2.3	C.52	2.52	0.04	2.81	0.95	2.99	0.96	3.2	0.97	3.5
0.98	3.9	0.99	4.6	0.995	5.3	0.998	6.2	0.999	7	0.99978	
1	GENERATE	17.FN1	ONE VEHICLE EVERY 17 SECONDS.								
2	QUEUE	1									
3	ENTER	1									
4	DEPART	1									
5	ADVANCE	20.10									
6	LEAVE	1									
7	TERMINATE	1									
8	TERMINATE	1									
9	TERMINATE	1									
10	STOPAGE	1									
11	TABLE	M1.10.10.20									
12	START	50.NP									
13	RESET	250									
14	START	250									

TOTAL

BLOCK CURRENT

TOTAL

BLOCK CURRENT

TOTAL

BLOCK CURRENT

TOTAL

ABSOLUTE CLOCK

TOTAL

RELATIVE CLOCK

BLOCK COUNTS

BLOCK CURRENT

1 0.95

2 0.00

3 0.00

4 0.00

5 0.00

6 0.00

7 0.00

8 0.00

NOTES

1. RELATIVE CLOCK INCLUDES TIME PER WITHINING WITH 50 SIMULATED VEHICLES

2. ABSOLUTE CLOCK INCLUDES ONLY RUN TIME FOR 250 SIMULATED VEHICLES

STORAGES

STORAGE	CAPACITY	AVERAGE CONTENTS	ENTRIES	AVERAGE TIME/UNIT	TOTAL TIME	UNAVAIL. TIME	CURRENT STATUS	PERCENT AVAILABILITY	CURRENT CONTENTS	MAXIMUM CONTENTS
1	1	1,000	250	19.556	1,000			100.0		1

Notes

1. STORAGE NO. 1 REPRESENTS THE TOLL BOOTH SYSTEM

2. "CAPACITY" IS THE NUMBER OF TOLL ROOMS IN THE SYSTEM

3. ALL TIMES ARE IN SECONDS.

 TABLES

TABLE 1 ENTRIES IN TABLE 250				MEAN ARGUMENT 811.379	STANDARD DEVIATION 356.000	SUM OF ARGUMENTS 202645.000	NON-WEIGHTED
UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN	
10	0	.00	.0	100.0	.012	-2.222	
20	0	.00	.0	100.0	.024	-2.194	
30	0	.00	.0	100.0	.036	-2.166	
40	0	.00	.0	100.0	.049	-2.138	
50	0	.00	.0	100.0	.061	-2.110	
60	0	.00	.0	100.0	.073	-2.082	
70	0	.00	.0	100.0	.086	-2.054	
80	0	.00	.0	100.0	.098	-2.026	
90	0	.00	.0	100.0	.110	-1.998	
100	0	.00	.0	100.0	.123	-1.970	
110	0	.00	.0	100.0	.135	-1.942	
120	0	.00	.0	100.0	.147	-1.913	
130	0	.00	.0	100.0	.160	-1.885	
140	0	.00	.0	100.0	.172	-1.857	
150	0	.00	.0	100.0	.184	-1.829	
160	0	.00	.0	100.0	.197	-1.801	
170	0	.00	.0	100.0	.209	-1.773	
180	0	.00	.0	100.0	.221	-1.745	
190	0	.00	.0	100.0	.234	-1.717	
OVERFLOW	250	100.00	100.0	100.0	.234	-1.717	
AVERAGE VALUE OF OVERFLOW		811.37					

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NOTES

1. WITH ONLY 1 TALL BOOTH THE SYSTEM IS OVERLOADED
2. TABLE 1 IS A LISTING OF THE TIME IN THE SYSTEM (ie WAITING TIME + SERVICE TIME)

1 CLEAR STORAGE START 2 250

NOTES

1. THESE 3 CARDS CLEAR THE STATISTICAL TABLES THEN REPLACE THE EXISTING STORAGE CAPACITY WITH A STORAGE CAPACITY OF 2 (IF CHANGE THE NUMBER

OF TOLL BOOTHS FROM 1 TO 2) THEN RERUN THE SIMULATION WITH 250 VEHICLES

RELATIVE CLOCK		3783 ABSOLUTE CLOCK		3783			
BLOCK COUNTS		BLOCK CURRENT	TOTAL	BLOCK CURRENT	TOTAL	BLOCK CURRENT	TOTAL
1	0	252	252				
2	1	252	252				
3	0	251	251				
4	0	251	251				
5	0	250	250				
6	0	250	250				
7	0	250	250				
8	0	250	250				

 STORAGES

STORAGE	CAPACITY	AVERAGE CONTENTS	ENTRIES	AVERAGE TIME/UNIT	-AVERAGE TOTAL TIME	UTILIZATION DURING- AVAIL. TIME	UNAVAIL. TIME	CURRENT STATUS	PERCENT AVAILABILITY	CURRENT CONTENTS	MAXIMUM CONTENTS
1	2	1.344	281	20.263	.672				100.0	1	2

