UNIVERSITY OF ALBERTA

# MULTICRITERIA EVALUATION OF RAIL TRANSIT CONNECTIONS TO AIRPORTS

BY

©

SRINIVASA R. MANDALAPU

A thesis submitted to
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# DEDICATION

To my loving parents and wife

## ABSTRACT

MULTICRITERIA EVALUATION OF RAIL TRANSIT CONNECTIONS TO AIRPORTS

By

Srinivasa R. Mandalapu

As air travel demand increases, the road access systems to many airports become congested with the road based modes used by travelers. Airport access times from city centres are increasing, particularly during peak hours. For some airports it may not be possible to expand the road access system and transit options are being considered. Fixed rail service is getting increased attention as the airport has become one of the major trip generators in the urban area. In the planning of such services, an evaluation of various ground access alternatives with respect to critical criteria would be of help before investing on such capital intensive projects.

A procedure for multicriteria analysis of alternatives is presented to examine the attractiveness of three concepts; (1) an exclusive rail link from the city centre, (2) an extension of existing rail links to the airport, and (3) an airport Automated People Mover or Shuttle Bus connection with the nearby rail station. The analysis involves a hierarchical analysis proposed by T. Saaty using fuzzy ratings for non-quantifiable criteria such as reliability, accessibility, and baggage convenience. Quantifiable criteria such as travel time and cost, are determined using computer models developed for Rail Rapid Transit, Automated People Mover, and Shuttle Bus

systems The multicriteria evaluation procedure is translated into a computer program that determines the relative attractiveness of alternatives.

Minimum passenger demands for which fixed rail service to airports become attractive are identified for three combinations of airport passenger characteristics; more business passengers, equal number of business passengers and vacationers, and more vacationers. A detailed examination of the influence of baggage handling facilities is also included. The results are presented in graphical form to enable planners to use the findings as guidelines during the conceptual phase of planning. The approach is applied to three case studies to demonstrate the use of the framework for specific applications.

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I would also like to thank all my colleague students for creating a joyful working atmosphere. Finally, my sincere thanks are due to my dear wife, Padma, who had supported me during my studies.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Problem

During the postwar period, air traffic has increased at a rate beyond the expectations of forecasters (Ashford 1985). This growth has been attributed mainly to the rapid increase of population, increase in the industrialization of developing countries, changes in the industrial structure in developed countries, worldwide urbanization, and technological changes. The growth of passenger and freight traffic between 1982 and 1991 are presented in Figure 1.1 and Figure 1.2 ("World Passenger" 1992). Until 1990 there was an average annual increase of 6.1 percent in passenger-km and 6.3 percent in tonne-km. Due to world wide recession there was a drop of 3.7 percent in passenger - km and 3.0 percent in tonne-km during 1991. However, it is expected that air traffic will grow in future with the recovery from recession. Douglas Aircraft Company forecasts world air traffic would increase by about 6.5 percent during the period 1989 - 2010 and over 7 percent during the 1999 - 2010 period (Ashford 1992).

The growth in air traffic has lead to capacity problems on the ground access system at many airports. The airport ground access system (Figure 1.3) is an important component of the transportation system of a metropolitan area as it connects the origin and destination of any airport related trip (An airport related trip is trip made by an air passenger, an airport employee, a visitor, a well wisher, or a cargo receiver or dispatcher). The purpose of a good access system is to provide safe, efficient, economical, fast, convenient, and reliable movement of people, baggage, and cargo. There are several modes operating on the system, and each has its own advantages and disadvantages.

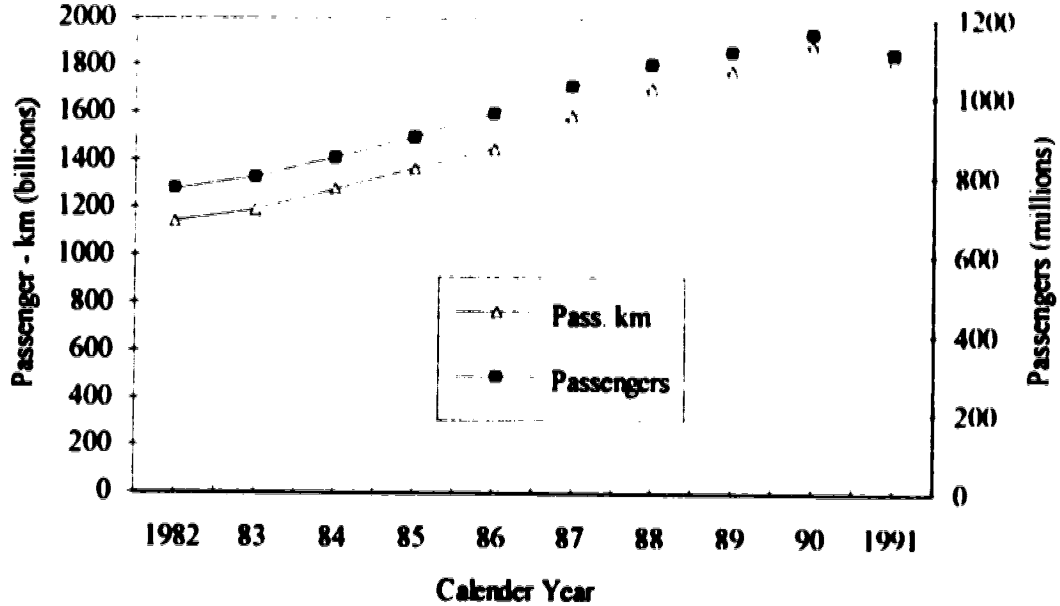



Figure 1.1: World Total International and Domestic Air Passenger Traffic, 1982-1991

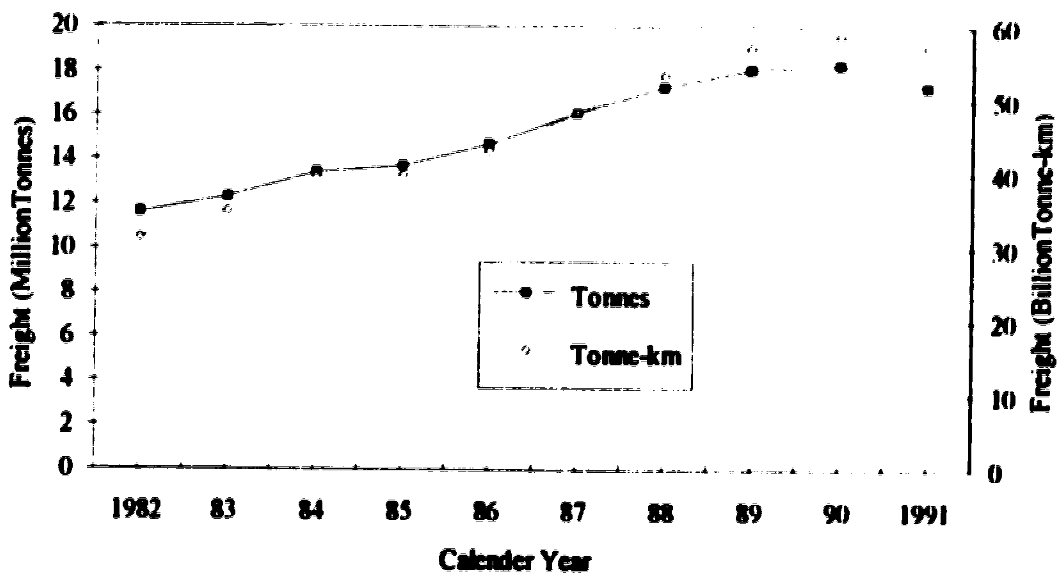



Figure 1.2: World Total International and Domestic Air Freight Revenue Traffic, 1982-1991 (Adapted from "World Passenger" 1992).

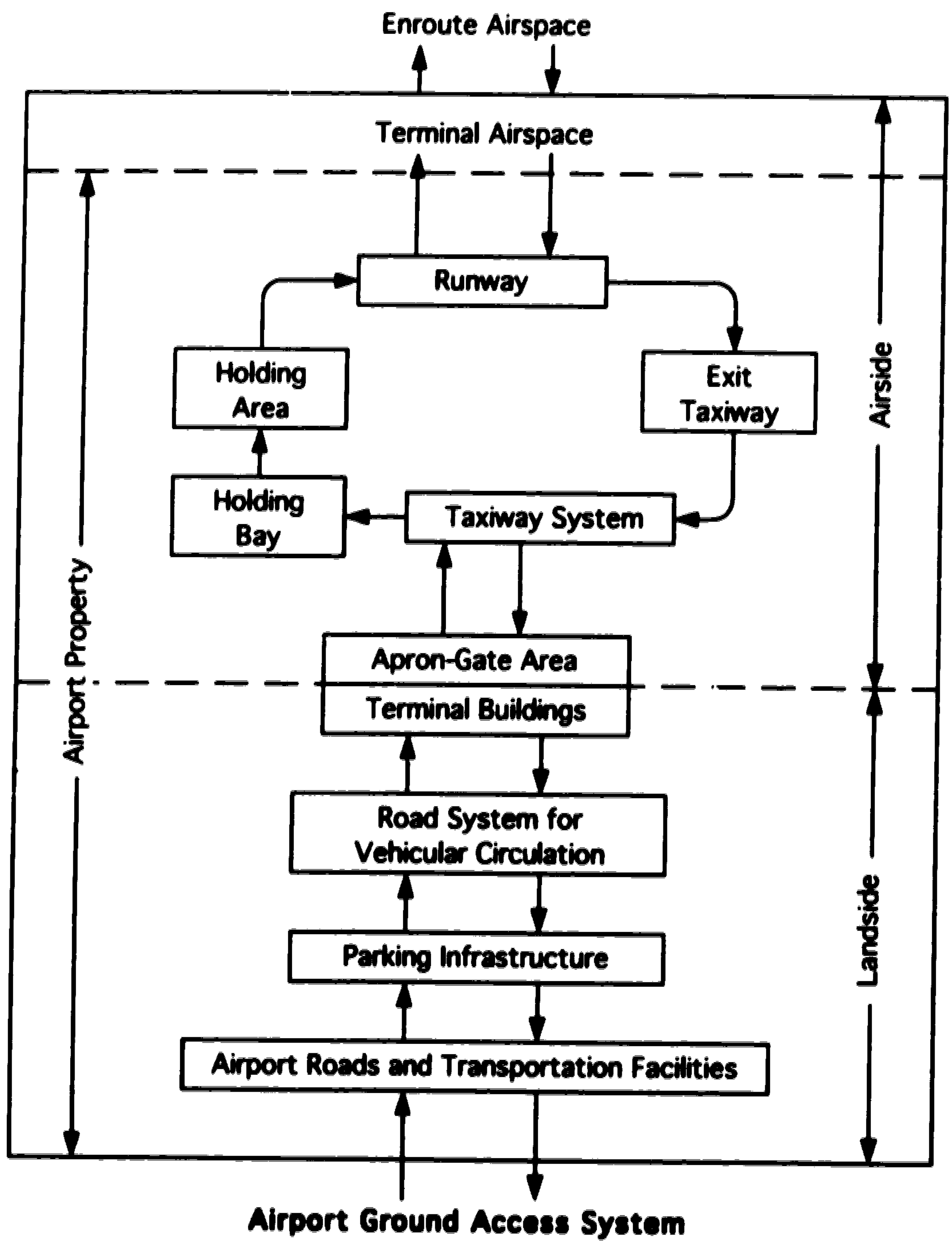



Figure 1.3: Airport Ground Access System in Relation to Landside and Airside Systems (Adapted from Wells 1992)

The United States Federal Aviation Administration reported that out of 3,219 airports in the United States, 40% are facing capacity problems and 60% of these airports have landside constraints (Lemer 1986). These problems have forced airport operators to expand terminal facilities and provide faster passenger processing systems. But these improvements have not been accompanied by corresponding improvements to the ground access systems. Since ground access is an important part of landside capacity, it has become the limiting factor in an airport's ability to handle passengers at many airports. Because of the unavailability of land and environmental restrictions, expansion of ground access systems and related facilities is almost impossible at most airports.

Apart from the ground access facilities within the vicinity of the airport, the ground access system from the city to the airport also faces capacity problems. Air travel demand typically experiences morning and evening peaks and access travel consequently exhibits the same pattern. Because airport related traffic has to share facilities with the non-airport traffic, the situation is even worse as the peaking airport traffic often overlaps with the peak urban travel periods as shown in Figure 1.4 (Ellis 1974). Expansion of the facilities is often prohibitively expensive and is opposed for environmental reasons in many developed urban areas.

Congestion on highways in the vicinity of many airports is expected to be severe in the future. Current capacities on highways connecting airports will not be sufficient to meet forecasted growth in airport usage (Cook 1970). Apart from expansion or improvement of the road network leading to airport, most effort to facilitate airport ground access has focused on substitutes to the automobile. Although some work was done on the airport segment of the system, limited research work has been published on the off airport segment of the access system.

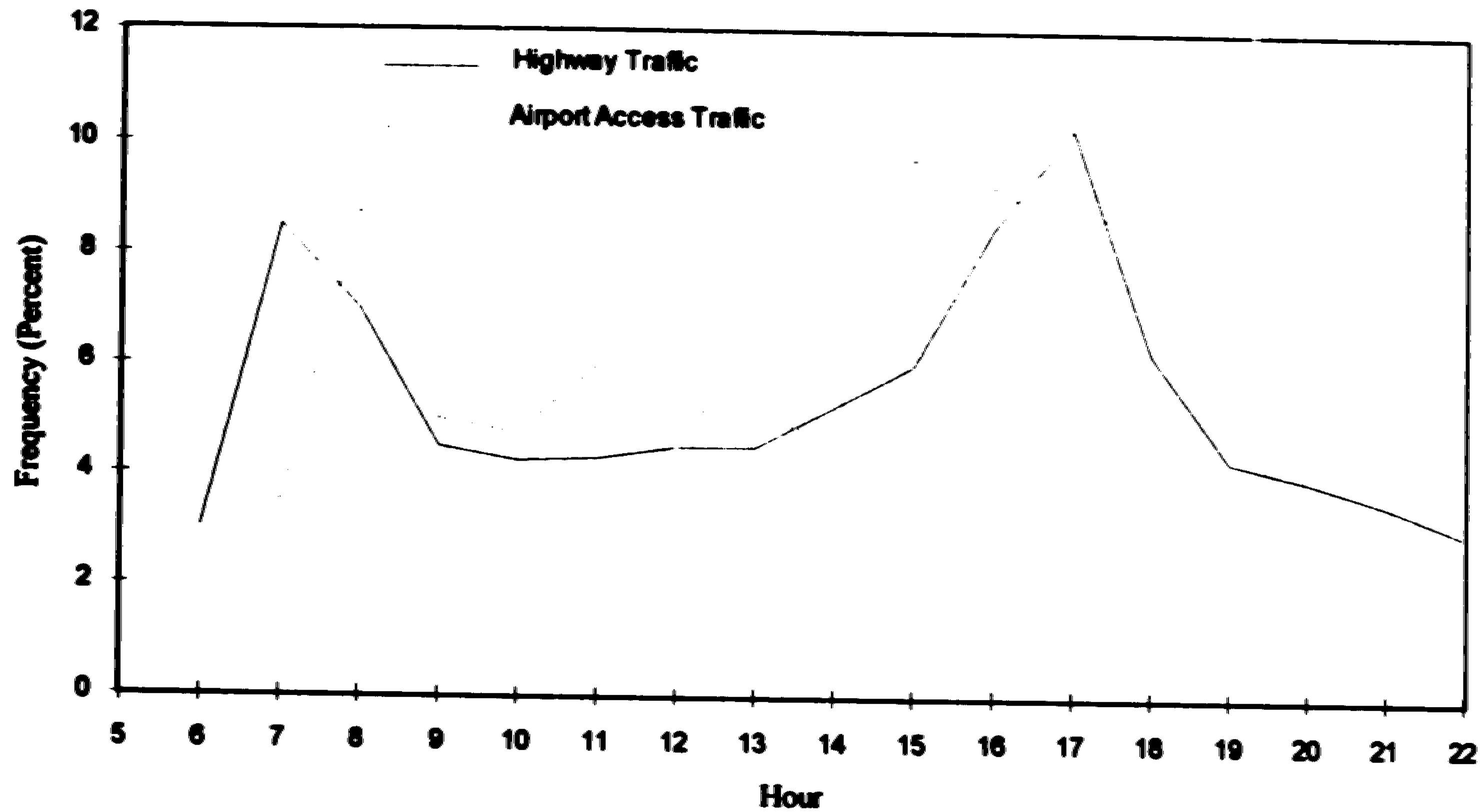



Figure 1.4: Temporal Distribution of Airport Access Travel to LaGuardia Airport and Highway Traffic in New York Area (Adapted from Ellis 1974)

Alternatives such as limited access busways, fixed guideway systems, and helicopters have been proposed to reduce the congestion problem. A solution that has been advocated by many planners is some form of fixed rail service. Fixed Rail Service can be identified as the service provided by Rail Rapid Transit (RRT), Light Rail Transit (LRT), Commuter Rail, and Intercity Rail. Rail technology is a proven one and expertise in the area is available around the world. Because these services do not experience the delays due to the surface road transportation system, air travelers have a reliable service that does not add to road traffic congestion and it relieves the congestion as some of the travellers that use automobiles may transfer to this service. Some of the options such as short spurs to existing systems could be relatively inexpensive. However, others such as exclusive systems which could provide non-stop express service between the CBD and the airport on an exclusive right-of-way would be very expensive.

Although some studies on these systems were conducted, they are site specific and very little can be used for general planning. There are several basic questions that can be addressed for planning of fixed rail systems. These questions include:

1. What user characteristics influence the mode choice and to what extent?
2. What attributes of different modes attract passengers?
3. What ranges of demand make different concepts of fixed rail service viable alternatives to other conventional modes?
4. Can general criteria, guidelines, or methods be established which will assist planners in planning such services?

## 1.2 Airport Access Planning Process

The airport access system components and requirements for facilities are illustrated in Figure 1.5. The facilities required at off site terminals and terminals at the airport are shown for the conventional modes: auto, taxi, bus, limousine, and fixed rail service and for non-conventional modes: VTOL, STOL, monorail, and others. At large airports, with large number of originating and terminating passengers, access by auto and limousine requires more space for internal circulation and parking. Yielding to these requirements is likely to be expensive to the community. At such airports higher capacity systems, such as conventional rail or rail rapid transit may be attractive.

Careful planning is required for the terminal facilities and rights-of-way on the airport. Involvement of airport planners in the aspects of planning and design of facilities outside the airport boundary should be initiated, although the airport may not be financially involved in these areas.

The need for various components of the system can be accomplished by a systematic approach. Figure 1.6 presents a simplified procedure to determine the needs of an airport access system. Demand estimates for passengers, employees, services, visitors, and freight are determined from available origin-destination data. A special survey has to be carried out for a reliable origin-destination data. This approach is useful in the preliminary planning process.

The planning of the system must be done along with the terminal planning in particular and airport in general. The principal parties involved in this process will include the airport authority, the consultants, the airlines, rental car agencies, taxi operators, city, town, or county administration, and other transport operators.

The initial process involves the approximating the requirements and alternatives for location of facilities and alternative route locations. For these plans, anticipated capital investments, operating and maintenance costs and other requirements for implementation, such as environmental concerns, for the alternatives will be assessed.

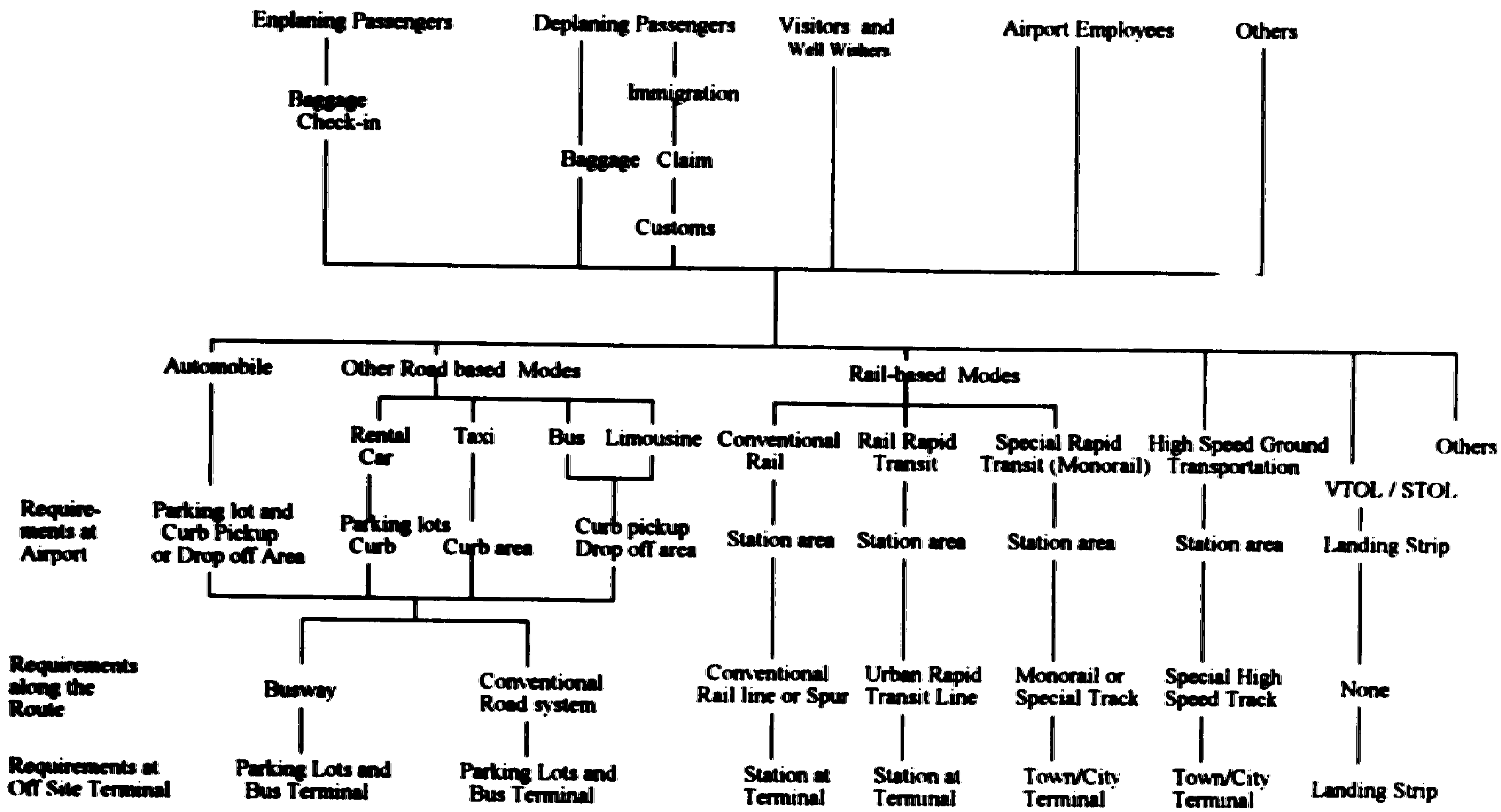



**Figure 1.5 : Airport Access System and Facilities Required**

(Adapted from Ashford 1992)

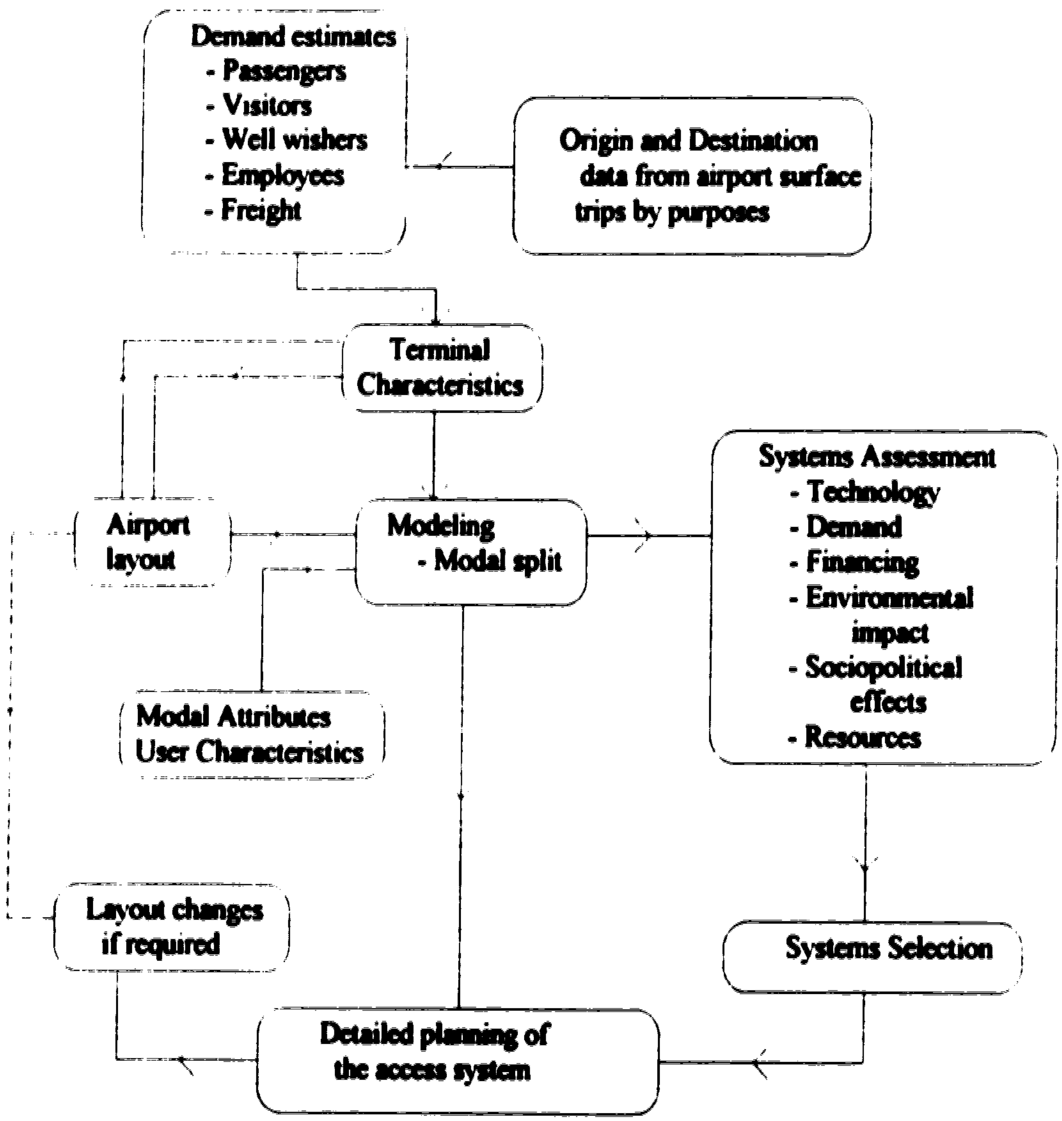



Figure 1.6 : Planning of Ground Access System

The next step is to review these plans thoroughly with the parties involved and evaluate the alternatives. The best alternative will be chosen for detailed design. The detailed designs for both the facilities at the airport and along the route to the airport of this alternative will be prepared. The project is then ready for implementation by preparing construction documents, awarding contracts, and building the system. In the general planning process, the work presented in this thesis would be useful in the process of evaluation of alternatives.

## 1.3 Objectives of Research

Many airports will face severe ground access problems if the present trend of growth of air traffic continues. Although fixed rail service is one of the potential solutions, it is not a short term solution. High costs are involved in the construction of fixed guideway systems and at poor patronage the maintenance costs exceed the revenues. A careful examination of potential passenger demand is absolutely necessary before implementing such projects. Hence, there is a need for planning guidelines and analytical tools to assist in the planning of fixed rail service to airports.

The purpose of this study is to develop a general planning technique to evaluate the potential of rail links for an airport. Specifically the objectives are:

1. to prepare an inventory of fixed rail systems that serve or are planned to serve airports,
2. to identify the characteristics of these systems,
3. to develop a technique to assess the potential for fixed rail service to an airport,
4. to study the influence of the attributes of fixed rail service on the attractiveness, and
5. to identify techniques of achieving higher patronage.

## 1.4 Scope of Research

The scope of this research is limited to air carrier airports, which handle airlines of all sizes carrying passengers and freight. The results of this research are applicable to the airports having an acivity of one million annual passengers and beyond. General aviation airports and military airports are not considered since they are not the regular generators of air passenger trips to and from city centres.

This research considered only fixed rail concepts between airports and city centres since many cities have some form of urban transportation network and fixed rail links connecting airports can easily be tied into the network at city centres. Regional rail connections to airports are not considered since the rail alternatives to airports are examined with North American perspective where regional rail networks are limited.

The distances examined are from 10 km to 50 km for new fixed rail links between airports and city centres, from 2.5 km to 15 km for rail extensions to airports, and from 0.5 km to 10 km for APM connections between airports and nearby rail stations.

In the evaluation of fixed rail concepts, auto, taxi, and bus are considered as competing modes which are the typical modes transportation available to and from airports. The results may not be valid if other modes are dominant at a particular airport. The costs of trips to and from airports are determined using 1991 U.S dollars. Since these values are used only for relative comparison among the modes the results can be valid to any reasonable time frame.

## 1.5 Outline of Dissertation

Existing fixed rail services and features for world airports are summarized in Chapter 2. A review of the literature on the work in the area of planning of fixed rail services is also presented Chapter 2. In Chapter 3, the method of collection and summary of systems is reported. The systems concepts and attributes of these systems are described in Chapter 3. In Chapter 4, a multicriteria evaluation of alternatives and models to determine the cost and operational characteristics are described. The application of these models is presented in Chapter 5. The multicriteria evaluation approach is then applied to three case studies to study the attractiveness of fixed rail alternatives with various conditions and the details of which are presented in Chapter 6. A special analysis on baggage handling facilities is also reported in this chapter. Finally, a summary of the work, guidelines for planning fixed rail service to airports, and conclusions are reported in Chapter 7.

# CHAPTER 2

# PAST WORK

## 2.1 Introduction

Ground access to airports can be subdivided into three interrelated components.

(1) The off-airport segment that makes use of the local transportation network and may include more than one mode,

(2) The on-airport segment that takes place within the airport boundary and, in most cases, uses the same access or egress mode on the earlier segment, and

(3) The interface segment that covers travel between the primary access or egress mode and the departure or arrival gate. This component involves predominantly the movement between terminal buildings or within a terminal building at a particular airport (Kurz 1975).

To a large extent, the operation of an airport depends on the efficiency of these components of ground access. The interaction among the components contributes to the satisfaction and convenience that the system user feels or derives. Several modes operate on these systems. Some modes, such as moving walkways in segment 3, operate exclusive on a particular segment while others operate on two or on all segments. This research particularly concentrates on segments 1 and 2. In most cases the modes that operate on segment 1 will continue on segment 2.

## 2.2 Airport Access Modes

The decision process that a user makes in choosing a mode by a user is presented in Figure 2.1 (Prideaux 1988). Although the auto mode dominates in most cases, no single mode of transportation qualifies as the best. A comparison of characteristics of the modes is presented in Table 2.1. Each mode has its own advantages and disadvantages.

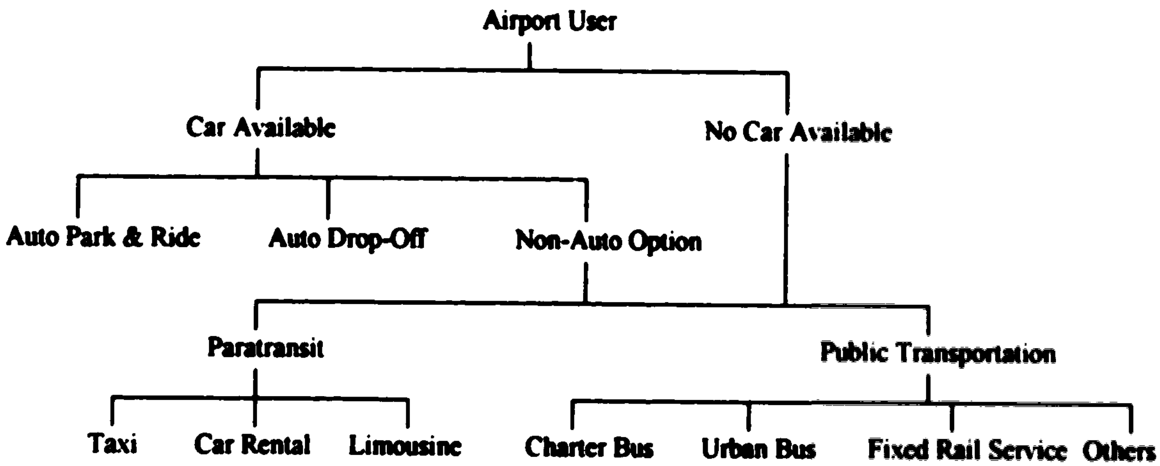



Figure 2.1: Decision Making Process for Selecting Mode by Airport User.

*Auto Mode*: The most attractive and dominant mode of access particularly in North America is the personal automobile. Because of the flexibility and convenience between origins and destinations, it continues to dominate all other modes. It is particularly convenient when a traveller has heavy baggage. When parking at the airport is required for relatively short periods, journeys can be made relatively inexpensively by this mode.

The principal disadvantage of this mode of access is the high congestion levels caused by individual autos on access routes, the high interaction with non-airport traffic, and the high level of parking infrastructure required at the airport. It is not reliable when congestion builds up and it is vulnerable to delays caused by traffic that is not associated with the airport. Parking in the immediate vicinity of the airport is often expensive and this will affect the choice of mode.

*Taxi*: If an airport attracts a high proportion of business traffic and the distance between airport and central business district is not too long this mode is frequently used. Tourists also prefer this mode if they are not familiar with a city or are not aware of the other opportunities. It offers a high degree of flexibility between origins and destinations

Table 2.1: Characteristics of Selected Modes of Transportation to and from Airports

| Mode | Characteristics of modes | | | | | | |
|---|---|---|---|---|---|---|---|
| | Travel Time | Route Flexibility | Cost of Trip | Baggage Convenience | # Transfers | Sensitive to Congestion | Accessibility |
| Auto | *moderate* | *flexible* | *inexpensive if parking costs are excluded* | *convenient* | *none* | *sensitive* | *accessible* |
| Rental Car | *moderate* | *flexible* | *expensive* | *convenient* | *none* | *sensitive* | *accessible* |
| Taxi | *moderate* | *flexible* | *very expensive (fare by meter)* | *convenient* | *none* | *sensitive* | *accessible* |
| Limousine | *moderate* | *flexible* | *very expensive (constant / zonal fare)* | *convenient* | *none* | *sensitive* | *accessible* |
| Urban Bus | *moderate* | *not flexible* | *moderate (mostly fixed fare)* | *not convenient* | *one* | *sensitive* | *should be accessed by another mode* |
| Fixed Rail Service | *less* | *not flexible* | *inexpensive (fixed fare)* | *not convenient unless special facilities are provided* | *one to two* | *not sensitive* | *should be accessed by another mode* |

and works on demand actuated operation. However, the cost of a taxi trip can be expensive. A trip is usually provided for a single party and fare is by meter on the basis of time and distance travelled.

*Limousine*: It operates similar to taxi, but sometimes it operates on predetermined routes. A flat fare by distance or zone is charged. It offers a high level of convenience for travelers. The disadvantages are that it is highly sensitive to surface congestion and trip reliability is less, and its service is poor except at busy airports. At some airports, shared limousine (taxi) service is available. A van used for such service and may also be called airporter or super shuttle.

*Rental Car*: This mode is preferred by many business travelers if their trips are for shorter periods. Rental cars are also extremely popular at airports that have resorts and tourist areas as many tourists prefer the flexibility offered by a rental car. It has similar advantages and disadvantages as that of auto or taxis. When compared to auto, the cost of trip is more by rental car.

*Charter Bus*: This mode is popular at airports in the areas of holiday destinations. This mode usually serves chartered air flights. These buses operate nonstop from their origin and offer a reasonably high level of service. Cost of the access trip is low because of high load factors and the cost is absorbed in the overall charter fare. If the service is independent a flat fare is charged per trip. Some hotels may provide a free service. The disadvantages of this mode are similar to other road based modes. It needs special pick-up and drop-off areas and parking areas.

*Urban Bus:* This mode usually connects airports to a limited number of pick up areas. In most cases they run between CBD and airports. The principle attractiveness of these modes is the cost of the trip. They provide high degree of convenience for the traveler originating or terminating near the pick up areas. A flat fare or zonal fare may be charged. The disadvantages of these modes are the sensitivity to surface congestion, except when priority lanes or exclusive right of ways are provided, and lack of service to areas other than CBD. Travel time increases with number of stops in between the origin and destination. The local Urban Transit Authority runs the service and offers the routes terminate at major transit terminal and is mostly used by airport employees. Some private or public agencies run express bus services from city centres with limited the number of enroute stops on flat fare. Minimum frequency of service is provided and it will be improved if there exists higher patronage.

*Fixed Rail Service:* Fixed Rail Service can be identified as the service provided by RRT (Rapid Rail Transit, Metro, Subway), LRT (Light Rail Transit), Commuter Rail, or Intercity Rail.

An RRT system generally serves one urban area, using high-speed, electrically powered passenger rail cars operating in trains in exclusive rights-of-way, without grade crossings and with high platforms. The tracks may be in underground tunnels, on elevated structures, in open cuts, at surface level, or a combination (Urban Public 1989).

An LRT system is a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways, or on streets with mixed rights-of-way and at grade crossings. Boarding or alighting may be at rail level or at high level platforms (Urban Public 1989).

A commuter rail service is a passenger railroad service that operates within metropolitan areas on trackage that usually is part of the general railroad system. The operations, primarily for commuters, are generally run as part of a regional system that is publicly owned or operated by a railroad company as part of its overall service. In some areas it is called regional rail (Urban Public 1989).

An Intercity rail service is the one that run with an electric or disel locomotive and serves cities and towns that are fairly close to each other. This mode usually operates on rights-of-way that are shared with freight trains.

Very few airports have these types of services, chiefly because of high construction costs and limited potential revenues. It is relatively inexpensive for single passengers that are originating or terminating near central business districts or near rail transit stations. The service is highly dependable with low travel times even in extreme weather conditions.

Its major disadvantage is that it has fixed route operation which requires higher passenger demands to justify the investment and operating expenditures. It has fixed schedules rather than a demand actuated operations. The rail transit routes are highly rigid and there is no flexibility in shifting or changing routes. As a result, the rail transit stations often are to be accessed by another mode. With large amounts of baggage, transfers are inconvenient, affecting the choice of mode. Overall travel time and total cost of trip increases with the number of transfers.

*Others*: Other modes include high-speed dedicated rail systems, VTOL, and STOL links. High-speed rail systems have speeds greater than the conventional rail speeds of 50 to 80 kmph. The attraction of these systems is the travel time and travel time savings will not be much for shorter distances. Travel time on these systems is significantly different from travel time on conventional modes for remote airports such as the Tokyo Narita Airport. These systems are very expensive because of segregated guideway in urban areas. The fares are either high or heavily subsidized.

The fastest and congestion-free (on ground access) method of linking city air passenger terminals or air passenger generators with the airport is the use of helicopters. The cost of a trip per passenger is very high and only business travelers and VIPs are the typical users. These systems have not yet established a strong enough service record of technical and financial feasibility that one could document the potential of these modes to improve access (Asford 1992). Moreover these modes are sensitive to weather and objectionable to communities because of noise.

## 2.3 Fixed Rail Service

In the early days of air travel more emphasis was placed on public transit access to airports and airlines generally organized their own transfers. By the 1930s the first rail-air links were built in Berlin and London. But private auto usage increased significantly after the World War Two. Concentration of this mode has lead to serious competition for surface access and excessive delays have been experienced by many travelers at several airports. Now public transportation is showing renaissance with the increasing congestion and pollution in urban areas. Future demands must be met at an acceptable cost and public transport, rail transit in this context, may play a larger role. Around the world there are about 40 airports that have rail service from their city centres. Table 2.2 presents the details of RRT connections to airports in the United States, Table 2.3 gives the details of Airport Shuttle service to metropolitan RRT systems in North America, and Table 2.4 presents the details of rail connections at other world airports (Sproule 1992a).

Rail access to airports can be categorized into three basic categories: conventional railway lines, urban rail transit systems, and exclusive service (Sproule 1992a, Ashford 1992).

*Conventional Railway Lines*: These are generally intercity rail systems or commuter rail systems. Examples of these systems are Amsterdam, Brussels, Frankfurt, Geneva, London, Philadelphia, and Zurich. Some of these systems have special purpose spurs or loops off the existing networks. The advantages of these systems are inexpensive as airport trains share lines with other rail services over much of the route, and availability of intercity connections from the airport station. The disadvantages are infrequent service, unless special service is provided, and service to limited destinations. Conventional railway systems are usually oriented to a main station in the central city and most travelers do not have a city centre origin or destination.