 *
 * TABLES *
 *

TABLE 1 ENTRIES IN TABLE 250		MEAN ARGUMENT 30.559	STANDARD DEVIATION 15.073		SUM OF ARGUMENTS 7640.000	* NON-WEIGHTED
UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
10	3	1.19	1.1	98.7	.327	-1.364
20	66	26.79	27.5	72.4	.654	-.700
30	84	33.59	61.1	38.8	.981	-.037
40	44	17.59	78.7	21.2	1.308	.620
50	27	10.79	89.5	10.4	1.636	1.289
60	11	4.43	93.9	6.0	1.963	1.953
70	10	3.99	97.9	2.0	2.290	2.617
80	3	1.13	99.1	.8	2.617	3.280
90	2	.79	100.0	.0	2.945	3.944

REMAINING FREQUENCIES ARE ALL ZERO

1
CLEAR
STORAGE
START 3 260

RELATIVE CLOCK		4319 ABSOLUTE CLOCK		4319			
BLOCK COUNTS		BLOCK CURRENT		BLOCK CURRENT			
BLOCK		TOTAL		TOTAL		TOTAL	
1	0	251	0	251	0	251	0
2	0	251	0	251	0	251	0
3	0	251	0	251	0	251	0
4	0	251	0	251	0	251	0
5	1	251	1	251	1	251	1
6	0	250	0	250	0	250	0
7	0	250	0	250	0	250	0
8	0	250	0	250	0	250	0

 *
 * TABLES *
 *

TABLE 1 ENTRIES IN TABLE 250		MEAN ARGUMENT 21.231	STANDARD DEVIATION 7.320		SUM OF ARGUMENTS 5308.000		NON-WEIGHTED	
UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN		
10	13	5.19	5.1	94.7	.470	-1.534		
20	97	38.79	43.9	50.0	.941	-1.168		
30	126	50.35	94.3	5.6	1.412	1.197		
40	11	4.39	98.7	1.2	1.883	2.563		
50	3	1.19	100.0	.0	2.354	3.929		

REMAINING FREQUENCIES ARE ALL ZERO

3 3

OF / DE

END

***** TOTAL RUN TIME (INCLUDING ASSEMBLY) = .12 MINUTES *****

P.1 OF.1

DATA SET NO. DATE

[illegible]

3J08

WATTV-LINES=60

ADelay(K)	ACCEPTABLE DELAY OF SHIP TO AWAIT MORE PASSENGERS
AVPASS	NO OF AUTOS THAT CAN BE LOADED IN 1 SIMULATION INTERVAL
CARCAP(J)	CAPACITY OF SHIP IF CARRYING ONLY AUTOS
CARS	NO OF AUTOS THAT A SHIP CAN ACTUALLY CARRY UNDER VARYING
CONVBI	CONDITIONS AND PRIORITY RULES
DAYFLA	CONVERSION FACTOR FOR TRUCKS TO AUTO EQUIVALENT UNITS
DAYFLT	DAILY TRAFFIC ON DESIGN DAY - AUTOS
DEPNOK(I)	DAILY TRAFFIC ON DESIGN DAY - TRUCKS
DEPS	DEPARTURE NO (FIRST OF DAY ETC)
DEPTIM(K)	NO OF DEPARTURES IN DESIGN DAY FROM PORT
ENDIT	SHIP DEPARTURE TIME
INT	NUMBER OF HOURS TO BE SIMULATED
	NO OF INTERVALS ACCUMULATED BEFORE SUM OF SIMULATED VEHICLES
	IS PRINTED OUT
INTNO	RUNNING RECORD OF SIMULATION INTERVAL NUMBER
IRD	NO OF THE "READ" UNIT FOR YOUR COMPUTER SETUP
IRW	NO OF THE "WRITE" UNIT FOR YOUR COMPUTER SETUP
KARS	COUNT OF CARS ACTUALLY LOADED ONTO A SHIP
LOADA	NO OF AUTOS LOADED ONTO A PARTICULAR SHIP
LOADAE	NO OF AUTO EQUIVALENTS LOADED UNDER FIFO PRIORITY
LOADT	NO OF TRUCKS LOADED ONTO A PARTICULAR SHIP
NPOINTA	COUNT OF POINTS USED TO DESCRIBE TRAFFIC PATTERN - AUTOS
NPOINT	COUNT OF POINTS USED TO DESCRIBE TRAFFIC PATTERN - TRUCKS
POINTT	NO OF POINTS USED TO DEFINE TRAFFIC PATTERN - TRUCKS
PORT	NAME OF PORT
POSS	NO OF VEHICLES THAT ARE LOADED IN 1 SIMULATION INTERVAL
QUEUEA	MAX QUEUE LENGTH OF AUTOS
QUEUET	MAX QUEUE LENGTH OF TRUCKS
SETNO	DATA SET NUMBER FOR A GIVEN PORT
SHIPNO(J)	CONSECUTIVE NO OF SHIP(1,2,3 ETC)
SHIPNO(K)	SHIP NUMBER THAT IS DEPARTING
SHIPS	NO OF VESSELS IN FLEET
SLTIM(K)	SIMULATION INTERVAL USED
STVOL	TIME WHEN YOU START TO LOAD THE SHIP
STVOLT	VOLUME OF TRAFFIC IN Q AT START OF SIMULATION - AUTOS
TA(I)	VOLUME OF TRAFFIC IN Q AT START OF SIMULATION - TRUCKS
TIMEAXA	TIMES OF DESIGN DAY FOR WHICH CUMULATIVE VOLS ARE GIVEN - CARS
TIMEAXT	TIME AT WHICH MAX AUTO QUEUE OCCURS
TKS(K)	TIME AT WHICH MAX TRUCK QUEUE OCCURS
TRKCAP(J)	COUNT OF TRUCKS ACTUALLY LOADED ONTO A SHIP
TRPOSS	MAX NO OF TRUCKS THAT CAN BE CARRIED
TRUCKS	NO OF TRUCKS THAT CAN BE LOADED IN 1 SIMULATION INTERVAL
TSIM	A COUNT OF TRUCK CAPACITY WHEN PRIORITY IS BEING GIVEN AUTOS
TVOLA	RUNNING RECORD OF TIME IN THE SIMULATIVE VOLS ARE GIVEN - TRKS
TVOLT	TIMES OF DESIGN DAY FOR WHICH CUMULATIVE VOLS ARE GIVEN - TRKS
VA(I)	RUNNING TOTAL OF CARS FOR WHOLE PROGRAM
VINTA	RUNNING TOTAL OF TRUCKS FOR WHOLE PROGRAM
VINTT	CUMULATIVE % OF DAILY TRAFFIC AT DIFF TIMES OF DESIGN DAY
	FOR AUTOS
	RUNNING COUNT OF TRUCKS IN SUM OF SIMULATED INTERVALS
	RUNNING COUNT OF AUTOS IN THE SUM OF THE SIMULATED INTERVALS
	USED FOR ACCUMULATION INTO LARGER TIME UNITS BEFORE PRINTING
YNAME(LJ)	NAME OF VESSEL
VSIMA(I)	VOLUME OF AUTOS SIMULATED IN INTERVAL I
VSIMT(I)	VOL OF TRUCK TRAFFIC SIMULATED IN INTERVAL I
VT(I)	CUMULATIVE % OF DAILY TRAFFIC AT DIFF TIMES OF DESIGN DAY
	FOR TRUCKS