*Urban Rail Transit Systems:* At some airports there is direct access in the airport terminal to the metropolitan urban rail rapid transit system. Short extensions of existing

Table 2.2: Airport Rail Rapid Transit in the United States

| City | Airport | Distance from City Centre (km) | Description |
|---|---|---|---|
| Atlanta | Hartsfield International | 13.0 | MARTA Station in main terminal |
| Chicago | Midway | 16.5 | CTA "south transit route" 14.5 km extension<br>Midway Station linked to terminal by moving walkways |
| Chicago | O'Hare International | 30.0 | CTA rail rapid station in terminal |
| Cleveland | Hopkins International | 16.5 | Station in terminal |
| St. Louis | Lambert International | 16.0 | Station in the terminal<br>Light Rail Transit link under construction (expected to open in 1994) |
| Philadelphia | Philadelphia International | 13.5 | Commuter rail service to all four terminals |
| Washington | National | 6.5 | Metro station is about 500 m from North Terminal, shuttle bus available between station and terminals |

Table 2.3: Airport Shuttle Service to Metropolitan Rapid Transit Systems in North America

| City | Airport | Distance from City Centre (km) | Description |
|---|---|---|---|
| Baltimore | Baltimore - Washington International | 14.5(Baltimore) 50 (Washington) | Shuttle bus to Amtrak rail station 2.4 km ride |
| Boston | Logan International | 5 | Shuttle buses between airport terminals and MBTA Airport Station (Blue Line) |
| Calgary | Calgary International | 17 | Shuttle buses to LRT system during change of shift hours |
| New York | JFK International | 24 | Shuttle buses to Howard Beach Station on New York Subway line. 5 to 8 km ride |
| New York | LaGuardia | 13 | Shuttle buses to New York Subway line 3.3 to 4 km ride |
| Newark | Newark International | 27 | Shuttle buses to PATH and Amtrak trains in Newark Penn Station |
| Oakland | Oakland International | 18 | Shuttle buses to Coliseum Station on BART system |
| San Francisco | San Francisco International | 26 | Shuttle buses to Daly City Station on BART system, 16 km ride |
| Toronto | Pearson International | 28 | Shuttle buses to station on TTC subway system |
| Washington | Dulles International | 42 | Shuttle buses to West Falls Church Station on Washington Metro |

Table 2.4: Rail Transit Service at Other World Airports

| City | Airport | Distance from City Centre (km) | Description |
|---|---|---|---|
| Amsterdam, The Netherlands | Sch.phol | 15 | Station in lower level of air terminal<br>Direct service to Central Station<br>17 to 20 minute ride to Central<br>Connections also available to Den Haag, Rotterdam, Rossendal, and Vissingne |
| Berlin, Germany | Schonefeld | 20 | Free Shuttle bus to S-Bahn station 400 m away from terminal |
| Barcelona, Spain | Barcelona | 14 | Intercity rail station on airport, 300m away from terminal connected by moving walkways<br>18 minute. ride to Sants Station in downtown |
| Birmingham, U.K. | Birmingham International | 11 | BR station is 2.5 km away from main terminal, connected by a people mover system<br>International connection available at airport station<br>12 minute ride to Birmingham New Street station |
| Brussels, Belgium | Brussels National | 12 | Rail station is in lower level of air terminal<br>19 minute ride to Brussels Central Station and 15 minute to Brussels Nord, a Eurorail transfer point. |
| Darlington, U.K. | Darlington Tees-Side | 9 (Darlington)<br>16(Middlesbrough) | Intercity line in terminal<br>9 minute ride to Darlington city centre.<br>20 minute to Middlesbrough |
| Dusseldorf, Germany | Dusseldorf | 8 | S-Bahn rail station linked to terminal by tunnel<br>11 minute ride to city centre |

Table 2.4: Rail Transit Service at Other World Airports continued

| City | Airport | Distance from City Centre (km) | Description |
|---|---|---|---|
| Frankfurt, Germany | Frankfurt-Main | 9 | Rail station in lower level of air terminal<br>Direct connects to many European destinations available<br>"Lufthansa Airport Express" operates between Frankfurt and Dusseldorf airports with intermediate stops at Bonn, Cologne, and Dusseldorf Central Station. |
| Geneva, Switzerland | Cointrin | 6 | Swiss Federal Railway station in terminal<br>6 minute ride to city centre<br>Direct connections available from airport to Bern, Zurich, Lausanne, and other destinations |
| Hong Kong | New International Airport | 34 | Railway Station in terminal<br>23 minute ride to Hong Kong Central<br>Trains will operate at 135 km/h |
| London, U.K. | Gatwick | 43 | BR station adjacent to South Terminal<br>APM links North Terminal with rail station<br>30 minute ride by 'Gatwick Express' to London Victoria |
| London, U.K. | Heathrow | 24 | 2 stations on Piccadilly line of London Underground<br>30 minute ride by Heathrow express to Paddington station |
| London, U.K. | Stansted | 61.5 | 45 minute ride to London |
| Malaga, Spain | Malaga International | 10 | Direct rail link to city centre<br>11 minute ride to Malaga main station |

Table 2.4: Rail Transit Service at Other World Airports continued.

| City | Airport | Distance from City Centre (km) | Description |
|---|---|---|---|
| Manchester, U.K. | Manchester | 15 | Construction underway for direct link to city centre |
| Munich, Germany | Munich | 28.5 | Rail station inside terminal<br>39 minute ride to city centre |
| Paris, France | Orly | 14 | Orly station adjacent to airport<br>OrlyVal train connects RER line B at Antony station where direct connection to Roissy airport available |
| Paris, France | Roissy (Charles de Gaulle) | 20 | Roissy Rail station inside terminal T9<br>Shuttle bus connection available from other terminals<br>34 minute ride to Paris Gare du Nord station |
| Rome, Italy | Fiumicino | 32 | Direct rail link to Roma Ostiense |
| Stuttgart, Germany | Stuttgart | 13 | Construction underway for direct link to city centre |
| Tokyo, Japan | Haneda | 29 | Monorail line between airport and Hamamatsu Cho rail station on the Tokyo subway system |
| Tokyo, Japan | Narita | 67 | Rail station in lower level of terminal<br>55 minute ride to Tokyo station in city centre<br>Narita Express service available to Yokohama, Hinjuku and Ikebukuro |
| Vienna, Austria | Schwechat | 18 | Rail service between airport and downtown<br>30 minute ride to downtown |
| Zurich, Switzerland | Kolton | 10 | Rail station in lower level of air terminal<br>10 minute ride to city centre<br>Direct rail connection to Lausanne, Geneva, Bern and many other destinations |

urban rail rapid transit systems were provided to some airports. Examples of these systems are Atlanta-Hartsfield, Chicago-O'Hare, Chicago-Midway, Cleveland-Hopkins, London-Heathrow, and Washington-National. The first Light Rail Transit link to an airport in North America will be in St. Louis to Lambert International Airport (Nensel 1988). These forms of access have several significant advantages. Usually, the rapid transit system is a coordinated part of the overall metropolitan transit system and this gives air passengers and airport employees a choice of multiple destinations within the network and good access to large portion of the urban area. These systems offer reliable service that does not suffer delays due to the congestion on the surface access system, because the rail rapid transit line operates on a reserved right-of-way.

*Exclusive service:* These systems are generally thought to be high-speed, non-stop, guided transit service between the airport and city centre. Many schemes have been suggested and investigated all over the world but none have been constructed. The system closest to exclusive service is at the Tokyo Haneda Airport. The airport is currently connected to the Tokyo subway system in east Tokyo by a monorail system. Although this service has few enroute stops, it exclusively serves the airport. The Heathrow Express at London-Heathrow is being planned for 1994 to provide a high-speed (capable of 160 km/h) express rail service to Paddington station (Le Blond 1990). Dedicated platforms will be provided at Paddington, and high quality on-board service and information are planned on the specially designed trains. These exclusive services provide high level of comfort and convenience. But, high construction and operational costs are involved. Service is only provided to limited destinations, specifically to city centres, wherein streets are already congested.

Many authors identified the need for a fixed rail service to airports. Some of them clearly outlined the advantages of having fixed rail service to city centre. Others advocated the idea that only fixed rail service can relieve the congestion.

Maxwell and Rockwell (1976) identified the need for adequate surface access and interface with other transport systems. According to them, airport staff or employees at the airport are the potential passengers on fixed rail systems.

Kurz (1975) perceived that a special access system would have to be financially self-supporting. He felt, "*Special transit should be designed to serve a particular use group rather than to solve general area wide transportation problems.*" But Tennyson (1975) has the opposite opinion. He felt that such services should also serve non-airport users for the service to be viable economically.

Barnes (1984) and Kizzia (1981) studied some of the existing fixed rail systems. They foresaw good potential for such systems at many airports around the world. Although some of the authors are skeptical about the prospects of fixed rail systems, they felt the need for such a system because it is the only reliable system for airport access from city centre and alleviates the congestion problems (Ashford 1992, Keith 1988, Kurz 1975, Lopez 1989, Prideaux 1988, Wiggers 1970).

Prideaux (1988), in his paper presented at 8th World Airport Conference London, discussed the benefits of providing a rapid rail link between airport and city centre with particular reference to Gatwick Airport and Stansted Airport.

According to Gosling (1986) "*...the additional landside capacity provided by a rail access may permit airports to increase their level of operations beyond the level that would otherwise impose unacceptable congestion on the surrounding highway system.*" He identified the need for the linking of any rail service into the regional rail network.

Strandberg (1990) categorized rail systems into three basic systems; dedicated lines, extensions of existing systems and planned rail systems. He foresaw many advantages to both passengers and the airline industry if good rail service is provided to the airports.

Malone (1986) also studied the existing systems in the United States. He felt the need for promotion and aggressive marketing to make the rail service to airports popular.

He joined Ashford (1992) and Kurz (1975) in supporting the idea of having transit stations within the terminal to avoid transfers and thereby attracting more passengers.

Ashford (1980) felt that dedicated links are uneconomical, so links must be built largely using existing rail road facilities. He proposed that the urban areas with a large population and a central core that is highly attractive for business and tourist travellers are good potential candidates for fixed rail service.

Young (1981) reported that although there has been no definitive study on the impact of rapid transit service to major airports in the United States, there seems to be a widely held belief that the high concentration of employees and passengers are a substantial new market to be tapped.

Most authors suggest that there is a need for fixed rail service at some airports, but they are skeptical about the feasibility and economic viability of such services. There is a need for a study to assess the feasibility and attractiveness of fixed rail services. When studying such proposals, fixed rail service should be compared with other services and the relative attractiveness, and the characters influencing the mode choice should be assessed before investing money on these projects. In this study some of the aspects are examined in detail.

## 2. 4 Factors Affecting Passengers Choice

The usage of the fixed rail systems varies widely from airport to airport. There are three principle user groups: air passengers, employees, and visitors. The literature indicates that if the metropolitan area has a dominant city centre, fixed rail system may attract more passengers to and from airport. Ridership levels on existing rail-to-airport systems in the United States range from 4% to 15% of airport passengers. London-Gatwick is the only airport that attracts more than 30% of airport related trips. It attracts 44% of air passengers. Literature also shows that the rail ridership for airport employees vary widely, from 5% to 70% (Campbell 1992)

The level of traffic attracted by any access mode depends basically on two factors: characteristics of passengers and attributes of the mode. The following are the user characteristics influencing users in choosing a mode of travel to or from the airport.

- origin / destination of trip
- trip purpose (business, vacation, or non-business)
- annual income
- availability of car
- availability of a person to drop off the air traveller(s)
- number of persons travelling together
- number of pieces of baggage
- others

The systems attributes that influence the mode choice are:

- travel time (door to door)
- cost of trip
- frequency of service
- number and type of transfers involved
- number of stops
- availability of baggage handling facilities
- walking distances
- safety and security
- information about mode
- sensitivity to congestion
- others

Reliability of trip depends on sensitivity of the mode to congestion. Travel time reflects the speed of the mode, baggage handling facilities, frequency of service, and number of transfers reflect the convenience, and walking distance, directional signs and information reflect the accessibility. Importance of these factors, to some extent, depends on the local conditions and location of a particular airport. There has been some work done to identify the factors and their influence. Prideaux (1988) identified the importance of travel time, travel cost, number of transfers, frequency of service and sensitivity of mode to weather as factors that influence travel decisionsm using a forecasting model developed by British Rail.

Ellis and others (1974) have examined the characteristics of airport access travel and identified improvements which would alleviate problems of access. Using the case studies of Washington Dulles International Airport and Washington National Airport they concluded that the dependence on the private automobile is inversely proportional to air traveler density and that diversion of travelers from taxi to limousine increases as distance from the CBD to airport increases. Concepts such as improvements in existing limousine service, demand actuated transportation service, priority access routes for public transportation, a satellite terminal and extension of regional rapid transit system to airport have been proposed for airport access improvements

Harvey (1986) studied the airport access mode choice for residents of San Francisco area. Although parking and related services provide considerable income to the airport, inadequate access facilities can limit airport capacity and access traffic can be a source of aggravation for travelers. Travelers view ease of access as a characteristic of the airport and it may affect the choice of departure or arrival. Access behaviour of travelers is useful for planning and management. Mode Choice Modeling was done using Multinominal Logit choice model for Bay Area airport access and five choice alternatives -- drive, drop-off, transit, airporter, and taxi, were considered. The characteristics considered were trip purpose, trip duration, travel cost, and number of pieces of luggage. Travel time, and travel costs were identified as the strong explanatory variables in choosing the airport access mode. Business travelers are less sensitive to cost and more sensitive to time. Non-business travelers are more sensitive to cost and less sensitive to time (0.6 times the business). Cost sensitivity decreases with increase of income.

Ashford (1980) has identified the importance of convenience and comfort apart from the cost, which influences the final decision of choosing a mode. He concluded that journey time is not criti:.!. Planners must always be concerned with the economic use of resources regardless of the fare/subsidy. According to Kurz (1981) geographic location of airport with respect to city centre and travel time are strong influencing parameters

In a paper on the economic feasibility of rail access projects in the San Francisco Bay area and the New York region, Gosling (1986) concluded that:

i) rail projects are extremely capital intensive and even the largest air carrier airports do not generate enough access trips to justify the investment in a dedicated system on economic grounds,

ii) special attention needs to be given to station design and the connection between the airport station and terminal building, and

iii) the reduction in highway traffic from rail access projects benefits a wider society than just air passengers and airport employees.

One of the critical points to the success or failure of airport rail systems is the location of the rail station at the airport. At Washington National Airport, the rail station is within a few blocks of the airport terminal and users are to walk or take a shuttle bus ride to reach the terminal. This considerably influences passengers when choosing the rail service for access. Location of rail station is also a factor for influencing the ridership of employees. Studies of rail transit to Cleveland Hopkins International Airport and Washington National Airport indicated that the relatively low employee ridership was attributed to station location. Multiple stations may be required for the convenience of employees (Campbell 1992).

Literature indicates that most of the work done is either specific to a location or a report on an existing system. Presently no planning guidelines are available for these systems. This work is an attempt to evaluate the rail connections to airports, provide planning tools and guidelines and to answer the questions raised in Chapter 1.

# CHAPTER 3

# INVENTORY OF FIXED RAIL SYSTEMS

## 3.1 Introduction

Airports around the world that have some form of fixed rail access have different characteristics. It is useful to study the characteristics of these fixed rail systems. In 1980, a U.S. Industry Working Group collected information on the fixed rail systems (fixed guideway systems) for Airport Operators Council International (Survey 1980). This data included general information of several systems and their attributes, and the system usage. Since the latest data would be more useful for the study and planning of such systems, a survey was undertaken to update the 1980 data. The following sections describe the method of collection and the type of the data collected for the world airports that are have fixed rail service or are planning such systems.

## 3.2 Method of Collection

An information form was prepared to collect such information as airport location, passenger activity, passenger peaking characteristics terminal types, parking, employees, and competing ground access modes. In addition to this basic information, information such as airport user characteristics, ground access modal attributes, and concepts of fixed rail systems was also requested.

The user characteristics include the usage of different modes, and breakdown of types of users, such as air passengers, well-wishers, visitors, and employees. The modal attributes include travel time, cost of trip, accessibility to other modes, walking distances to check-in, fare subsidy, type of service, frequency of service, and operation hours.

Information forms were mailed to the managers of the airports having some form of fixed rail service, fixed rail system under construction, or planning to have fixed rail service in future. These airports were selected based on the information available in the literature. The information was mailed to sixty airports around the world. The list of airports selected is presented in Table 3.1. The mailing addresses of the airports is presented in Appendix A. Fifty percent of returns was achieved.

## 3.3 Compilation of Data

The airports that responded to the information request is presented in Table 3.2. The passenger activity of these airports is reported in the form of annual passenger (enplaned and deplaned), months peak activity, passengers in peak month, passengers on an average day of peak month, and percentage of originating and terminating (O & D) passengers. Heathrow, London, has largest number of passengers, 42.5 millions (1991), and Schonefeld, Germany, has lowest number of passengers, 1.10 millions. The peak month activity varies among these airports although August was reported to be peak at eight airports.

### 3.3.1 Passenger Peaking Characteristics

Passenger traffic during the peak month varies between 8.5% and 14.3% of annual passengers with an average of 10.6%. The variation of number of passengers on an average day of peak month is also presented for these airports. It varies between 0.29% of annual passengers at LaGuardia, New York, and Philadelphia International, Philadelphia, and 0.38% at JFK International, New York. The average number of passengers on an average day of the peak month is about 0.33% of annual passengers. Of the airports that responded, London Gatwick reported to have largest number of O & D passengers (99% of total passengers) and Baltimore Washington International has the lowest level (50%).

Table 3.1: List of Airports Contacted with Existing or Proposed Fixed Rail Services (FRS)

| NORTH AMERICA | FRS |
|---|---|
| ***Canada*** | |
| Calgary Intl. | ○ |
| Montreal-Dorval | ○ |
| Montreal-Mirabel | ○ |
| Toronto Pearson Intl. | ● |
| ***U.S.A.*** | |
| Atlanta, | ● |
| Baltimore Washington Intl. | ●,○ |
| Boston-Logan Intl. | ● |
| Cleveland | ● |
| Chicago-O'Hare | ● |
| Chicago-Midway | ○ |
| Los Angeles Intl. | ○ |
| Miami Intl. | ○ |
| New York - JFK | ●,○ |
| New York - LaGuardia | ● |
| Newark Intl. | ● |
| Oakland Intl. | ●,○ |
| Ontario Intl., Ca. | ○ |
| Philadelphia Intl. | ● |
| San Francisco Intl. | ●,○ |
| Washington National | ● |
| Washington - Dulles Intl. | ● |
| **SOUTH AMERICA** | |
| ***Argentina*** | |
| Buenos Aires | ● |
| **ASIA** | |
| ***Australia*** | |
| Kingsford Smith, Sydney | ○ |
| Melbourne Intl. | ○ |
| ***Japan*** | |
| Kansi(Osaka) | ○ |
| Sapporo(Chitose Airport) | ○ |
| Tokyo - Haneda | ● |
| Tokyo - Narita | ● |
| **AFRICA** | |
| ***Algeria*** | |
| Alger(Algiers) | ● |
| Oran | ● |
| ***Morocco*** | |
| Casablanca | ○ |

| EUROPE | FRS |
|---|---|
| ***Austria*** | |
| Vienna - Schwechat | ● |
| ***Belgium*** | |
| Brussels | ● |
| ***France*** | |
| Paris - Orly | ● |
| Paris - Roissy CDG | ● |
| ***Germany*** | |
| Berlin-Schonefeld | ● |
| Berlin-Tegel | ○ |
| Cologne-Bonn | ○ |
| Dusseldorf | ●,○ |
| Frankfurt/main | ● |
| Munich | ● |
| Stuttgart | ○ |
| ***Italy*** | |
| Pisa, Florence | ● |
| Palermo | ● |
| Milan-Malpensa | ○ |
| Rome | ● |
| ***Netherlands*** | |
| Amsterdam | ● |
| ***Spain*** | |
| Barcelona | ● |
| Madrid | ○ |
| Malaga | ● |
| ***Sweden*** | |
| Stockholm, Arlanda | ○ |
| ***Switzerland*** | |
| Geneva - Cointrin | ● |
| Zurich | ● |
| ***U.K.*** | |
| Birmingham | ●,○ |
| Darlington | ● |
| London - Gatwick | ● |
| London - Heathrow | ● |
| London, City Airport | ● |
| London, Stansted | ● |
| Manchester | ○ |
| Southampton | ● |

● FRS existing in some form ○ Proposal for FRS or modifications

Table 3.2: Annual Passengers and Peaking Characteristics of the Airports Responded to Mail Back Information(1991)

| Name of the Airport | Annual Enplaned/Deplaned passengers (millions) | Peak month(s) | Passengers in peak month in millions (% of annual Pass.) | Pass. on an average day of peak month (% of annual Pass.) | % Originating & Terminating passengers |
|---|---|---|---|---|---|
| Baltimore Washington Intl., USA | 9.9 | Apr., Oct., Nov. | | 29,485 (0.30) | 50 |
| Birmingham Intl., UK | 3.4 | | | | 96 |
| Calgary Intl., Canada | 4.7 | Aug. | 0.513 (10.9) | 16,500 (0.35) | 60 |
| Cleveland Hopkins Intl., USA | 8.1 | Aug. | 0.791 ( 9.7) | 25,527 (0.31) | 63 |
| Dulles Intl., Washington DC, USA | 10.9 | Aug. | 1.086 (10.0) | 35,032 (0.32) | 65 |
| Dusseldorf, Germany | 11.3 | | 1.300 (11.5) | 42,000 (0.37) | 94 |
| Frankfurt Main, Germany | 27.4 | Sept. | 2.900 (10.6) | 96,000 (0.35) | 70 |
| Gatwick, London, UK | 18.7 | July , Aug. | | 75,000 (0.40) | 99 |
| Geneva, Switzerland | 5.6 | March | 0.570 (10.2) | 19,000 (0.34) | 90 |
| Heathrow, UK | 42.5 | Aug., Sept. | | 130,000 (0.31) | 74 |
| JFK Intl., New York, USA | 26.3 | | 3.100 (11.8) | 100,000 (0.38) | 66 |
| Kingsford Smith, Sydney, Australia | 13.0* | Dec., Jan., Feb. | | 18,400 (0.14) | |
| Los Angeles Intl., USA | 45.7 | Aug. | 4.800 (10.5) | 160,000 (0.35) | 80 |
| LaGuardia, New York, USA | 19.7 | | 1.800 ( 9.1) | 58,065 (0.29) | 96 |
| Madrid Barajas, Spain | 16.3 | Sept. | | | 50 |
| Manchester, UK | 10.8 | | 1.250 (11.6) | 50,000 (0.46) | 93 |
| Munich, Germany | 14.0 | | | | 70 |
| Oakland Intl., USA | 6.1 | | | | |
| Ontario Intl., USA | 5.7 | June, Dec. | | | 95 |
| Orly, Paris, France | 24.3 | | | | 86 |
| Philadelphia Intl., USA | 15.5 | Aug. | | 45000 (0.29) | 62 |
| Roissy(CDG), Paris, France | 22.5 | Sept. | 2.260 (10.0) | | 73 |
| San Francisco Intl., USA | 31.0 | | 3.000 ( 9.7) | | 97 |
| Schonefeld, Germany | 1.1 | June | 0.157 (14.3) | | |
| Stansted, London, UK | 1.1 | | | | 98 |
| Stuttgart, Germany | 4.2 | | 0.470 (11.2) | 15000 (0.36) | 96 |
| Tegel, Germany | 6.5 | | 0.555 ( 8.5) | | |
| Zurich Intl., Switzerland | 12.2 | Oct. | 1.280 (10.5) | 41176 (0.33) | 71 |
| | | | mean = 10.6% | mean = 0.33% | |

* 1990 data

### 3.3.2 Employee Information

The number of employees at an airport is typically related to the passenger activity at the airport. Various types of employees engage in different activities. The breakdown of employees for 1991 at these airports is presented in Table 3.3. Frankfurt Main, Heathrow, London, and Los Angeles International have total more than 50,000 employees. Although, the variation in the number of employees at these airports is primarily due to the passenger activity at the respective airport, other factors such as concession activities, cargo activity, aircraft maintenance activity, and other service activities contribute to the variation. The concession activity depends on the percentage of transferring passengers and the percentage of tourists and vacationers. The hub activity at an airport would be reflected through percentage of transferring passengers and aircraft maintenance of the airline company.

A regression analysis was conducted on this data and it showed that there is a very good relationship between the employees and the annual passengers. Figure 3.1 displays the relationship. Frankfurt Main seems to be off the trend and has more employees relative to the number of passengers. The relationship is presented in Equation 3.1. This relationship is later used in the analysis of case studies.

$$TE = -2503.4 + 1259.8 * AP \qquad \text{......... 3.1}$$

Where

T E = Total Employees at an Airport

AP = Total Annual Passengers (Enplaned and Deplaned) at an Airport in millions.

Table 3.3: Employees Details at Selected World Airports

| Name of Airport | Airport Employees | | | | | Annual Empl./Depl. |
|---|---|---|---|---|---|---|
| | Ground Employees | Flight Crew | Business Employees | Others | Total | Pass. (millions) |
| Baltimore Washington Intl. | | | | | 7,500 | 9.9 |
| Birmingham Intl. | | | | | | 3.4 |
| Calgary Intl. | | | | | 5,000 | 4.7 |
| Cleveland Hopkins Intl. | | | | | 4,000 | 8.1 |
| Dulles Intl. | 2,513 | 2,600 | 5,569 | 493 | 11,175 | 10.9 |
| Dusseldorf | | 3,133 | 4,377 | 2,068* | 9,578 | 11.3 |
| Frankfurt Main | 54,377 | 11,078 | | | 65,455 | 27.4 |
| Gatwick | | | | | 20,000 | 18.7 |
| Geneva | | | | | 6,500 | 5.6 |
| Heathrow | 48,439 | ** | 5,485 | | 53,924 | 42.5 |
| JFK Intl. | | | | | 46,072 | 26.3 |
| Kingsford Smith, Sydney | | 5,000 | | | 22,500 | 13.0* |
| LA Intl. | | | | | 50,029~ | 45.7 |
| LaGuardia | | | | | 10,472 | 19.7 |
| Madrid Barajas | | | | | 7,000 | 16.3 |
| Manchester | 2,000 | | | | 10,000 | 10.8 |
| Munich | | | | | 12,000 | 14.0 |
| Oakland Intl. | | | | | | 6.1 |
| Ontario Intl. | 75 | 40 | 50 | | 165 | 5.7 |
| Orly | 23,162 | 2,952 | + | 1,900 | 28,014 | 24.3 |
| Philadelphia Intl. | 5,500 | 1,000 | 2,500 | | 9,000 | 15.5 |
| Roissy(CDG) | 27,600 | 9,400 | 5,072 | | 37,000 | 22.5 |
| San Francisco | | | | | | 31.0 |
| Schonefeld | 800 | + | 100 | 300 | 1,200 | 1.1 |
| Stansted | | | | | 5,400 | 1.1 |
| Stuttgart | 1,750 | 100 | 1,000 | 2,150 | 5,000 | 4.2 |
| Tegel | | | | | 5,292 | 6.5 |
| Zurich Intl. | 3,660 | 4,350 | + | 6,840 | 14,850 | 12.2 |

* Authority employees ** included in ground employees ~ 1990 data + data included in 'others' column

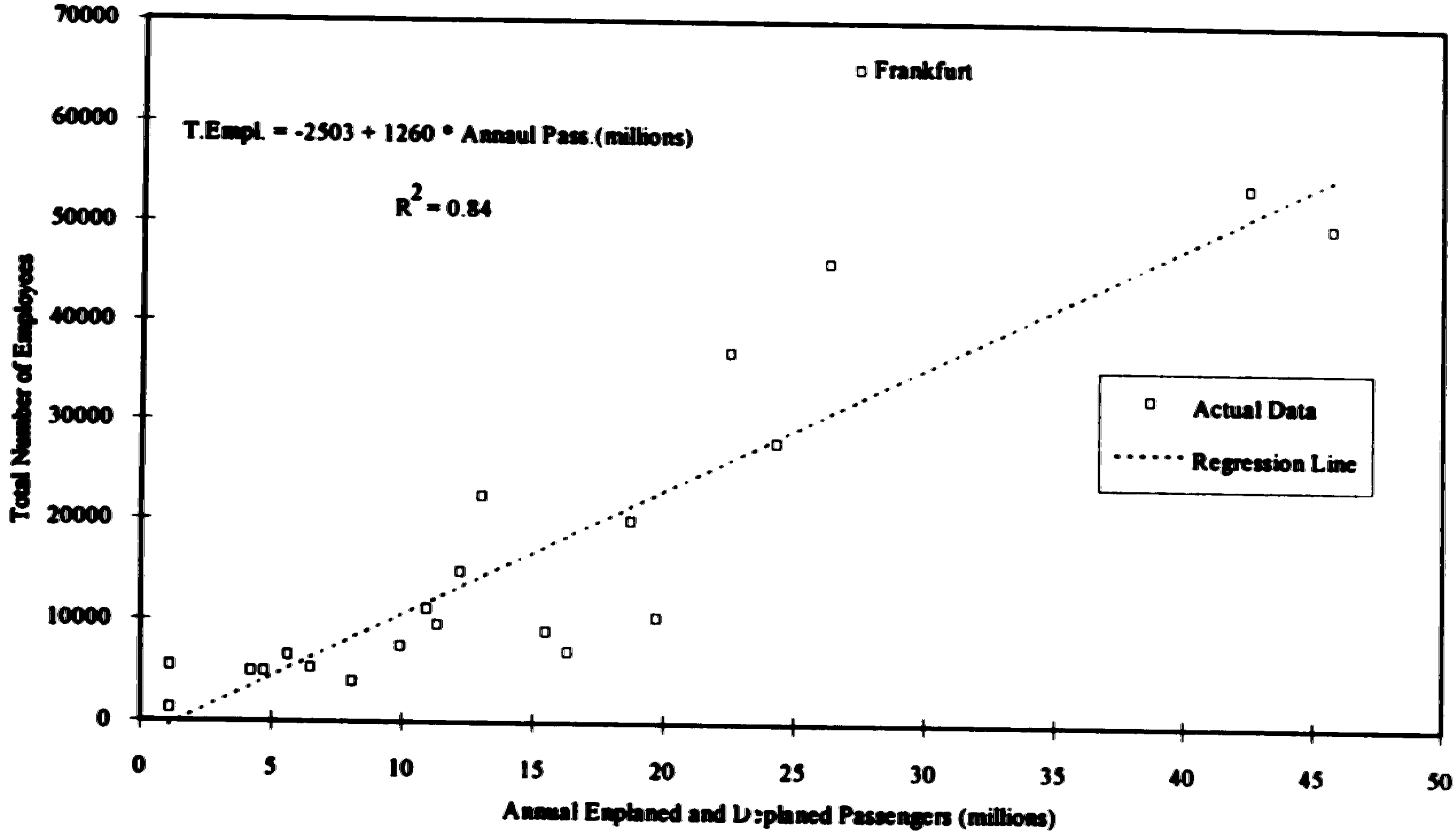



Figure 3.1 : Relationship Between Annual Air Passengers and Airport Employees

### 3.3.3 Location Details and General Information

Location details and general information of North American and World airports are presented in Tables 3.4 and 3.5 respectively. The details include major cities served, distance from CBD, number and type of terminals, average spacing between terminals, and inter-terminal transportation. Of the North American airports, the farthest airport from the major city it serves is Washington Dulles International, and the closest is Philadelphia International. In the other world airports category, London Stansted and London Gatwick are beyond 40 km from the city centres.

### 3.3.4 Ground Access Modes and their Attributes

Information on ground access and the attributes of fixed rail systems to selected airports around the world are presented in Table 3.6. These airports have direct service to airports. Cost details of a one way trip by competing ground access modes are also presented. The cost per kilometre by rail varies from $0.05 (U.S.) on Cleveland system to $ 0.65 (U.S.) on Zurich system although this does not represent the cost of providing a trip. Several systems have subsidies from various levels of governments. Similar observations can be made in shuttle bus fares. Buses operated by private operators charge more when compared to city operated buses. This variation is evident from the bus fares. For all these airports, except London Heathrow, distances from check-in to rail stations are within general accepted planning guideline for walking of 300 m (Sproule 1985). Travel times by rail indicate that average speed varies with distance between airport and CBD and number of enroute stops, farther the airport from CBD, higher the average speed. The average speed by rail from London Stansted to the city centre is approximately 87 km/hr. The average of these systems is found to be around 55 km/hr.

Table 3.4: General Information on Selected North American Airports

| Name of Airport | City (cities) Serving | Distance from Airport to CBD (km) | Number of Terminals | Type of Terminal(s) | Average spacing Between Terminals (m) | Inter terminal Transportation |
|---|---|---|---|---|---|---|
| Baltimore Washington Intl. | Baltimore, | 14.5 | 1 | linear | | |
| | Washington | 50.0 | | | | |
| Calgary Intl. | Calgary | 17.0 | 1 | mixed | | |
| Cleveland Hopkins Intl. | Cleveland | 24.0 | | | | |
| Dulles Intl. | Washington | 42.0 | 2 | linear | 700 | shuttle bus |
| JFK Intl. | New York | 24.0 | 9 | unit | 90 to 120 | moving walkways, shuttle bus |
| Los Angeles Intl. | Los Angeles | 25.0 | 8 | | 250 | shuttle bus |
| Oakland Intl. | Oakland | 18.0 | 2 | pier | | |
| | San Francisco | 30.0 | | linear | | |
| Ontario Intl. | Los Angeles, | 64.0 | 2 | linear | 1000 | |
| | San Bernardino | 28.0 | | | | |
| Philadelphia Intl. | Philadelphia | 13.5 | 5 | pier | 200 | shuttle bus, electric carts |
| San Francisco | San Francisco | 26.0 | 3 | pier | 420 | shuttle bus |

Table 3.5: General Information on Selected Other World Airports

| Name of Airport | City(cities) Serving | Distance from Airport to CBD (km) | # terminals | Type of Terminal(s) | Average spacing between terminals(m) | Inter terminal transportation modes |
|---|---|---|---|---|---|---|
| Birmingham Intl. | Birmingham | 11.0 | 2 | linear | | |
| Dusseldorf | Dusseldorf, | 8.0 | 1 | linear & | | |
| | | | | piers | | |
| | Essen | 30.0 | | | | |
| Frankfurt Main | Frankfurt, | 9.0 | 3 | linear & | | moving walkways, |
| | | | | satellite | | shuttle bus |
| | Wiesbaden | 30.0 | | | | |
| Gatwick | London | 43.0 | 2 | unit | | people mover |
| Geneva | Geneva, | 6.0 | 1 | | | |
| | Lansanne | 60.0 | | | | |
| Heathrow | London | 24.0 | 4 | satellite & | 2000 | moving walkways, |
| | | | | linear | | shuttle bus |
| Kingsford Smith | Sydney | 9.0 | 3 | linear | 1000 | shuttle bus, taxi |
| Madrid Barajas | Madrid | 15.0 | 2 | linear | 500 | moving walkways |
| Manchester | Manchester | 15.0 | 1* | | | |
| Munich | Munich | 28.5 | 1 | linear | | moving walkways |
| Orly | Paris | 14.0 | 2 | mixed | | shuttle bus |
| Roissy(CDG) | Paris | 20.0 | 2 | satellite | | shuttle bus |
| Schonefeld | Berlin | 20.0 | 3 | unit | 150 | |
| Stansted | London, | 61.5 | 1 | satellite | | people mover |
| | Cambridge | 40.0 | | | | |
| Stuttgart | Stuttgart | 13.0 | 3 | linear | | |
| Tegel | Berlin | 8.0 | 1 | | | |

Table 3.6: Ground Access Modes, Cost of Trip, and Type of Service to Selected World Airports

| Airport | Distance by rail to CBD (km) | One way fare to CBD in U.S. $ by | | | | # Enroute stops for rail service to CBD | distance from check-in to rail station (m) | Travel time by rail to CBD(min.) |
|---|---|---|---|---|---|---|---|---|
| | | rail | taxi | bus | limo | | | |
| Cleveland HIA | 25.0 | 1.25 | 18.00 | 17.00 | | 8 | 200 | 25 |
| Cointrin, Geneva | 6.0 | 2.60 | 16.60 | 1.30 | | | 100 | 6 |
| Dusseldorf | 8.0 | 1.70 | 16.50 | 1.70 | | 4 | 200 | 11 |
| Frankfurt Main | 9.0 | 2.60 | 23.00 | 2.60 | | 2 | 50 | 11 |
| Gatwick, London | 48.0 | 13.70 | | | | | 100 | 35 |
| Heathrow, | 24.0 | 3.80 | 46.00 | 9.00 | | 19 | 150 to 375 | 42* |
| London | | | | | | | | 54 |
| Munich | 28.5 | 6.60 | 57.00 | 8.00 | | 12 | | 39 |
| Orly, Paris | 16.0 | 4.80 | 24.00 | | 56.00 | | | 35 |
| Philadelphia Intl. | 20.5 | 5.75 | 20.00 | 1.50 | 8.00 | 3 | 230 | 22 |
| Stansted, London | 59.5 | 16.00 | 76.00 | 11.30 | | 1 | 150 | 41 |
| Zurich Intl. | 10.0 | 6.50 | 54.00 | 13.50 | 20.00 | 0 or 2 | 250 | 10 |

* Non-stop Service

### 3.3.5 Usage of Ground Access Modes

Data on mode usage for ground access was obtained from four U.S. airports and eleven other airports. Actual numbers were not available, but percentages were provided. The most recent data from these airports is presented in Table 3.7. Generally, automobiles attract more trips than any other mode. The Berlin Schonefeld Airport is an exception with only 26.8 percent of access trips are by auto. Fixed rail systems at Schonefeld, Cointrin, Gatwick, Zurich, and London Heathrow Airports attract more than 20 percent of airport trips. Data on employee usage for some airports is included in Table 3.7. Also at all these airports, automobile is most used by employees. The largest usage of fixed rail system by employees is at Dusseldorf Airport and it is about 20 percent.

Figures on the breakdown of passenger on the fixed rail systems to airports are presented in Table 3.8. Munich data is from the system connecting the old airport. It is expected that 7840 passengers per day will ride on the system to new airport. On the Dusseldorf system, air passengers dominate the patronage. More than 50 percent of the users of Munich, Heathrow, Frankfurt Main, and Cleveland systems are air passengers. More than 20 percent of passengers are employees on Frankfurt, Gatwick and Munich systems. Visitors are significant on Gatwick and Heathrow systems. In terms of numbers, Gatwick system is attracting around 25,000 daily passengers to the airport, and others are less than 10,000 per day.

## 3.4 Identification of Systems Concepts and Attributes

Table 3.9 presents a brief explanation of type of fixed rail service to selected airports. It also presents the details of proposed fixed rail systems. Presently 12 airports have direct service to airports, a system is under construction for two airports, and 11 airports have rail stations that are near the terminal but require a change of

Table 3.7 : Modes Operating on Ground Access and Usage.

| Name of the Airport | Usage of different modes in percent | | | | | | | Description |
|---|---|---|---|---|---|---|---|---|
| | Automobile | Taxi | Rental car | Limousine | Bus | Rail | Others | |
| *North American Airports* | | | | | | | | |
| Cleveland Hopkins Intl. | 55.3 | 4.9 | 24.7 | 4.3 | | 4.2 | 6.6 | business Pass. |
| | 85.0 | 6.1 | 3.5 | 2.3 | | 2.0 | 1.1 | non-business Pass. |
| Dulles Intl., Washington DC. | 59.0 | 11.0 | 19.0 | 6.0 | | | 5.0 | |
| LaGuardia, New York | 31.0(85.0) | 33.0 | 5.0 | 21.0 | 7.0(10.0) | | 2.0(5.0) | air Pass.(employees)** |
| Ontario Intl. | 92.0 | 4.0 | 2.0 | 1.0 | 1.0 | | | air Pass. |
| | 98.0 | 0.0 | 0.0 | 0.0 | 2.0 | | | employees |
| | 98.0 | 0.5 | 0.5 | 0.0 | 0.0 | | | visitors** |
| *European Airports* | | | | | | | | |
| Cointrin, Geneva | 35.0 | 20.5 | * | * | 9.5 | 35.0 | | |
| Dusseldorf | 61.0(75.0) | 19.0 | 3.0 | | 3.0(5.0) | 14.0(20.0) | | air Pass.(employees) |
| Frankfurt Main | 53.0(83.0) | 11.0 | 5.0 | | 4.0(3.0) | 25.0(12.0) | 2.0(3.0) | air Pass.(employees)** |
| Gatwick, London | 48.7 | 8.7 | 2.3 | | 10.2 | 29.0 | 1.1 | |
| Heathrow, London | 40.0(81.0) | 20.0(0.7) | 4.0 | | 15.0(8.4) | 20.0(4.0) | 1.0(5.9) | air Pass.(employees) |
| Manchester | 67.0 | 19.0 | 3.0 | | 10.0 | | 2.0 | ** |
| Roissy(CDG), Paris | 34.0(80.0) | 40.0 | | | 13.0(9.0) | 13.0(11.0) | | air Pass.(employees) |
| Schonefeld, Berlin | 26.8 | 5.0 | | | 12.0 | 56.1 | | 1988 data** |
| Stansted, London | 65.0 | 7.0 | 3.0 | | 9.0 | 15.0 | | ** |
| Stuttgart | 62.0(91.0) | 17.0 | 6.0 | | 13.0(4.0) | | 2.0(5.0) | air Pass.(employees) |
| Zurich Intl. | 56.0 | 12.0 | | 2.0 | 5.0 | 22.0 | 3.0 | |

*included in automobiles ** sums of individual percentages may not equal to 100

Table 3.8: Usage of Fixed Rail System at Airports having Direct Service from CBD on a Typical Day

| Airport | Air Passengers | Employees | Visitors | Others | Total Passengers | |
|---|---|---|---|---|---|---|
| | | | | | Departing rail station to airport | Arriving at rail station from airport |
| Cleveland HIA* | 58% | 7% | 11% | 24%⊕ | | |
| Dusseldorf* | 69% | 3% | 9% | 19% | 2710 | 2710 |
| Frankfurt Main* | 57% | 22% | 7% | 12%◊ | 8000 | |
| Gatwick, London | 44% | 24% | 24% | 8% | 25400 | 24800 |
| Heathrow, London | 57% | 0.3M@ 13% | 0.9M@ 17% | 13% | | |
| Munich* | 63% | 22% | 2% | 13% | 7840# | 7840# |
| Zurich Intl.** | 49% | 17% | 7% | 27% | 8750 | 8750 |
| Washington National | | | | | 5300 | 2600 |

* From 1979 survey
⊕ Includes 7% commuters
◊ Includes 5% commuters
** 1989 data, expecting a total of 6.8M /year
@ 1987 annual figures
# Expected with the new airport in operation

Table 3.9: Concepts of Existing, Under Construction, and Proposed Fixed Rail Systems

| Airport | Direct service to airports | Fixed Rail System under construction | Connection by Shuttle Bus or APM | Type of FRS* Proposal |
|---|---|---|---|---|
| Baltimore Washington Intl. | | | ◆ | spur |
| Tegel, Berlin | | | | direct |
| Birmingham Intl., UK | | | ◆** | |
| Calgary Intl., Canada | | | | LRT extension |
| Cleveland HIA, USA | ◆ | | | |
| Dusseldorf, Germany | ◆ | | | |
| Frankfurt Main, Germany | ◆ | | | |
| Geneva, Switzerland | ◆ | | | |
| Gatwick, London, UK | | | ◆** | |
| Heathrow, London, UK | ◆ | | | |
| Stansted, London, UK | ◆ | | | |
| Madrid Barajas, Spain | | | ◆ | |
| Manchester, UK | | ◆ | | |
| Munich, Germany | ◆ | | | |
| JFK Intl., New York | | | ◆ | exclusive |
| LaGuardia, New York | | | ◆ | exclusive |
| Oakland Intl., USA | | | ◆ | APM connection |
| Ontario Intl., USA | | | ◆ | |
| Orly, Paris, France | | | ◆** | |
| Roissy, Paris, France | ◆ | | | |
| Philadelphia Intl., USA | ◆ | | | |
| San Francisco, USA | | | ◆ | extension |
| Kingsford Smith, Sydney, Australia | | | ◆ | extension or exclusive |
| Stuttgart, Germany | | ◆ | | |
| Dulles Intl., Washington DC | | | ◆ | spur |
| Zurich Intl., Switzerland | ◆ | | | |
| Schonefeld, Berlin, Germany | | | ◆ | |

* Fixed Rail Service ** by People Mover

mode to reach terminal. Table 3.10 presents characteristics of these systems. The connecting shuttle buses provided between the rail stations and terminals is either free or nominal fare is charged. Birmingham International has free APM service. The frequencies of these shuttle services vary between 7 minutes and 30 minutes. Most frequent service is provide at Paris Orly Airport, by a people mover system called the OrlyVal train.