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1  C      PROGRAM SEGMENT NO 1 - DIMENSIONS, INTEGER AND REAL DECLARATIONS
2  DIMENSION PORT(10)
3  DIMENSION VAI(100), VT(100), TA(100), TT(100), SHIPNO(20), VNAME(20),
4  1 CARCAP(20), TRKCAP(20), DEPN(50), SLTIM(50), DEPTIM(50), ADELAY(50),
5  2 PRIORITY(50), VESSNO(50), VSIMT(2500), VSIMT(2500), CARS(50), TRKS(50),
6  3 KARS(50), TRUCKS(50)
7  REAL KARS
8  INTEGER SETNO
9  INTEGER DEPS, SHIPNO, CARCAP, TRKCAP, SHIPS, DEPN, STVOLA, STVOLT,
10 2 DAYFLA, DAYFLT, POINTA, POINTT, VESSNO, TRUCKS, CARS, PRIORITY
11  PROGRAM SEGMENT NO 2 - READ IN THE INPUT DATA
12  IRD=1
13  IPR=1
14  WRITE(IWR,4)
15  4 FORMAT (I1,1X)
16  5 READ (IRD,5) (POBI(L),L=1,5),SETNO
17  5 FORMAT (5A4,13)
18  WRITE(IWR,7)
19  7 FORMAT (IWR,7)
20  WRITE(IWR,8)
21  8 FORMAT (IWR,8)
22  9 FORMAT (IX,3H***,44X,3H***)
23  WRITE (IWR,9) (POBI(L),L=1,5),SETNO
24  9 FORMAT (IX,3H***,3X,5A4,15HDATA SET NUMBER,IX,13,2X,3H***)
25  WRITE(IWR,8)
26  WRITE(IWR,7)
27  READ(IRD,10) STVOLA,STVOLT
28  10 FORMAT (I6,16)
29  READ(IRD,12) DAYFLA,DAYFLT
30  12 FORMAT (I6,16)
31  READ(IRD,20) SINT
32  20 FORMAT (F6,3)
33  READ(IRD,22) ENOIT
34  22 FORMAT (F6,2)
35  READ(IRD,26) CONVERT
36  26 FORMAT (F6,2)
37  READ (IRD,24) SHIPS
38  24 FORMAT (I6)
39  READ (IRD,24) (SHIPNO (J),VNAME (J),CARCAP (J),TRKCAP (J),J=1,SHIP
40  15)
41  15)
42  READ(IRD,14) POINTA,POINTT
43  14 FORMAT (I6,16)
44  DO 17 I=1,POINTA
45  READ(IRD,16) VALI, TA(I)
46  16 FORMAT (F5,4,F7,2)
47  17 CONTINUE
48  DO 19 I=1,POINTT
49  READ (IRD,18) VT(I),TT(I)
50  18 FORMAT (F5,4,F7,2)
51  19 CONTINUE
52  READ (IRD,30) DEPS
53  30 FORMAT (I6)
54  READ(IRD,32) (DEPN(K),VESSNO(K),SLTIM(K),DEPTIM(K),PRIORITY(K),
55  1 TRUCKS(K),K=1,DEPS)
56  32 FORMAT (I6,16,F7,2,F7,2,I6,16)