After reviewing the systems, three basic concepts may be identified. As shown in Figure 3.2, these systems can be grouped into the following categories.

a) Concept A: a dedicated line or an exclusive line

e.g. Brussels, London Gatwick, Tokyo Narita

b) Concept B: an extension or a loop to suburban line or inter-city line

e.g. Cleveland, Chicago, Atlanta, Philadelphia,

c) Concept C: a suburban or inter-city line connected by a shuttle bus or people mover system

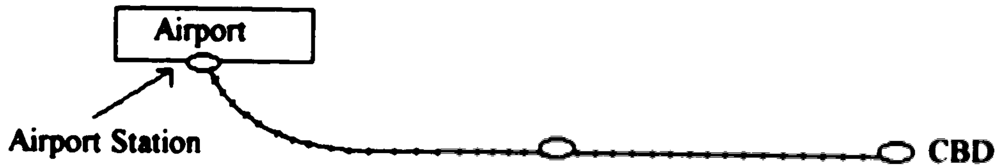
e.g. Frankfurt Main, JFK International, Baltimore Washington.

The concepts are further studied in detailed with respect to characteristics of user and attributes of system.

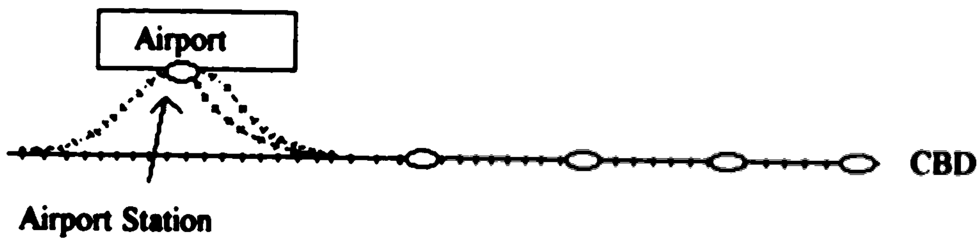
The data collected through the information sheet was useful in helping to define the scope of the research. Limits for the distances from the city centre to the airport, the passenger demands, air passenger and employee usage of fixed rail systems are determined from the data.

Table 3.10: Characteristics of World Airports of Concept C - Fixed Rail Services to Airports having Rail Station at a distance from Airport(terminal)

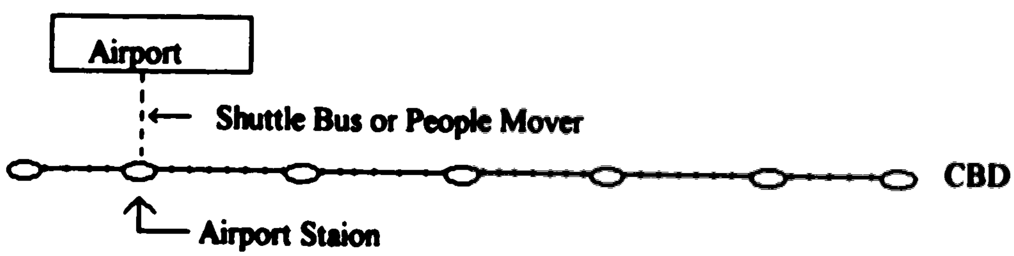
| Airport | Details of Mode connecting terminal(s) and rail station near Airport | | | | | Distance from Airport to Rail Station* (km) | Distance from Airport to Rail Station* (km) | Travel time by train to CBD from rail station* (min.) | Fare in U.S. $ by train to CBD from rail station* | # stops between CBD rail station* |
|---|---|---|---|---|---|---|---|---|---|---|
| | Type of Mode | Travel time (min) | fare (U.S. $) | Headway during peak | Headway during off-peak | | | | | |
| Baltimore Washington Intl. | Shuttle Bus | 10 | free | | | 3.3 | 13 | 22 | 4.25 | 2 |
| | Taxi | 10 | 5.00 | | | | | | | |
| Birmingham Intl. | APM | 1.5 | free | | | 0.6 | 11 | 10 | | |
| | Spl Bus | 10 | 1.00 | | | | | | | |
| Dulles Intl., Washington DC | Shuttle Bus | 20 | 11.00 | 30 | 30 | 30.5 | 16 | 20 | 1.25 | 10 |
| | Taxi | 25 | 43.00 | | | | | | | |
| JFK Intl., New York | Shuttle Bus | 15 | free | 10 | 30 | 7 | 22.5 | 50 | 1.25 | 15 or 30** |
| Kingsford Smith, Sydney | Shuttle Bus | 20 | 3.50 | 15 | 20 | 8 | close to CBD | | | |
| | Taxi | 18 | 12.00 | | | | | | | |
| | Limousine | 18 | 17.00 | | | | | | | |
| LaGuardia, New York | Shuttle Bus | 15 | 1.25 | | | 3.5 | 8 | 30 | 1.25 | 17 |
| | Taxi | 20 | 20.00 | | | | | | | |
| Oakland International | Shuttle Bus | 10 | 2.00 | 15 | 15 | 3.7 | 6 | 10 | 0.80 | 2 |
| | Taxi | 10 | 8.00 | | | | | | | |
| Ontario Intl., California | Shuttle Bus | 20 | 15.00 | | | 14.5 | | 40 | | 1 |
| | Taxi | 20 | 18.00 | | | | | | | |
| | Limousine | 30 | 65.00 | | | | | | | |
| Orly, Paris | VAL train | | | 7 | 15 | 7.2 | 14 | | 4.80 | |
| San Francisco | Bus | 30 | 0.85 | 30 | 30 | 16 | 16 | 18 | 1.45 | 6 |
| | Taxi | 15 | 15.00 | | | | | | | |
| | Limousine | 15 | 30.00 | | | | | | | |
| Schonefeld, Berlin | Shuttle Bus | 2 | free | 7.5 | 15 | 0.4 | 20 | 45 | 2.00 | 19 |




a) Concept A: Dedicated or Exclusive Line




b) Concept B: Suburban or Intercity Line with an Extension or Loop to Serve Airport




c) Concept C: Suburban or Intercity Line Connected By Shuttle Bus or People Mover

Figure 3.2: Concepts of Fixed Rail Systems to Airports

# CHAPTER 4

# MODEL DEVELOPMENT

## 4.1 Introduction

The three basic concepts considered for the research are as follows.

1) Concept A: a dedicated line or an exclusive line
2) Concept B: an extension or a loop to suburban line or intercity line and
3) Concept C: a suburban or intercity line connected by a shuttle bus or people mover system

These three concepts are studied in detail by developing models for the components of the system. The major components of these concepts are rail links, automated people mover (APM) links, and shuttle bus links. These components also include the supplementary facilities, such as stations to make them into a complete system. Models are developed for each of these components for costs and operating characteristics. The details of the model inputs and outputs and the defaults within the model are presented in Section 4.2 to 4.4.

To compare and evaluate the concepts with other conventional modes, cost and travel time models were developed for automobile, and taxi. The components, inputs, and output of these models are described in Section 4.5.

The basic purpose of these models is to study the performance of each component in terms of cost of the system, travel time, and other operational features. These models need various parametric inputs, the details of which are presented in the following sections.

The concepts are evaluated with the other conventional modes and the attractiveness of a concept is identified for specific criteria preference. A multi-criteria evaluation procedure was used to rank the alternatives. A model was developed for this procedure and is explained in Section 4.6.

## 4.2 Cost Model for Rail Rapid Transit System

The basic component in all the concepts is the rail link. There are different types of rail transit systems such as Light Rail Transit (LRT) Systems, Rail Rapid Transit (RRT) Systems, Commuter Rail, or Intercity Rail. Considerable variations exist in the costs of the components of system. The operating and maintenance costs also vary with the type of system. A typical model is developed that reflects RRT systems which are common means of rail access to airports. The defaults in the model assume characteristics of a ty: :al RRT system. Some variables can be changed to reflect the actual situation.

### 4.2.1 Costs of System Components

Costs of Rail Rapid Transit systems are generally divided into two categories, capital costs, and operating and maintenance costs. The capital costs include cost of land, construction, and equipment. The operating and maintenance costs are the costs incurred to operate, administer, and maintain the system.

The capital costs for Rail Rapid Transit systems include all the costs of the basic components of the system. The components are listed as follows.

- right-of-way (R/W)
- permanentway
- road bed and track structure
- stations
- power supply and distribution system
- control and communication systems
- vehicles (cars)
- garages and maintenance facilities.

The R/W acquisition costs consist of land purchases for the alignment and stations. These costs vary greatly with the type of R/W. Tunnels, street medians, and public land do not involve direct costs, whereas at-grade or aerial alignments, and stations on a private property do involve acquisition costs. The permanentway costs also vary with the type of construction. Tunnel construction and underground stations are expensive when compared to at-grade alignment and at-grade stations. The cost of track structure, power supply and distribution systems, and control and communication systems are more or less independent of the type of R/W. One of the components that contributes considerably to the capital cost is the cost of vehicles or cars as the cost of each car depends on extent of sophistication and technology. The cost of garages and maintenance facilities depends on the number of vehicles operating in the system. Ranges in these capital costs are presented in Table 4.1. The costs of the various components were originally presented in 1973 dollars (Vuchic 1981) and have been updated to 1991 dollars by using the Engineering News Record (ENR) cost index (Grogan 1992). The cost model was run using these costs and the results are comparable to estimates made for Bay Area Rapid Transit extensions and for St. Louis LRT (Gosling 1986, "Intermodal" 1992, Nensel 1988).

The operating and maintenance costs are directly related to the operation of the system. These costs include energy costs, salaries of employees, permanentway maintenance costs, Vehicle maintenance costs, and other administrative costs. The costs are often expressed in dollars per car kilometres, dollars per passenger kilometres, dollars per revenue vehicle hours, or in some combination of these. The most useful measure for planning purpose is dollars per car kilometers. This measure reflects the use of different train lengths during different periods of the day. Since many of the operating cost components depend on the usage of the cars, this measure is useful in estimating the operating cost for planning purpose. The average cost of operation of the North

American Rail Rapid Transit Systems is US 0.96 $ / car-km in 1973 dollars (Vuchic 1981). The cost was then adjusted to 1991 dollars and was found to be 2.40 $ / car-km.

Table 4.1: Unit Capital Costs for Rail Rapid Transit Systems (thousands of 1991 US $)

| Component | Range/unit | | Average |
|---|---|---|---|
| | Minimum | Maximum | |
| Permanentway ($/ km of double track) | | | |
| At-grade , with crossings | 872.0 | 1308.0 | 1090.0 |
| At-grade, with no crossings | 3270.0 | 9156.0 | 6213.0 |
| Embankment | 7630.0 | 13080.0 | 10355.0 |
| Aerial | 10900.0 | 17440.0 | 14170.0 |
| Cut | 5450.0 | 7630.0 | 6540.0 |
| Tunnel, cut -and-cover | 21800.0 | 47960.0 | 34880.0 |
| Tunnel, bored | 45780.0 | 54500.0 | 50140.0 |
| Stations (each) | | | |
| On-street | 109.0 | 545.0 | 327.0 |
| At-grade, controlled | 7630.0 | 9047.0 | 8338.5 |
| Aerial | 2834.0 | 10028.0 | 6431.0 |
| Subway | 15260.0 | 32700.0 | 23980.0 |
| Track superstructure ($/km) | 763.0 | 1308.0 | 1035.5 |
| Power supply ($/km) | | | |
| Third rail | 981.0 | 2398.0 | 1689.5 |
| Overhead | 654.0 | 1744.0 | 1199.0 |
| Controls and communications ($/km) | 872.0 | 3488.0 | 2180.0 |
| Vehicle (each) | 436.0 | 872.0 | 654.0 |
| Maintenance and storage ($/veh) | 218.0 | 654.0 | 436.0 |

#### 4.2.2 Equivalent Annual Cost

To compare alternatives and to calculate average cost per passenger the Equivalent Annual Cost method is used. Capital costs are converted into equivalent annual cost by multiplying the capital cost by a Capital Recovery Factor. Capital Recovery Factors (Equation 4.1) for all the component are calculated based on the expected life of each component. The expected life of the components are presented in Table 4.2 (Armstrong 1985). The combined interest-inflation rate is calculated from prevailing interest rate and inflation rate using Equation 4.2 (Riggs 1986).

$$CRF = I_{ef} (1 + I_{ef})^n /((1 - I_{ef})^n - 1) \quad ..4.1$$

where CRF = capital recovery factor

n = expected life of component in years

$I_{ef}$ = combined interest-inflation rate and is given by

$$I_{ef} = (1 + I_p) * (1 + I_{in}) - 1 \quad ..4.2$$

where $I_p$ = prevailing interest rate and

$I_{in}$ = inflation rate

Table 4.2: Expected Life of Rail Rapid Transit System Components

| Component | Expected life(years) |
|---|---|
| Tunnel, Elevated, or Cut and Cover structures | 100 |
| At-grade stations | 50 |
| Underground stations | 100 |
| Track structure | 30 |
| Power supply and distribution system | 30 |
| Control and communications | 25 |
| Vehicles | 25 |
| Maintenance and storage facilities | 50 |

### 4.2.3 Model Structure and Features

A model was developed to study alternatives of Rail Rapid Transit options. The main objective of the model is to calculate the total cost of the project, equivalent annual cost, annual operating cost, cost per passenger, and other operational details such as number of cars required during the peak hours of operation, and number of trains required for peak-hour and off-peak-hour operation. The flow chart shown in Figure 4.1 presents

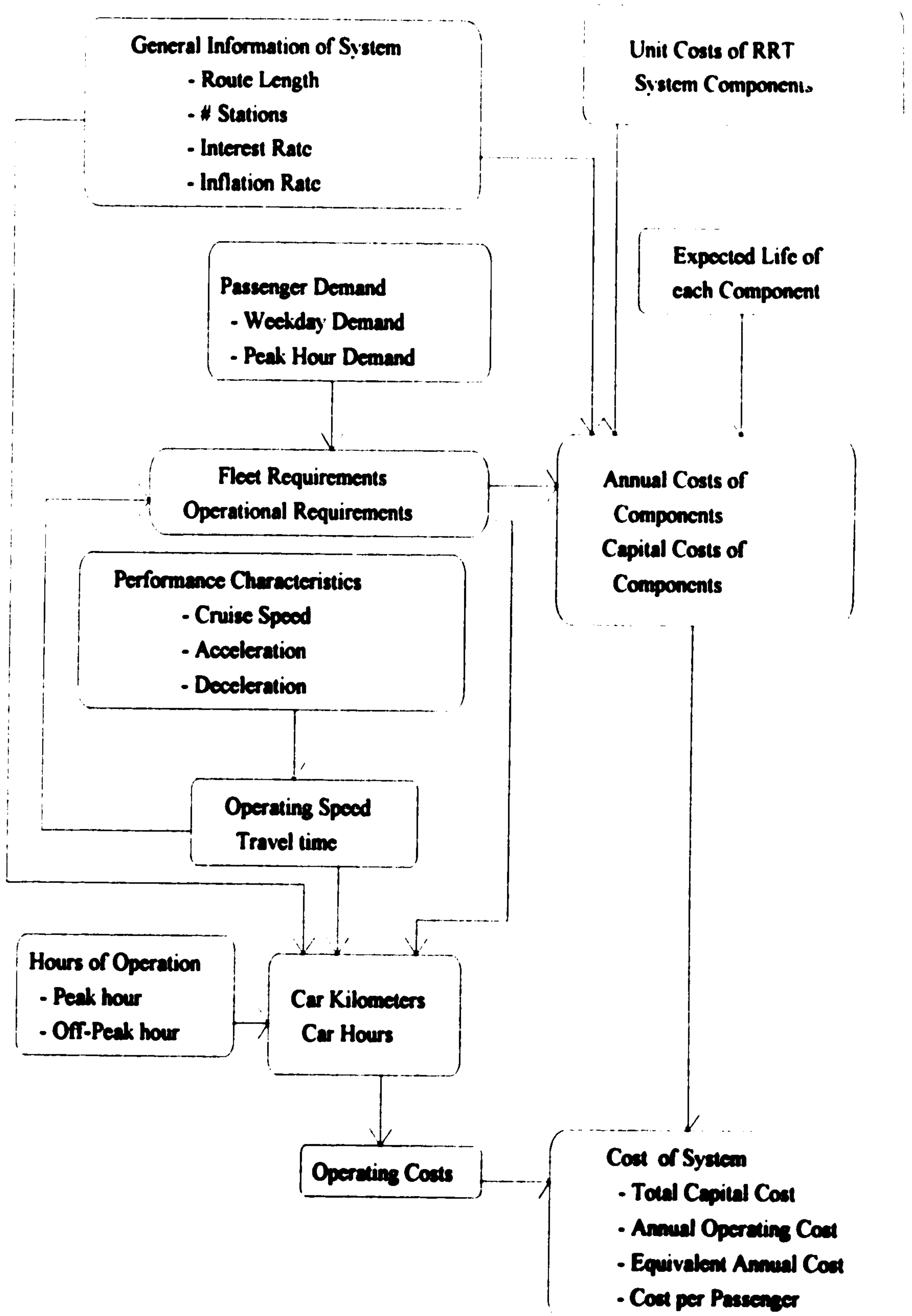



**Figure 4.1: Cost Model Flow Chart for Rail Rapid Transit**

the general interaction of different components of the model. The inputs to the model are grouped into four categories. The data required in these categories are as follows.

1. general information of the system,
2. expected life of different components of the system,
3. constructional details, and
4. operational details.

The general information includes length of the route, numbers of stations planned, prevailing interest rate, and inflation rate. The number of stations can be entered directly if known or the model will calculate the number of stations using the Equation 4.3. This equation has been developed from the data presented in Table 4.3 which is collected from the existing systems (Characteristics 1985). The data show that station spacing increases with the increase of route length and this lead to the assumption of a quadratic function. This equation displays the general applied rule for average spacing (a station every 1.6 km) up to a route length of 25 km. Beyond 25 km the station spacing increases as the route approaches the suburbs which is consistent with sparse development in the suburbs. It is assumed that the route starts at city centre and extends into the suburbs. The number of stations calculated from the equation will be reasonable if the route lengths are between 5 and 100 km. In this research the relationship is used to estimate number of stations for route lengths between 5 and 50 km.

$$n = 0.704\,L - 0.00356\,L^2 \qquad \ldots (4.3)$$

$$R^2 = 0.99$$

where n = number of stations on the route including the end stations.

L = route length in kilometres

Table 4.3: Route Length and Number of Stations of Selected Rail Systems

| City | Route Length (km) | Actual # stations | Predicted # stations |
|---|---|---|---|
| Baltimore | 12.9 | 9 | 9 |
| Philadelphia | 23.3 | 13 | 15 |
| Atlanta | 26.2 | 17 | 16 |
| Cleveland | 30.6 | 18 | 18 |
| Miami | 33.8 | 20 | 20 |
| Chicago | 36.9 | 19 | 21 |
| San Francisco | 114.3 | 34 | 34 |

The default interest and inflation rates are set at 7% and 3% respectively. These rates change from time to time. Since these rates are applicable for the life of the project, generally accepted rates for the life of the project may be chosen. The effect of these rates is not as significant if the life of the project is long and it is not critical when comparing different alternatives with same interest and inflation rates.

The second part of the input includes expected life for each component of the system. Default values for each component are shown in Table 4.2.

The third part identifies the percentage of the line that will be constructed in tunnel, cut-and-cover, and elevated structure. The rest of the link is assumed to be at-grade construction. The model assumes the entire length to be at-grade as the default. Number of underground stations is calculated from the length of tunnel and cut and cover construction and number of elevated stations are calculated from the length of the elevated construction. The rest of the stations are assumed to be at-grade.

The fourth part identifies average daily passengers, the percentage of average daily passengers in the peak hour, headway information, car capacity, round trip time, and hours of operation. The default for the peak hour passengers of the average daily passengers is set at 10%. Headway of 15 minutes and 30 minutes for peak hour and off-peak hour respectively are set as defaults. Since most of the existing systems have cars with capacity around 120 passengers, the same is chosen as default. The round trip time can either be chosen based on experience or it can be calculated based on the performance characteristics of the proposed system. The characteristics needed are dwell time at stops, maximum speed of the train, and acceleration and deceleration rates of the train. The default values for these characteristics are chosen from the existing systems and are set at 30 seconds, 80 km/h, 1.5 m/sec$^2$ and 1.3 m/sec$^2$ respectively. The hours of operation of peak hour service and off-peak hour service are defaulted at 4 hours and 16 hours respectively.

The route length is divided into equal segments as shown in Equation 4.4. Each segment is separated into three zones; accelerating zone, cruising zone, and deceleration zone. Travel times for each of these zones are calculated using standard equations of dynamics. Total travel time is calculated by summing up the travel times of all segments and the dwell times at enroute stops. Average operating speed and round-trip time are calculated from the total travel time.

$$l = L/(n-1) \qquad \ldots 4.4$$

where l = segment length (km)

L = route length (km)

n = number of stations

Peak hour passenger demand is calculated by considering the peaking, direction split, and occupancy rate. Fleet calculations are done based on the round-trip times, and passenger demand. The car kilometers are calculated by considering both peak and off-peak operations and weekday and weekend operations. The operating and maintenance cost is calculated based on car kilometers. The same approach has been applied in APM Cost model and Bus Cost model. The differences among the models are explained in the respective structures of the models.

The model takes the cost data (Table 4.1) of the components and then calculates the equivalent annual cost and average total cost of the system. The number of cars required for operation and trains peak and off-peak hours are calculated for the operational details. The model assumes 90% occupancy of cars, 60/40 split between the peak and off-peak direction of traffic, and 90% of fleet size required for peak hour operation. The model calculates number of car kilometres, operating cost, cost per passengers, number of trains during peak and off-peak hour, number of cars required for peak hour operation, and number of cars per train during peak hour and off-peak hour. It also determines the average operating speed and travel time for a single trip. The defaults, calculation details and the program listing are presented in Appendix B. A computer model was developed using Quick Basic, and the listing is presented in Appendix B.

## 4.3 Cost Model for Automated People Mover (APM) Systems

In the Concept C, an airport is connected to the nearby rail station by a Shuttle Bus system or an Automated People Mover (APM) system. To compare the rail + APM alternative with other alternatives a computer model was developed for the APM system. Using this model the cost and operation characteristics of APM systems were generated for its use in the multicriteria analysis of alternatives.

Automated People Mover Systems are a class of transportation systems in which fully automated unmanned vehicles operate on fixed guideways along an exclusive right-of-way. The electrically powered vehicles may operate either in single units or in trains (International 1983).

There are over sixty systems that operate around the world and several others are under construction or are being planned. APMs have found their applications in major activity centres such as downtowns, airports, and amusement parks. APM systems essentially serve to reduce walking distances and reduce congestion in and around high density developments One of the major applications of APM systems is at airports to reduce walking distances and relieve congestion. Currently there are sixteen airports with APM systems and three of these link terminals with fixed rail stations (Birmingham, Gatwick, and Paris). Several airports such as Oakland International and Boston Logan International are planning similar links. Table 4.4 summarizes characteristics of APM systems at selected airports.

### 4.3.1 Characteristics and Components of APM Systems

The components of APM systems are similar to the RRT systems except the technology involved in each of the components. The right-of-way is fully grade separated, and typically it is either elevated or in tunnel. The guideway is relatively expensive because of grade separation, precision required in construction, and complicated switches. The costs of control and communication systems are considerably high when compared to RRT systems because of high degree of automated operation. The cars (vehicles) of APM systems are of typically about the size of a standard urban bus with less seated capacity and high standing capacity. The ride on the vehicles is usually short. Cars can be linked to form trains. These trains operate under a centralized automatic control. The operating and maintenance cost includes guideway maintenance costs such as heating and cleaning of guideway, energy costs, vehicle maintenance costs, and administrative cost. Because of the differences in physicalconfigurations and operating characteristics, it is difficult to estimate costs for a typical installation. The most complete information source of North American systems cost data was compiled in the early eighties. The costs have been adjusted to 1991 dollars using the ENR Cost Index (Grogan 1992). The unit costs for APM systems components that were used in the research are presented in Table 4.5 (Tsukio 1985).

Table 4.4: Characteristics of Automated People Mover Systems at Selected Airports

| Characteristics | Atlanta | Birmingham | Dallas/Fort Worth | Gatwick | Houston | Miami | Orlando | Tampa |
|---|---|---|---|---|---|---|---|---|
| **Operational Characteristics of Vehicles:** | | | | | | | | |
| Peak Headway (sec) | 102 | | 108 | | 180 | 84 | 90 | 72 |
| Max. Cruise Speed (km/hr) | 43 | 47 | 27 | 40 | 25 | 38 | 42 | 42 |
| Service Acceleration (m/s) | 1.1 | 0.5 | 1.03 | 1.1 | 0.9 | 0.9 | 1.0 | 0.9 |
| Service Deceleration (m/s) | 1.1 | 0.5 | 1.03 | 1.1 | 1.3 | 0.9 | 1.0 | |
| Min. Dwelling Time (sec) | 21 | 20 | 18 | 21 | 25 | 30 | 30 | |
| Hours of Schedule operations | 20.5 | 13 | 24.00 | | 21.5 | 24 | 21.5 | 24 |
| Total # Personnel Employed | 63 | | 98 | | 11 | 18 | 16 | |
| Veh. Design. Cap.( Seat + Stand) | 16+64 | 6+30 | 16+22 | 16+64 | | 2+92 | 0+94 | 100 |
| **Construction and Fleet data:** | | | | | | | | |
| Total Single Lane Length (m) | 3,660 | 1,240 | 20,490 | 3,060 | 2,600 | 820 | 1500 | 3,000 |
| Type of Construction | Tunnel | Elevated | Elev. + At-grade | | Tunnel | Elevated | Elevated | Elevated |
| Number of Stations | 10 | 2 | 20(13) | 4 | 11 | 2 | 6 | 10 |
| Fleet Size | 24 | | 68 | | 7 | 6 | 18 | 12 |
| **Operational Data of the System:** | | | | | | | | |
| Passengers per year (M) | 27(1978) | | 6.285(1978) | | | 5.000 | | 14.5(1976) |
| Ave. Pass. / Weekday (M) | 0.074 | | 0.0176(1978) | | | .0095 | | 0.04 |
| Annual Veh.km. Traveled (M) | 1.207 | | 5.658(1978) | 0.195 | | .094 | | 0.648 |
| Annual Pass. km. (M) | | | 13.300 | | | 2.00 | | 3.952 |
| **Costs in 1991 U.S. $:** | | | | | | | | |
| Cost per Vehicle (M$) | 1.127 | | 0.487 | | 0.276 | 0.556 | 0.925 | 0.687 |
| Cost of Guide way(M$//lane.km.) | 8.472 | | 1.264 | | 5.346 | 6.044 | 3.263 | 3.203 |
| Cost per Station (M$) | 1.276 | | 0.502 | | 0.790 | 2.726 | 1.554 | 0.568 |
| Control & Communications (M$lane.km.) | 2.099 | | 0.639 | | 1.584 | 1.963 | 3.457 | 1.294 |
| Power & Utilities (M$/lane.km.) | 1.573 | | 0.489 | | 0.366 | 0.991 | 0.581 | 1.996 |
| Maintn., Support, Equipment, & Facilities (M$/veh) | 0.33 | | 0.152 | | 0.732 | 0.377 | 0.403 | 0.230 |
| Total System Capital Cost (M$/Lane.km.) | 28.13 | 2.80(1980 U.K.) | 6.051 | | 14.65 | 24.378 | 16.005 | 13.417 |
| Operation and Maintenance cost per year (M$) | | | 6.548 | | 0.822 | | | 0.914 |
| Developer | Westing-house | People Mover Group (GEC) | Vought Corporation | Westing-house | C.T. Service Inc | Westing-house | Westing-house | Westing-house |
| Year of Inauguration | 1980 | 1984 | 1974 | 1983 | 1981 | 1980 | 1981 | 1971 |

Table 4.4: Automated People Mover at Selected Airports Contd...

| Characteristics | Chicago | Pittsburgh | Las Vegas | Seattle | Paris Orly | Singapore | Stansted |
|---|---|---|---|---|---|---|---|
| **Operational Characteristics of Vehicles:** | | | | | | | |
| Peak Headway | 120 | 72 | | 102 | | | |
| Veh. Design. Cap.( Seat + Stand) | 114 | 100 | | 100 | | | |
| **Construction and Fleet data:** | | | | | | | |
| Total Single Lane Length (m) | 4,200 | 1,500 | 800 | 2,700 | 7,200 | 1,300 | 2,700 |
| Type of Construction | Elev. + At-grade | Tunnel | | Tunnel | Elevated | Elevated | |
| Number of Stations | 5 | 2 | | 8 | | 3 | 4 |
| Fleet Size | 13 | 4 | | 24 | | | |
| Developer | Marta/ VAL | Westing-house | Westing-house | Westing-house | Marta/ VAL | Westing-house | Westing-house |
| Year of Inauguration | 1993 | 1992 | 1985 | 1973 | 1991 | 1981 | 1991 |

Source: International 1983, Moore 1991, and Sproule 1992b.

Table 4.5: Unit Capital Costs and Operating and Maintenance Costs of North American Automated People Mover Systems

| Components of System | Unit Cost in Millions (in 1991 U.S. $)* |
|---|---|
| ***Capital Costs*** | |
| Guideway ( per km) | 2.505 |
| Vehicle (per Vehicle) | 0.356 |
| (per Seat) | 1.000 |
| Control Facility (per km) | 1.002 |
| Power Facility (per km) | 0.541 |
| Total per km | 7.152 |
| ***Operating and Maintenance Costs*** | **U.S. $** |
| $ / Passenger | 0.300 |
| $/ Passenger.km | 0.164 |
| $ / Veh. km | 0.926 |
| $ / Seat. km. | 0.030 |

Source: Tsukio 1985.

* Costs are updated from 1980 using ENR Cost Index

### 4.3.2 Model Features

To study various APM system alternatives a cost model was developed. The model uses similar basic information that was input into the RRT cost model with a few exceptions. The Model calculates total cost of the system, equivalent annual cost, annual operating cost, cost per passenger and operational details such as number of cars and trains required during peak and off-peak operation. The operating and maintenance costs are determined based on Car Kilometre.

Unlike the RRT cost model, this model does not have a default procedure to calculate the number of stations or stops, but rather it has a default of '2' (one station at either end of the link). The defaults for peak and off-peak headways are set at 10 and 15 minutes respectively. For speed, acceleration, and deceleration the defaults are set at 42 kmph, 1.1 $m/sec^2$, and 1.1 $m/sec^2$. These characteristics are typical for Westinghouse systems, the most common system in airport application. Table 4.6 presents the defaults used in the model and the range of values for each characteristic.

One additional feature of the model is that it selects the type of guideway and operation such as shuttle operation on a single guideway, double shuttle on a dual guideway or pinched loop operation on a dual guideway. If a system operation requires one train, the model selects a shuttle service on a single guideway as shown in Figure 4.2. If two trains are required for operation, a dual guideway is selected with either double shuttle operation or pinched loop operation as shown in Fig. 4.3 and 4.4 respectively. If more than two train are required, the pinched loop operation is selected. The total cost of guideway depends on which guideway -single, dual, or pinched loop is selected for the operation. The listing of the program is presented in Appendix B.

Table 4.6 : Model Defaults and Possible Range for APM Characteristics

| Characteristics | Defaults used in the model | Range of values |
|---|---|---|
| Interest rate (%) | 7 | 6 to 14 |
| Inflation rate (%) | 3 | 1 to 10 |
| Number of stations | 2 | > 1 |
| Tunnel construction (%) | 0 | 0 to 100 |
| Elevated construction (%) | 0 | 0 to 100 |
| Peak hour factor | 0.1 | 0.05 to 0.2 |
| Peak headway (min.) | 5 | 1.5 to 30 |
| Off-Peak headway (min.) | 10 | 1.5 to 60 |
| Capacity of car | 80 | 36 to 100 |
| Dwelling time (sec.) | 30 | 20 to 60 |
| Cruise speed (kmph) | 42 | 25 to 47 |
| Acceleration rate | 1.1 | 0.5 to 1.1 |
| Deceleration rate | 1.1 | 0.5 to 1.3 |
| Peak hour operation (hrs.) | 4 | 2 to 6 |
| Off-peak operation (hrs.) | 16 | 15 to 20 |

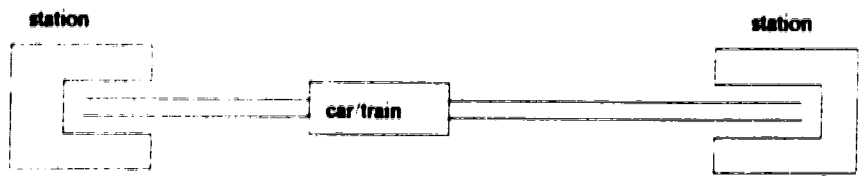



Figure 4.2: APM Shuttle Operation on a Single Guideway.

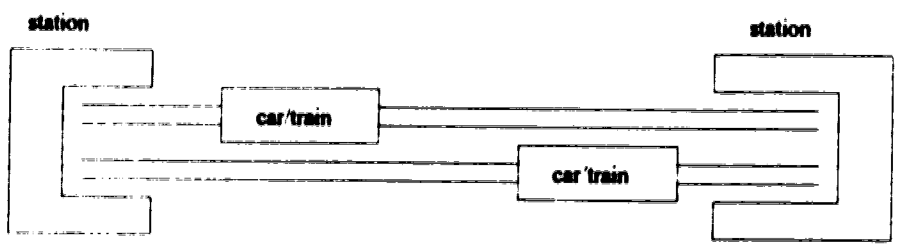



Figure 4.3: APM Double Shuttle Operation on Dual Guideway

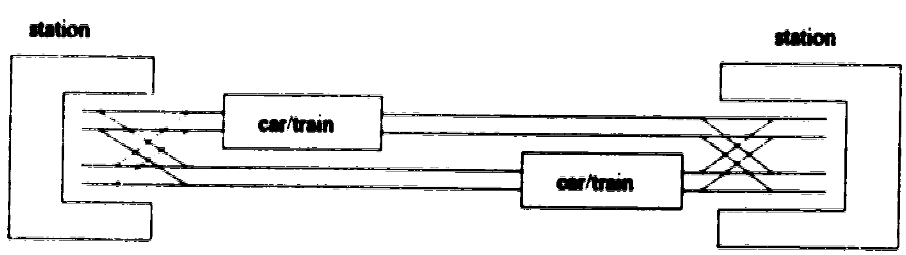



Figure 4.4: APM Pinched Loop Operation on Dual Guideway

## 4.4 Cost Model for Bus System

One of the concepts identified is having a fixed rail link passing by an airport and connected by a shuttle bus. The speed of operation or the travel time, convenience, cost of trip are quite different from rail systems and APM systems. A model is developed to study the performance of the link and to compare with other alternatives. The structure, features, and defaults of the model are discussed in the following sections.

### 4.4.1 Model Structure and Features

The basic structure of the model is similar to the RRT and the APM model with a few exceptions. The major cost components are the capital cost which includes cost of bus, garages, and buses stops and operating and maintenance cost Labour costs are dominant parts of operating and maintenance costs. There are various types of buses in operation for airport application. They vary in size from a small bus of capacity of 20 seats to a standard bus of 50 seats. The operating cost decreases with the increase of vehicle size. This is mostly due to higher labour productivity. Increase in other costs such as energy and maintenance are marginal with the increase of capacity. Obviously, capital investment also varies with size, from US $ 120,000 for a minibus to US $ 250,000 for standard bus with special features. For this research a standard bus with basic features was used with a cost of $ 200,000. In this model an average cost of US $ 50,000 is assumed per bus for necessary facilities, repair, maintenance, and storage. The facilities at bus stops would not be as extensive as in the case of rail stations. But, the cost varies with the facilities provided at the stop. The terminal would cost much more than a simple stop. Even a simple bus stop for airport application should have more facilities than a simple urban transit stop or a shelter. A bus terminal is much more expensive than a simple bus stop. Because a considerable variation exists in costs depending on facilities available, an average cost of US $ 57,500 is considered in the model (Armstrong 1985, Vuchic 1981).

These capital costs are converted into to annual costs by considering the life of each of the components. Table 4.7 presents the components of bus system, costs, and their life. It is assumed that the bus can share road facilities with other traffic, so the cost of providing roads is not included in the model. If the model were to be applied to include preferential lane treatment or exclusive busways, a cost for road construction and operations would be added.

Table 4.7: Cost and Life of Components of Bus Transit Systems

| Component | Cost (1991 US $) | Life (years) |
|---|---|---|
| Bus | 200,000 | 12 |
| Bus Terminal/Station | 57,500 | 40 |
| Garage | 50,000 | 40 |

The operating and maintenance costs are consistent when it is measured on the basis of bus kilometres. In 1975 US dollars the average is found to be $ 0.885 per bus kilometer (Vuchic 1981). In 1991 dollars it would be $ 1.94 per bus kilometre. According to a World Bank report (Armstrong 1985) the operating cost is $ 1.23 in 1991 dollars. In the model $ 1.94 is considered, because it is an average of fourteen North American systems which is a better representative of North American systems.

The number of enroute stops are defaulted at zero. The default cruise speed is set at 30 kmph. This is reasonable because the speed limits within airport internal road systems would be very low. This could vary considerably with the distance of rail station from terminal building. The model has an option to input the appropriate speed. The variation of acceleration and deceleration is not linear. For a cruise speed of 40 kmph the average acceleration rate for most of the buses is between 0.58 m/sec/sec and 0.75

m/sec/sec. For higher speeds it is lower than these values. A value of 0.58 is chosen for this model. The braking rate in normal operation with a well-trained driver is approximately uniform. In an emergency situation under all except very slippery conditions they decelerated at rates as high as 3 m/sec/sec. This is an extreme condition well beyond the tolerable situation for standing passengers. This model considers a rate of 1.1 m/sec/sec which is comfortable to seated passengers (Vuchic 1991). The capacity of bus is chosen to be 40 passenger. An occupancy rate of 90% is considered to determine the fleet and frequency. The model calculates the headways based on demand. The complete listing of the computer program, written in Quick Basic, is presented in Appendix B.

These three basic models; RRT, APM, and Bus systems, are used to calculate the cost of a single trip given the number of users and travel time. If a particular alternative has any combination of the three basic components, the cost of a trip and travel time are calculated by adding the individual costs and travel times of each component. The use of these parameters in the multicriteria analysis are explained in Chapter 5.

### 4.5 Travel Time and Cost of Trip by Automobile and Taxi

To compare the alternative concepts to the traditional modes such as automobile or taxi, techniques to develop operating costs and travel times for automobiles and taxis were required. The feasibility of alternative concept is evaluated by considering the travel time, cost of trip, convenience, reliability, accessibility, and others. Travel times for automobile or taxi are calculated for a generic situation. The following sections explain the details of the assumptions for a generic situation.

### 4.5.1 Travel Time by Auto or Taxi

The travel times by automobile and taxi are same for a given route and distance. These travel times depend on the speed limits on the links of the route and the amount of traffic flow on the links. The average speeds on the links are quite lower than the speed limits even at free flow conditions, because of the signals and other traffic control. For an airport related trip, an auto or a taxi usually takes some access routes first, followed by collectors, and ultimately joins a freeway. At the other end of the trip there will be some gradual reduction in speed till the destination is reached. On the airport side the access to the freeway or highway is better than the city end. For a generic city and generic airport the average speed is assumed to be a step function. The assumed variation of speeds with distance for a generic situation are presented in Table 4.8 (Quick Response 1978).

Table 4.8: Average Speeds for Automobile and Taxi for an Airport Access Trip

| Distance Range | Average Speed (kmph) |
|---|---|
| First 5 km | 35 |
| Between 5 and 10 km | 45 |
| Between 10 and 20 km | 60 |
| Between 20 and 40 km | 70 |
| Beyond 40 km | 90 |

Using the average speeds presented in Table 4.8, travel times are calculated for various distances ranging from 5 km to 50 km. The variation of travel times is presented in Figure 4.5. These values are later used in the evaluation of concepts.

### 4.5.2 Cost of Trip by Auto

Another important attribute of a mode is the cost of the trip. The earlier models for RRT, APM, and bus can calculate the cost of providing a trip by the respective modes.