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C PROGRAM SEGMENT NO 3 - SIMULATE AUTO AND TRUCK TRAFFIC ON DESIGN DAY

C WRITE TITLES FOR TABLE OF SIMULATED TRAFFIC FLOWS

52 WRITE (IWR,100)

53 100 FORMAT (I11,50H SUMMARY OF SIMULATED TRAFFIC VOLUMES ON DESIGN DAY)

54 WRITE (IWR,10)

55 110 FORMAT (I11,50H SUMMARY OF AUTOS,10X,12HNO OF TRUCKS)

56 WRITE (IWR,15)

57 115 FORMAT (I11,50H SUMMARY OF AUTOS,10X,12HNO OF TRUCKS)

58 TSIM = 0

59 I=1

60 INT = 1

61 NPOINT=1

62 NPOINA = 1

63 VINTT = STVOLT

64 VINTA = STVOLA

65 JA = NPOINA + 1

66 JT = NPOINT + 1

67 120 CONTINUE

68 IF (TSIM.LE.TA(JA)) GO TO 125

69 NPOINA = NPOINA + 1

70 JA = JA + 1

71 125 CONTINUE

72 VSIMA(I) = ((VA(JA) - VA(NPOINA)) / (TA(JA) - TA(NPOINA)))

73 VSIMT(I) = ((VT(JT) - VT(NPOINT)) / (TT(JT) - TT(NPOINT)))

74 IF (TSIM.LE.TT(JT)) GO TO 127

75 NPOINT = NPOINT + 1

76 JT = JT + 1

77 127 CONTINUE

78 VSIMT(I) = ((VT(JT) - VT(NPOINT)) / (TT(JT) - TT(NPOINT)))

79 1* SINT = DAYFLT

80 VINTA = VINTA + VSIMA(I)

81 VINTT = VINTT + VSIMT(I)

82 IF (INT.LT.21) GO TO 150

83 WRITE (IWR,130) TSIM,VINTA,VINTT

84 130 FORMAT (I10,2X,F5.2,14X,F6.2,19X,F6.2)

85 INT = 1

86 VINTA = 0

87 VINTT = 0

88 150 CONTINUE

89 I=I+1

90 INT = INT + 1

91 TSIM = TSIM + SINT

92 IF (TSIM.LE.FENDIT) GO TO 120

93 PROGRAM SEGMENT NO 4 - GENERATE VEHICLES, MAX Q LENGTH, CHECK IF

94 LOADING UNDERWAY, SEGREGATE BY LOADING PRIORITY

95 WRITE (IWR,197)

96 197 FORMAT (I11,50H SUMMARY OF QUEUE LENGTH IN MARSHALLING AREAS ON DESI

97 GN DAY)

98 WRITE (IWR,198)

99 198 FORMAT (I11,50H SUMMARY OF AUTOS,10X,12HNO OF TRUCKS)

100 WRITE (IWR,199)

101 199 FORMAT (I11,50H SUMMARY OF AUTOS,10X,12HNO OF TRUCKS)

102 INITIALIZE SIMULATION TIME, VOLUMES, QUEUE LENGTHS ETC

103 TSIM = 0

104 TVOLA = STVOLA

105 TVOLT = STVOLT

106 QUEUA = STVOLA

107 QUEUET = STVOLT

108 LOADT = 0

109 LOADA = 0

104	LOADAE = 0
105	I = 1
106	L = 0
107	INTER = 1
108	M = 1
109	200 CONTINUE
110	C CHECK TO SEE IF THE SIMULATION IS COMPLETE
111	IF(TSIM.GT.EQ.1) GO TO 200
112	IF(TSIM.GT.EQ.1) GO TO 200
113	IF(TSIM.GT.EQ.1) GO TO 200
114	IF(TSIM.GT.EQ.1) GO TO 200
115	IF(TSIM.GT.EQ.1) GO TO 200
116	IF(TSIM.GT.EQ.1) GO TO 200
117	IF(TSIM.GT.EQ.1) GO TO 200
118	IF(TSIM.GT.EQ.1) GO TO 200
119	IF(TSIM.GT.EQ.1) GO TO 200
120	IF(TSIM.GT.EQ.1) GO TO 200
121	IF(TSIM.GT.EQ.1) GO TO 200
122	IF(TSIM.GT.EQ.1) GO TO 200
123	IF(TSIM.GT.EQ.1) GO TO 200
124	IF(TSIM.GT.EQ.1) GO TO 200
125	IF(TSIM.GT.EQ.1) GO TO 200
126	IF(TSIM.GT.EQ.1) GO TO 200
127	IF(TSIM.GT.EQ.1) GO TO 200
128	IF(TSIM.GT.EQ.1) GO TO 200
129	IF(TSIM.GT.EQ.1) GO TO 200
130	IF(TSIM.GT.EQ.1) GO TO 200
131	IF(TSIM.GT.EQ.1) GO TO 200
132	IF(TSIM.GT.EQ.1) GO TO 200
133	IF(TSIM.GT.EQ.1) GO TO 200
134	IF(TSIM.GT.EQ.1) GO TO 200
135	IF(TSIM.GT.EQ.1) GO TO 200
136	IF(TSIM.GT.EQ.1) GO TO 200
137	IF(TSIM.GT.EQ.1) GO TO 200
138	IF(TSIM.GT.EQ.1) GO TO 200
139	IF(TSIM.GT.EQ.1) GO TO 200
140	IF(TSIM.GT.EQ.1) GO TO 200
141	IF(TSIM.GT.EQ.1) GO TO 200
142	IF(TSIM.GT.EQ.1) GO TO 200
143	IF(TSIM.GT.EQ.1) GO TO 200
144	IF(TSIM.GT.EQ.1) GO TO 200
145	IF(TSIM.GT.EQ.1) GO TO 200
146	IF(TSIM.GT.EQ.1) GO TO 200
147	IF(TSIM.GT.EQ.1) GO TO 200
148	IF(TSIM.GT.EQ.1) GO TO 200

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149 C POSS = ((TRKCAP(J) + CARS(K)) / (DEPTIN(K) - SETIN(K))) * SINY
150 C CHECK TO SEE IF THERE IS ANY TRUCK CAPACITY LEFT IN THE SHIP.
151 C IF (LOADT * GE. TRKCAP(J)) GO TO 262
152 C CHECK TO SEE IF THERE ARE ANY TRUCKS IN THE QUEUE
153 C IF (TVOLT * GE. 1.0) GO TO 255
154 C LOAD 1 INTERVALS WORTH OF TRUCKS (MAXIMUM) WITHOUT OVERLOADING
155 C THE SHIP DECREASE D LENGTH
156 C 255 IF (TVOLT * GT. POSS) GO TO 258
157 C IF (LOADT + TVOLT * GT. TRKCAP(J)) GO TO 256
158 C GO TO 257
159 C 256 REMCAP = TRKCAP(J) - LOADT
160 C LOADT = LOADT + REMCAP
161 C TVOLT = TVOLT - REMCAP
162 C REMCAP = 0.0
163 C GO TO 280
164 C 257 LOADT = LOADT + TVOLT
165 C TVOLT = 0.0
166 C GO TO 280
167 C 258 IF (LOADT + POSS) * GT. TRKCAP(J)) GO TO 259
168 C GO TO 260
169 C 259 REMCAP = TRKCAP(J) - LOADT
170 C LOADT = LOADT + REMCAP
171 C TVOLT = TVOLT - REMCAP
172 C REMCAP = 0.0
173 C GO TO 290
174 C 260 LOADT = LOADT + POSS
175 C TVOLT = TVOLT - POSS
176 C GO TO 280
177 C CALCULATE REMAINING CAPACITY AFTER TRUCKS LOADED (CCAP)
178 C CCAP = CARCAP(J) - (LOADT + CONVRT)
179 C IF (CCAP * LT. 0) CCAP = 0
180 C CHECK TO SEE IF THERE IS ANY AUTO CAPACITY LEFT IN THE SHIP
181 C IF (LOADA * GE. CCAP) GO TO 280
182 C CHECK TO SEE IF THERE ARE ANY CARS IN THE QUEUE
183 C IF (TVOLA * GE. 1.0) GO TO 265
184 C GO TO 283
185 C 265 CONTINUE
186 C DECREASE THE NO OF AUTOS IN THE JO BY NO OF AUTOS TO BE LOADED (TO
187 C A VALUE POSS. AND WITHOUT GOING OVER CAP OF THE SHIP)
188 C IF (TVOLA * GT. POSS) GO TO 268
189 C IF (TVOLA * GT. CCAP) GO TO 266
190 C GO TO 267
191 C 266 REMCAP = CCAP - LOADA
192 C LOADA = LOADA + REMCAP
193 C TVOLA = TVOLA - REMCAP
194 C REMCAP = 0.0
195 C GO TO 280
196 C 267 LOADA = LOADA + TVOLA
197 C TVOLA = 0.0
198 C GO TO 280
199 C 268 IF (LOADA + POSS) * GT. CCAP) GO TO 269
200 C GO TO 270
201 C 269 REMCAP = CCAP - LOADA
202 C LOADA = LOADA + REMCAP
203 C TVOLA = TVOLA - REMCAP
204 C REMCAP = 0.0
205 C GO TO 280
206 C 270 LOADA = LOADA + POSS
207 C TVOLA = TVOLA - POSS