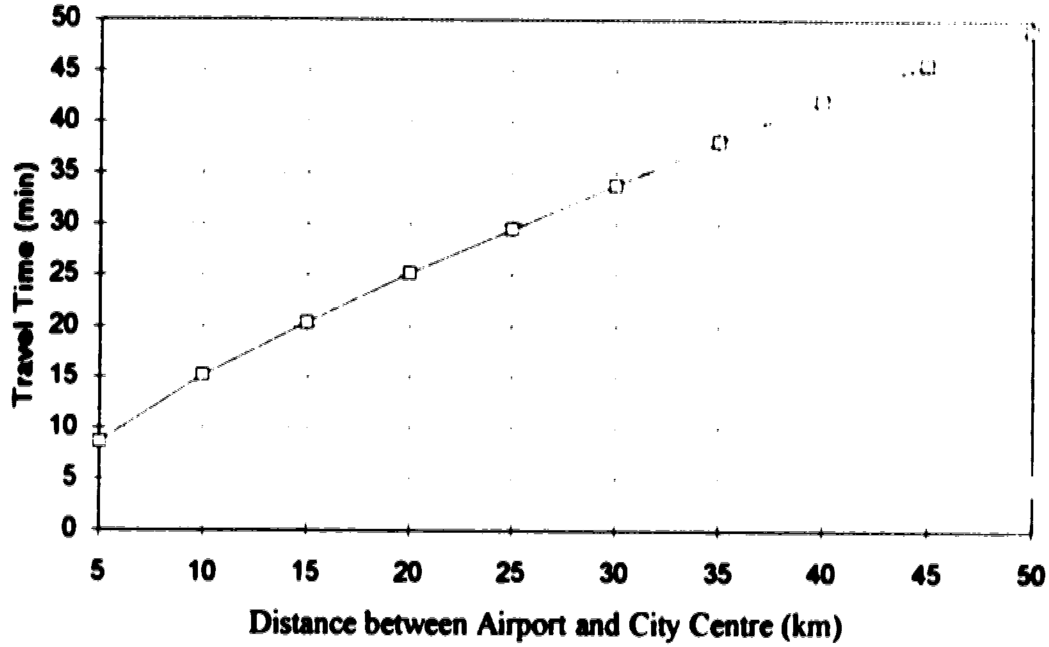



Figure 4.5: Travel Time Variation with Distance for Typical Airport Access Trips

To study the feasibility of the concepts cost of the trips by the alternative modes should be compared to the traditional modes. Cost of a trip by automobile is difficult to determine. The true cost should include gasoline costs, oil and tire costs, maintenance costs, insurance, depreciation, finance charges, and taxes. Table 4.9 presents the costs of owning and operating various cars and trucks in suburban environment calculated over twelve years, based on 205,600 kilometres (17,200 km/year). For the research an intermediate auto was selected to be the representative.

#### 4.5.3. Cost of Trip by Taxi

The cost of a trip by taxi is basically the fare charged. The fare generally has a fixed charge for a certain distance or initial call and then changes linearly with distance or time. There are certain additional charges involved in case waiting or for a pickup call.

Table 4.9 Cost of Owning and Operating Automobiles, Vans, and Light Trucks

| Type of Vehicle | Cost (U.S. cents per km) |
|---|---|
| Subcompact | 18.1 |
| Compact | 18.4 |
| Intermediate | 20.9 |
| Full-size car | 23.7 |
| Compact Pickup | 19.1 |
| Full-size Pickup | 21.9 |
| Minivan | 22.1 |
| Full-size Van | 28.0 |

Source: "Our Nations" 1992.

For this research these additional charges are not considered. Taxi fares are typically regulated by city commissions where they operate. Although minor variations exist in the structure, they can be treated uniform across many cities. For this research the fare structure of Edmonton, Canada, is chosen and fares are calculated in U. S dollars using an exchange rate of Can. $ 1.20 = US $ 1. The taxi fare structure of Edmonton is $2 for the first 150 m and 10 cents for every 150 m (Edmonton Taxi Commission). Figure 4.6 presents the variation of taxi fares with distances. When applying to a specific city, local rates can be used.

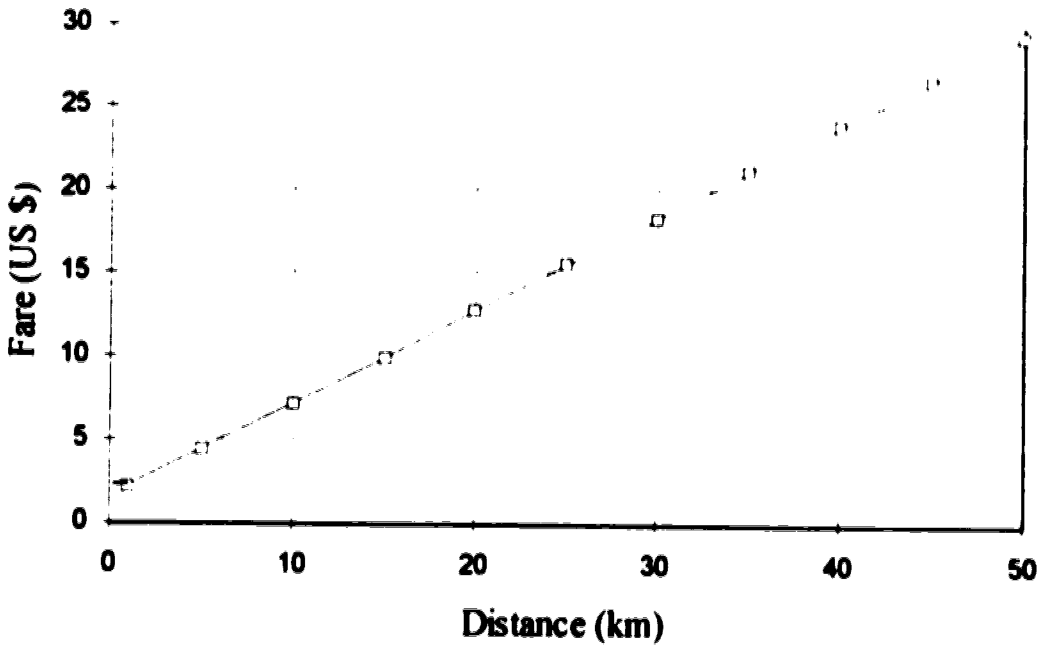



Figure: 4.6: Taxi Fares for Various Distances (Source: Edmonton Taxi Commission)

## 4.6 Multi Criteria Evaluation of Airport Access Alternatives

### 4.6.1 Introduction

Evaluation of airport access alternatives is quite complex. One has to consider several different factors or criteria to rank alternatives. Preferences may vary with individual criteria. If ranking of alternatives is done based on each criterion, one may select a different alternative depending on the specific criterion. It is difficult to rank the alternatives based on the combined criteria because some criteria such as travel time and cost can be quantifiable, but other criteria such as convenience or inconvenience, reliability, modal attraction, or environmental impacts can not easily be quantifiable. This leads to the need for a technique that could rank alternatives without expert judgment to rank alternatives.

The following sections explain some of the approaches available. An approach proposed by L. Thomas Saaty (1980) is explained in detail to compare alternatives. Fuzzy ratings on a common scale are used to compare alternatives with respect to criteria that are difficult to quantify. These ratings along with the quantifiable criteria have been used to rank alternatives. The relative merits of this approach and its application to evaluate airport access alternatives is presented in the following sections.

**4.6.2 Past Approaches**

*Engineering Economic Approach:* In this approach, problems are eventually defined by dollar dimensions and alternatives are evaluated by their monetary consequences. Evaluations rely mainly on mathematical models, but judgment and experience are pivotal inputs for the comparison of alternatives. Many acceptable models such as Benefit-Cost Ratio, Present-Worth, Equivalent Annual-Worth, and Rate-of-Return are available for the analysis and ranking of alternatives. There is considerable debate on the usage of these models where all the criteria can not easily be converted into dollar terms. If the criteria that can be converted into dollar values are only used to rank alternatives, one ends with biased ranking. To avoid this problem, judgmental inputs and expert advice are required. Sometimes the results may not reflect the views and preferences of the users or the affected parties. Because of these difficulties considerable time is involved in reaching consensus.

*Delphi Technique:* This can be considered as an interpersonal comparison of preferences. It is more subjective than mathematical. This is used where decision making or ranking of alternatives is complex. Decisions are taken by exchanging information, analyzing subjectively, and discussing among the participants until a consensus is reached. This process involves considerable amount of time and consensus can often not be easily achieved (Goicoechea 1982).

*Utility Function Approach:* This approach is used as a reasonable substitute for the Engineering Economic approaches and Delphi technique. As shown in Equation 4.5, the function is generally of linear form. The final utility values of alternatives are compared to rank alternatives.

$$U_i = \sum_j W_j . u_{ij} \qquad 4.5$$

$i$ = alternative

$j$ = criterion

$u_{ij}$ = preliminary utility value (criterion value) for alternative i and criterion j

$W_j$ = scaling factor or criterion weight assigned to criterion $j$

$U_i$ = utility value for alternative $i$ on a common utility scale

There are various approaches in practice to determine the weights ($W_j$) and preliminary utility values ($u_{ij}$) (Lifson 1982, Gomes 1989, Dee 1973). Lifson (1982) described a commonly used approach where the preliminary utility values are obtained from preliminary utility functions developed for each criterion. To develop these functions, cardinal utility scales are defined. Cardinal scale of measurement requires two points, representing the extreme values. In-between these two values, using a variety of techniques to elicit the judgmental data, preliminary utility functions are constructed. Preliminary utility functions represent the relationships between utility and various amounts of the criterion. The preliminary utility will be 1 (unity) for the most preferred amount of criterion ($y_m$), zero for threshold values ($y_t$) and negative for all the undesired values. The two frequently used relationships are the straight line, Equation (4.6), and the exponential, Equation (4.7).

$$u_j(y_j) = A_j y_j + B_j \qquad ...4.6$$

$$u_j(y_j) = A_j e^{B_j y_j} + C_j \qquad ...4.7$$

e = 2.7183, the base of the natural logarithm

$A_j, B_j, C_j$ = constants to be determined for the utility function of a particular decision criterion $y_j$.

$u_j(y_j)$ = preliminary utility function of criterion $y_j$

The purpose of the scaling factors or criterion weights ($W_j$) is to provide the relationship needed to assure a common scaling for the utilities of all criteria. In most cases these values are determined by judgment ( Lifson 1982 ), or by Delphi Technique (Dee 1973). Hence, determination of these weights by these methods has the same disadvantage as that of Delphi Technique. Saaty (1980) proposed a simple method to determine the weights and criterion values that reflect the user's preference. The utility value of an alternative is represented by Equation 4.8.

$$U = \sum_{j} w_j . c_j \qquad \text{.... (4.8)}$$

$U$ = utility value

$w_j$ = weight of criterion $j$

$c_j$ = criterion value of criterion $j$

The critical part of this method is to determine the criterion weights. This approach uses pairwise comparisons and eigenvectors to determine the weights. The eigenvectors of pairwise comparison matrix are proved to be an acceptable substitutes for criterion weights (Gomes 1989, Takeda 1987, Zimmerman 1983, and Saaty 1980). A linear utility function is generally acceptable with mutually exclusive criteria. In the linear utility function approach the criterion weights are to be determined in such a way that they reflect relative weights, therefore the utility value represents the aggregate value of an alternative. The hierarchical analysis proposed by Saaty (1977) is presented in the following section. The approach is successfully used in resource allocation, planning for public and private projects, conflict management, and construction management (Saaty 1980, AbouRizk 1993).

### 4.6.3 Application of Saaty's Approach to Compare Airport Access Alternatives

Saaty's method can be applied to measure the relativity of fuzziness by structuring the functions of the system hierarchically in a multiple objective framework. In this method relative criterion weights are computed from a pairwise comparison of criteria.

The eigenvector corresponding to the largest eigenvalue of the positive, non-zero, reciprocal matrix reflects the criteria weights.

The hierarchy of evaluation of the airport access problem is presented in the Figure 4.7. The first hierarchy level has a single objective: the overall attractiveness of an alternative. The second hierarchy level represents the criteria of evaluation, and the third level is the evaluation of alternatives using the criteria.

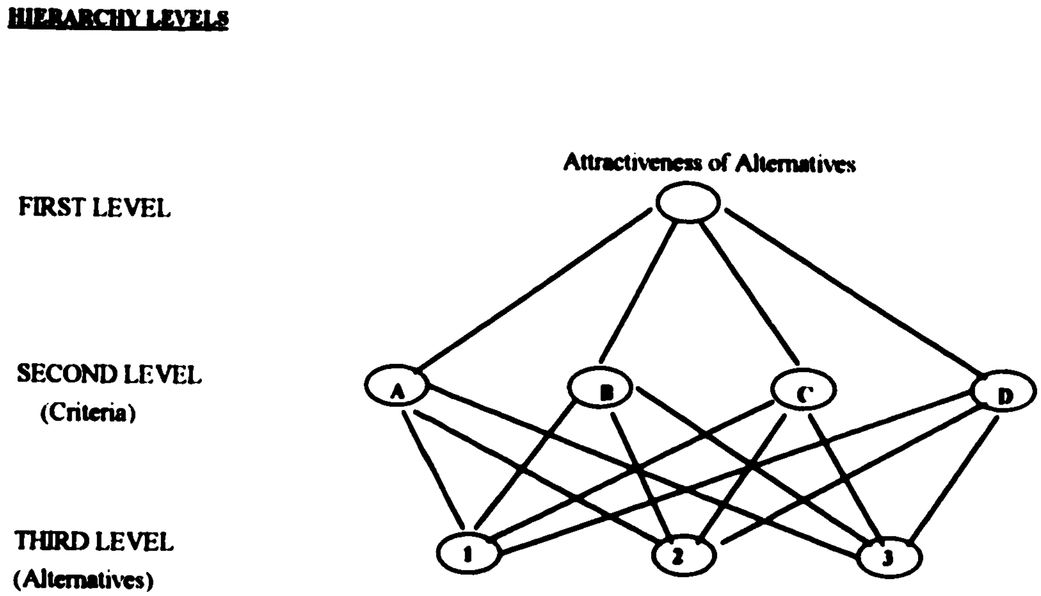



Figure 4.7: Hierarchy of Evaluation of Alternatives with Respect to Criteria

The first step in this analysis is to identify the criteria. The criteria for evaluation in the present context can be travel time, reliability of trip, cost of trip, baggage convenience, accessibility of mode, or parking convenience. The second step is to prioritize these criteria and assign weights to the criteria. This is done by comparing each criterion with others and assigning a fuzzy weight of importance on a scale of 1 through 9. For example, when criterion A is compared with criterion B a value of 1 is assigned if both criteria are equally important. A value of 9 is assigned if A is absolutely more important than B. Fuzzy weights for the intermediate importances are presented In Table 4.10. Various scales were tested for better suitability and reflectivity of human thinking process. It was found that 1 through 9 scale is a better representative of human cognitive process. This assignment of fuzzy values is thoroughly discussed and tested in real situations and proved to be very good approach to decision making (Saaty 1980).

Table 4.10: Fuzzy Weights for Comparison

| Comparison | Fuzzy Value |
|---|---|
| Equaliy important | 1 |
| Weakly more important | 3 |
| Strongly more important | 5 |
| Demonstratedly more important | 7 |
| Absolutely more important | 9 |

Values 2, 4, 6, and 8 may be assigned for compromise in judgment between 1 & 3, 3 & 5, 5 & 7, and 7 & 9 respectively

These values of pairwise comparison are represented in matrix form as shown in Equation 4.10. The criteria on the left side of the matrix are compared with the criterion on the top. This is a reciprocal matrix ($a_{ij} = 1/a_{ji}$) with unit diagonal indicating the fact that a criterion is equally important to the same criterion.

$$
[PWC] = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ . \\ C_n \end{array}
\begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots\cdots & C_n \end{array} \\
\left[\begin{array}{ccccc}
1 & a_{12} & a_{13} & \cdots & a_{1n} \\
1/a_{12} & 1 & a_{23} & \cdots & a_{2n} \\
1/a_{13} & 1/a_{23} & 1 & \cdots & a_{3n} \\
\cdots & \cdots & \cdots & \cdots & . \\
1/a_{1n} & 1/a_{2n} & 1/a_{3n} & & 1
\end{array}\right] \end{array} \quad ..(4.10)
$$

$a_{ij}$ = Fuzzy value for importance of criterion i to criterion j

$C_i$ = Criterion i

n = number of criteria

The eigenvector (CW) corresponding to the largest eigenvalue of the matrix [PWC] represents the criteria weights of each criterion. The determination of eigenvectors and eigenvalues are presented in Section D.1 of Appendix D. The largest eigenvalue of a reciprocal matrix lies between the largest and the smallest row sums and it is greater than or equal to the size of the matrix for a reciprocal matrix. For a consistent pairwise comparison matrix the largest eigenvalue would be equal to the size of the matrix and other eigenvalues would be zeros. Small perturbations of the entries in a positive reciprocal matrix imply small perturbations in the eigenvalues. The consistency of comparison can be checked by Consistency Index (CI) which is given by the Equation 4.11. The value could vary between zero and eight for pairwise comparison using 1-9 scale. The closer the value of CI is to zero the better the comparison. Any value less than 0.1 (less than 2%) is considered to be a valid comparison (Saaty 1980).

$$CI = (\lambda_{max} - n) / (n-1) \qquad \text{.... (4.11)}$$

CI = Consistency Index

$\lambda_{max}$ = Largest Eigenvalue

n = Number of Criteria

It is desirable that the priorities do not fluctuate widely with small changes in judgment. It is shown that reciprocal matrices are the typical matrices which produce stable eigenvectors on small perturbations of the consistent case (Saaty 1980).

The third step is to evaluate alternatives with respect to each criterion. For non-quantifiable criteria the procedure is similar to the pairwise comparison described earlier. Each alternative is compared with all other alternatives with respect to the criterion in question and a fuzzy value is assigned. The eigenvector corresponding to largest eigenvalue of this matrix would give the criterion values of alternatives with respect to the considered criteria. Similar values are determined for other criteria.

Since the basic idea of the pairwise comparison matrix is to obtain the weights to be used in the linear utility function, the approach is extended to quantifiable criteria. The criterion values are obtained for each alternative and the matrix for comparison can be determined by normalizing the criterion values. For example, if auto, taxi, and RRT are compared with respect to cost criterion, the cost of a trip by each mode is normalized using Equation 4.12 to get the first row of criterion values. The remaining rows can be developed from these values by maintaining 100% consistency ( CI = 0) by using Equation 4.12. The eigenvector for the largest eigenvalue gives the relative weights of the alternatives with respect to that criteria. In case of 100% consistency the eigenvector would have the normalized values of the reciprocals of any row of pairwise comparision matrix.

$$b_{ij} = b_{ij} / b_{ii} \qquad \ldots(4.12)$$

where $i = 1 \ldots a$

$j = i \ldots a$

$a$ = number of alternatives

The fourth step is to aggregate all the criteria values of the alternatives with respect to each criteria into one matrix as shown in Equation 4.13. Column 1 corresponds to the eigenvector of pairwise comparison matrix with respect to criterion 1, column 2 for criterion 2 and so on.

The final step is to multiply the matrix of criterion values [CV] by the criterion weights [CW], determined earlier, to get the final weights of alternatives. These final values on a ratio scale reflect all the criteria in proportion to their importance and can be used to rank the alternatives. The values can be treated as attractiveness on a relative scale. If the value of one alternative is slightly more than an another, it does not mean that latter is of considerably lower importance. If an important criterion is missing, addition of that criteria may widen the gap or change the order of ranking. Hence in such cases, caution has to be exercised in the interpretation of the result.

$$
\text{Criteria values}[CV] = \begin{array}{c} \\ \text{Alternatives} \\ A \\ B \\ C \\ D \end{array} \begin{array}{c} \text{Criteria} \\ \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \left[ \begin{array}{cccc} c_{a1} & c_{a2} & \cdots & c_{an} \\ c_{b1} & c_{b2} & \cdots & c_{bn} \\ c_{c1} & c_{c2} & \cdots & c_{cn} \\ c_{d1} & c_{d2} & \cdots & c_{dn} \end{array} \right] \end{array} \quad \ldots\ (4.13)
$$

If a dummy alternative, which has similar attributes as one of the basic alternatives, is included in the evaluation, the final weight of the dummy alternative has to be added to other alternatives in proportion to the weights. This will eliminate the error incurred by including any dummy alternative.

The differences between this approach and Delphi method are discussed in Section 4.6.3. This approach is applied to study the relative attractiveness of alternatives. The application of the method and the results are discussed in the following chapters.

#### 4.6.4 Differences between Delphi Method and Saaty's Hierarchical Method

1) *Anonymous versus operating group discussion:* In the Delphi method each member of the group responds anonymously to a previously prepared questionnaire to avoid disproportionate influence of strong personalities. In Hierarchical method the criteria and judgments are established by an open group process.

2) *Adjustment is series of rounds versus dynamic discussion:* In the Delphi method there must be a review of questionnaire results, and adjustments are requested on an anonymous basis. In the Hierarchical method dynamic discussion is used while constructing the hierarchy and judgments are provided throughout the process.

# 2

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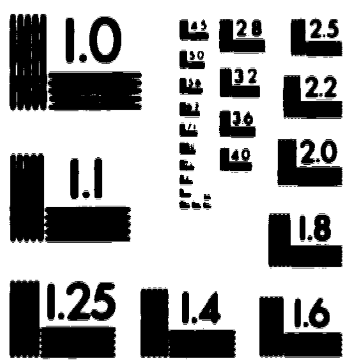


PRECISION℠ RESOLUTION TARGETS

3) *Questionnaire versus hierarchy structure as a basis for judgments:* In the Delphi method, the design of questionnaire implies the choice of the variables involved by the person who creates the questionnaire. In the Hierarchical method the group chooses the variables which have effect on the judgment to be made. Initially all variables suggested are accepted. Later in the procedure some might be ignored due to the assignment of low priority.

4) *Statistical and quantitative analysis versus qualitative analysis:* The Delphi method requires numerical responses which are to be analyzed statistically as a basis for the next round. In the Hierarchical method the judgments involve absolute numbers from 1 to 9 reflecting qualitative judgment on pairwise comparison and these are used as a part of a rigorous derivation of an estimate for an underlying ratio scale. Consistency is an important criterion as necessary condition to valid scaling of reality (Saaty 1980)

### 4.6.5 Computer Model

The Hierarchical analysis of alternatives was translated into a computer program. For the research, the computer model is written in Quick Basic to facilitate in any DOS environment. The model is capable of working at three levels of hierarchy, and can be used to accommodate seven criteria and seven alternatives. These limitations were imposed to fit the input and output data in one computer screen and for the airport application seven alternatives and seven criteria are considered to be good enough. The model can be expanded to accommodate more criteria and alternatives.

The model takes in the number of criteria, number of alternatives, pairwise comparison of criteria, and pairwise comparison of alternatives with respect to all the criteria and develops the final weight matrix. The power method is adopted to find the largest eigenvalue (dominant eigenvalue) and the corresponding eigenvector. The algorithm of the power method is described as follows.

Suppose $\lambda$ is the largest eigenvalue of A and V is the eigenvector corresponding to $\lambda$. The vector V and its eigenvalue $\lambda$ can be found by the following iterative procedure. Start with the vector in Equation 4.14 (Mathews 1987).

$Vo = (1,1,\ldots,1)$ .... (4.14)

Generate the $\{V_k\}$ recursively, using Equations 4.15 and 4.16

$U_k = A * V_k$ ....(4.15)

$V_{k+1} = U_k / c_{k+1}$ ....(4.16)

where $c_{k+1}$ is the element of $U_k$ of largest magnitude. The sequences $\{V_k\}$ and $\{c_k\}$ will converge to the V and $\lambda$ respectively:

$\lim_{k \to \infty} V_k = V$ and $\lim_{k \to \infty} c_k = \lambda$ ....(4.17)

The computer model iterates the procedure to an accuracy of 0.0001 between two successive iterations. The model needs only the upper diagonal elements in the pairwise comparison matrices. The model generates the rest of the elements from the reciprocal property of matrices. The listing of the model is presented in Appendix D.

The models described in this chapter are applied to identify the feasibility of fixed rail concepts and the evaluation of the concepts against the conventional airport access modes. Travel time by each component of a concept and the cost of providing trip are calculated using the RRT, APM, and/or Bus models. These parameters are supplied as some of the criteria in the multicriteria evaluation of alternatives for various demands.

# CHAPTER 5

# APPLICATION OF MODELS

## 5.1 Introduction

The three concepts developed for the research are evaluated at various passenger demand levels. The passenger demand level at which a particular concept becomes feasible is identified. The procedure followed for the evaluation is presented in Figure 5.1

To begin the evaluation, a set of criteria has been identified. The criteria include both the user's viewpoint and the operator's viewpoint. The criteria identified are explained in the following sections. For the criteria a pairwise comparison matrix is developed. The matrix consists of fuzzy preferences on 1 to 9 scale as described in Chapter 4. These preference weights can vary by city and airport and would be infuenced by factors such as the location of the airport, traffic congestion on the road network leading to airport, perceptions of the users, or the type and the major purpose of air travel This matrix would be developed locally by conducting a market survey of users to reflect the user preferences.

On the other hand, the concept considered for evaluation enters the model as one of the alternatives. This concept or alternative is compared with the competing modes to determine the relative attractiveness of each alternative. Some of the criteria considered for the evaluation may be quantifiable (cost or travel time) while other criteria are subjective. In case of subjective or non-quantifiable criteria, the criterion value matrix is developed using the scale of 1 to 9. These values can be developed by conducting a survey with the users specifying the alternatives and asking them to assign preferences to the alternatives with respect to each criterion. The values vary from airport to airport. For case specific studies, these values have to be developed for the airport under consideration. For quantifiable criteria, the criterion values may be obtained from the actual systems operation, or from estimates made in the planning process. For this

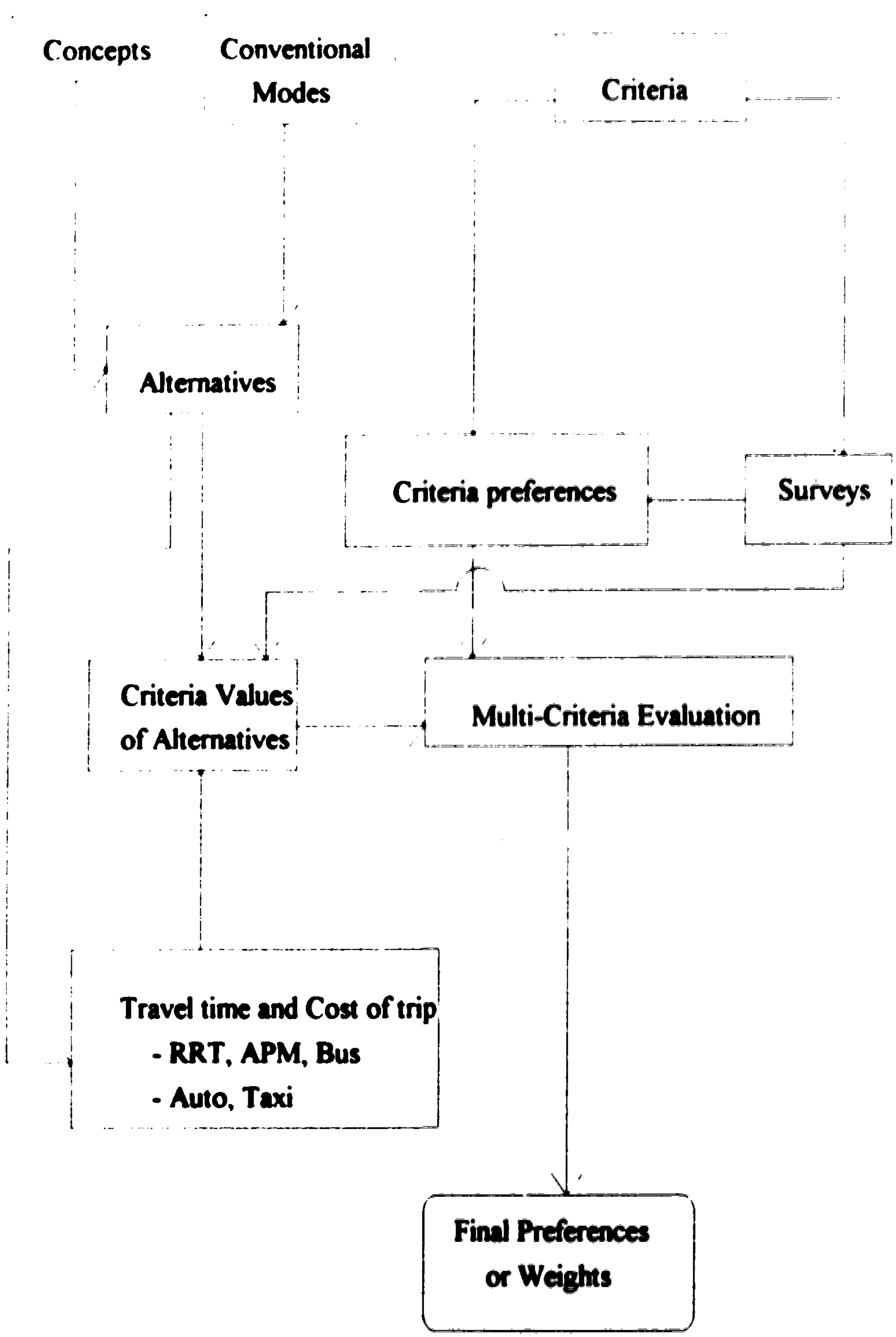


Figure 5.1: Procedure for Multi-Criteria Evaluation of Concepts

research, the values are obtained from the models developed for the components of the concepts and for the conventional modes which are explained in Chapter 4

With these two basic inputs, the model calculates the relative preferences of the alternatives. The following sections explain the use of this approach for the three concepts

## 5.2 Criteria of Evaluation

The criteria for evaluation for operator's point of view are often different from user's point of view. The operator of a system may be more interested in capital cost, operating and maintenance cost, and other costs. The cost that can reflect various cost components of the system is the annual cost per user. This cost is determined by annualizing all the capital costs and adding the annual operating and maintenance cost and then distributing the costs among the users. This reflects the cost of providing a trip and does not include subsidies. These costs can be calculated using the models developed for the RRT, APM, and Bus systems. If an alternative has different components of these basic systems, the cost per passenger on each system is calculated individually for the corresponding length of the trip and added together to get the total cost of the trip. The cost of trips for various distances on the three systems in 1991 US dollars are provided in Table C.1 to C.4 of Appendix C. The defaults used in developing these costs are explained in Appendix C. In case of private automobile, the cost of trip is calculated, as explained in Section 4.5.2, proportional to the distance that includes energy, depreciation, insurance, and other costs. Determination of the cost of trip by taxi is the fare as explained in Section 4.5.3.

A system user will be concerned with general factors including both cost and convenience measures. The criteria for user evaluation can be as follows.

- travel time
- reliability of trip
- cost of trip
- accessibility
- number of transfers
- baggage convenience
- walking distances
- safety and security

***Travel Time:*** It is the time taken for a trip with normal traffic and [illegible] free flow conditions. It does not include the delay caused due to congestion [illegible] ability of experiencing delay will be considered in reliability of trip. Travel time reflects the average operating speed of the trip under free flow conditions, in other words a vehicle travels in all the segments of the trip at the speed limits and obeys all traffic control devices. The time also includes the waiting time for transfers, and this [illegible] assumed to be half the headway at the transfer point. The travel times for various distances under certain defaults for the RRT, APM, and Bus systems are presented in Tables C.1 to C.4 in the Appendix C.

***Reliability of Trip:*** This reflects the congestion delay experienced by a mode and it directly relates to the interaction with other vehicles on the system. The reliability of fixed rail transit is extremely good while the road based modes have poorer reliability during peak periods because of interaction with other traffic.

***Cost of Trip:*** It is the actual cost incurred per passenger for the operator to provide the service. If required, the sensitivity of subsidies can be studied using the multicriteria evaluation by considering the actual fare.

***Baggage Convenience:*** It is the convenience on a mode that reflects the ease of carrying baggage on a particular mode. Transfer inconvenience can be considered in this criterion or can be treated separately. Automobiles or taxis generally have the best baggage convenience, whereas with fixed rail transit the baggage convenience is not as convenient unless special provisions are made available

*Transfer Convenience:* Each mode is associated with a certain number of transfers and each transfer is associated with some degree of inconvenience This has direct relevance with the number of bags carried by a passenger. The general perception of passengers is that they do not mind transferring if they do not have heavy baggage although, there is some inconvenience associated with transfers due to waiting and changing modes. Most people choose an automobile or a taxi to avoid the inconvenience of transferring with baggage.

*Accessibility:* This criterion reflects the ease with which a particular mode can be reached, availability of information, walking distances, and the directional signs and other information. The automobile provides the best accessibility at the city end, while the taxi is probably the best at the airport end. The accessibility of fixed rail transit at the airport end depends on the location of the station and at the city end it is next to auto and taxi. Taxi and bus are in between auto and fixed rail at the city end of a trip

*Parking:* Parking availability or parking cost is another important factor that influences the mode selection. If a trip is made by an automobile to the airport the vehicle has to be parked. It involves some cost for parking and the cost depends on the demand for parking. The parking costs vary from airport to airport and with the proximity of the parking to the terminal. Apart from the cost some inconvenience is involved in parking particularly with baggage. In case of drop off or pick up two trips are involved compared to one trip in case of drive in. In this research only driving in is considered for analysis. On the other hand, if a trip is made by taxi, bus, fixed rail transit, or limousine, there are no parking costs involved. Since both cost and convenience are involved and variations in costs exist, fuzzy ratings are considered for criteria values.

*Modal Attraction:* This is a overall quality of a mode that reflects the image, appearance, technology, and maintenance of the vehicles and stations. A service with new technology may attract some passengers. Conventional modes like bus have lower modal attraction. This is not an important criterion to be considered unless attractive new technologies are considered as alternatives.

In this multicriteria evaluation the number of criteria that can be incorporated is unlimited. The sensitivity of the evaluation will be effected if more criteria are considered. So it is often better to limit the number of criteria used in the evaluation. A small survey of users can indicate the important criteria to be considered for evaluation. The criteria considered in this research are defined in such a way that they are mutually exclusive as far as possible, so that a linear utility function approach can be applied to determine the overall attractiveness of an alternative.

## 5.3 Evaluation of Concept A: Dedicated or Exclusive Fixed Rail Link to Airport

The concept is applicable for airports which are proposing a new fixed rail link between the airport and the city centre. The probable competing modes for this alternative are automobile, taxi, and bus. For this concept, six evaluation criteria are considered: travel time, reliability of trip, accessibility of mode, cost of trip, baggage convenience, and parking.

Three cases were considered for the evaluation of dedicated rail links. In each case a generic airport is considered with varying attractiveness of business travelers and vacationers. Since business travelers are sensitive to travel time and tourists or vacationers are sensitive to cost (Tennyson 1975), the preferences of travel time and cost are varied among these cases depending on the proportion of the business trips or pleasure trips. In each case the analysis is done for various route lengths and minimum demand required for the rail alternative to be attractive is identified. The details of variations are presented in the following sections.

### 5.3.1 Case A-1: Travel Time is More Important than Cost

The first set of preferences considered is presented in Matrix 5.1. The criteria in first column are compared with the criteria on the top row. If the value is one, then the criteria on the left hand side is equally important than the criteria on the top. For example, a value of 9 means that the criteria on the left is much more important than the criteria on the top. In the reciprocal matrix presented in Matrix 5.1, travel time is considered to be more important than cost of trip. For this generic case study airport there are more business trips (around 90%) than pleasure or vacation trips. The city is assumed to have strong business activity and the reliability is equally important to travel time. This is true in case of air passenger, they are prepared to go early to the airport in order not to miss the flight. The reliability is more important for a trip to the airport and it is not as important for a trip from the airport, when compared to the travel time. A compromise value of 1 for equal importance is chosen. This importance is true for all kinds of passengers. Hence, the preference weight is not changed among threee cases of passenger combinations by purpose.

A fuzzy value of 2 is assigned to mode accessibility when compared to travel time. This indicates that reliability is more important than accessibility. Baggage convenience and parking convenience are considered to be next to travel time and accessibility of mode. They are assigned with a value 3 when compared to travel time. The remaining comparisons are presented in Matrix 5.1, which are chosen to maintain consistency with the earlier comparison. The consistency index of the pairwise comparison matrix is 0.0036 ( $\lambda < 0.1$), which is considered to be very good. These comparisons are chosen independent of alternatives, and reflect the user preferences in case of site specific study. The preferences presented in Matrix 5.1 are for a generic airport. The eigenvector corresponding to largest eigenvalue, presented in Matrix 5.2, represents criteria weights assigned to each criterion.

$$
PWC = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{array}
\begin{array}{c}
\begin{array}{cccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \end{array} \\
\begin{bmatrix}
1 & 1 & 2 & 2 & 3 & 3 \\
1 & 1 & 2 & 2 & 3 & 3 \\
1/2 & 1/2 & 1 & 1 & 2 & 2 \\
1/2 & 1/2 & 1 & 1 & 2 & 2 \\
1/3 & 1/3 & 1/2 & 1/2 & 1 & 1 \\
1/3 & 1/3 & 1/2 & 1/2 & 1 & 1
\end{bmatrix}
\end{array} \quad .....(5.1)
$$

$C_1$ = Travel Time $\qquad$ $C_4$ = Cost of trip

$C_2$ = Reliability $\qquad$ $C_5$ = Baggage Convenience.

$C_3$ = Accessibility $\qquad$ $C_6$ = Parking

$$
[CW] = \begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{array}
\begin{bmatrix} 0.270 \\ 0.270 \\ 0.148 \\ 0.148 \\ 0.082 \\ 0.082 \end{bmatrix} \quad .... (5.2)
$$

Consistency Index ($\lambda$) = 0.0036

Criterion values for the alternatives are generated for each criterion. For quantifiable criteria, travel time and cost of trip, the respective values are used to develop the criterion value matrix. For subjec· ·e or non-quantifiable criteria fuzzy values are assigned and explained later. In this research, the values are chosen for a generic airport and a generic city. For a specific application these values can be developed by conducting a market survey.

Travel times and cost of trips by RRT are calculated using the RRT cost model with all the defaults explained in Section 4.2.3. Travel times by automobile and taxi are calculated as described in Section 4.5.1. Travel times and costs of a trip by bus are calculated by making some modification to the Bus cost model, since this model is developed for the use as shuttle between the terminal and a rail station. The average operating speed and number of enroute stops are considered as presented in Table 5.1.

Table 5.1: Average Operating Speed and Enroute Stops Used in Bus Cost Model for the Evaluation of Concept A.

| Route Length | Average Operating Speed (kmph) | Number of Enroute Stops |
|---|---|---|
| L< 5.5 | 25 | 0 |
| 5.5 < L < 10.5 | 35 | 1 |
| 10.5 < L < 20.5 | 40 | 3 |
| 20.5 < L < 40.5 | 50 | 5 |
| L > 40.5 | 65 | 7 |

The travel times for 10 km. distance are 15.2 minutes by auto and taxi, 18.1 minutes by bus, and 11.6 minutes by rail transit. The alternatives are compared with respect to travel time and the normalized pairwise comparison matrix is presented in Matrix 5.3. Costs of a trip for 10 km distance by automobile and taxi are \$ 2.09 and \$ 7.17 respectively. Costs of a trip by bus and RRT with an average daily passenger of 1000 are \$ 1.41 and \$ 87.50 respectively. The alternatives are compared with respect to cost of trip and the normalized pairwise comparison matrix is presented in Matrix 5.4.

$$\begin{array}{ll} & \\ \text{PWC} = & \\ \text{(Travel time)} & \end{array} \begin{array}{c} \\ \text{Auto} \\ \text{Taxi} \\ \text{Bus} \\ \text{Rail} \end{array} \begin{array}{c} \begin{array}{cccc} \text{Auto} & \text{Taxi} & \text{Bus} & \text{Rail} \end{array} \\ \left[ \begin{array}{cccc} 1 & 1 & 18.1/15.2 & 11.6/15.2 \\ & 1 & 18.1/15.2 & 11.6/15.2 \\ & & 1 & 11.6/18.1 \\ & & & 1 \end{array} \right] \end{array} \quad \ldots (5.3)$$

PWC = (Cost of Trip) ... (5.4)

| | Auto | Taxi | Bus | Rail |
|---|---|---|---|---|
| Auto | 1 | 7.17/2.09 | 1.41/2.09 | 87.50/2.09 |
| Taxi | | 1 | 1.41/7.17 | 87.50/7.17 |
| Bus | | | 1 | 87.50/1.41 |
| Rail | | | | 1 |

The pairwise comparison of alternatives with respect to the reliability of a trip is presented in Matrix 5.5. The values reflect the degree of exposure of each mode to congestion. The most reliable alternative is the rail transit since as it is not exposed to any congestion and it is preferred most. A value of 1/4 is assigned to rail when auto is compared to rail transit. Since buses have to stop at enroute stops by pulling off the main traffic stream and joining after stopping, the reliability is less when compared to auto or ta. When auto is compared to bus, it is assigned a value of 2. These values may vary with the congestion situation of a city.

PWC = (reliability) ... (5.5)

| | Auto | Taxi | Bus | Rail |
|---|---|---|---|---|
| Auto | 1 | 1 | 2 | 1/4 |
| Taxi | | 1 | 2 | 1/4 |
| Bus | | | 1 | 1/5 |
| Rail | | | | 1 |

The pairwise comparison of alternatives with respect to accessibility (Matrix 5.6) reflects that auto is the most accessible, and taxi is the next best. Buses have better accessibility when compared to rail transit which has a fixed route. Buses can be diverted around problem areas. Fuzzy values of 1,3,5, and 7 are assigned when auto is compared to atuo, taxi, bus, and rail transit, respectively.