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248 REMCAP = 0.0
249 GO TO 380
250 LOADA = LCADA + TVOLA
251 TVOLA = 0.0
252 GO TO 380
253 IF (LOADA + POSS) .GT. CARS(K) GO TO 359
254 GO TO 360
255 REMCAP = CARS(K) - LOADA
256 LOADA = LOADA + REMCAP
257 TVOLA = REMCAP
258 REMCAP = 0.0
259 GO TO 380
260 LOADA = LOADA + POSS
261 TVOLA = TVOLA - POSS
262 GO TO 380
263 CONTINUE
C IF NO CARS IN QUEUE BUT STILL CAPACITY IN SHIP ALLOCATE ONE INTERVAL
C WORTH OF CAPACITY TO TRUCKS (ADDITIONAL TO ORIGINAL ALLOCATION)
C BUT DO NOT EXCEED TRUCK CAPACITY OF SHIP
IF (TRUCKS(K) + POSS) .GE. TRKCAP(J) GO TO 380
TRUCKS(K) = TRUCKS(K) + POSS
CARS(K) = CARS(K) - (POSS + CONVERT)
IF (INTER - LT + 21) GO TO 390
IF (TVOLA - LT + 21) TVOLA = 0
IF (TVOLA - LT + 21) TVOLT = 0
WRITE (11R,385) TSIM,TVOLA,TVOLT
385 FORMAT (1H0,2A,F5.2,12X,F8.2,15X,F8.2)
390 INTER = 1
390 CONTINUE
TSIM = TSIM + SINT
I = I + 1
INTER = INTER + 1
L = L + 1
GO TO 200
C 400 CONTINUE SEGMENT NO 7 - PRIORITY = 3 (FIFO)
J = VESSNO (K)
CALCULATE MAX VEH THAT CAN BE LOADED IN ONE INTERVAL
NOTE: ALL VEHICLES TO BE MEASURED IN AUTO-EQUIVALENTS
RATIO = DAYFLA / (DAYFLA + (DAYFLT + CONVERT))
POSS = (RATIO * CARCAP(J) + ((1.0-RATIO) * CARCAP(J)/CONVERT)) /
1 (DETERM(K) - SINT(K)) * SINT
CHECK TO SEE IF THERE IS ANY CAPACITY LEFT IN THE SHIP
410 IF (LOADA + GE * CARCAP(J)) GO TO 480
CHECK TO SEE IF THERE ARE ANY CARS IN THE QUEUE
420 IF (TVOLA + GE * 1.0) GO TO 455
GO TO 462
C DECREASE NO OF CARS IN Q BY NO LOADED AND LOAD CARS TO MAX OF AVPOSS
455 IF (TVOLA + GE * POSS) GO TO 458
IF (LOADA + TVOLA) .GT. CARCAP(J) GO TO 456
GO TO 457
456 REMCAP = CARCAP(J) - LCADA
LOADA = LOADA + REMCAP
LOADA = LOADA + REMCAP
TVOLA = TVOLA - REMCAP
REMCAP = 0.0
GO TO 450
457 LOADA = LOADA + TVOLA
LOADA = LOADA + TVOLA

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307 TVOLA = P*400
308 GO TO 460
309 IF (TVOLA > 0) THEN
310   RENCAP = CARCAP(J) - LOADAE
311   LOADAE = LOADAE + RENCAP
312   TVOLA = TVOLA - RENCAP
313   RENCAP = 0
314 GO TO 460
315
316
317 LOADAE = LOADAE + POSS
318 TVOLA = TVOLA + POSS
319 GO TO 460
320
321
322 CHECK TO SEE IF THERE IS ANY CAPACITY LEFT IN SHIP
323 CHECK TO SEE IF THERE ARE ANY TRUCKS IN THE QUEUE
324 IF (TVOLA > 0) THEN GO TO 460
325 GO TO 460
326
327
328 THE NO OF TRUCKS IN THE Q BY THE NO TO BE LOADED AND LOAD
329 SHIP TO A MAX OF POSS AND WITHOUT OVERLOADING THE SHIP
330 IF (TVOLA > 0) THEN GO TO 460
331 IF (TVOLA > 0) THEN GO TO 460
332 IF (TVOLA > 0) THEN GO TO 460
333 IF (TVOLA > 0) THEN GO TO 460
334 IF (TVOLA > 0) THEN GO TO 460
335 IF (TVOLA > 0) THEN GO TO 460
336 IF (TVOLA > 0) THEN GO TO 460
337 IF (TVOLA > 0) THEN GO TO 460
338 IF (TVOLA > 0) THEN GO TO 460
339 IF (TVOLA > 0) THEN GO TO 460
340 IF (TVOLA > 0) THEN GO TO 460
341 IF (TVOLA > 0) THEN GO TO 460
342 IF (TVOLA > 0) THEN GO TO 460
343 IF (TVOLA > 0) THEN GO TO 460
344 IF (TVOLA > 0) THEN GO TO 460
345 IF (TVOLA > 0) THEN GO TO 460
346 IF (TVOLA > 0) THEN GO TO 460
347 IF (TVOLA > 0) THEN GO TO 460
348 IF (TVOLA > 0) THEN GO TO 460
349 IF (TVOLA > 0) THEN GO TO 460
350 IF (TVOLA > 0) THEN GO TO 460
351 IF (TVOLA > 0) THEN GO TO 460

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[illegible]

SUMMARY OF SIMULATED TRAFFIC VOLUMES ON DESIGN DAY

INTERVAL ENDING AT	NO OF AUTOS	NO OF TRUCKS
0.20	0.00	0.00
0.40	0.00	0.00
0.60	0.00	0.00
0.80	0.00	0.00
1.00	0.00	0.00
1.20	0.00	0.00
1.40	0.00	0.00
1.60	0.00	0.00
1.80	0.00	0.00
2.00	0.00	0.00
2.20	0.00	0.00
2.40	0.00	0.00
2.60	0.00	0.00
2.80	0.00	0.00
3.00	0.00	0.00
3.20	0.00	0.00
3.40	0.00	0.00
3.60	0.00	0.00
3.80	0.00	0.00
4.00	0.00	0.00
4.20	0.80	0.04
4.40	0.80	0.04
4.60	1.20	0.06
4.80	1.59	0.08
5.00	1.59	0.08
5.20	2.39	0.11
5.40	2.39	0.11

5.60	3.19	0.15
5.60	3.98	0.19
6.00	3.98	0.19
6.20	6.37	0.30
6.40	6.37	0.30
6.60	7.17	0.34
6.80	7.97	0.38
7.00	7.97	0.38
7.20	10.36	0.49
7.40	10.36	0.49
7.60	11.55	0.55
7.80	12.75	0.60
8.00	12.75	0.60
8.20	14.34	0.68
8.40	14.34	0.68
8.60	15.14	0.71
8.80	15.94	0.75
9.00	15.94	0.75
9.20	19.12	0.90
9.40	19.12	0.90
9.60	20.32	0.96
9.80	21.51	1.02
10.00	21.51	1.02
10.20	23.90	1.13
10.40	23.90	1.13
10.60	25.50	1.20
10.80	27.09	1.28
11.00	27.09	1.28
11.20	30.28	1.43
11.40	30.28	1.43

11.60	32.27	1.52
11.80	34.26	1.62
12.00	34.26	1.62
12.20	38.25	1.80
12.40	38.25	1.80
12.60	39.04	1.84
12.80	39.84	1.88
13.00	39.84	1.88
13.20	39.84	1.88
13.40	39.84	1.88
13.60	41.04	1.94
13.80	42.23	1.99
14.00	42.23	1.99
14.20	39.84	1.88
14.40	39.84	1.88
14.60	39.84	1.88
14.80	39.84	1.88
15.00	39.84	1.88
15.20	38.25	1.80
15.40	38.25	1.80
15.60	36.25	1.71
15.80	34.26	1.62
16.00	34.26	1.62
16.20	31.08	1.47
16.40	31.08	1.47
16.60	29.48	1.39
16.80	27.89	1.32
17.00	27.89	1.32
17.20	24.70	1.17
17.40	24.70	1.17

17.60	23.51	1.11
17.80	22.31	1.05
18.00	22.31	1.05
18.20	20.72	0.98
18.40	20.72	0.98
18.60	19.92	0.94
18.80	19.12	0.90
19.00	19.12	0.90
19.20	17.53	0.83
19.40	17.53	0.83
19.60	16.73	0.79
19.80	15.94	0.75
20.00	15.94	0.75
20.20	15.14	0.71
20.40	15.14	0.71
20.60	14.34	0.68
20.80	13.55	0.64
21.00	13.55	0.64
21.20	11.16	0.53
21.40	11.16	0.53
21.60	10.36	0.49
21.80	9.56	0.45
22.00	9.56	0.45
22.20	7.97	0.38
22.40	7.97	0.38
22.60	7.17	0.34
22.80	6.37	0.30
23.00	6.37	0.30
23.19	4.78	0.23
23.39	4.78	0.23

23.59	4.36	6.21
23.79	3.98	0.19
23.99	3.98	0.19

SUMMARY OF QUEUE LENGTH IN MARSHALLING AREAS ON DESIGN DAY

INTERVAL ENDING AT	NO OF AUTOS	NO OF TRUCKS
0.20	0.00	0.00
0.40	0.00	0.00
0.60	0.00	0.00
0.80	0.00	0.00
1.00	0.00	0.00
1.20	0.00	0.00
1.40	0.00	0.00
1.60	0.00	0.00
1.80	0.00	0.00
2.00	0.00	0.00
2.20	0.00	0.00
2.40	0.00	0.00
2.60	0.00	0.00
2.80	0.00	0.00
3.00	0.00	0.00
3.20	0.00	0.00
3.40	0.00	0.00
3.60	0.00	0.00
3.80	0.00	0.00
4.00	0.00	0.00
4.20	0.00	0.04
4.40	1.59	0.08
4.60	2.79	0.13
4.80	4.38	0.21
5.00	5.98	0.28
5.20	6.37	0.39
5.40	10.76	0.51