Baggage convenience is generally very good if passengers use autos or taxis. At least one transfer is involved with bus and rail transit, and some degree of inconvenience is associated with each transfer. So values of 1,1,7, and 7 are assigned when auto is compared with auto, taxi, bus, and rail transit respectively with respect to baggage convenience (Matrix 5.7). Matrix 5.8 presents the pairwise comparison of alternatives with respect to parking convenience. Only auto requires parking, hence fuzzy values of 1, 1/9, 1/9, and 1/9 are assigned to auto, taxi, bus, and rail transit respectively. Since a value of zero can not be assigned (the reciprocal becomes infinity), a small value of 1/9 is assigned to be consistent with 1 to 9 scale. The aggregation of all the eigenvectors corresponding to the largest eigenvalues of the Matrices 5.3 - 5.8 is presented in Matrix 5.9.

PWC = (Accessibility) ... (5.6)

| | Auto | Taxi | Bus | Rail |
|---|---|---|---|---|
| Auto | 1 | 3 | 5 | 7 |
| Taxi | | 1 | 2 | 3 |
| Bus | | | 1 | 2 |
| Rail | | | | 1 |

PWC = (bag. conv.) ... (5.7)

| | Auto | Taxi | Bus | Rail |
|---|---|---|---|---|
| Auto | 1 | 1 | 7 | 7 |
| Taxi | | 1 | 7 | 7 |
| Bus | | | 1 | 1 |
| Rail | | | | 1 |

PWC = (parking. conv..) ... (5.7)

| | Auto | Taxi | Bus | Rail |
|---|---|---|---|---|
| Auto | 1 | 1/9 | 1/9 | 1/9 |
| Taxi | | 1 | 1 | 1 |
| Bus | | | 1 | 1 |
| Rail | | | | 1 |

$$CV = \begin{array}{c} \\ \text{Auto} \\ \text{Taxi} \\ \text{Bus} \\ \text{Rail} \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \end{array} \\ \begin{bmatrix} 0.241 & 0.163 & 0.587 & 0.357 & 0.438 & 0.036 \\ 0.241 & 0.163 & 0.218 & 0.104 & 0.438 & 0.321 \\ 0.202 & 0.092 & 0.123 & 0.530 & 0.063 & 0.321 \\ 0.316 & 0.582 & 0.072 & 0.009 & 0.063 & 0.321 \end{bmatrix} \end{array} \quad \ldots (5.9)$$

The criteria preferences (Matrix 5.1), and alternative preferences with each criteria (Matrices 5.3 - 5.8) are input into the model. The output gives the final preferences and the eigenvectors of Matrices 5.3 - 5.8. The final weights for the case of 10 km route length and with a demand of 1000 passengers/day are presented in Matrix 5.10. This reflects the relative attractiveness of each mode. For a demand of 1000 passengers/day and on a route length of 10 kilometres, the auto mode is most. Auto gets a weight of 0.288 whereas, the final weight of rail transit is 0.286. Taxi has an edge over bus, but can not be as attractive as auto or rail transit.

$$\text{Final Weights} = \begin{array}{c} \text{Auto} \\ \text{Taxi} \\ \text{Bus} \\ \text{Rail} \end{array} \begin{bmatrix} 0.288 \\ 0.219 \\ 0.208 \\ 0.286 \end{bmatrix} \quad \ldots (5.10)$$

The process is repeated for various passenger demands and the level at which fixed rail transit is attractive is determined. Figure 5.2 presents the variation of final weights of alternatives with passenger demands for a route length of 10 km. Similar procedures are applied for route lengths of 15 km to 50 km in increments of 5 km. The variations of final weights are presented in Figures 5.3 - 5.10. Finally the variation of minimum passenger demand required for a dedicated fixed rail link to be attractive for a specific distance and for the set of preferences presented in Matrix 5.1 is presented in Figure 5.11.

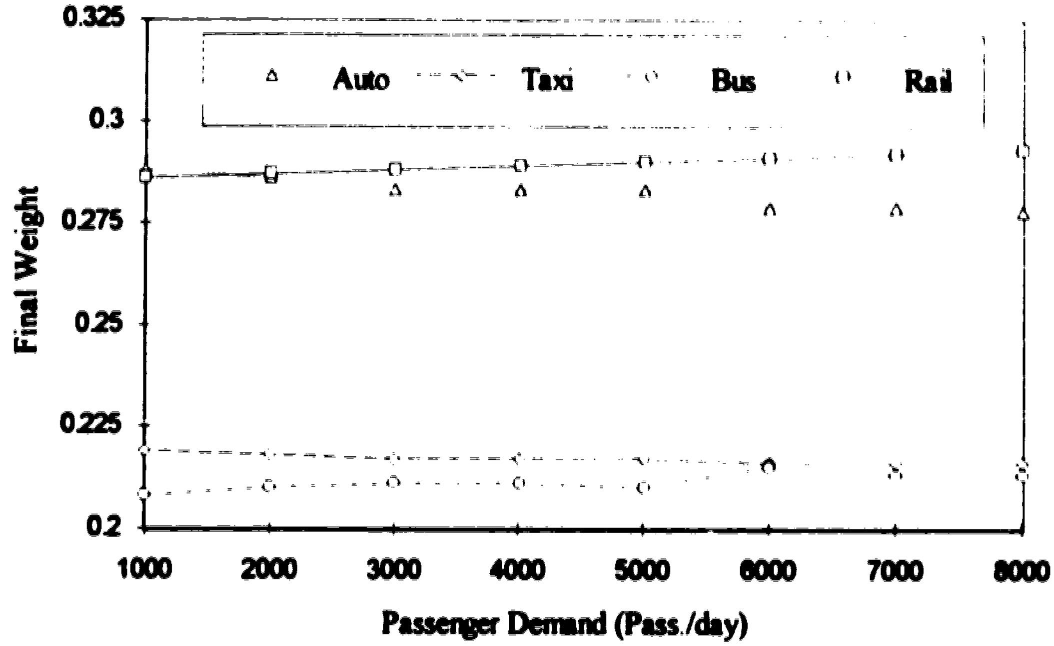


**Figure 5.2: Variation of Attractiveness with Passenger Demand for 10 km Route Length**

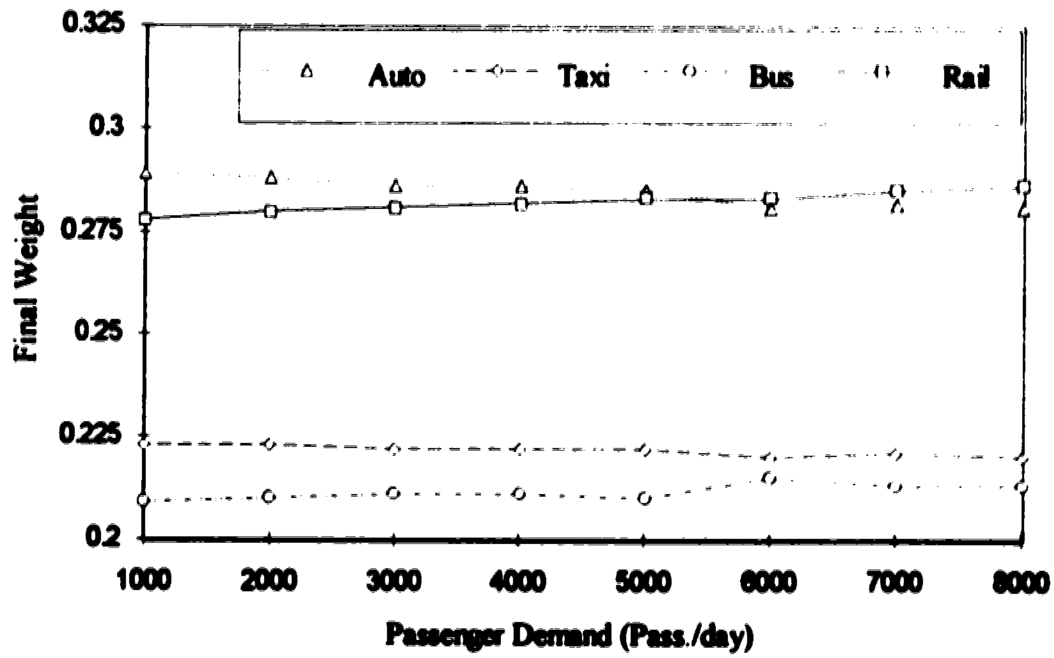


**Figure 5.3: Variation of Attractiveness with Passenger Demand for 15 km Route Length**

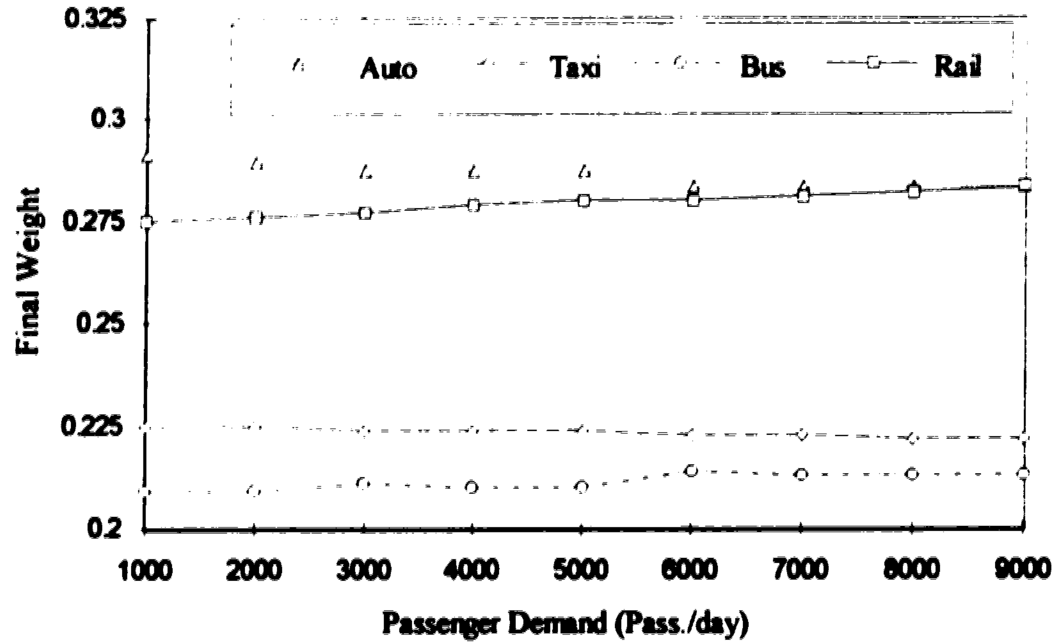


Figure 5.4: Variation of Attractiveness with Passenger Demand for 20 km Route Length

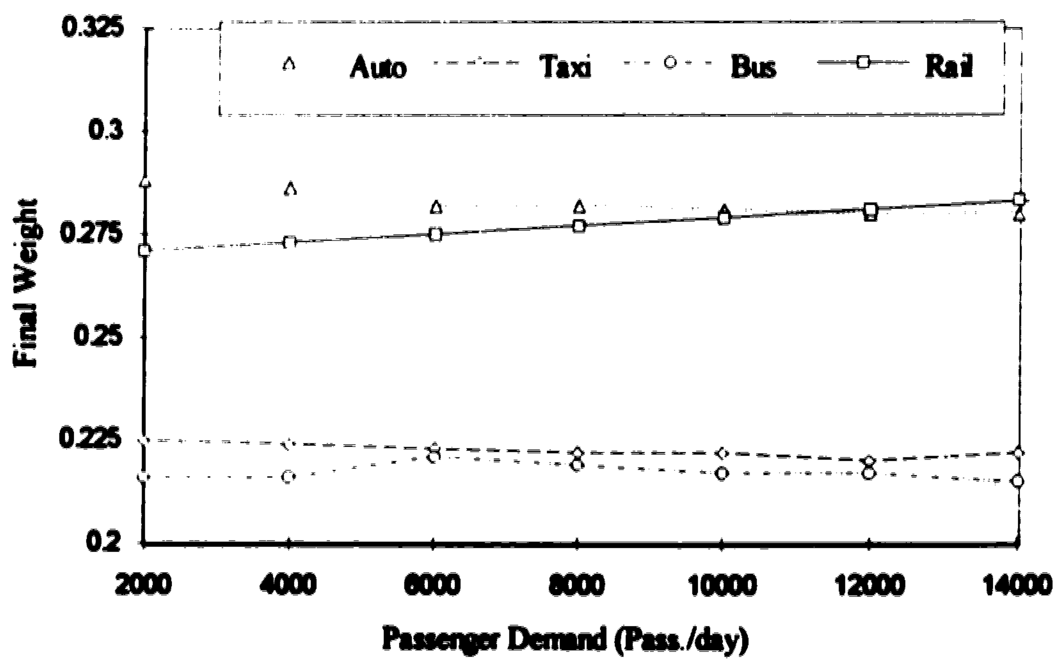


Figure 5.5: Variation of Attractiveness with Passenger Demand for 25 km Route Length

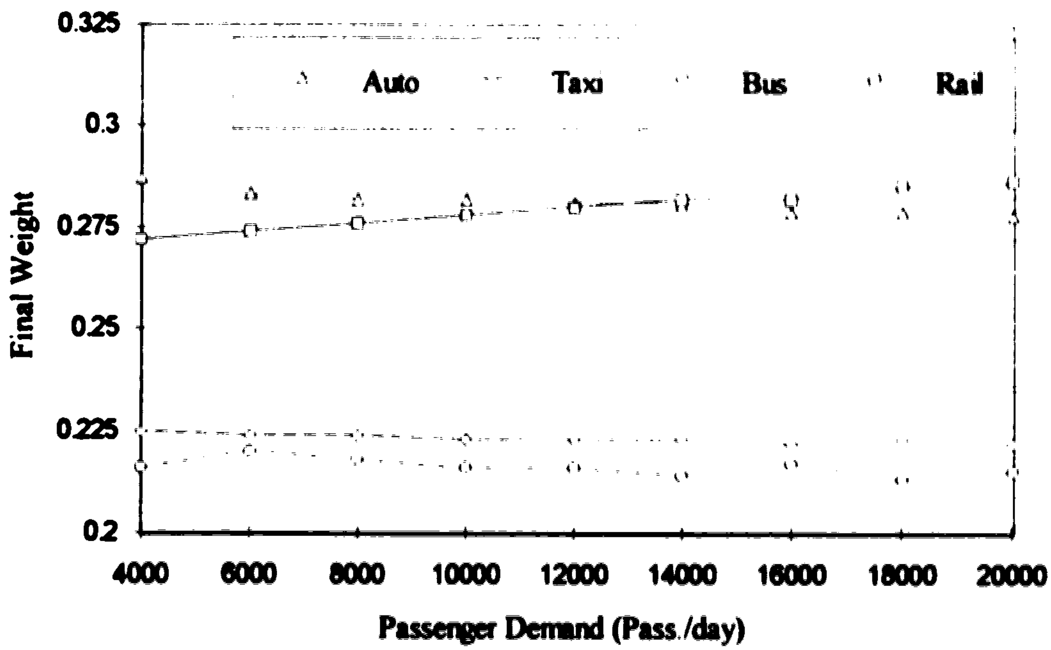


Figure 5.6: Variation of Attractiveness with Passenger Demand for 30 km Route Length

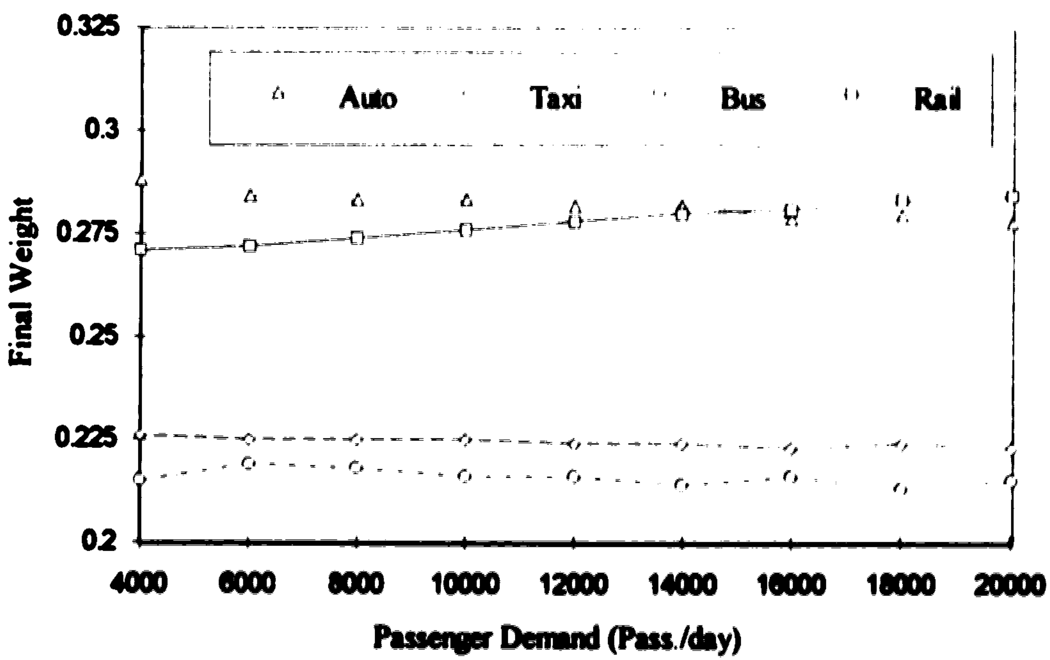


Figure 5.7: Variation of Attractiveness with Passenger Demand for 35 km Route Length

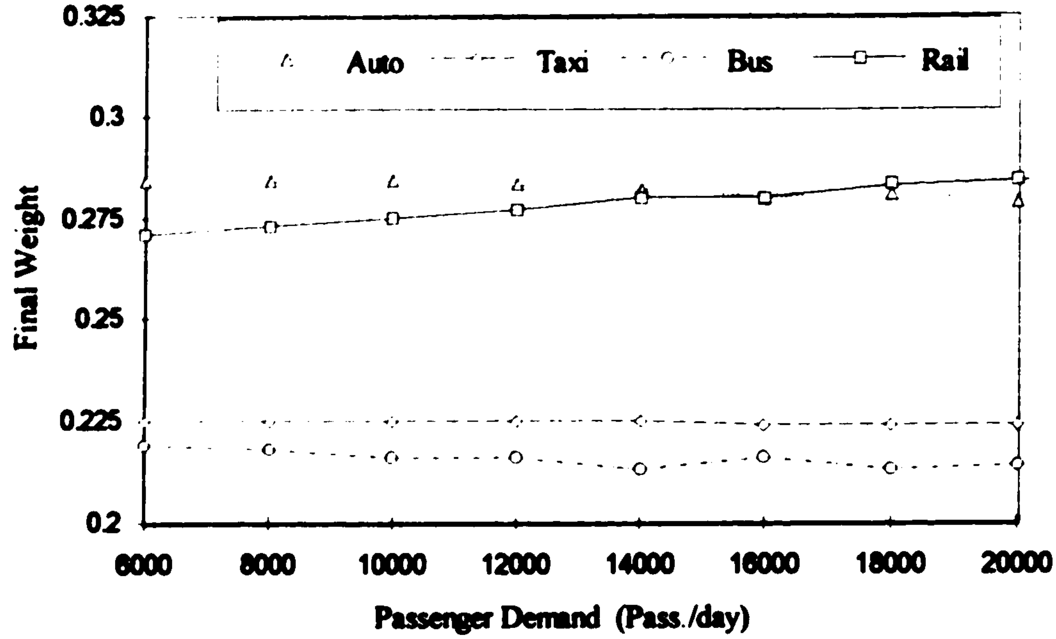


Figure 5.8: Variation of Attractiveness with Passenger Demand for 40 km Route Length

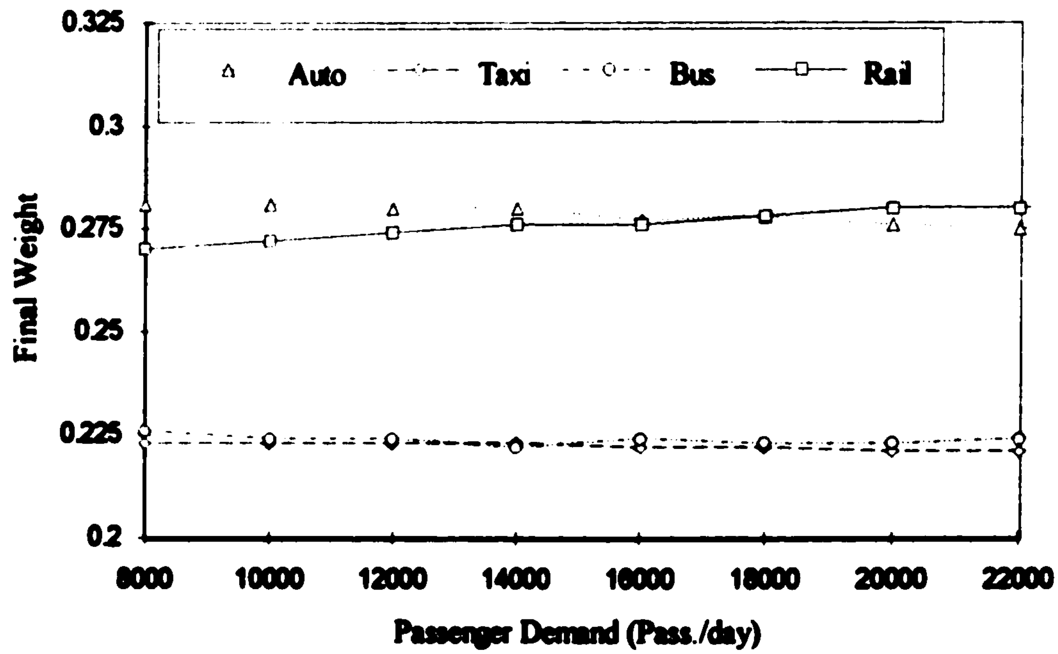


Figure 5.9: Variation of Attractiveness with Passenger Demand for 45 km Route Length

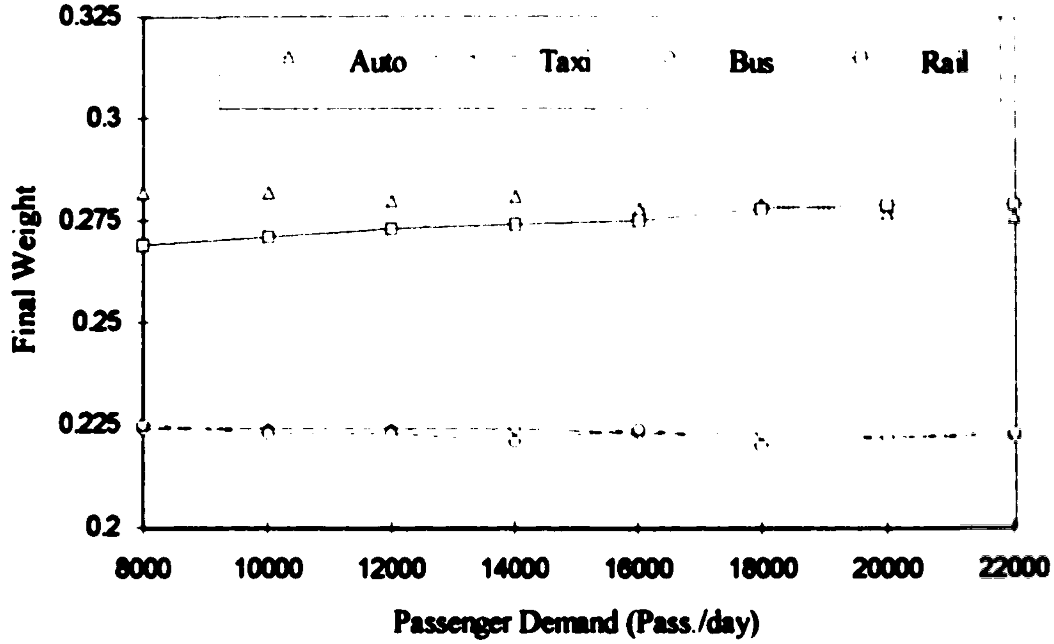


Figure 5.10: Variation of Attractiveness with Passenger Demand for 50 km Route Length

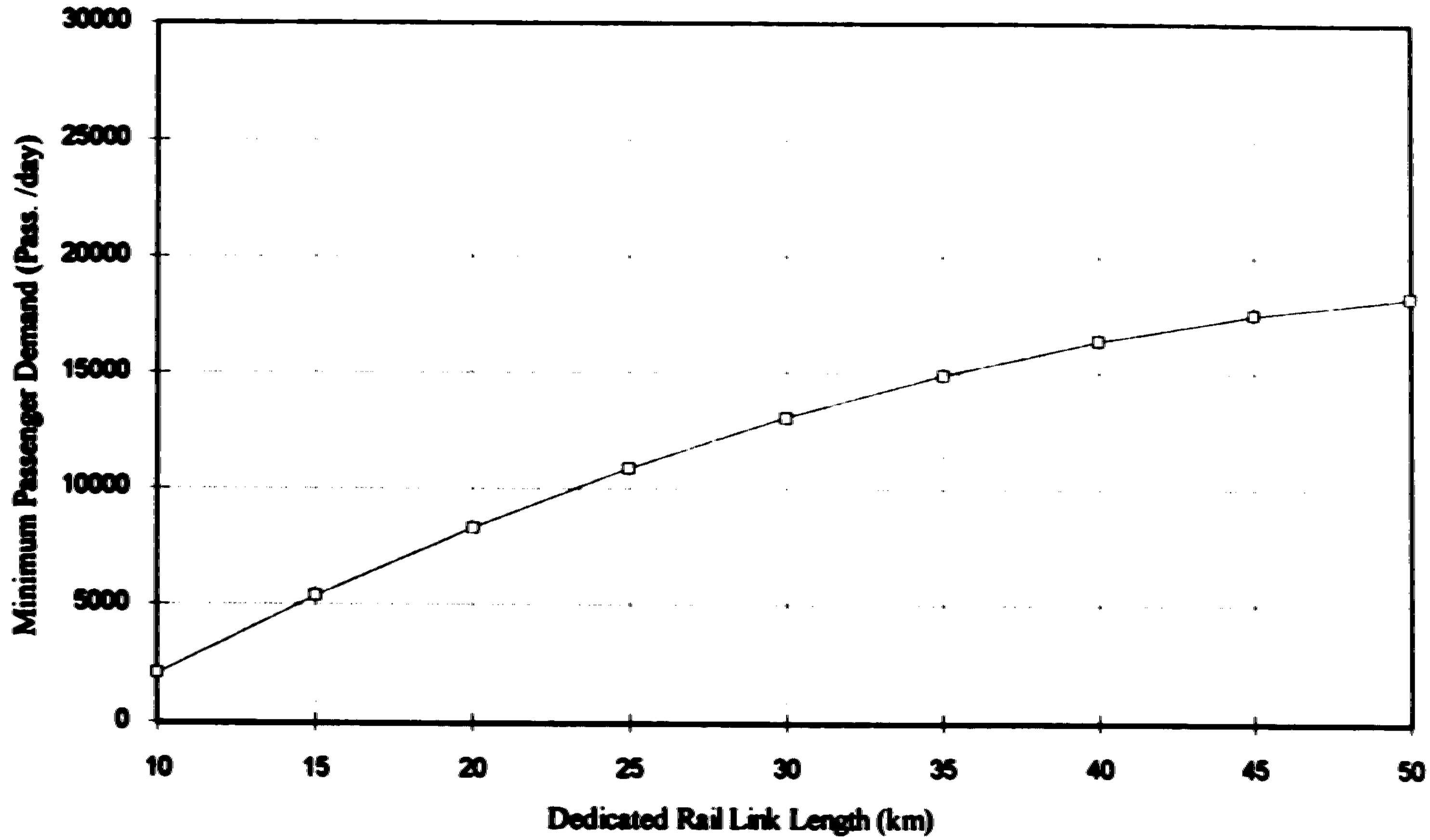


Figure 5.11: Variation of Minimum Passenger Demand Required for Dedicated Fixed Rail Links to be Attractive where Travel Time is more Important than Cost.

### 5.3.2 Case A-2: Travel Time is as Important as Cost

For the second case, the preferences considered are presented in Matrix 5.11. In this matrix, travel time is considered as important as cost and a fuzzy value of 1 is assigned. The generic case study airport is assumed to attract equal number of business and pleasure trips. The city is assumed to have a mixture of business and tourist activity. Since the airport attracts equal number of business and pleasure trips and business passengers are sensitive to travel time and tourists are sensitive to cost, the same fuzzy weight is assigned to both travel time and cost. Apart from changes made for maintaining the consistency, the remaining preferences are unchanged as presented in Matrix 5.3.1. The changes are represented in italics. The eigenvector for the largest eigenvalue is presented in Matrix 5.12.

$$PWC = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \end{array} \\ \left[\begin{array}{cccccc} 1 & 1 & 2 & \mathit{1} & 3 & 3 \\ 1 & 1 & 2 & \mathit{1} & 3 & 3 \\ 1/2 & 1/2 & 1 & \mathit{1/2} & 2 & 2 \\ \mathit{1} & \mathit{1} & \mathit{1/2} & \mathit{1} & \mathit{3} & \mathit{3} \\ 1/3 & 1/3 & 1/2 & \mathit{1/3} & 1 & 1 \\ 1/3 & 1/3 & 1/2 & \mathit{1/3} & 1 & 1 \end{array}\right] \end{array} \quad .....(5.11)$$

$C_1$ = Travel Time $\qquad$ $C_4$ = Cost of trip

$C_2$ = Reliability $\qquad$ $C_5$ = Baggage Convenience

$C_3$ = Accessibility $\qquad$ $C_6$ = Parking

$$[CW] = \begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{array} \left[\begin{array}{c} 0.239 \\ 0.239 \\ 0.132 \\ 0.239 \\ 0.076 \\ 0.076 \end{array}\right] \quad .... (5.12)$$

Consistency Index ($\lambda$) = 0.0027

Multiple criteria analysis is performed in the similar lines of case 1. The passengers demand level for rail alternative to be attractive is determined for route lengths 10 to 50 km with 5 km increments. The variation of minimum passenger demand required for a dedicated fixed rail link to be attractive for a specific distance and for the set of preferences presented in Matrix 5.13 is presented in Figure 5.12.

### 5.3.3 Case A-3: Cost of Trip is more Important than Travel Time

For the third case, cost of trip is treated to be more important than travel time. A value of 1/2 is assigned to cost when travel time is compared with cost, since travel time is less important than cost. The remaining preferences are unchanged, but consistency is maintained to reflect the change. The generic airport considered for this case assumed to have to attract more pleasure trips (around 90%) than business trips. The preferences are presented in Matrix 5.13. The changes are represented in italics. The largest eigenvector for this matrix is presented in Matrix 5.14.

$$PWC = \begin{array}{c|cccccc|} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \\ C_1 & 1 & 1 & 2 & \mathit{1/2} & 3 & 3 \\ C_2 & 1 & 1 & 2 & \mathit{1/2} & 3 & 3 \\ C_3 & 1/2 & 1/2 & 1 & \mathit{1/4} & 2 & 2 \\ C_4 & \mathit{2} & \mathit{2} & \mathit{4} & \mathit{1} & \mathit{6} & \mathit{6} \\ C_5 & 1/3 & 1/3 & 1/2 & \mathit{1/6} & 1 & 1 \\ C_6 & 1/3 & 1/3 & 1/2 & \mathit{1/6} & 1 & 1 \end{array} \quad .....(5.13)$$

$C_1$ = Travel Time $\quad$ $C_4$ = Cost of trip

$C_2$ = Reliability $\quad$ $C_5$ = Baggage Convenience.

$C_3$ = Accessibility $\quad$ $C_6$ = Parking

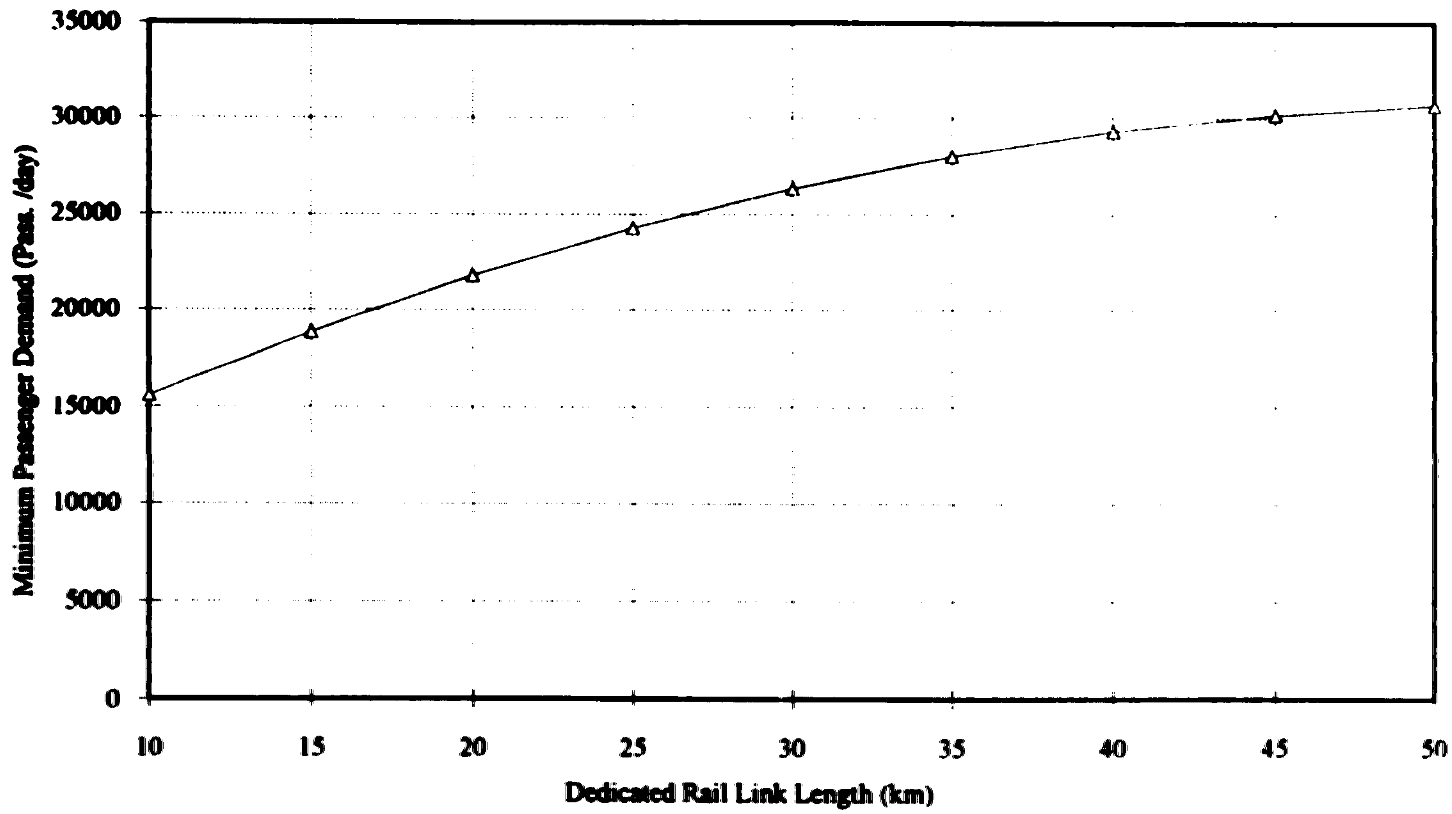


**Figure 5.12: Variation of Minimum Passenger Demand Required for Dedicated Fixed Rail Links to be Attractive where Travel Time is as Important as Cost.**

$$[CW] = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{matrix} \begin{bmatrix} 0.193 \\ 0.193 \\ 0.107 \\ 0.385 \\ 0.061 \\ 0.061 \end{bmatrix} \quad \text{.... (5.14)}$$

Consistency Index ($\lambda$) = 0.0027

Multiple criteria analysis is performed with the set of preferences presented in Matrix 5.14. The passenger demand levels for the rail alternative to be attractive are identified. The analyses suggest that rail alternative with the preferences presented in Matrix 5.14 would not be attractive at demands below 50,000 per day. For a 10 km route length the system needs 50,000 passengers per day and for 15 km it needs 53,000 per day. The system needs subsidies for it to be attractive at lower demands. The analysis was not carried out for demand levels beyond 55,000 passengers per day, since for an airport application 50,000 passengers on rail system is on the higher side.

Figure 5.13 presents the consolidated form of variation for the three cases considered for the dedicated rail link concept (Concept A).

## 5.4 Evaluation of Concept B: Extension of Existing Fixed Rail Links to Airport

The concept is applicable for airports that are proposing to extend an existing fixed rail line from its present location to the airport. The railway station of the rail link is assumed to be located with in the terminal and has good access and information about the service. The competing modes considered for this alternative are automobile, taxi, and bus. For this concept also the same evaluation criteria are considered: travel time, reliability of trip, accessibility of mode, cost of trip, baggage convenience, and parking.

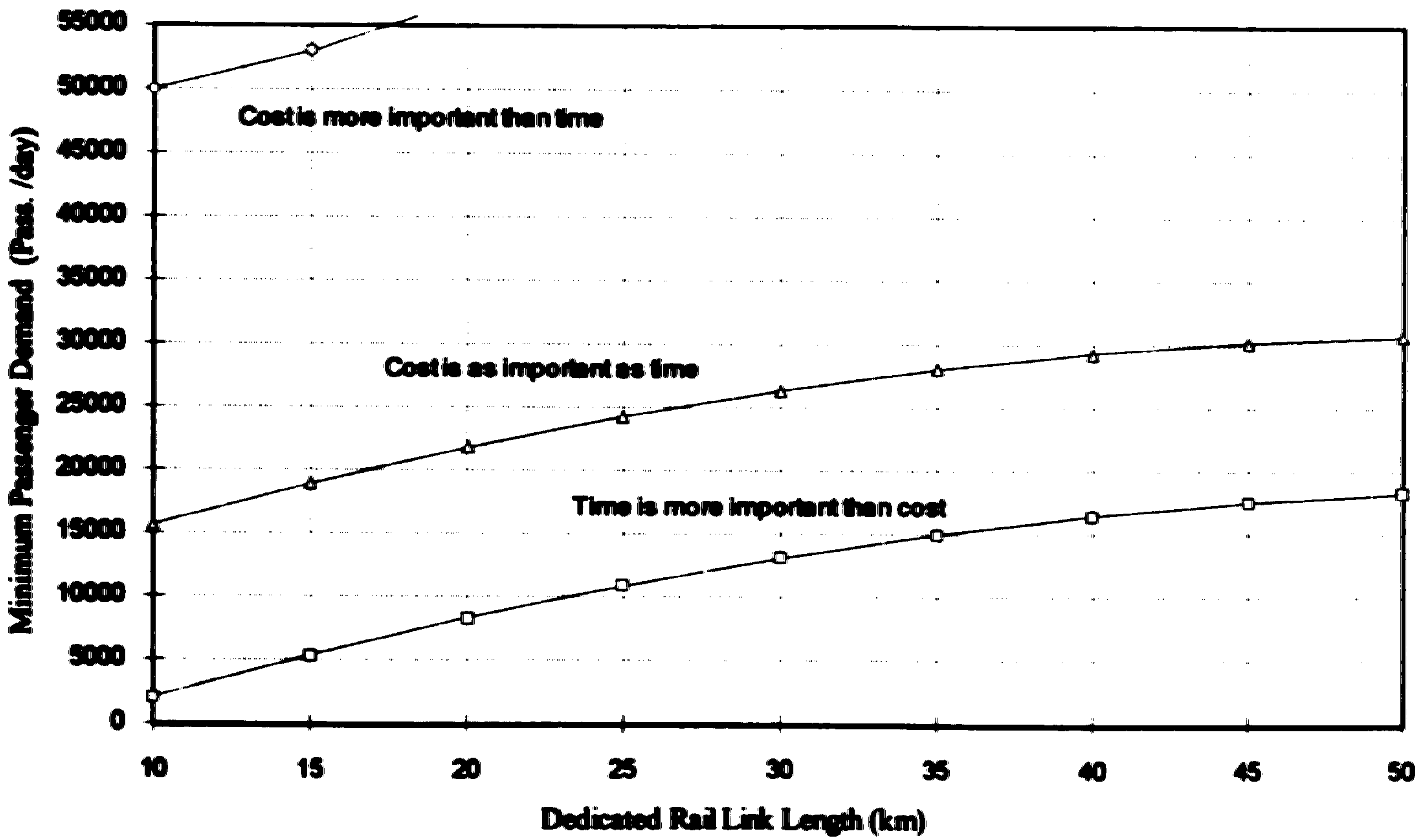


**Figure 5.13: Variation of Minimum Passenger Demand with Route Length for Direct Rail Link to Airports to be Attractive for Various Preferences of Cost and Travel Time**

In this concept also, three cases have also been studied for the evaluation. The three cases are similar to the dedicated link concept. In each case the analysis is done for total route lengths of 15, 20, 25 and 30 km. The extensions analyzed are from 2.5 km to 50% of the total route length with 2.5 km increments. For example, 2.5 km, 5 km, 7.5 km extensions are examined for a 15 km route length. The cost of the trip on rail transit is determined by adding the actual cost per user on the extension and a $ 3 fare on the existing line. The $ 3 fare seems to be reasonable since in most of the existing systems the fare varies between $1 and $5. The cost of trip on the extension is calculated using the RRT cost model for various passenger demand levels. With the exception of the cost calculation the rest of the procedure for the evaluation of the concepts is repeated for the three cases of preference weights as considered in the case of concept A. Minimum demands required for the rail extension to be attractive are identified for each extension corresponding to each route length. The analysis showed that there is no considerable difference among the cases of same extensions of different route lengths, that is 2.5 km extension of 15 km total route length, 2.5 km extension of 20 km route length and so on. The averages of the result for the three cases are presented in Figure 5.14.

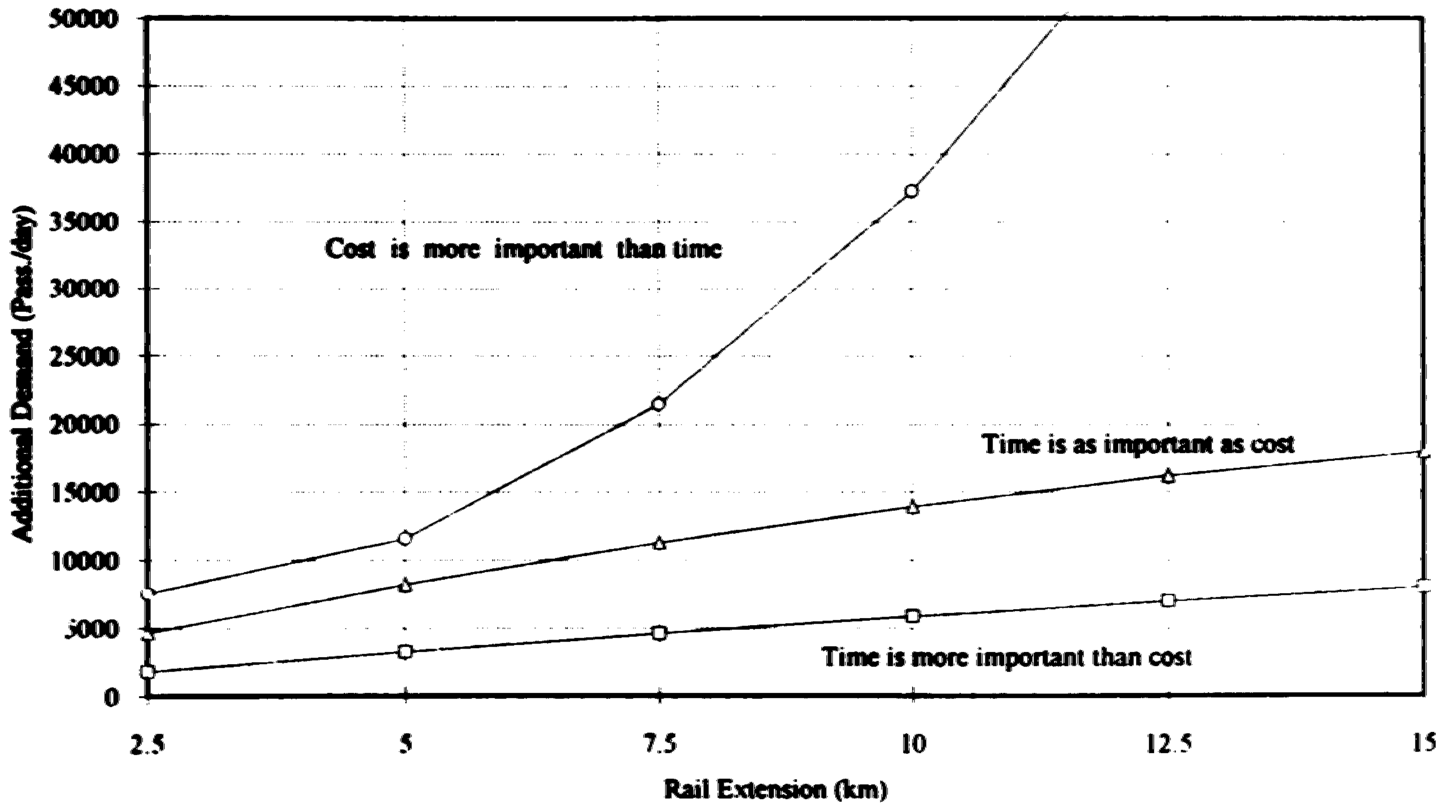


Figure 5.14: Minimum Additional Demand Required for Rail Extensions to Airport (Concept B) to be Attractive for various cost and travel time preferences.

### 5.5 Evaluation of Concept C: Connecting Rail Transit Station Near the Airport and the Terminal with Shuttle Bus or Automated People Mover Systems

This concept is applicable for airports that have a rail line that passes the airport. This may be an intercity, commuter rail line, or rail rapid transit line. This concept can also be applied to the rail links terminated at some distance from airport. A Shuttle Bus or an Automated People Mover (APM) service connects the rail transit station and the terminal(s) of the airport. Generally these systems have good access at the airport end.

The competing modes considered for evaluation of this generic case are automobile, taxi, and direct bus from city centre. These competing modes are evaluated against the alternatives of the concept, rail service on the existing link + shuttle bus service and rail service on the existing line + APM service. The criterion, modal attraction is added to the earlier list of criteria, travel time, reliability, accessibility, cost of trip, baggage convenience, and parking convenience. The relevance of this criterion can be justified by the presence of APM service in the options.

Once again three cases of criteria preferences have been considered for the evaluation to represent a spectrum of user preferences. The three cases are travel time is more important than cost of trip, travel time is as important as cost of trip, and cost of trip is more important than travel time. The upper diagonal elements of pairwise comparison of criteria matrices of these cases are presented in Matrices 5.15, 5.17, and 5.19 respectively and their relative weights are presented in Matrices 5.16, 5.18, and 5.20 respectively. When travel time is compared to modal attraction a fuzzy value of 5 is assigned and it is considered to be least important in the present set of criteria. The rest of fuzzy values for modal attraction, shown in italics of Matrix 5.15, are assigned to maintain consistency. The changes made for the cases where time is as important as cost and cost is more important than time are represented in italics in Matrix 5.17 and 5.19 respectively.

$$PWC = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \end{array} \begin{array}{c} \begin{array}{ccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \end{array} \\ \left[ \begin{array}{ccccccc} 1 & 1 & 2 & 2 & 3 & 3 & 5 \\ & 1 & 2 & 2 & 3 & 3 & 5 \\ & & 1 & 1 & 2 & 2 & 3 \\ & & & 1 & 2 & 2 & 3 \\ & & & & 1 & 1 & 2 \\ & & & & & 1 & 2 \\ & & & & & & 1 \end{array} \right] \end{array} \quad .....(5.15)$$

$C_1$ = Travel Time

$C_2$ = Reliability

$C_3$ = Accessibility

$C_4$ = Cost of trip

$C_5$ = Baggage Convenience

$C_6$ = Parking Convenience

$C_7$ = Modal Attraction

$$[CW] = \begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_5 \\ C_6 \end{array} \left[ \begin{array}{c} 0.255 \\ 0.255 \\ 0.142 \\ 0.142 \\ 0.080 \\ 0.080 \\ 0.046 \end{array} \right] \quad .... (5.16)$$

Consistency Index ($\lambda$) = 0.0042

$$PWC = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \end{array} \begin{array}{c} \begin{array}{ccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \end{array} \\ \left[ \begin{array}{ccccccc} 1 & 1 & 2 & 1 & 3 & 3 & 5 \\ & 1 & 2 & 1 & 3 & 3 & 5 \\ & & 1 & 1/2 & 2 & 2 & 3 \\ & & & 1 & 3 & 3 & 5 \\ & & & & 1 & 1 & 2 \\ & & & & & 1 & 2 \\ & & & & & & 1 \end{array} \right] \end{array} \quad .....(5.17)$$

$$[CW] = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_5 \\ C_6 \end{matrix} \begin{bmatrix} 0.227 \\ 0.227 \\ 0.127 \\ 0.227 \\ 0.075 \\ 0.075 \\ 0.042 \end{bmatrix} \quad .... (5.18)$$

Consistency Index (λ) = 0.0032

$$PWC = \begin{matrix} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \end{matrix} \begin{bmatrix} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \\ 1 & 1 & 2 & 1/2 & 3 & 3 & 5 \\ & 1 & 2 & 1/2 & 3 & 3 & 5 \\ & & 1 & 1/4 & 2 & 2 & 3 \\ & & & 1 & 6 & 6 & 9 \\ & & & & 1 & 1 & 2 \\ & & & & & 1 & 2 \\ & & & & & & 1 \end{bmatrix} \quad .....(5.19)$$

$$[CW] = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_5 \\ C_6 \end{matrix} \begin{bmatrix} 0.186 \\ 0.186 \\ 0.104 \\ 0.367 \\ 0.061 \\ 0.061 \\ 0.035 \end{bmatrix} \quad .... (5.20)$$

Consistency Index (λ) = 0.0079

Travel times for the rail + shuttle bus and rail + APM alternatives are determined by adding the travel time on the existing rail link using the RRT model and the travel times on the connections which are calculated by the Shuttle Bus model and the APM model. For the shuttle bus operation, a maximum speed of 30 kmph is assumed since the speed limits within the airport circulation roads is often low and the bus has to interact with other airport traffic. The time lost for the transfer from rail to the connection is added to the actual travel time. The lost time added to APM connection is half the headway of the APM service. Since transfers can be made possible across the platform, no other penalty is added. In case of shuttle bus connection apart from the transfer waiting time, half the headway, a penalty of 2.5 minutes is added to reflect the fact that the passengers have to come out of the station to transfer on to shuttle buses. The headways of both shuttle bus service and APM service are assumed to be 5 minutes. The travel times for other alternatives are calculated as described in the evaluation of Concept A and Concept B.

The costs of trips by shuttle bus and APM are calculated using the respective models. The cost of a trip by APM system is calculated by assuming a 100% elevated guideway. The final cost of a trip from the city centre to the airport is calculated by adding the cost of a trip on the connection and the basic fare on the rail link. For reasons mentioned in Section 5.4 a basic fare of $ 3 is assumed for the evaluation. The cost of trips by other alternatives are calculated as described in the earlier concepts.

The pairwise comparison of alternatives with respect to the reliability of a trip is presented in Matrix 5.21. The values reflect the degree of exposure of each mode to congestion. The most reliable alternative is the rail transit + APM since it is not exposed to any congestion and it is preferred most. A value of 1/4 is assigned when auto is compared to rail + APM. A value of 1/3 is assigned for the alternative rail + shuttle bus, since part of the trip has to interact with other airport traffic and the reliability is less when compared to rail + APM alternative. The fuzzy value for auto, taxi, and direct bus service are as presented in the earlier concepts.

PWC = (reliability) ... (5.21)

| | Auto | Taxi | Bus | Rail+S.Bus | Rail+APM |
|---|---|---|---|---|---|
| Auto | 1 | 1 | 2 | 1/3 | 1/4 |
| Taxi | | 1 | 2 | 1/3 | 1/4 |
| Bus | | | 1 | 1/4 | 1/5 |
| Rail+S.Bus | | | | 1 | 1/2 |
| Rail+APM | | | | | 1 |

The pairwise comparison of alternatives with respect to accessibility is presented in Matrix 5.22 and reflects that auto is the most accessible, and taxi is the next best. Buses have better accessibility when compared to rail transit options. Fuzzy values of 1,3,5,7, and 7 are assigned when auto is compared to atuo, taxi, bus, rail + shuttle bus, and rail + APM respectively.

Baggage convenience is generally very good if passengers use autos or taxis. At least two transfers are involved with rail + shuttle bus and rail + APM. An additional degree of inconvenience is associated with rail + shuttle bus alternative since buses are not as accessible as APM systems where a cross platform transfer is possible. So values of 1,1,5,9, and 7 are assigned when auto is compared with auto, taxi, bus, rail + shuttle bus, and rail + APM respectively with respect to baggage convenience (Matrix 5.23). Matrix 5.24 presents the pairwise comparison of alternatives with respect to parking convenience. Only auto requires parking, hence fuzzy values of 1, 1/9, 1/9,1/9, and 1/9 are assigned to auto, taxi, bus, rail + shuttle bus, and rail + APM respectively. Since a value of zero can not be assigned (the reciprocal becomes infinity), a small value of 1/9 is assigned to be consistent with 1 to ⁰ scale.

PWC = (Accessibility) ... (5.22)

| | Auto | Taxi | Bus | Rail+S.Bus | Rail+APM |
|---|---|---|---|---|---|
| Auto | 1 | 3 | 5 | 7 | 7 |
| Taxi | | 1 | 2 | 3 | 3 |
| Bus | | | 1 | 2 | 2 |
| Rail+S.Bus | | | | 1 | 2 |
| Rail+APM | | | | | 1 |

$$\text{PWC} = \atop \text{(bag. conv.)} \quad \begin{array}{l|ccccc|} & \text{Auto} & \text{Taxi} & \text{Bus} & \text{Rail+S.Bus} & \text{Rail+APM} \\ \text{Auto} & 1 & 3 & 5 & 9 & 7 \\ \text{Taxi} & & 1 & 5 & 9 & 7 \\ \text{Bus} & & & 1 & 3 & 2 \\ \text{Rail+S.Bus} & & & & 1 & 1/2 \\ \text{Rail+APM} & & & & & 1 \end{array} \quad \ldots (5.23)$$

$$\text{PWC} = \atop \text{(parking. conv.)} \quad \begin{array}{l|ccccc|} & \text{Auto} & \text{Taxi} & \text{Bus} & \text{Rail+S.Bus} & \text{Rail+APM} \\ \text{Auto} & 1 & 1/9 & 1/9 & 1/9 & 1/9 \\ \text{Taxi} & & 1 & 1 & 1 & 1 \\ \text{Bus} & & & 1 & 1 & 1 \\ \text{Rail+S.Bus} & & & & 1 & 1 \\ \text{Rail+APM} & & & & & 1 \end{array} \quad \ldots (5.24)$$

The evaluation of each case with the criterion value matrices described above is done for total route lengths (including connections) of 15, 20, 25, 30 kilometres. The connecting lengths considered are 0.5, 1.0, 1.5, 2.0, 2.5, 5.0, 7.5, and 10.0 kilometres. For example for a route length of 20 km route length the combinations examined are 19.5 km of existing rail link + 0.5 km connection by shuttle bus or APM, 19.0 + 1.0, 18.5 + 1.5, 18.0 + 2.0, 17.5 + 2.5, 15.0 + 5.0, 12.5 + 7.5, and 10.0 + 10.0 km. The results showed that there is no considerable difference among the route lengths for the same connecting length and the averages are matching with 20 km route lengths. The results also showed that rail + shuttle bus is not attractive at any demand level. In case of the preferences time is more important than cost and time is as important as cost either automobile or APM are attractive and in case of cost is more important than time direct bus and APM are attractive. The variation of minimum demand required for APM systems to be attractive for various route lengths for the three cases of preferences is presented in Figure 5.15.

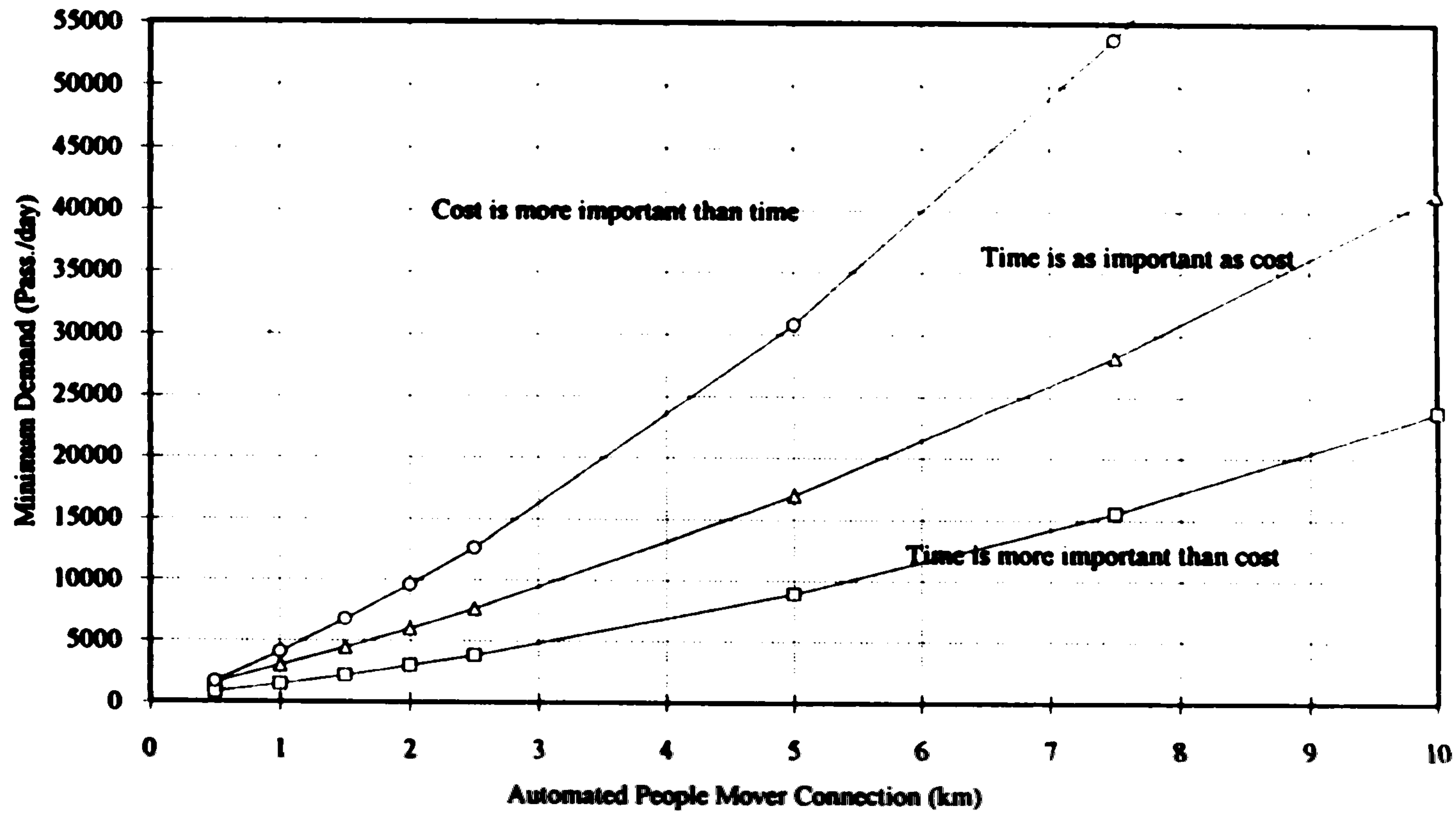


Figure 5.15: Minimum Additional Demand Required for Automated People Mover Connection from Rail Station to Airport (Concept C) to be Attractive for various cost and travel time preferences.

# CHAPTER 6

# SPECIAL ANALYSIS AND CASE STUDIES

## 6.1 Introduction

In Chapter 5, the procedure developed for the evaluation of alternatives is applied to the three basic concepts of rail access to airports. In the analysis certain basic assumptions about the facilities are made for generic applications. The procedure can also be applied to study the influence of changes in the facilities and services such as introduction of baggage check-in at stations, non-stop service, and fare changes. The procedure is valuable to study the influence of such changes on the attractiveness of alternatives.

In Section 6.2, the influence of various baggage handling options on the attractiveness of fixed rail options to the airports is presented. The procedure is also applied to three cases where available information and characteristics are supplied to the model and the feasibility of fixed rail alternatives is studied. These cases represent potential applications of rail access and are described in Sections 6.3, 6.4, and 6.5. These applications demonstrate the usage of the approach for specific purposes and for sensitivity analysis of parameters that influence the mode choice.

## 6.2 Special Analysis with Baggage Handling Options

### 6.2.1 Introduction

Baggage convenience is one of the important factors that influences the selection of airport access mode. Most vacationers have considerable baggage while business travelers have few bags that are checked. If special baggage handling facilities are provided, the influence on the modal attraction changes depending upon the composition of passengers with the two basic journey purposes. To study the influence, the concepts with various baggage handling options were examined with the multi-criteria analysis.

The following sections present the analyses of concepts and the ranges of demands that would make fixed rail alternatives attractive.

### 6.2.2 Analysis of Concept A (Exclusive Fixed Rail Service)

In Section 5.3, Concept A was evaluated by assuming that there are no special baggage handling facilities provided at stations or on trains and minimum ranges of demands are identified for various route lengths. Further analysis was undertaken with two types of baggage handling facilities:

1) special baggage handling facilities on trains, and

2) baggage check-in facilities at railway stations.

The details of these facilities and the criterion values are discussed below.

*The Special Baggage Handling Facilities on Trains:* With this kind of facility the baggage is dropped off at the stations. The rail authority or an agency handles the bags and delivers them at the destination of the rail journey. The passengers have to collect the bags at the airport or at the rail station on the destination end. The advantages and disadvantages of these facilities are as follows.

Advantages:

1. There is no inconvenience of carrying the bags into and out of trains
2. It is faster and convenient to board and alight trains during short dwelling times along with the non-airport passenger

Disadvantages:

1. There is an additional responsibility with the rail operators and would cost more to set up and operate the facility.
2. The passengers have to come in advance of schedule departure of the train to submit the bags that enables the system operator to ship the bngs along with the passengers and it is not a problem if the service is frequent.
3. There is an element of risk involved for passenger that bags may miss or may not be delivered in time for check-in with airlines.

*Baggage Check-in Facilities at Stations:* With these facilities, the baggage is checked-in at the rail station(s), shipped to the airport and loaded onto the respective airplanes. The responsibility of the baggage lies with the airline or the airline agent. There will be an additional cost involved for the airline to set up such facility. The passengers have to take the risk that the baggage may not go along with them on the aircraft on which they travel.

The criterion values for the alternatives for the two baggage handling options are presented in Matrices 6.1 and 6.2. These values reflect the risks described earlier. In the Matrix 6.1, fixed rail option is given a fuzzy value of 5 when compared to automobile against the value of 7 if such facilities are not provided. The rest of the matrix is developed to maintain the consistency. In the Matrix 6.2, fixed rail option is assigned with a fuzzy value of 3 when compared to automobile. Even when check-in facilities are provided at stations, rail is not perceived better than automobile or taxi because of the risks mentioned earlier. The rest of the matrix is developed to maintain the consistency.

$$\begin{array}{ll} & \\ \text{PWC} = & \\ \text{(bag. conv.)} & \end{array} \begin{array}{l} \\ \text{Auto} \\ \text{Taxi} \\ \text{Bus} \\ \text{Rail} \end{array} \begin{array}{cccc} \text{Auto} & \text{Taxi} & \text{Bus} & \text{Rail} \\ \end{array} \left[ \begin{array}{cccc} 1 & 1 & 7 & 5 \\ & 1 & 7 & 5 \\ & & 1 & 1/2 \\ & & & 1 \end{array} \right] \quad \ldots (6.1)$$

$$\begin{array}{ll} & \\ \text{PWC} = & \\ \text{(bag. conv.)} & \end{array} \begin{array}{l} \\ \text{Auto} \\ \text{Taxi} \\ \text{Bus} \\ \text{Rail} \end{array} \begin{array}{cccc} \text{Auto} & \text{Taxi} & \text{Bus} & \text{Rail} \\ \end{array} \left[ \begin{array}{cccc} 1 & 1 & 7 & 3 \\ & 1 & 7 & 3 \\ & & 1 & 1/3 \\ & & & 1 \end{array} \right] \quad \ldots (6.2)$$

The analysis is carried out keeping the criterion values of travel time, reliability, accessibility, and parking unchanged and with the two sets of criterion values for baggage convenience. The minimum daily passenger demands required for the fixed rail alternative to be attractive are identified for various route lengths, ranging from 5 km to 50 km, for the three criteria preferences: (1) more business passengers, (2) equal number of business passengers and vacationers, and (3) more vacationers using the airport. The evaluation of alternatives is carried out using the same procedure as discussed in Section 5.2. The minimum passenger demands required for the fixed rail options be attractive for various route lengths with baggage handling facilities at stations and baggage check-in facilities at stations are presented in Figures 6.1 and 6.2 respectively.

For example, a 20 km rail link to an airport attracting equal number of business passengers and vacationers will be attractive above an average daily demand of

- 22,000 passengers if no facilities are provided,
- 19,000 passengers if baggage handling facilities are provided (about 14% reduction), and
- 16,500 passengers if baggage check-in facilities are provided ( about 25% reduction).

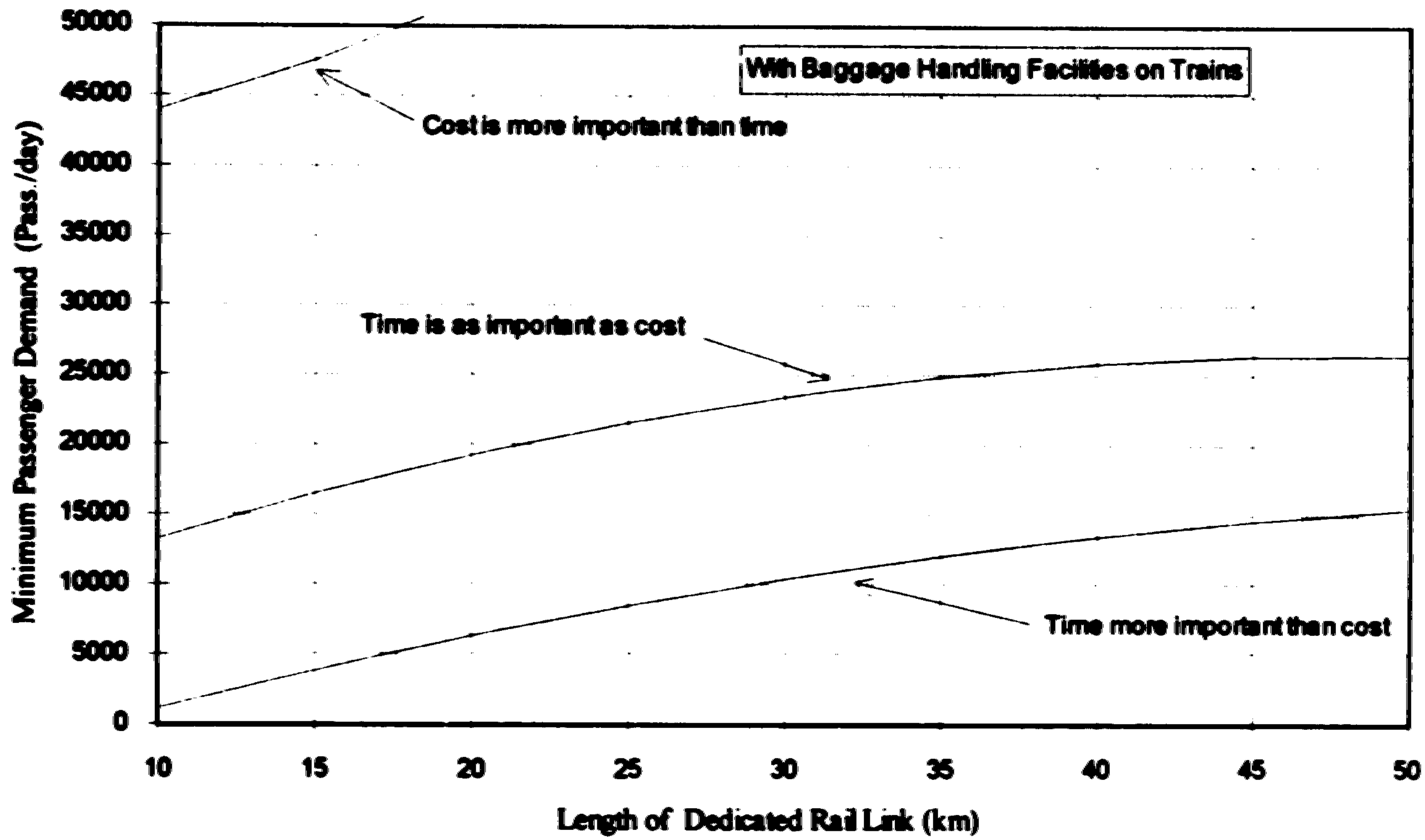


Figure 6.1: Minimum Passenger Demand Required for the Exclusive Rail Links to be Attractive if Baggage Handling Facilities are Provided on Trains.

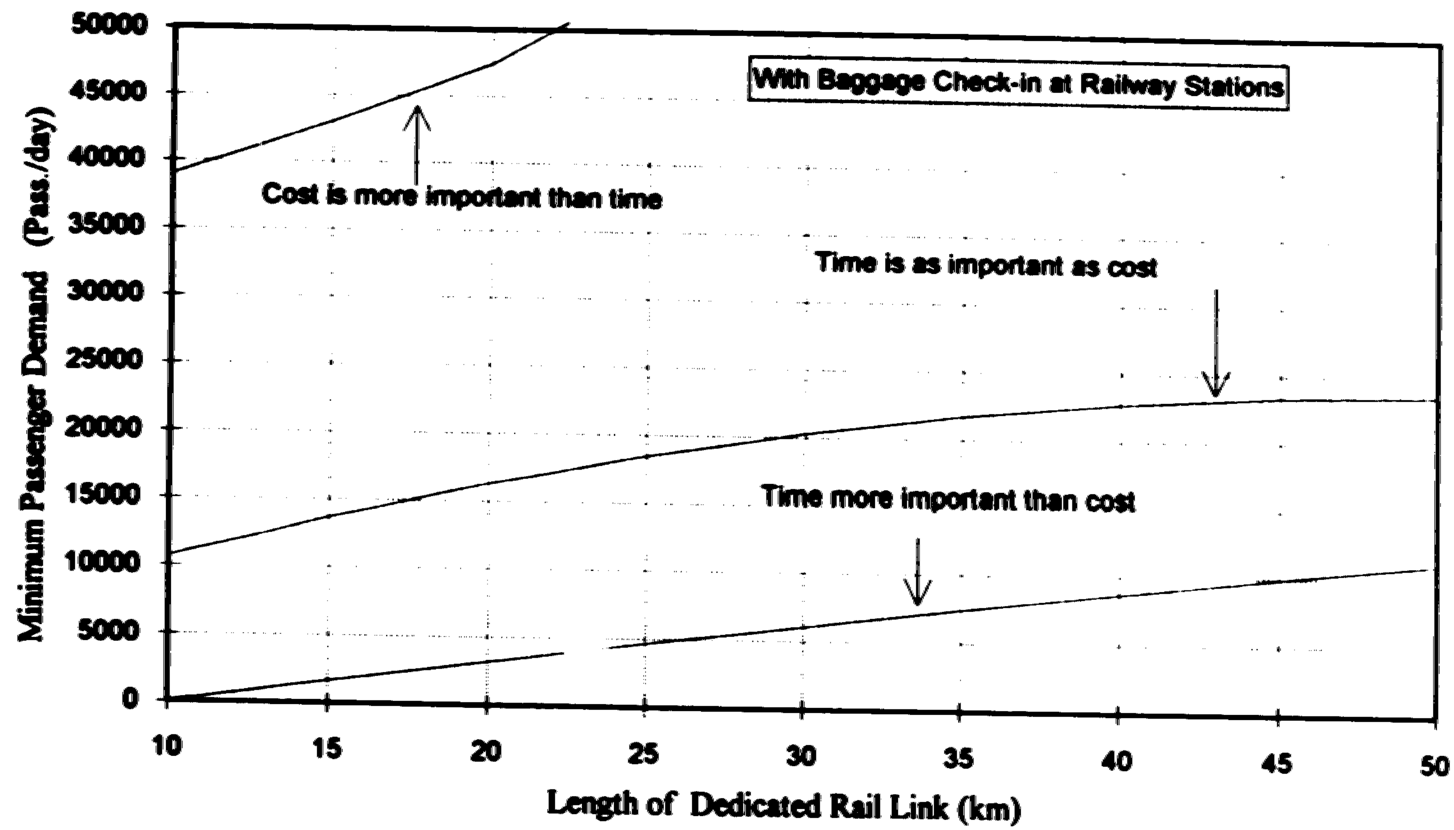


**Figure 6.2: Minimum Passenger Demand Required for the Exclusive Rail Links to be Attractive if Baggage Check-in Facilities are Provided at Stations.**

### 6.2.3 Analysis of Concept B (Extension of Rail Links to Airport)

Concept B, with no baggage handling facilities, was evaluated earlier in Section 5.4. Here the extensions of rail links to the airports are evaluated with the two baggage handling options. The two options: (1) special baggage handling facilities on trains and (2) baggage check-in at stations are similar to the facilities considered in Concept A.

The criterion values for the alternative modes to airports for the two baggage handling options are presented in Matrices 6.3 and 6.4. The fuzzy values assigned to the modes reflect the inconveniences and risks associated with each mode. The analysis is carried out with the same criterion values of travel time, reliability, accessibility, and parking as described in the Section 5.4. The procedure presented in Section 5.4 is repeated with the new baggage handling options and minimum passenger demands for the rail extensions to be attractive are identified for the three preference sets: (1) more number of business passengers, (2) equal number of business passengers and vacationers, and (3) more number of vacationers. The results of the analysis of having baggage handling facilities on trains and baggage check-in facilities at stations are presented in Figures 6.3 and 6.4 respectively.

PWC = (bag. conv.) ... (6.3)

| | | Auto | Taxi | Bus | Rail Ext. |
|---|---|---|---|---|---|
| PWC = | Auto | 1 | 1 | 7 | 5 |
| | Taxi | | 1 | 7 | 5 |
| (bag. conv.) | Bus | | | 1 | 1/2 |
| | Rail Ext. | | | | 1 |

PWC = (bag. conv.) ... (6.4)

| | | Auto | Taxi | Bus | Rail Ext. |
|---|---|---|---|---|---|
| PWC = | Auto | 1 | 1 | 7 | 3 |
| | Taxi | | 1 | 7 | 3 |
| (bag. conv.) | Bus | | | 1 | 1/3 |
| | Rail Ext. | | | | 1 |

For example, a 5 km extension of rail link to an airport attracting equal number of business passengers and pleasure trips would be attractive above a demand of

- 8,000 passengers per day if no baggage handling facilities are provided,
- 7,000 passengers per day if baggage handling facilities provided on trains (a reduction of 12.5%), and
- 6000 passengers per day if baggage check-in is provided at stations (a reduction of 25%)

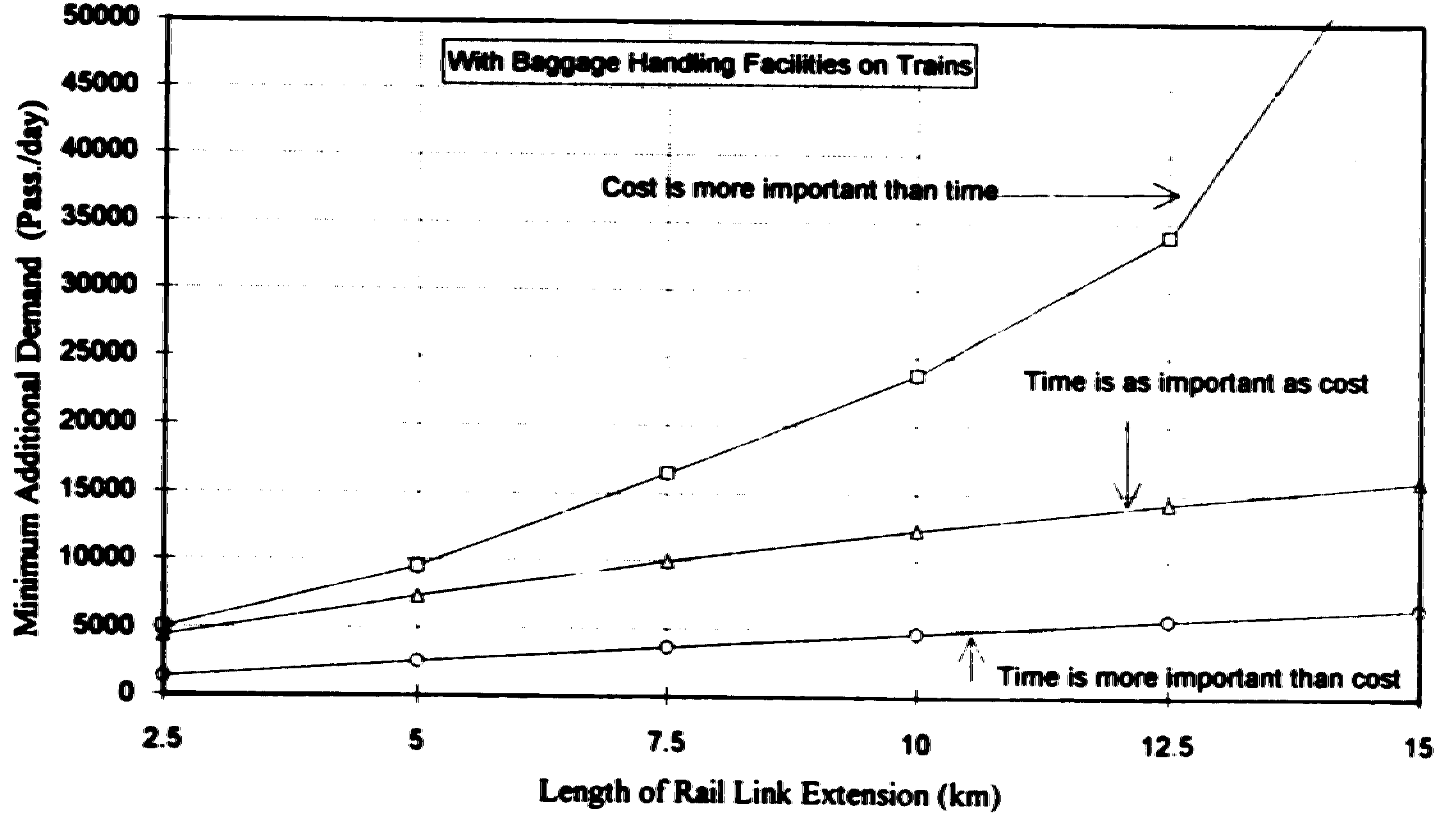


Figure 6.3: Minimum Passenger Demand Required for the Extension of Rail Links to Airport to be Attractive if Baggage Handling Facilities are Provided on Trains.

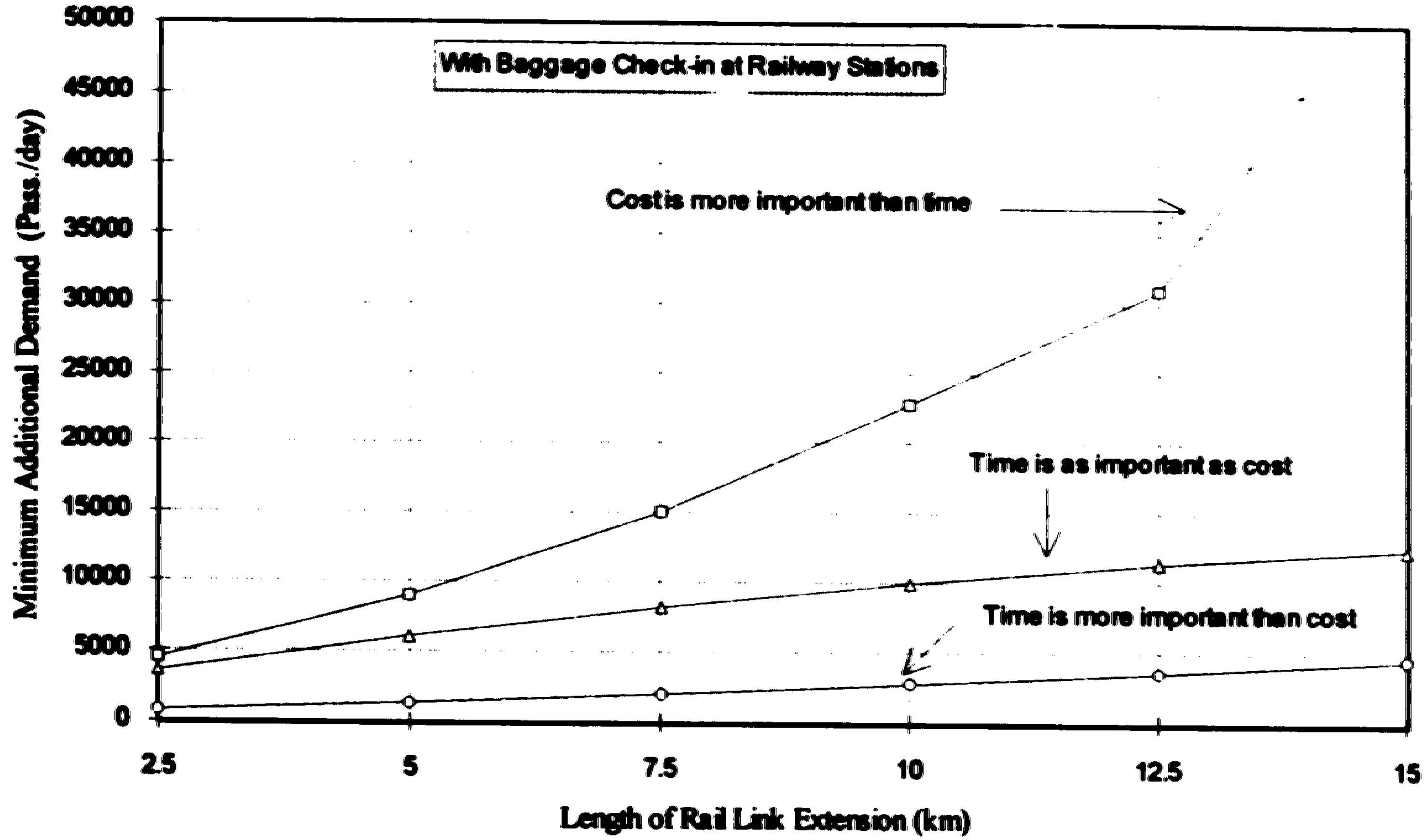


Figure 6.4: Minimum Passenger Demand Required for the Extension of Rail Links to Airports to be Attractive if Baggage Check-in Facilities are Provided at Stations.

### 6.2.4. Analysis of Concept C (Shuttle Bus or APM connection to Rail Stations Close to Airports

Concept C is also examined for the influence of special baggage handling options In this concept, the rail station near the airport is connected by either a shuttle bus or APM. There is a transfer involved at the connecting point. This transfer is a negative attribute of fixed rail alternative. The influence is considerable if passengers have baggage. In this analysis, only the baggage check-in at rail station option is studied. The other option of having baggage handling facilities on trains is not considered because there is no real advantage of delivering the bags at rail station by the rail authorities and transferring the bags by the passengers to the connecting service.

The baggage check-in at rail station would operate like a remote terminal. The airline or an agent is responsible in shipping the baggage to the ultimate destination and passengers take trains and the connecting service to airports. The advantage of the APM service over the shuttle bus service is the cross-platform transfer and it is not significant factor if passengers do not have baggage. The fuzzy values assigned to these alternatives when compared with automobile reflect the above mentioned fact. The fuzzy values are presented in the Matrix 6.5.