5.60	13.94	0.66
5.80	17.93	0.85
6.00	0.40	0.03
6.20	6.77	0.33
6.40	0.00	0.63
6.60	4.62	0.97
6.80	12.59	1.34
7.00	20.56	1.72
7.20	30.92	2.21
7.40	1.73	2.70
7.60	6.89	0.50
7.80	19.64	1.10
8.00	0.64	0.24
8.20	14.98	0.92
8.40	20.37	0.31
8.60	11.20	0.00
8.80	1.54	0.75
9.00	0.69	0.49
9.20	19.61	1.39
9.40	38.93	2.29
9.60	59.25	3.25
9.80	5.38	0.81
10.00	26.89	1.83
10.20	50.80	2.96
10.40	74.70	4.08
10.60	90.53	0.45
10.80	49.95	0.73
11.00	77.05	2.01
11.20	40.32	0.43
11.40	22.71	1.86

11.60	54.98	3.38
11.80	89.24	5.00
12.00	123.50	6.61
12.20	108.58	2.59
12.40	122.66	4.39
12.60	161.71	6.23
12.80	201.55	8.11
13.00	118.55	1.99
13.20	158.39	3.87
13.40	198.23	5.75
13.60	239.27	7.69
13.80	281.49	9.68
14.00	246.39	5.84
14.20	286.23	7.72
14.40	314.90	1.60
14.60	243.07	3.48
14.80	282.91	5.36
15.00	322.75	7.24
15.20	360.99	9.05
15.40	370.23	5.02
15.60	358.15	6.73
15.80	392.40	8.34
16.00	303.83	1.96
16.20	334.90	3.43
16.40	365.98	4.89
16.60	395.46	6.29
16.80	423.34	7.60
17.00	373.89	3.08
17.20	398.58	4.25
17.40	423.28	5.42

17.60	446.79	6.52
17.80	346.26	0.84
18.00	368.56	1.90
18.20	389.28	2.87
18.40	376.15	0.34
18.60	347.73	1.28
18.80	366.95	2.18
19.00	385.98	3.09
19.20	353.50	0.25
19.40	329.36	1.08
19.60	346.09	1.86
19.80	362.03	2.62
20.00	377.96	3.37
20.20	372.93	0.42
20.40	378.90	1.13
20.60	393.24	1.81
20.80	406.78	2.45
21.00	282.72	3.09
21.20	292.88	3.61
21.40	305.03	4.14
21.60	300.55	4.63
21.80	235.96	5.08
22.00	245.52	5.53
22.20	253.49	5.91
22.40	238.52	6.28
22.60	131.02	6.62
22.80	137.40	6.92
23.00	143.77	7.22
23.19	148.55	7.45
23.39	113.78	7.67

SUMMARY OF VEHICLES CARRIED ON EACH DEPARTURE

DEPARTURE NO	DEPARTURE TIME	VESSEL NO	TRUCKS CARRIED	AUTOS CARRIED
1	6.00	1	3.	18.
2	6.50	2	0.	14.
3	7.50	3	8.	38.
4	8.00	4	4.	29.
5	9.00	1	3.	60.
6	9.75	2	3.	74.
7	10.75	3	5.	64.
8	11.25	4	3.	113.
9	12.25	1	5.	64.
10	13.00	2	8.	121.
11	14.00	3	5.	64.
12	14.50	4	8.	121.
13	15.50	1	5.	64.
14	16.00	2	8.	121.
15	17.00	3	5.	64.
16	17.75	4	6.	121.
17	18.50	1	3.	68.
18	19.25	2	3.	88.
19	20.25	3	2.	16.
20	21.00	4	0.	132.
21	21.75	1	0.	72.
22	22.50	2	0.	132.
23	23.50	3	0.	72.

MAXIMUM NO OF AUTOS IN MARSHALLING AREA IS 452. AUTOS AT 17.65 HOURS

MAXIMUM NO OF TRUCKS IN MARSHALLING AREA IS 10. TRUCKS AT 15.33 HOURS

REQUIRED SIZE OF MARSHALLING AREA FOR QUEUED UP VEHICLES IS 9660. LINEAR FEET OF PARKING LANE

CORE USAGE OBJECT CODE= 17144 BYTES,ARRAY AREA= 23960 BYTES,TOTAL AREA AVAILABLE= 51200 BYTES
DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0, NUMBER OF EXTENSIONS= 0
COMPILE TIME= 2.08 SEC,EXECUTION TIME= 5.51 SEC. 14.25.07 WEDNESDAY 2 NOV 77 WATPIV JAN 1976 VILS

CsSTOP

SIMPLIFIED
FLOWCHART FOR
CALCULATION OF
SIZE OF MARSHALLING
AREA

END

06 0 79

FIN