PWC = (bag. conv.)

| | Auto | Taxi | Bus | Rail+S.Bus | Rail+APM |
|---|---|---|---|---|---|
| Auto | 1 | 3 | 5 | 3 | 3 |
| Taxi | | 1 | 5 | 3 | 3 |
| Bus | | | 1 | 1/2 | 1/2 |
| Rail+S.Bus | | | | 1 | 1 |
| Rail+APM | | | | | 1 |

... (6.5)

The evaluation of the alternatives, auto, taxi, direct bus, rail + shuttle bus, and rail + APM, was described in Section 5.5. For the analysis described here the criterion values for baggage convenience are changed. The minimum passenger demands required for rail

+ APM alternative to be attractive are identified for the three sets of preferences: (1) more number of business passengers, (2) equal number of business passengers and vacationers, and (3) more number of vacationers. The results are presented in Figure 6.5. For preference sets 1 and 2, auto alternative is competing with rail + APM alternative and for preference set 3, rail + shuttle bus is competing with rail + APM alternative for all lengths of the connection.

For example, a 2 km APM connection between an airport and nearby rail station attracting equal number of business passengers and pleasure trips would be attractive above a demand of

- 6,000 passengers per day if no baggage handling facilities are provided, and
- 4000 passengers per day if baggage check-in is provided at stations (a reduction of 33%).

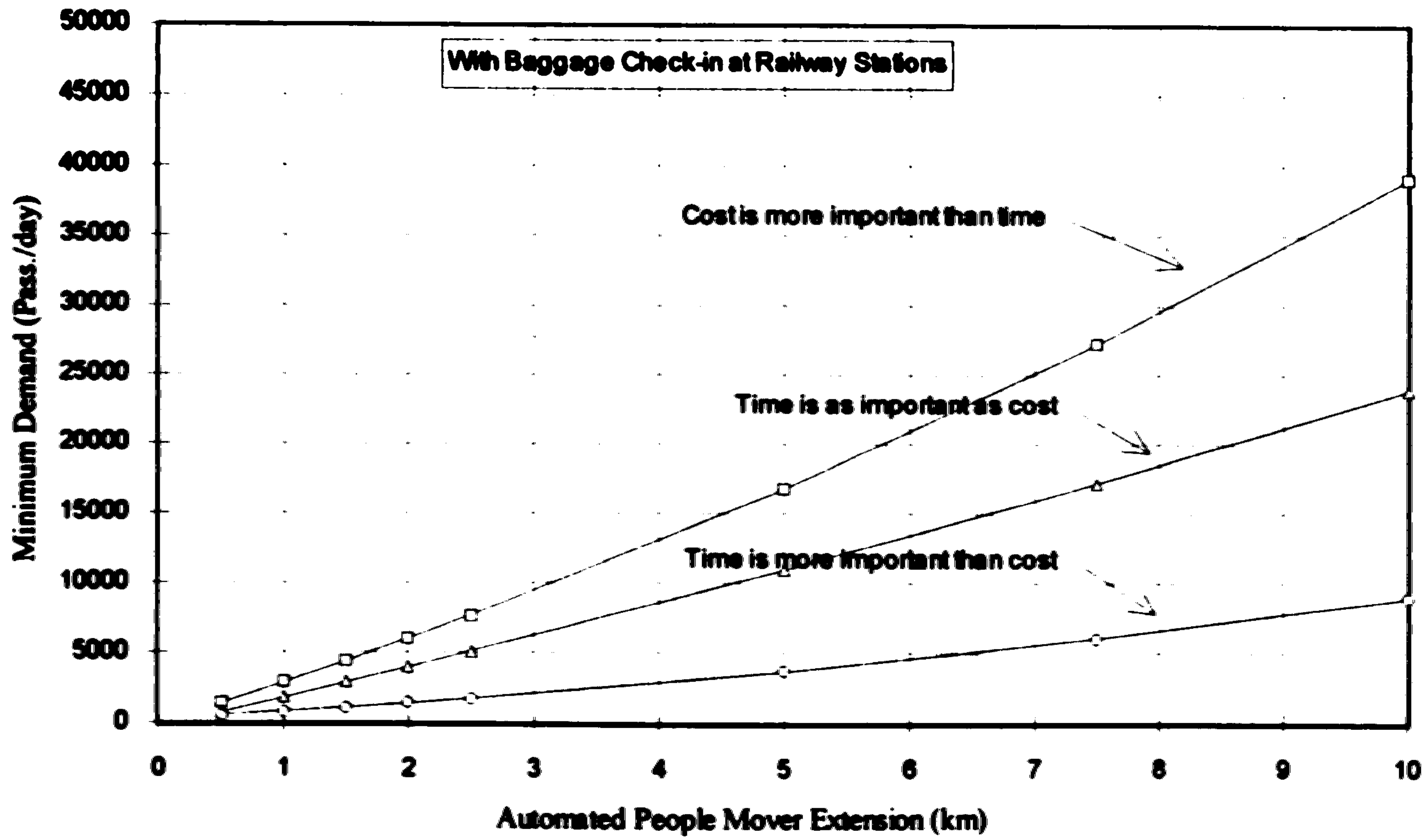


Figure 6.5: Minimum Passenger Demand Required for the APM Connection Between Airports and nearby Rail Station to be Attractive if Baggage Check-in Facilities are Provided at Stations.

## 6.3 Case Study 1: Denver International Airport

### 6.3.1. Introduction

The New Denver International Airport is considered for the Case Study 1. The city of Denver does not have an urban rail transit network. If a rail link were to be built to the airport, it could be an exclusive link. This case might be used as example of Concept A; an exclusive line.

The Denver International Airport is located northeast of Denver, 37 kilometres from downtown Denver (Figure 6.6). The airport will open in March 1994 and it replaces the existing Stapleton International Airport which is currently handling about 27.5 million annual passengers. It has experienced a growth of 21.4% in the past decade. It is ranked tenth in world in terms of number of passengers ("World Passenger" 1992). The fast growth and the constraints for expansion at the Stapleton Airport prompted the city to build a new airport.

Presently an airporter service is available between Stapleton Airport and downtown Denver. The airport is mainly accessible by automobile or taxis. Since the airport is located far from the city centre, the authorities are studying the feasibility of rail rapid link between the airport and the city centre ("Colorado" 1992). This case is used to examine the feasibility of an exclusive rail link.

### 6.3.2. Analysis

To study the feasibility of an exclusive fixed rail service to the Denver International Airport, the approach used for the evaluation of the Concept A is applied. The criteria considered for evaluation are travel time, reliability, accessibility, cost of trip, baggage convenience, and parking inconvenience. Passenger demand estimates and cost estimates used for the analysis are determined for the current passenger activity and are presented in Table 6.1.

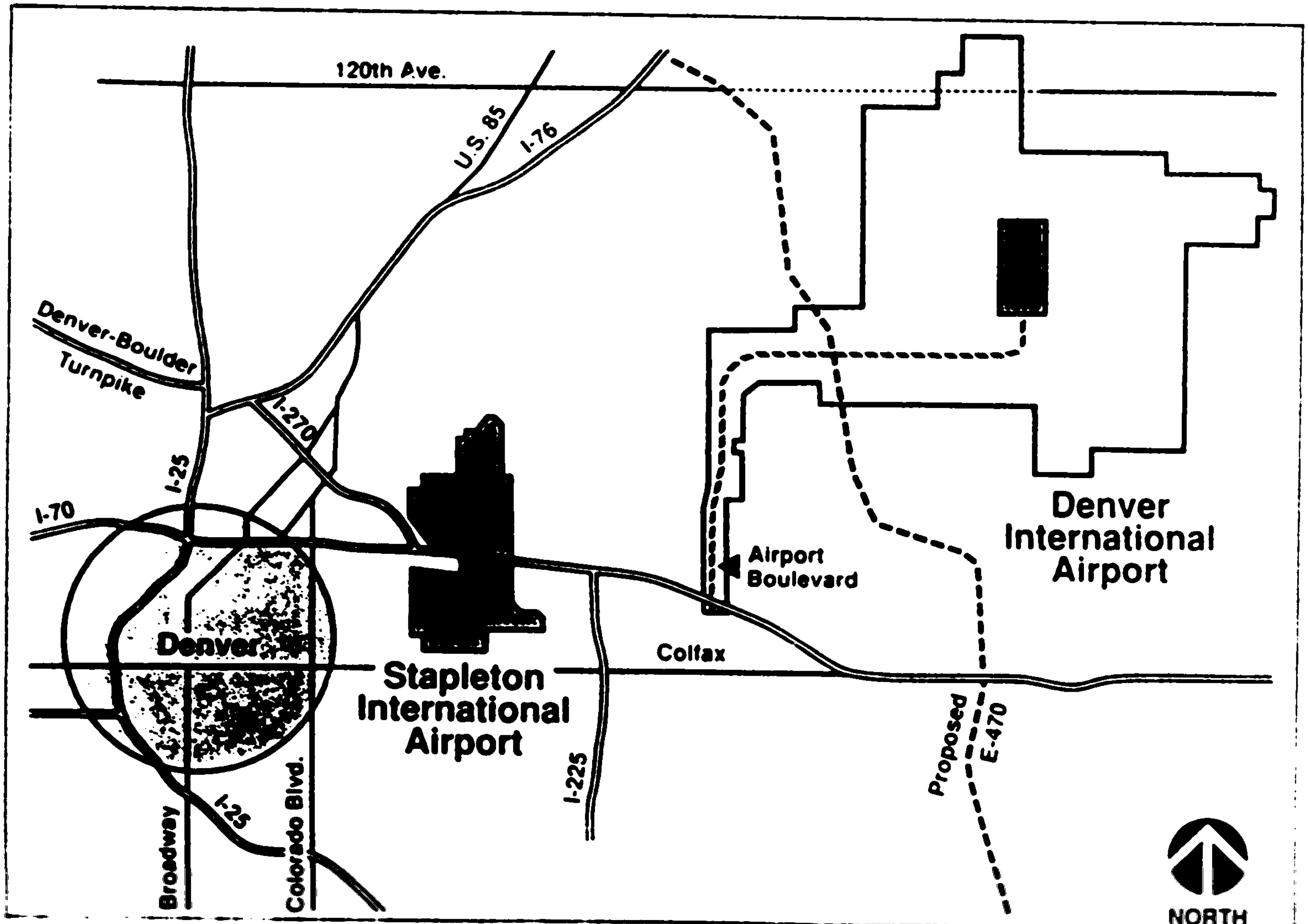


Figure 6.6: Location of Denver International Airport and Stapleton International Airport.

Table 6.1: Passenger and Cost Estimates for an Exclusive Rail Link to Denver International Airport.

| Description | Calculations |
|---|---|
| Annual Air Passenger (1990): Enplaned-Deplaned | = 27,500,000 |
| Annual O & D Passengers (assuming 10% are transferring passengers) | = 0.90 * 27,500,000<br>= 24,750,000 |
| Annual Trips made by Air Passengers on RRT Link (15% of O&D passenger) | = 24,750,000 * 0.15<br>= 837,000 |
| Employees (predicted by model for 1990 Pass. data) | = 32,200 |
| Annual Employee Trips (assuming 260 working days) | = 32,200* 2 * 260 =16,744,400 |
| Annual Trips made by Employees on RRT Link (15% of trips) | = 0.15 * 16,744,400= 2,511,000 |
| Annual Trips made on the RRT Link by Visitors (10% of annual O&D Passenger) | = 0.10 * 24,750,000 = 558,000 |
| Total Annual Passenger trips on RRT Link | = 8,700,000 |
| Average Daily Passengers on RRT Link ( 0.0027 * annual Passengers) | = 0.0027 * 8,700,000<br>= 24,000 |
| Capital cost of link (calculated by the model) | = M$ 1101.27 (1991 dollars) |
| Operating Cost (calculated by the model) | = M$ 10.08 (1991 dollars) |
| Equivalent Annual Cost (calculated by the model) | = M$ 102.79 (1991 dollars) |
| Cost of trip per passenger (calculated by the model) | = $ 14.71 (1991 dollars) |

The alternatives studied are auto, taxi, bus, and RRT. Since the data on the trip purpose of air passengers and their preferences are not available, the analysis is done for the three sets of preferences: Case 1 - travel time is more important than cost, Case 2 - time is as important as cost and Case 3 - cost is more important than travel time. The Case 1 reflects the scenario of more business passenger than vacationers, Case 2 reflects the scenario of equal number of business passengers and vacationers, and Case 3 reflects the scenario of many vacationers using the airport. The preference weights used for these three cases were presented in Section 5.3.

The characteristics of the alternatives are presented in the Table 6.2. The cost of a trip and travel time on the rail link are calculated using the RRT model for 10 percent tunnel construction and 12 stations. The cost of trips by automobile and by taxi are determined as presented in Sections 4.5.2 and 4.5.3 respectively. The travel times by automobile and taxi are calculated as described in Section 4.5.1. The Bus model is used to calculate the cost of the trip and travel time. The fuzzy values for reliability of trip, accessibility of trip, and parking inconvenience, are similar to the ones used for the evaluation of the Concept A. For baggage convenience three case are considered; Case A - no baggage handling facilities available at stations or on trains, Case B - baggage handling facilities on trains are available, and Case C - baggage check-in is available at railway stations. The fuzzy values for these three cases are presented in Table 6.2.

The multi-criteria analysis is done for various cases and the results are reported in Table 6.3. The discussion of the results is presented in the following sections. Case 1 in Table 6.3 corresponds to criteria preference set 1, Case 2 is to criteria preference set 2, and Case 3 is to criteria preferences set 3. Each case has three sub-cases, A with no baggage handling facilities, B with baggage handling facilities on trains (dropping at railway stations and picking up at destination), and C with baggage check-in facilities at stations (airlines take care of baggage). Case 4 is similar to Case 3, except the alternatives are analyzed with the subsidies to .... RRT link.

Table 6.2: Characteristics of the Alternative Modes for Denver International Airport.

| Characteristics | Alternatives | | | |
|---|---|---|---|---|
| | Auto | Taxi | Direct Bus | RRT Link |
| Route length (km) | 37 | 37 | 37 | 37 |
| Travel time (minutes) | 40 | 40 | 49 | 36 |
| Cost of trip (US $) | 7.73 | 26.60 | 3.69 | 14.71 |
| Fuzzy values for reliability of mode when compared to automobile | 1 | 1 | 2 | 1/4 |
| Fuzzy values for accessibility of mode when compared to automobile | 1 | 3 | 5 | 7 |
| Fuzzy values for baggage convenience Case A of mode when compared to automobile | 1 | 1 | 7 | 7 |
| Fuzzy values for baggage convenience Case B of mode when compared to automobile | 1 | 1 | 7 | 5 |
| Fuzzy values for baggage convenience Case C of mode when compared to automobile | 1 | 1 | 7 | 3 |
| Fuzzy values for parking inconvenience of modes when compared to automobile | 1 | 1/9 | 1/9 | 1/9 |

Table 6.3: Results of Multi-Criteria Analysis of Alternatives for Denver International Airport.

| Case No. and Description | Attractiveness of alternative modes | | | | Remarks |
|---|---|---|---|---|---|
| | Auto | Taxi | Direct bus | New RRT link | |
| 1A. Preference set 1 and no baggage handling facilities on trains or stations | 0.276 | 0.218 | 0.210 | **0.295** | New RRT link is attractive |
| 2A. Preference set 2 and no baggage handling facilities on trains or stations | 0.274 | 0.204 | 0.245 | **0.277** | New RRT link is attractive |
| 3A. Preference set 3 and no baggage handling facilities on trains or stations | 0.271 | 0.179 | **0.301** | 0.250 | New RRT link is not attractive |
| 3B. Preference set 3 and with baggage handling facilities on trains | 0.270 | 0.178 | **0.300** | 0.252 | New RRT link is not attractive |
| 3C. Preference set 3 and with baggage check-in at stations | 0.268 | 0.177 | **0.300** | 0.255 | New RRT link is not attractive |
| 4A. Preference set 3 and no baggage handling facilities on trains or stations with subsidy of $6.41 | 0.261 | 0.176 | **0.281** | **0.281** | New RRT link is attractive with subsidies |
| 4B. Preference set 3 and with baggage handling facilities on trains with subsidy of $6.16 | 0.261 | 0.175 | **0.282** | **0.282** | New RRT link is attractive with subsidies |
| 4B. Preference set 3 and with baggage check-in facilities at stations with subsidy of $6.01 | 0.260 | 0.174 | **0.283** | **0.283** | New RRT link is attractive with subsidies |

**6.3.3. Discussion of Results**

The alternatives are analyzed and the relative attractiveness is determined for the cases described in Section 6.3.2. Since the present usage of airport by purpose is not available, the alternatives are analyzed for the three different combination of business and pleasure trips. The results of the analysis are summarized as follows.

1. The exclusive rail link is attractive at the current level of passenger demand if more business passengers or equal number of business passengers and vacationers are using the airport.

2. If the airport is used by more vacationers, fixed rail alternative is not attractive without subsidies. Even by providing baggage check-in facilities at the station the alternative is not able to improve the attractiveness to compete with direct bus. If no baggage handling facilities are provided, the RRT link will be attractive if a subsidy of $6.41 is provided per passenger trip. If baggage handling facilities are provided on trains, the subsidy needed would be $6.16. If baggage check-in facilities are provided at station the subsidy needed would be $6.01. The annual subsidies would be of the order of M$ 52 to M$ 56.

3. The fixed rail alternative may be attractive without subsidies if it can attract 43,000 to 45,000 passengers per day and if the airport is used by more vacationers. That means the airport should have an activity of over 50 million passengers.

## 6.4 Case Study 2: San Francisco International Airport

### 6.4.1. Introduction

For Case Study 2, San Francisco International Airport which would fall into the Concept B (rail extension to airports) is considered. San Francisco is the second largest airport on the United States west coast handling over 30 million passengers per year. It is ranked seventh in the world passenger airports based on the total commercial aircraft movements and passengers ("World Passenger" 1992). This airport is considered to be the third largest airport in terms of handling origin and destination passengers (92%). According to the recent data, there are over 31,000 employees working at the airport.

The airport is located at 22.5 km from downtown San Francisco (Figure 6.7). It is served by a variety of transportation services to choose from depending on the origin or destination and time of arrival or departure of air passengers. A scheduled bus service (SamTrans) is available to and from airport from most Bay Area communities and this express service to downtown is frequent and inexpensive ($1.75). In addition, door-to-door van service, luxury limousines, taxis, and share-a-ride arrangements are available.

The Bay Area Rapid Transit (BART), which has extensive service to both the East Bay and West Bay areas, terminates at Daly City station 13.3 km from San Francisco International Airport (Figure 6.7). The BART system has over 115 km of track and 34 station in San Francisco, Alameda and Contra Costa counties. It provided nearly 7.2 million passenger trips in the year 1991. It is in the process of expansion and the ridership is projected to increase to nearly 100 millions annual trips by the year 2000.

The local transit agency, SamTrans, operates scheduled bus service between Daly City and the Airport. It operates between 6:00 a.m. and 8:00 p.m. with 30 minute headways. This service is commuter oriented. It takes 30 minutes to reach airport from Daly City station. The flat fare on local SamTrans services is $ 0.85. The fare on BART from downtown to Daly City is $ 1.45.

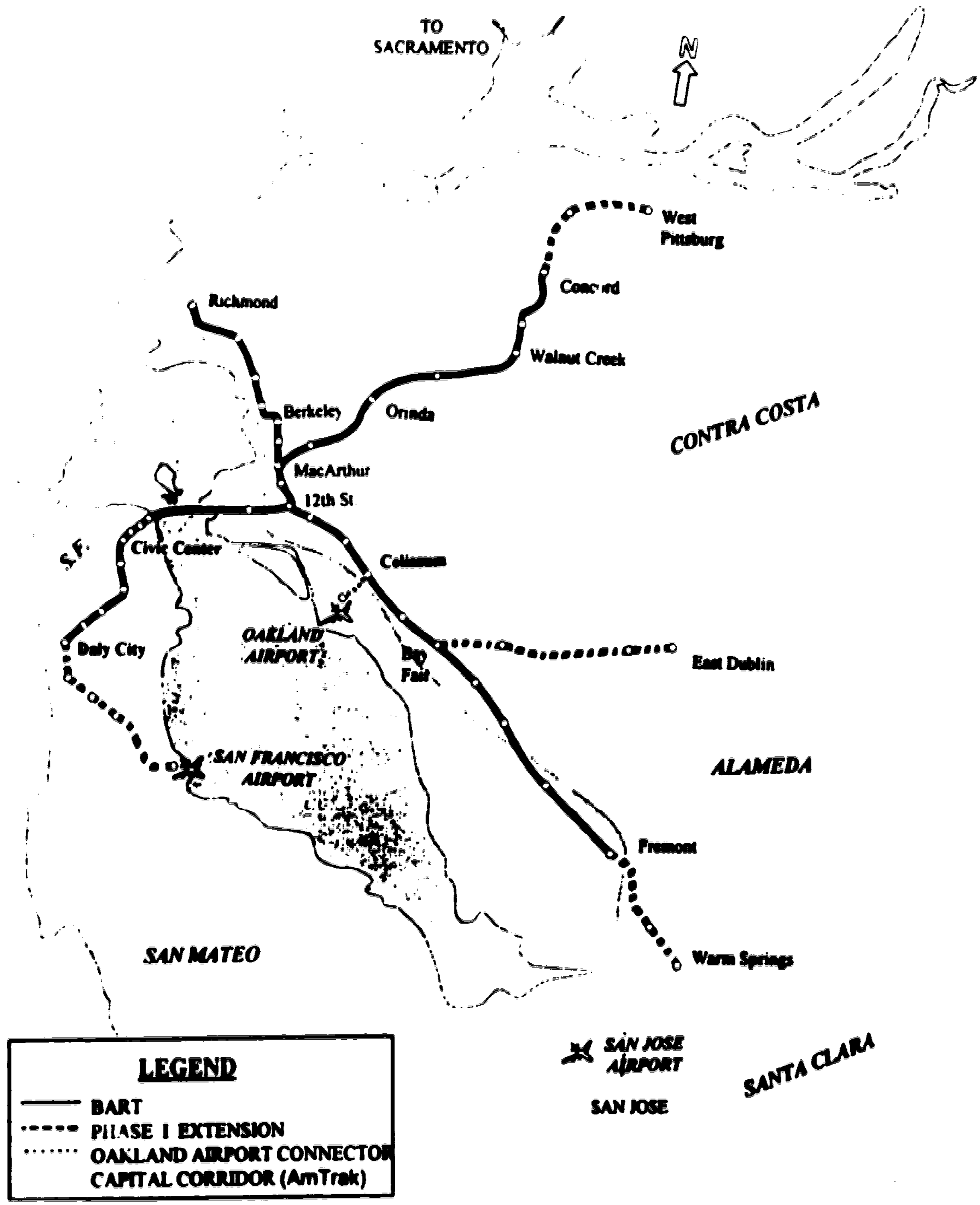


Figure 6.7: San Francisco Bay Area, BART Network, and Planned Connection to Airports. (Source: "Intermodal" 1992.)

According to a survey conducted in 1980 (Gosling 1986) only 4% of air passengers use public transit. Most trips to the airport are made by automobile. The ground access system is congested with automobile, limousines, and charter buses. The authorities have been trying different traffic management schemes. Presently, the authorities are examining of various options of linking the airport with the rail transit system ("Train" 1992).

One of the options is the extension of BART system from Daly City to the airport. One study (Gosling 1986) reports that the extension would cost M$ 810 in 1983 dollars (M$ 950 in 1991 dollars). The passenger estimates on the extension are presented in the Table 6.4. Another study (News letter) reports that the extension would cost $ 1.1 billion (1991 dollars) and the total activity at the new stations would be 66,000 boardings and alightings. The estimate made by the RRT model for this extension with 50% elevated track and 50% tunnel is M$ 931 (1991 dollars).

Table 6.4: Traffic Estimates on BART Extension to San Francisco Airport (Millions of Annual Passengers)@.

| Market Segment | County of Trip Origin | | | |
|---|---|---|---|---|
| | Alameda | Contra Costa | San Francisco | Total |
| Air Passengers | 0.58 | 0.62 | 3.91 | 5.11 |
| Visitors and Employees | 0.32 | 0.32 | 1.94 | 2.58 |
| Non-airport Riders | 1.23 | 1.10 | 1.04 | 3.37 |
| Total | 2.13 | 2.04 | 6.89 | 11.02 |

@ Source: Gosling 1986

### 6.4.2. Analysis

The approach presented in Chapter 5 has been adopted to examine an extension of the BART system to San Francisco International Airport. Travel time, reliability, accessibility, cost of trip, baggage convenience, and parking criteria are used in the

Table 6.5: Passenger Demand Estimate on BART Extension to San Francisco Airport.

| Description | Calculations |
|---|---|
| Annual Air Passenger (1992) | = 31,000,000 |
| Annual O & D Passengers (92.3%) | = 0.923 * 31,000,000<br>= 28,600,000 |
| Annual Trips made by Air Passengers on BART Extension (15% of O&D passenger) | = 28,600,000 * 0.15 = 4,290,000 |
| Employees (predicted by model for 1992 Pass. data) | = 36,500 |
| Annual Employee Trips (assuming 260 working days) | = 36,500 * 2 * 260 =18,980,000 |
| Annual Trips made by Employees on BART Extension (15% of trips) | = 0.15 * 18,980,000<br>= 2,850,000 |
| Annual Trips made by Visitors (10% of annual O&D Passenger) | = 0.10 * 28,600,000 = 2,860,000 |
| Annual non-airport riders (as per previous studies) | = 3,370,000 |
| Total Annual Passenger trips on BART Extension<br>Estimates of Total Annual Passenger trips form previous study (Gosling) | = 13,370,000<br>= 11,0200,000 |
| Average Daily Passengers on BART Extension ( 0.0027 * annual Passengers)<br>Estimates of daily passenger from previous study (news letter) | = 0.0027 * 13,370,000<br>= 36,100<br>= 33,000 |
| Capital cost of Extension (calculated by the model) | = M$ 931.71 (1991 dollars) |
| Annual Operating Cost (calculated by the model) | = M$ 5.19 (1991 dollars) |
| Equivalent Annual Cost (calculated by the model) | = M$ 82.14 (1991 dollars) |
| Cost of trip per passenger (calculated by the model) | = $ 7.84 (1991 dollars) |

evaluation. Passenger estimates and cost estimates were made as presented in Table 6.5 and they are comparable with previous studies.

The alternatives studied are auto, taxi, bus, and BART extension. Since the data on the trip purpose of air passengers and their preferences are not available, the analysis is done for the three sets of preferences: Case 1 - travel time is more important than cost, Case 2 - time is as important as cost and Case 3 - cost is more important than travel time. The Case 1 reflects the scenario of more business passenger than vacationers, Case 2 reflects the scenario of equal number of business passengers and vacationers, and Case 3 reflects the scenario of many vacationers using the airport. The preference weights used for these three cases are presented in Section 5.4. The characteristics of the four alternatives are presented in Table 6.6. The cost of trip on the 13.3 kilometre extension is calculated using the RRT model for 36,000 passengers per day. The track is assumed to be 50% elevated and the rest in tunnel, because of the development in the area between the airport and Daly City. The cost of trip on BART is the sum of the existing fare to Daly City from downtown and the cost per passenger on the extension. The cost of a trip by automobile is calculated as described in Section 4.5.2. The rest of the data has been compiled from the survey. Since the fuzzy values considered in the evaluation of Concept B reflect the characteristics of a typical city, similar values are considered for evaluation for this case study. The cases are subdivided into three cases: Case A - no additional baggage handling facilities are available on trains or at stations, Case B - baggage handling facilities are available at station(s) and the baggage has to be collected at the end of the trip, and Case C -baggage check-in is available at railway station(s). In the latter case, although check-in facilities are available, there is an element of risk that the baggage might not go with the passenger to the destination. The fuzzy values presented in Table 6.6 reflect the above mentioned risks and inconvenience.

The multi-criteria analysis is done for various cases and the results are reported in Table 6.7 and the discussion of the results is presented in the following section. The

Table 6.6: Characteristics of the Alternative Modes for San Francisco International Airport.

| Characteristics | Alternative Modes | | | |
|---|---|---|---|---|
| | Automobile | Taxi | Bus | BART Extension |
| Route length (km) | 22.5 | 22.5 | 22.5 | 9.15 km existing + 13.3 km extension |
| Travel time (minutes) | 28 | 28 | 33 | 26 |
| Cost of trip (US $) | 4.70 | 15.00 | 1.75 | 1.45+7.84 = 9.29 |
| Fuzzy values for reliability of mode when compared to automobile | 1 | 1 | 2 | 1/4 |
| Fuzzy values for accessibility of mode when compared to automobile | 1 | 3 | 5 | 7 |
| Fuzzy values for baggage convenience Case A of mode when compared to automobile | 1 | 1 | 7 | 7 |
| Fuzzy values for baggage convenience Case B of mode when compared to automobile | 1 | 1 | 7 | 5 |
| Fuzzy values for baggage convenience Case C of mode when compared to automobile | 1 | 1 | 7 | 3 |

Case 1 in Table 6.7 corresponds to criteria preference set 1 with no baggage handling facilities on trains or at stations, Case 2 is to criteria preference set 2 with no baggage handling facilities on trains, Case 3A is to criteria preferences set 3 with no baggage handling facilities on trains, Case 3B is to criteria preferences set 3 with baggage handling facilities on trains, Case 3C is to is to criteria preferences set 3 with baggage check-in facilities at railway station(s) and Cases 4A, 4B, and 4C are similar to corresponding Case 3 with fare subsidies.

### 6.4.3. Discussion of Results

Since the present usage of airport by purpose is not available, the alternatives are analyzed and the relative attractiveness is determined for three different combination of business and pleasure trips. The results of the analysis are summarized as follows.

1. If more business passengers are using the airport or equal number of business passengers and vacationers are using the airport, extension of BART is the most attractive alternative at the current demand level.

2. If more vacationers are using the airport, BART extension is not attractive without subsidies even with baggage check-in facilities at railway stations. If no baggage handling facilities are provided on trains or at stations the subsidy needed to make BART extension attractive would be $5.24 per passenger. If baggage handling facilities are provided on trains the subsidy needed to make BART extension attractive would be $5.19. If baggage check-in facilities are provided at stations by airlines the subsidy needed for BART extension to be attractive would be $5.04. The annual subsidies for these options would be between M$ 67 to M$70.

3. If the airport attracts more pleasure travellers and the system to be attractive without subsidies, extension of BART should attract over 60,000 passengers per day. If the system purely depends on airport related trips, the airport should have an activity of about 60 million enplaned-deplaned passengers. Otherwise, it should attract more non-airport related trips.

Table 6.7: Results of Multi-Criteria Analysis of Alternatives for San Francisco Airport.

| Case No. and Description | Attractiveness of alternative modes | | | | Remarks |
|---|---|---|---|---|---|
| | Auto | Taxi | Bus | BART | |
| 1. Preference set 1 and no baggage handling facilities on trains or stations | 0.271 | 0.217 | 0.221 | **0.290** | BART extension is attractive |
| 2. Preference set 2 and no baggage handling facilities on trains or stations | 0.266 | 0.203 | 0.261 | **0.270** | BART extension is attractive |
| 3A. Preference set 3 and no baggage handling facilities on trains | 0.261 | 0.182 | **0.313** | 0.241 | BART extension is not attractive |
| 3B. Preference set 3 and baggage handling facilities on trains | 0.260 | 0.182 | **0.313** | 0.242 | BART extension is not attractive |
| 3C. Preference set 3 and baggage check-in facilities at stations | 0.258 | 0.180 | **0.313** | 0.249 | BART extension is not attractive |
| 4A. Preference set 3, no baggage handling facilities on trains, and with a fare of $4.05 on BART | 0.250 | 0.179 | 0.285 | **0.286** | Needs a subsidy of (9.29 - 4.05 = 5.24) for BART extension to be attractive |
| 4B. Preference set 3, baggage handling facilities on trains, and with a fare of $4.10 on BART | 0.250 | 0.178 | **0.286** | **0.286** | Needs a subsidy of (9.29 - 4.10 = 5.19) for BART extension to be attractive |
| 4C. Preference set 3, baggage check-in facilities at stations, and with a fare of $4.20 on BART | 0.249 | 0.177 | **0.287** | **0.287** | Needs a subsidy of (9.29 - 4.20 = 5.09) for BART extension to be attractive |

## 6.5 Case Study 3: Oakland International Airport

### 6.5.1. Introduction

The Oakland International Airport that falls into the Concept C (APM or Shuttle Bus connection to nearby fixed rail stations) is selected for Case Study 3. The airport is located in the East Bay of San Francisco Bay area. It serves most communities on the East Bay area (Figure 6.7). This is the second largest airport in the area after San Francisco International. It handles 6.2 million passengers per year and more than 5000 persons are employed at the airport. The airlines serving the airport provide more than 800 non-stop, direct, or connecting flights weekly to cities throughout the United States.

The airport is located at 18 km from downtown Oakland and 30.5 km from downtown San Francisco. Presently the airport is mostly accessed by automobiles. From the airport, door-to-door van service, luxury limousines and taxis are available. The closest bus terminal is at BART Coliseum station. The BART line passes by the airport and the closest station is Coliseum which is about 6 km from the airport. The downtown Oakland is 12 minute ride and San Francisco is 21 minute ride from Coliseum station. A shuttle bus, "Air-BART," presently operates between the airport terminals and BART Coliseum station on 10 minute headways. Each bus seats 20 passengers. The journey time is between 10 and 15 minutes and the fare is $2. On average about 1,000 passengers are using the bus per day.

There are currently several drawbacks to the Air-BART system. There is no information available about the fare at the station. The driver does not carry change and exact fare has to be deposited. Change machines are not available at the stops. Passengers have been experiencing inconvenience of exchanging dollar bills among themselves to pay the fare. To change from BART to shuttle bus passengers have to change levels.

The airport has been facing congestion problems on the ground access system. The airport is facing many constraints for expansion of its facilities because of the location. Studies are underway to link the airport with the BART Coliseum station. BART will be accessible to more areas with the extensions into Oakland airport market area

The BART district and the Oakland International Airport operators have proposed a fixed guideway transit or people mover system to link the Coliseum BART station with the airport terminals. The proposed connector will provide a fast transit access to the airport from anywhere within the BART service areas (Figure 6.8). The fixed guideway will connect with the future Oakland Coliseum stop on Amtrak's Capital Corridor inter-city route between San Jose and Sacramento and divert auto traffic from the region's highways and surface streets, reducing air pollution and traffic congestion.

According to the project proposal the system would operate non-stop between the Coliseum station and airport on 6.1 km guideway at 2 minute headways during peak hour. It would cost between M$ 100 and M$ 150 (1992 dollars).

### 6.5.2. Analysis

To study the feasibility of the APM connection to the BART Coliseum station the approach used for the evaluation of Concept C has been followed. The same criteria, travel time, reliability, accessibility, cost of trip, baggage convenience, parking, and modal attraction have been used in the evaluation. Passenger estimates and cost estimates were made for the present demand and are presented in Table 6.8.

The alternatives studied are auto, taxi, BART+shuttle bus, and BART+APM Connection. Direct bus is not considered in this case because there is no existing service to the airport and there are no plans to introduce such service. The bus in the region serves as feeder service to BART. Since the data regarding the trip purpose of air passengers and their preferences is not available, the analysis is done for the three sets of preferences: Case 1 - travel time is more important than cost, Case 2 - time is as important as cost and Case 3 - cost is more important than travel time. The Case 1 reflects the scenario of more business passenger than vacationers, Case 2 reflects the scenario of

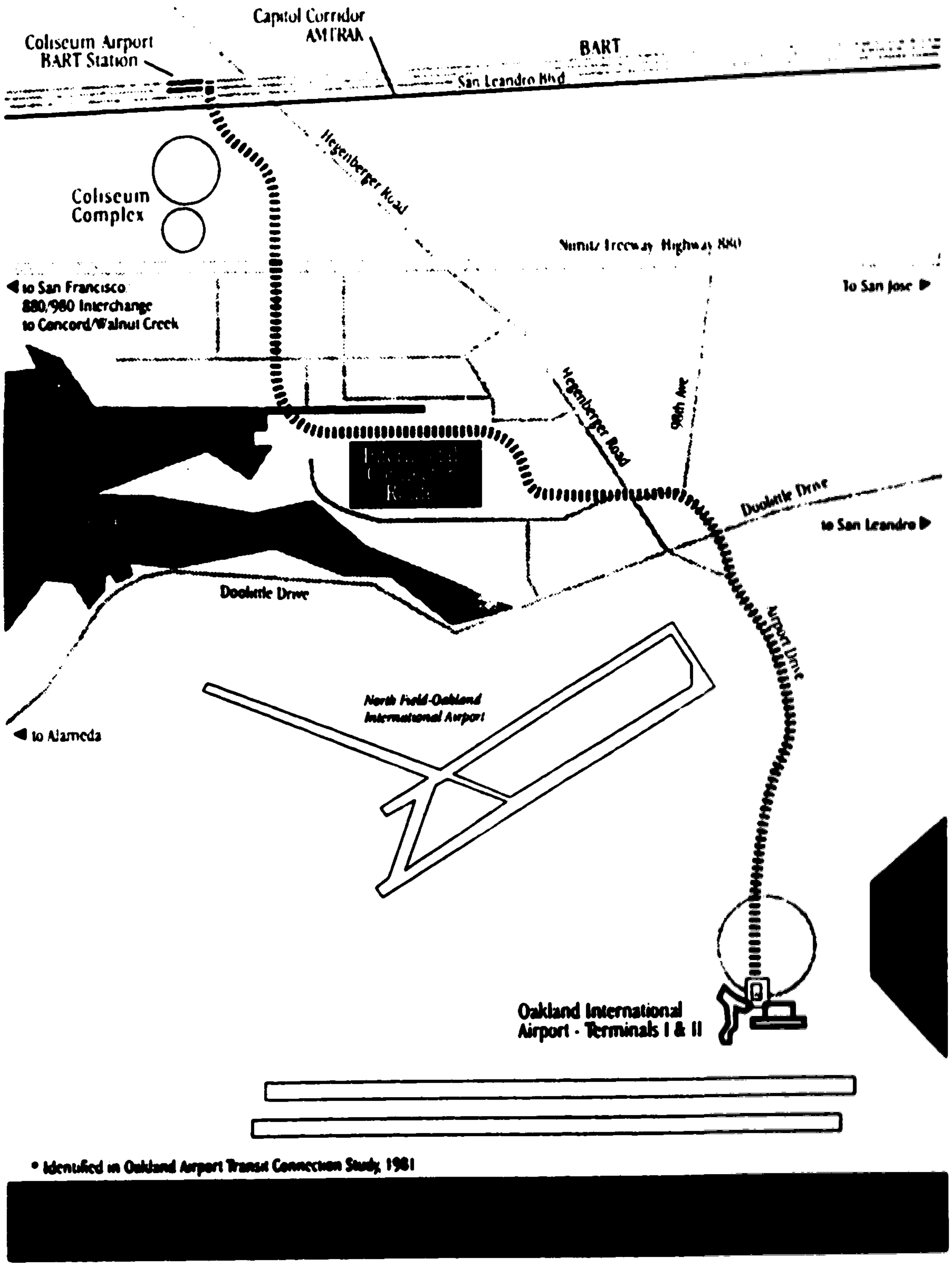


**Figure 6.8: Proposed APM Connection Between BART Coliseum Station and Oakland International Airport (Source: "Intermodal" 1992)**

Table 6.8: Passenger and Cost Estimates for the APM link Between BART Coliseum Station and Oakland International Airport.

| Description | Calculations |
|---|---|
| Annual Air Passenger (1992) | = 6,200,000 |
| Annual O & D Passengers (assuming 10% are transferring passengers) | = 0.90 * 6,200,000<br>= 5,580,000 |
| Annual Trips made by Air Passengers on APM Connection (15% of O&D passenger) | = 5,580,000 * 0.15 = 837,000 |
| Employees (predicted by model for 1992 Pass. data) | = 5,770 |
| Annual Employee Trips (assuming 260 working days) | = 5,770 * 2 * 260 =3,000,400 |
| Annual Trips made by Employees on APM Connection (15% of trips) | = 0.15 * 3,000,400= 450,000 |
| Annual Trips made by Visitors (10% of annual O&D Passenger) | = 0.10 * 5,580,000 = 558,000 |
| Total Annual Passenger trips on APM Connection | = 1,845,000 |
| Average Daily Passengers on APM Connection ( 0.0027 * annual Passengers) | = 0.0027 * 1,845,000<br>= 5,770 |
| Capital cost of Extension (calculated by the model) | = M$ 162.32 (1991 dollars) |
| Operating Cost (calculated by the model) | = M$ 1.50 (1991 dollars) |
| Equivalent Annual Cost (calculated by the model) | = M$ 18.61 (1991 dollars) |
| Cost of trip per passenger (calculated by the model) | = $ 12.78 (1991 dollars) |

equal number of business passengers and vacationers, and Case 3 reflects the scenario of many vacationers using the airport. The preference weights used for these three cases presented in Section 5.5. The characteristics of the four alternatives are presented in Table 6.9. The cost of trip on the 6.1 kilometre guideway is calculated using the APM model for a demand of 5,770 passengers per day. The guideway is assumed to be 75% elevated and the rest is at grade. The cost of trip on BART+shuttle bus is the sum of the existing fare on BART to Coliseum from downtown Oakland and the cost per passenger ($2) on the Shuttle bus connection. The cost of trip on BART+APM is the sum of the existing fare on BART to Coliseum from downtown Oakland and the cost per passenger on the APM connection. The cost of a trip by automobile is calculated as described in Section 4.5.2. The travel times on BART connections include the travel time on BART, waiting time for the connection, and the travel time on the connection. For the shuttle bus connection a waiting time of 5 minutes and for APM connection 2 minutes are considered. The rest of the data has been compiled from the survey. Since the fuzzy values considered in the evaluation of concept C reflect the characteristics of a typical city, same values are considered for evaluation for this case study. For the baggage convenience Case A, no additional baggage handling facilities are available on trains or at stations, and for the Case B, baggage check-in is available at railway station(s). The fuzzy values presented in Table 6.9 reflect the above mentioned risks and inconveniences.

The multi-criteria analysis is done for various cases and the results are reported in Table 6.10 and the discussion of the results is presented in the following sections. The Case 1 in Table 6.10 corresponds to criteria preference set 1, Case 2 is to criteria preference set 2, and Case 3 is to criteria preferences set 3. Each case has three sub-cases, A with no baggage handling facilities, B with baggage check-in facilities at stations and C with fare subsidies.

Table 6.9: Characteristics of the Alternative Modes for Oakland International Airport.

| Characteristics | Alternatives | | | |
|---|---|---|---|---|
| | Auto | Taxi | BART + shuttle Bus | BART + APM |
| Route length (km) | 18 | 18 | 9.7 km BART + 6.1 km S. Bus | 9.7 km BART + 6.1 km APM |
| Travel time (minutes) | 23 | 23 | 12+5+12=29 | 12+2+9=23 |
| Cost of trip (US $) | 4.81 | 14.42 | 0.80+2.00 = 2.85 | 0.80+12.78 = 13.58 |
| Fuzzy values for reliability of mode when compared to automobile | 1 | 1 | 1/3 | 1/4 |
| Fuzzy values for accessibility of mode when compared to automobile | 1 | 3 | 7 | 7 |
| Fuzzy values for baggage convenience Case A of mode when compared to automobile | 1 | 1 | 9 | 5 |
| Fuzzy values for baggage convenience Case B of mode when compared to automobile | 1 | 1 | 3 | 3 |
| Fuzzy values for modal attraction of modes when compared to automobile | 1 | 1 | 1 | 1/3 |

Table 6.10: Results of Multi-Criteria Analysis of Alternatives for Oakland International Airport.

| Case No. and Description | Attractiveness of alternative modes | | | | Remarks |
|---|---|---|---|---|---|
| | Auto | Taxi | BART +S.Bus | BART +APM | |
| 1A. Preference set 1 and no baggage handling facilities on trains or stations | **0.270** | 0.211 | 0.252 | 0.267 | APM connection is not attractive |
| 1B. Preference set 1 and baggage check-in facilities at stations | 0.265 | 0.206 | 0.257 | **0.272** | APM connection is attractive |
| 1C. Preference set 1 and no baggage handling facilities and a subsidy of $1.33 | **0.269** | 0.211 | 0.251 | **0.269** | APM connection is attractive if subsidized |
| 2A. Preference set 2 and no baggage handling facilities on trains or stations | 0.272 | 0.201 | **0.276** | 0.251 | APM connection is not attractive |
| 2B. Preference set 2 and with baggage check-in facilities at stations | 0.268 | 0.196 | **0.281** | 0.255 | APM connection is not attractive |
| 2C. Preference set 2 and no baggage handling facilities and a subsidy of $6.18 | **0.267** | 0.199 | **0.267** | **0.267** | APM connection is attractive if subsidized |
| 3A. Preference set 3 and no baggage handling facilities on trains or stations | 0.277 | 0.186 | **0.309** | 0.288 | APM connection is not attractive |
| 3B. Preference set 3 and with baggage check-in facilities at stations | 0.273 | 0.182 | **0.313** | 0.232 | APM connection is not attractive |
| 3C. Preference set 3 and no baggage handling facilities and a subsidy of $8.98 | 0.260 | 0.180 | **0.280** | **0.280** | APM connection is attractive if subsidized |

**6.5.3. Discussion of Results**

The alternatives are analyzed and the relative attractiveness is determined for various cases described in Section 6.5.2. Since the present usage of airport by purpose is not available, the alternatives are analyzed for the three different combination of business and pleasure trips. The results of the analysis are summarized as follows.

1. For the three different combinations of business passengers and vacationers using the airport, APM connection between the BART Coliseum station and the airport is not attractive without baggage handling facilities at stations at current demand level.

2. In case of more business passengers using the airport, APM connection would be attractive if baggage check-in facilities are provided at the station(s). Without baggage handling facilities, the APM link would be attractive either with a subsidy of $1.33 per passenger or with a demand of 5,500 passengers per day (7 million annual enplaned-deplaned passengers at the airport).

3. If equal number of business passengers and vacationers using the airport, APM connection in not attractive even baggage check-in facilities are provided at railway stations. The shuttle bus connection is more attractive than the APM connection. The subsidy needed with the current demand would be $ 6.18 per passenger or an annual subsidy of M$ 11.4. The connection would be attractive without subsidy if it can attract 9,500 passengers per day or there should be over 11 million annual enplaned-deplaned passengers at the airport.

4. If more vacationers using the airport, the system would need a subsidy of $ 8.98 per passenger or an annual subsidy of M$ 16.5 to make APM connection attractive. If the APM connection has to be attractive without subsidies it should attract 16,000 passengers per day which is beyond the extreme limits of the airport passenger activity.

# CHAPTER 7

# SUMMARY AND CONCLUSIONS

## 7.1 Summary

The analysis of various transportation access alternatives to reduce congestion and to provide efficient movement of passengers on the system is expected to get greater attention in the planning of airport ground access. A framework for the planning of fixed rail service to airports has been developed to assist planners in the conceptual phase of ground access planning. Computer models have been developed to determine costs and operational characteristics and requirements of Rail Rapid Systems, Automated People Mover Systems, and Shuttle Bus Systems.

A procedure for the multi-criteria analysis of alternatives was presented to study the feasibility of various alternatives. This procedure is a valuable tool to study the influence of various changes in the systems and helps planners in decision-making. A model was also developed using this procedure in which the relative attractiveness of alternatives given the criteria preferences and criterion values can be determined.

The procedure was applied in a study of the feasibility of several fixed rail alternatives and the results are presented in the form of graphs for three generic concepts: (1) an exclusive rail link, (2) an extension of existing rail line, and (3) an airport APM or Shuttle Bus connection with the nearby rail station. Three different uses of airport by journey purposes: 1) more business passengers or travel time is more important than travel cost, 2) equal number of business passengers and vacationers or travel time is as important as cost, and 3) more vacationers or travel cost is more important than travel time, were examined and the influence of baggage handling facilities was also studied. The approach was applied to three case studies to examine the feasibility of fixed rail alternatives and to demonstrate the use of the approach in specific cases. The general findings, guidelines, and implications of the study are presented in the following sections.

## 7.2 Conclusions

A procedure to evaluate airport access alternatives, using Saaty's Approach, was developed and the attractiveness of fixed rail alternatives was studied. The concepts: (1) exclusive rail links to airports, (2) extension of rail lines, and (3) an airport APM or Shuttle Bus connection with a nearby rail station, were developed that can suit most situations. The procedure can easily be applied for specific case studies to examine the impact of various attributes of systems. The criteria considered for the evaluation of alternatives are travel time, reliability of trip, accessibility of mode, cost of trip, baggage convenience, parking, and modal attraction.

The influence of travel time, cost of trip, and baggage on attractiveness of fixed rail alternatives is considerable. The attractiveness of fixed rail alternatives increases with the increase of demand. The variability of attractiveness of the three concepts with passenger demands is presented in the form of graphs.

The attractiveness also varies with the level of business passengers and vacationers. The rail alternatives are attractive at lower passenger demand levels if more business passengers use the airports and at higher demand levels if more vacationers use the airports. If airports are used by more vacationers, the fixed rail alternatives are not as attractive without subsidies.

By providing baggage handling facilities at stations or on trains rail alternatives are attractive at demand levels 10 to 50 percent lower than not having such facilities.

Rail extensions are more attractive at much lower demand levels (50 to 80%) than exclusive links. For lower demands and short connections (2.5 km) shuttle bus systems are attractive to APM connections to nearby rail stations.

The specific conclusions and findings of this study to the generic concepts of fixed rail access to airports include the following:

1. There is a considerable difference in the minimum passenger demands required for fixed rail alternatives to be attractive among the three cases of preferences sets: (1) more business passengers (time is more important than cost), (2) equal number of business passengers and pleasure travelers (time is as important as cost), and (3) more vacationers (cost is more important than time).

2. If an airport attracts a large number of vacationers, fixed rail alternatives are not attractive until a demand of over 50,000 passengers per day is reached on the system. If only airport users use the system, the airport must have an activity beyond 50 million annual passengers. Very few airports (Chicago, Dallas Ft. Worth, Atlanta, Los Angeles, and Heathrow) are close to such level. To make fixed rail alternatives attractive the system either needs subsidies or it must attract many non-airport passengers.

3. If an airport attracts an equal number of business passengers and vacationers, exclusive rail links are attractive at demands over 15,000 passengers per day for 10 km distance to over 30,000 passengers per day for 50 km distance. If only airport users use the system, exclusive links are attractive for airports attracting over 18 million annual passengers. For a rail extension to be attractive the demand should be over 5,000 passengers for 2.5 km extension to over 18,000 passengers per day for 15 km extension. An Automated People Mover connection to airports from a nearby rail stations would be attractive if the demands are over 500 passengers per day for 0.5 km guideway to over 41,000 passengers per day for 10 km guideway.

4. If an airport is used by more business passengers, exclusive links are attractive at demands over 2,500 to over 18,000 passengers per day depending on the distance. Rail extensions are attractive over 2,500 to over 7,500 passengers per day depending on the extension length. APM connections are attractive over 500 to over 22,000 passengers per day depending on the guideway length.

5. In the case of exclusive rail links the following observations are made

(a) If more business passengers using the airport:

- exclusive rail service competes closely with automobile,
- taxi competes with bus, and
- taxi is preferred over bus with in the range of demands studied.

(b) For the case of equal number of business passengers and vacationers using the airport:

- automobile competes with exclusive rail service,
- both automobile and rail are preferred to taxi and bus, and
- bus competes closely with taxi with an edge to bus over taxi.

(c) In the case of more vacationers using the airport:

- bus competes with rail and both have an edge over taxi and automobile and
- automobile is preferred to taxi.

6. In case of rail link extensions to airports the following observations are made.

(a) If more business passengers using the airport:

- automobile competes closely with rail extensions and
- taxi has a clear edge over bus within the range of demands studied.

(b) If equal number of business passengers and vacationers using the airport:

- automobile competes with rail extension,
- both automobile and rail are preferred to taxi and bus,
- bus and taxi are competing closely with an edge to bus over taxi.

(c) If more vacationers use the airport:

- bus competes with rail extensions and automobile closely follows behind,
- both bus and rail extensions have a slight edge over taxi, and
- automobile is preferred to taxi.

7. In the case of connecting an airport and nearby rail stations with APM systems or Shuttle Buses the following observations are made.

(a) If more business passengers using the airport:

- rail + APM competes closely with automobile, and
- rail + shuttle bus follows closely behind automobile.

(b) If equal number of business passengers and vacationers using the airport:

- automobile competes with rail + APM,
- both rail + shuttle bus and direct bus are preferred to taxi, and

- rail + shuttle bus is preferred over direct bus for short connections (up to 5 km) and the opposite is true for long connections (beyond 5 km).

(c) If more vacationers using the airport:

- automobile competes with rail + APMs and both have an edge over others and
- rail + shuttle bus is preferred over direct bus for short connections (up to 2.5 km) and the opposite for long connections (beyond 2.5 km).

8. By providing baggage handling facilities on trains the attractiveness of fixed rail alternatives improves. From the analysis of alternatives with baggage handling facilities at railway stations the following conclusions are drawn:

a) Exclusive links are attractive at demand levels from 500 to 6000 passengers per day lower than the demand required for the system to be attractive without having any baggage facilities depending on the route length and criteria preferences. In other words, it is lower by 12 to 20%.

b) The rail extensions with baggage handling facilities on trains are preferred to others at demands 500 to 2,500 passengers per day lower than the demands required for the system to be attractive without having such facilities. The reduction is about 12 to 33%.

9. By providing baggage check-in facilities at stations there is a further improvement in the attractiveness of fixed rail alternatives. The specific conclusions are:

a) Exclusive links are attractive at demand levels up to 6000 passengers per day lower than the demand levels required for the system to be attractive with baggage handling facilities at stations depending on the route length and criteria preferences, and there is an overall reduction 25 to 95% over not having any baggage handling facilities.

b) Rail extensions with baggage check-in facilities at station are preferred to other alternatives at demands 500 to 5000 passengers per day lower than the demands required for system to be attractive with baggage handling facilities at stations, and there is an overall reduction of 25 to 60% over not having any facilities.

c) An APM connection between an airport and a rail station nearby with baggage check-in at railway stations is attractive at demand levels 12,500 to 17,500 passengers per day lower than the demands required for system to be attractive without having any such facilities and the percentage of reduction is of the order of 25 to 60% depending on the connection length.

### 7.3 Guidelines for Planning

One of the objectives of this research was to assist planners in planning fixed rail systems to airports. This study is helpful to planners in the conceptual phase of planning. These guidelines will be useful in studying the feasibility of fixed rail alternatives to airports. The following is general procedure that may be adopted to determine the attractiveness of a fixed rail alternative over other conventional alternatives. The procedure is also presented in the form of the flowchart in Figure 7.1.

The first step is to identify the fixed rail concept to be considered. This has a direct bearing on the transportation facilities available in the city and its relative location from the airport. If no urban rail transit, commuter rail, or inter-city rail service is available, Concept A (exclusive rail link) may be selected. If such services are available, either Concept B (extension of existing rail link to airport) or Concept C (connecting the airport and the rail station nearby by an Automated People Moves system or Shuttle Bus system) may be selected depending on the distance from the airport and physical feasibility.

The next step is the determination of average daily passenger demand that would use the system. The estimates depend on the annual passengers at the airport, airport employees, and visitors. If the new link or extension passes through communities, non-airport passengers attracted by the system may also be included. The passengers attracted to the system may also depend on the attributes of the system. A detailed analysis of demand would typically be undertaken.

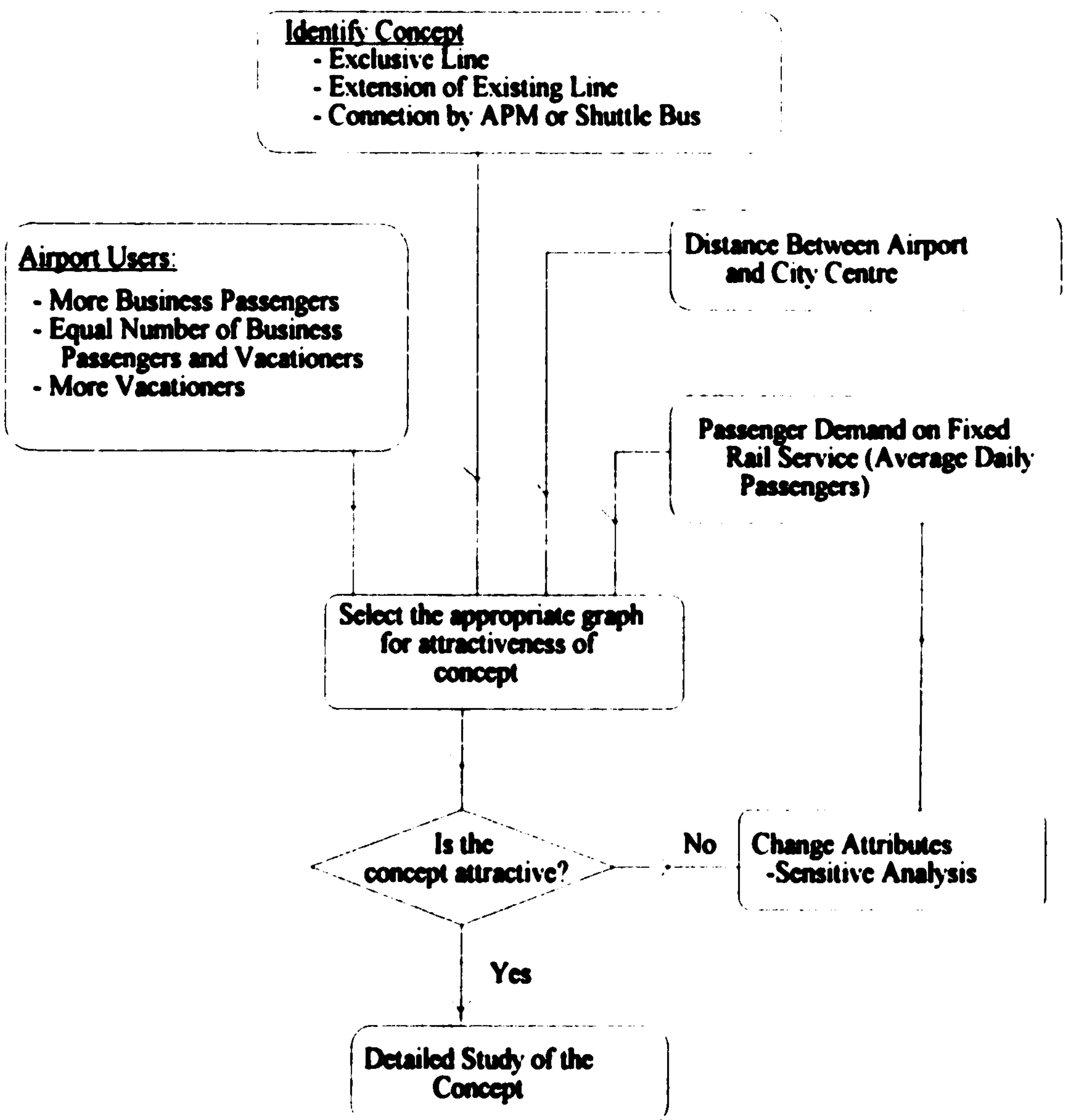


Figure 7.1: Flowchart for Checking the Attractiveness of a Concept

The third step is to check attractiveness of the fixed rail alternative. Depending on the concept chosen the appropriate graph is selected. If majority of the passengers (90%) are business passengers, the "time is more important than cost" curve has to be selected. If there is equal number of business passengers and vacationers, the "time is as important as cost" curve has to be selected, and if majority of the passengers (90%) are vacationers, the "cost is more important than time" curve has to be selected. If the point for average daily demand and the distance falls below the curve, then the fixed rail alternative is not attractive over the conventional alternatives, otherwise it is attractive. The influence of providing baggage handling facilities can be found using the appropriate graph depending on the type of baggage handling facilities provided.

## 7.4 Implication of the Study

The framework developed in this study has general application of fixed rail access to airports. The results presented in the study are suitable to the generic situations described in Chapters 4, 5, and 6. Modifications are required to apply to a specific airport.

The criteria preferences and criterion values for non-quantifiable criteria are assumed for generic situations and they reflect the behaviour of average typical individuals and characteristics of systems. For specific applications and for more accurate result, a market survey has to be conducted with the users to get the average pairwise comparison data of criteria preferences and criterion values while comparing alternatives.

In the RRT, APM, and Shuttle Bus models the costs of components of systems represent average costs in 1991 US dollars. There are some defaults used in determining the costs of systems and the operational characteristics. These defaults were explained in the description of models. These models have some degree of flexibility to change to change the defaults. The defaults chosen in developing the planning guidelines are described in Chapters 5 and 6. Several other assumptions have been made in the determination of travel time by alternative modes. The operating speeds reflect typical city traffic conditions.

Although the approach, techniques, and application, have been demonstrated, care must be taken in applying them directly to an actual airport situation because of the various assumptions and default values. The guidelines presented can not be used as a substitute to a detailed study of alternatives. However, this research is extremely valuable in the conceptual phase of planning of fixed rail service to airports.

### 7.5 Identification of Future Research

During the course of this study, areas for refinement and for future research were identified. The study included the influence of the variation of travel time and travel cost criteria preferences. Work can be undertaken to study the variation of other criteria preferences. A market survey of users at some typical airports and the analysis of the data can be done to determine the variation of preferences among the airports and their relation with typical characteristics.

A study can also be undertaken to refine the results of this research by collecting the actual operating speeds and travel times to airports from city centres by automobiles, taxis, and buses.

A detailed study can be done on the baggage handling systems. The implications of the installation and operation of such systems, and costs of systems can be studied. The costs of such systems were not considered in this study. The results can be refined if such data is available.

An analysis can be performed to study the influence of non-stop fixed rail services between city centres and airports. Since such service would influence passenger usage, the study has to be supplemented with mode split analysis. Finally, an integration of mode split model with the models developed in this study would be a valuable tool for planners in the planning of fixed rail services to airports.

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## APPENDIX A

### A.1 A Sample of Information Sheet Mailed to Airports

**INFORMATION FORM**

***SURVEY ON FIXED RAIL SERVICE TO AIRPORTS***

'Fixed Rail Service' can be referred to rail road, subway, elevated, monorail, light rail, tram, street car or other such services that operates on trackage.

**Please check off boxes where provided.**

1. Name of the Airport :...................................

2. Name(s) of major city(cities) served : City 1 .... ..............................
   City 2 ...................................

3. Distance by road from airport to central business district(CBD) of
   city 1.................................. km or miles
   city 2....................................km or miles

4. Number of terminals in the airport :.......................

5. Type of terminal(s) i.e., linear, satellite, unit or transporter:
   Terminal 1............... Terminal 2................
   Terminal 3 ............. Terminal 4................

6. Average spacing between terminals :.............. km or miles

7. Types of systems available for inter-terminal transportation:
   ○ Moving walk ways ○ People movers
   ○ Shuttle bus ○ Walking
   ○ Others (please specify)..............

8. What are the total number of airport employees at the airport ?

   a) Ground employees ....................

b) Flight crew personnel ....................

c) Airport business employees ....................
(employees working for restaurants, rental cars, duty free shops etc.)

d) Others(please specify) ....................

9. Number of passengers using the airport and peaking characteristics for 1991
(if other year, please specify).

a) Annual enplaned + deplaned passengers :............millions

b) Peak month(s) : ....................................

c) Enplaned + deplaned on an average day of peak month :................

10. Percentage of ORIGINATING AND TERMINATING passengers of
total (enplaned + deplaned) passengers..................................................

11. Please provide information for the following regarding PARKING :

| Type of Parking | # Parking spaces available |
|---|---|
| a) Long term parking close to terminal(s) (more than 3 hours) | |
| b) Short term parking (less than 3 hours) | |
| c) Employee parking | |
| d) Off-site parking | |

12. Please provide information about the usage of different modes of transportation to the airport in year 1991 (if other year, please specify).

| Mode | Air passenger | Employees | Visitors | Occupancy rate |
|---|---|---|---|---|
| a) Personal automobile | | | | |
| b) taxi | | | | |
| c) rental car | | | | |
| d) limousine | | | | |
| e) bus | | | | |
| f) fixed rail service | | | | |
| g) others (specify) | | | | |

**Question # 13 is applicable to airports having direct fixed rail service, # 14 is applicable to airports with fixed rail systems under construction, and # 15 is applicable to airports that are planning for fixed rail service. Please choose the appropriate one and check off boxes where provided.**

13. Is there any fixed rail service presently serving the airport directly (with transit rail transit station(s) inside the terminal(s).)?

( ) Yes. ( ) No.

If NO, please go to question # 14.
If YES, please complete the following.

a) Distance by rail from CBD of major city to airport........................km or miles

b) Present one way fare from airport to CBD of major city in $US (if other currency, please specify) :.......................................

c) One way fare by competing modes in $US (if other currency, please specify):

i) taxi : ......................

ii) bus/limousine: ......................

iii) others (please specify): ......................

d) Number of stops between CBD of major city and the airport :.............

e) Average distance from station to Check in:..................metres or ft.

f) Travel time from airport to CBD of major city:.....................minutes

g) Present time headway during peak hour:....................minutes
off peak hour:....................minutes

h) Present service hours during weekdays:........................
weekends:........................

i) Is this an exclusive service to the airport or an extension of regional or urban or suburban service ?

( ) Exclusive. ( ) Extension.

j) Portion of the railway (guideway) line exclusively built for airport service:
...............................km or miles

k) Facility of special baggage handling systems on trains :

( ) available. ( ) not available.

l) At the airport, how many rail stations are provided ? ...........................

m) Year in which the service was started :...............................

n) Cost details in $ US (if other currency, please specify the currency and the year of the currency value): ........................................................

i) Total cost of construction : ........................

ii) Cost of right of way (cost of land): ........................

iii) Cost of station, trackage etc. provided for airport service : ........................

iv) Cost of rolling cost (Cars, locomotive, etc.): ........................

v) others (please specify) : ........................

o) If fare subsidized , what is the ratio of subsidy to fare?..................

Who subsidizes the fare ? ........................

p) Passenger Data for the year 1991(if other year, please specify)..................

| Type of passengers | Passengers DEPARTING trains to Airport from station on a typical day | Passengers ARRIVING from Airport to station on a typical day |
|---|---|---|
| Air passengers | | |
| Employees | | |
| Well wishers | | |
| Visitors with Passengers | | |
| Others (specify) ............ | | |
| TOTAL | | |

q) Does this service serve beyond the CBD of major city (away from airport) ?

○ Yes. ○ No.

q) Does this service serve beyond airport (away from the CBD of major city) ?

○ Yes. ○ No.

**PLEASE GO TO QUESTION # 17**

14. Is there any fixed rail service to airport from CBD of major city under construction?

◯ Yes. ◯ No.

If NO, please go to question # 15

If YES, please provide information for the following

a) Proposed fare from CBD to the airport in $US
(if other currency, please specify) :........................

b) One way fare by competing modes in $US (if other currency, please specify):

i) taxi : .....................

ii) bus/limousine: .....................

iii) others (please specify): .....................

c) Proposed number of stops between the airport and the CBD of major city :.........

d) Expected travel time from the airport to the CBD of major city :........minutes

e) Proposed headway of service between the airport and the CBD of major city :

peak hour:.............minutes

off peak hour:.............minutes

f) Year in which the service between the airport and the CBD of major city is proposed to start......................

f) Cost details in $US (if other currency, please specify the currency and year of the currency value)

i. Total cost of construction : .....................

ii. Cost of right of way (cost of land) : .....................

iii. Cost of station, trackage etc., provided for airport service: .....................

iv. Cost of rolling stock (Cars, locomotives, etc.): .....................

v. others (please specify) :..................... .....................

**PLEASE GO TO QUESTION # 17**

15. Is there any proposal for direct fixed rail service to airport?

◯ Proposal for extension (spur) ◯ Proposal for exclusive line ◯ No proposal

If there is any proposal for extension or exclusive line, please send the information or reports, or the source for getting the reports.

16. **If the airport is not directly served by fixed rail service, please provide the details of connecting mode of transportation between the AIRPORT and the NEAREST FIXED RAIL TRANSIT STATION:**

**a) Characteristics of different modes in operation:**

| Mode | travel time (minutes) | fare * (US $) | frequency during off peak | frequency during peak |
|---|---|---|---|---|
| Shuttle bus | | | | |
| Taxi | | | | |
| Limousine | | | | |
| People mover | | | | |
| Others (specify)............. | | | | |

***if other currency, please specify**

**b) Distance from airport to fixed rail transit station:.......... km or miles**

**c) Distance from transit station near airport to CBD :............km or miles**

**d) Fare from station near airport to CBD of major city $US: ..................**
**(if other currency, please specify)**

**e) Travel time from transit station near airport to CBD of major city :............minutes**

**f) Number of stops between station and CBD of major city :................**

**g) If fare subsidized, what is the ratio or subsidy to fare ?......................**
**Who subsidizes the fare ? .....................**

**h) If available, please provide the distribution of passenger usage of the service.**

| Type of passengers | Passengers DEPARTING trains to Airport from station on a typical day | Passengers ARRIVING from Airport to station on a typical day |
|---|---|---|
| i) Air passengers | | |
| ii) Employees | | |
| iii) Visitors with Passengers | | |
| iv) Others (specify) ............ | | |
| TOTAL | | |

17. Please mention any other information or sources of information.

---

Please provide, if available, relevant route maps and time tables.

**THANK YOU FOR YOUR COOPERATION**

Please return to :

Srinivasa Mandalapu
220 Civil/ Elec. Building
University of Alberta
EDMONTON, AB
Canada, T6G 2G7
Phone: (403) 492-5125
Fax: (403) 492-0249

Filled By:.......................................
Title:...............................................
Airport:..........................................
..........................................
Date:.............................................
Phone:...........................................
Fax:...............................................

To:

Date:

Subject: Information on Fixed Rail Access to Airports.

Dear Sir/Madam,

I am a graduate student in Civil Engineering at the University of Alberta, Edmonton, Canada, and I am undertaking research on Fixed Rail Service to Airports. The major objectives of this research are to identify airport user and system characteristics and to develop a technique to assess the potential for fixed rail service to airports.

As a part of this work, information from airports served by or planned to be served by Fixed Rail Systems such as railroad, light rail, subway, elevated track, monorail, streetcar, or tram, will be invaluable. I hope to update the survey done by Airport Operators Council International, Washington, D.C., in early 80's. Could you please help by completing the enclosed information form and mailing it back.

I would also be grateful if you could include additional information or material, studies, maps, and schedules. Your cooperation and assistance is highly appreciated.

Thank you very much.

Yours truly,

Mandalapu Srinivasa

Encl.

## A.2 List of Airports Contacted

Table A.1: List and Address of Airports Contacted for Information

| City | Airport | Address |
|---|---|---|
| ALGERIA | Algiers El-djazair Houari | Boumedienne International Airport, Algiers, Algeria |
| AMSTERDAM | Amsterdam Airport Schiphol | P.O. Box 7501, NL-1118 ZG, Schiphol Airport, Netherlands |
| ATLANTA | William B. Hartsfield Atlanta International Airport | Airport Commissioner's Office, 68 Mitchell St., S.W., Atlanta, GA, 30335, USA. |
| BALTIMORE | Baltimore-Washington International Airport (BWI) | P.O. Box. 8766, BWI Airport, MD 21240-0766, USA, |
| BARCELONA | Barcelona Airport | Barcelona, Spain |
| BERLIN | Berlin Tegel Airport | D - 1000, Berlin 51, Germany |
| BERLIN | Berlin-Schonefeld Airport | DDR - 1189, Berlin - Schonefeld, Germany |
| BIRMINGHAM | Birmingham International Airport | Birmingham, England, B26 3QJ |
| BOSTON | Boston General Edward Lawrence Logan International Airport | Massachusetts Port Authority, Aviation Department, New Tower, 18th Fl., East Boston, MA 02128, USA. |
| CALGARY | Calgary International Airport | 2000 Airport Road, N.E., Calgary AB, T2E 6W5 |
| CASABLANCHA | Casablancha Novusser Airport | B.P. 8101, Casablanca, Morroca |
| CHICAGO | Chicago - O'Hare International Airport | Box. 66142, Chicago, IL 60666, USA |
| CHICAGO | Chicago Midway Airport | 5700 Scicero Avenue, Chicago, IL 60638, USA. |
| CLEVELAND | Cleveland Hopkins International Airport | 5300 River Dr., Cleveland, OH 44135, USA |
| COLOGNE | Cologne/Bonn International Airport | Postfach 98 01 20, D-5000, Kolon, Germany |
| DUSSELDORF | Dusseldorf / .rport | Postfach 30 03 63, D - 4000, Dusseldorf 30, Germany |
| FIRENZE | Firenze Peretola Airport | Firenze, Italy |
| FORLÌ | Forli Airport | Forli, Italy |
| FRANKFURT | Frankfurt - Main International Airport | D-6000, Frankfurt 75, Germany |
| GENEVA | Geneva - Cointrin Airport | CH-1215 Geneva 15 Airport, Switzerland |

Table A.1: List and Address of Airports Contacted for Information. Contd.

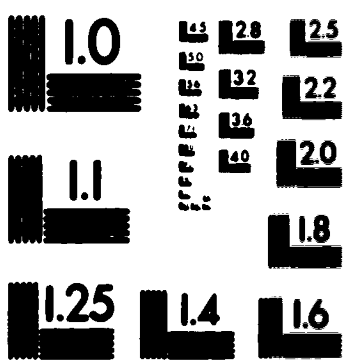
| City | Airport | Address |
|---|---|---|
| KANSAI | Kansi (Osaka) International Airport | 3-555 Hotarugaike - Nishimachi, Osaka, Japan 560 |
| LONDON | London Heathrow Airport | Hounslow, London, Middx, England, TW6 1JH |
| LONDON | London Stansted Airport | Enterprise House, Stansted Airport Ltd., Stansted, Essex, England, CM24 1QW |
| LONDON | London Gatwick Airport | Gatwick, W. Sussex, England, RH6 0NP |
| LOS ANGELES | Los Angeles International Airport | Los Angeles Department of Airports, 1 World Way, Los Angeles, CA 90045, USA |
| MADRID | Madrid Barjas Aiport | Gerencia Del Aeropuerto, Madrid, Spain |
| MALAGA | Malga Airport | Apt. de Correos 371, Caretera Nacional 340, E - 29071, Malaga, Spain. |
| MANCHESTER | Manchester International Airport | Manchester, England, MZ2 5PA |
| MELBOURNE | Melbourne Airport. | PO Box. 116, VIC, Australia 3045 |
| MIAMI | Miami International Airport | Box 59-2075, AMF, Miami, Fl 33159, USA |
| MILAN | S.E.A (Societa Esercizi Aeroportuali A.p.A) | I-21010, Varese, Italy |
| MONTREAL | Montreal International Airport, Dorval | Suite 387, 975 Romeo Vachou Nord, Dorval, PQ, Canada - H4Y 1H1 |
| MONTREAL | Montreal International Airport Airport, Mirabel | Local 622, 12655, Commerce A-4 ST., Admn.. Bldg., Mirabel, PQ, J7N 1E1 Canada |
| MOSCOW | Moscow Sheremetyevo Airport | Moscow, Soviet Union, SU-10334U |
| MUNICH | Munichen International Airport | Postfach 87 02 20, D-8000, Munich 87, Germany |
| NEW YORK | New York LaGardia Airport | LaGardia Airport Station, Flushing, NY 11371 |
| NEW YORK | New York JFK International Airport | d/b/a/ Port Authority of NY & NJ, Bldg. 141, Jamaica, NY 11430 |
| NEWARK | Newark International Airport | Tower Rd., Building 10, Newark, NJ 07114, USA |
| OAKLAND | Oaklnad International Airport | BOX. 45, 1 Airport Dr., Oakland, CA 94621, USA. |
| ONTARIO | Ontario International Airport | Terminal Bldg. Rm. 200, Ontario, CA 91761, USA |
| PALERMO | Palermo Punta Raisi Airport. | I-90045, Palermo, Sicily, Italy |

Table A.1: List and Address of Airports Contacted for Information. Contd.

| City | Airport | Address |
|---|---|---|
| PARIS | Paris Charles De Gaulle Airport | B.P. 20101, F-95711, Roissy Cedex, France |
| PARIS | Paris Orly Airport | Orly SUD 102, F- 94396, Orly Aerogare Cedex, France. |
| PHILADELPHIA | Philadelphia International Airport | Philadelphia, PA 19153, USA |
| ROME | Rome Ciampino Airport | C/O Soc. Aeroporti Di Roma, Dirigenza Scalo, Ciampino, I - 00040, Rome, Italy. |
| SAN FRANCISCO | San Francisco International Airport | PO Box 8097, San Francisco, CA 94128, USA. |
| SOUTHAMPTON | Southampton / Eastleigh Airport | Airports UK(Southampton) Ltd., Southampton, England, S09 1RH |
| STOCKHOLM | Stockholm Arlanda Airport | S - 190 45, Stockholm-Arlanda, Sweden |
| STUTTGART | Stuttgart Airport | Postfach 23 04 61, D-7000, Stuttgart 23, Germany |
| SYDNEY | Kings Ford Smith Airport. | PO Box 63, FAC House, Keint Smith Avenue, Mascot, NSW, Australia |
| TOKYO | Tokyo International Airport / Haneda | Japan Airport Terminal Co. Ltd., 4-3 Haneda - Kuko 2- Chome, Ota-Ku, Tokyo, Japan 144. |
| TOKYO | New Tokyo International Airport / Narita | PO BOX 80, Narita -Shi, Chiba 282, Japan |
| TORONTO | Toronto Lester B. Pearson International Airport | Transport Canada, PO Box 6003, Toronto AMF, ON, Canada -L5P 1B5 |
| VIENNA | Vienna International Airport. | BOX 1, A-1300, Vienna, Austria |
| WASHINGTON | Washington Dulles International Airport | Box 17045, Washington, D.C. 20041 |
| WASHINGTON NATIONAL | Washington National Airport. | Washington, DC, 20001, USA |
| ZURICH | Zurich Kolton Airport. | Zurich, Switzerland |

3 of/de 3

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT




PRECISION℠ RESOLUTION TARGETS

# APPENDIX B

## B.1 RRT Model Details

In the development of the cost model for RRT systems some defaults are set. The defaults and the basic calculations used in the model are presented. A listing of the computer model is also presented.

### B.1.1 Defaults for RRT Cost Model

The following are the defaults used in the model. The model is flexible to change some of the defaults to input known information.

1. Number of Stations: Calculated using the equation b.1

   $$n = 0.704 * L - 0.00356 * L2 \qquad \ldots b.1$$

   where n = number of stations (includes end stations)

   L = length of the route

2. Costs of components of the system: Average costs updated from 1973 costs (Vuchic, 1981) using Engineering New Record's cost index for 1991 (Grogan, 1992).
3. Interest rate: 7%; Inflation rate: 3%.
4. Expected lives of each of the components of system: These are taken from World Bank report (Wright 1985). The defaults are presented in Table 4.2.
5. Construction details: Percent of tunnel construction, percent of cut and cover construction, and percent of elevated construction are set to zero.
6. Percentage of peak hour passenger traffic of average day's passenger traffic: 10%
7. Directional split: peak direction 60% and 40% in the opposite direction
8. Off-peak hour passenger traffic: 3% of average day's passengers traffic.
9. Headways during peak hour: 15 minutes.
10. Headway during off-peak hour: 30 minutes.
11. Duration of Peak hour operation: 4 hours; Off-peak operation: 16 hours.
12. Car capacity: 120 passengers

13 Occupancy rate 0 9 of capacity

14 Dwelling time 30 sec

15 Turnaround time 2 minutes

**B.1.2 Calculations**

The route length is divided into equal segments as shown in Equation b.2. Each segment is separated into three zones; accelerating zone, cruising zone, and deceleration zone. Travel times for each of these zones are calculated using standard equations of dynamics. Total travel time is calculated by summing up the travel times of all segments and the dwell times at enroute stops. Average operating speed and round-trip time are calculated from the total travel time.

$$l = L / (n-1) \quad \text{... b.2}$$

where l = segment length (km)

L = route length (km)

n = number of stations

Peak hour passenger demand is calculated by considering the peaking, directional split, and occupancy rate. Fleet calculations are done based on the round-trip times and passenger demand using the Equations b.3 - b.6.

$$f = rdt / hw \quad \text{... b.3}$$

$$nt = 60 / hw \quad \text{... b.4}$$

$$nc = dem / cap \quad \text{... b.5}$$

$$ncpt = nc / nt \quad \text{... b.6}$$

Where f = number of trains required for operation

rdt = round trip time in minutes

hw = headways in minutes

nt = number of services per hour

nc = number of cars required for operation per hour

dem = passenger demand per hour

cap = capacity of each car and

ncpt = number of cars per train

The car kilometers are calculated by considering both peak and off-peak operations and weekday and weekend operations. The operating and maintenance cost is calculated based on car kilometers. The same approach has been applied in APM cost model and Bus Cost model. The differences among the models are explained in the respective structures of the models.

The program is written in Quick Basic. The listing of the program is presented in the following section.

**B.1.3 Listing of RRT Cost Model:**

The model is developed using Quick Basic Ver. 4.00 on DOS environment. This enable to work on most of IBM compatible personal computers. The following is the listing of the program.

```
DECLARE SUB box (rlt%, clt%, rlb%, clb%)
DECLARE SUB oprspeed (LENGTH!, NST%, tt!)
DECLARE SUB TITLE ()
DECLARE SUB NVEH (PKFT%)
DECLARE SUB CRF (LIFE%, EFR!, RF!)
DECLARE SUB inbox (rlt%, clt%, rlb%, clb%)
DECLARE SUB outbox (rlt%, clt%, rlb%, clb%)
DECLARE SUB EMPTY (S, E)
COMMON SHARED PKHW%, OFPKHW%, RDTRIPTIME%, PHF!, avs%, PKFT%, OFPKFT%,
PKNOCARS%, OFPKNOCARS%, NOCARPERTRAIN%, PKTRAIN%, NOCAROFPERTRAIN%,
OFPKTRAIN%, NPAX&, LENGTH!, NST%, tt!
COMMON SHARED sthor, botlc, botrc, toplc, toprc, stver, PLUS, TEE,
INVTEE, rtee, ltee
'
*************************************************************************

SCREEN 9
COLOR 8, 3
200 CALL EMPTY(1, 23)
CLEAR a - z
CALL inbox(8, 11, 21, 72)
CALL TITLE
COLOR 8
PRINT CHR$(7)
LOCATE 9, 25: PRINT "  ** General Information **   "
COLOR 15
'
*************************************************************************
'    CALCULATION OF EQUIVALENT ANNUAL COST OF RAIL RAPID TRANSIT PROJECT
```

```
'
'*************************************************************************
'
LOCATE 11, 65: PRINT "None"
30 LOCATE 11, 17: INPUT "1. Length of New Line(in kilometres) = ",
LENGTH!
IF (LENGTH! <= 0! OR LENGTH > 120!) THEN
PRINT CHR$(7)
GOTO 30
ELSE
END IF
'                   NUMBER OF STATIONS PLANNED
'
LOCATE 13, 18: PRINT "     Calculates if entered ZERO"
LOCATE 12, 65: PRINT "Calc."
LOCATE 12, 17: INPUT "2. Number of Stations Planned        = ", NST%

IF NST% = 0 THEN
        NST% = INT(.704 * LENGTH! - .00356 * LENGTH ^ 2 + .49)
        IF NST% < 2 THEN NST% = 2
        LOCATE 15, 17: PRINT "Calculated number of stations        =",
NST%
    ELSE
END IF

'*************************************************************************
'          MINIMUM AND MAXIMUM COSTS OF COMPONENTS OF RAIL TRANSIT
SYSTEM
'*************************************************************************
ROFWAY! = 5.22                              'RIGHT OF WAY COST PER KM
PWATMIN! = 3.27:   PWATMAX! = 9.165         'AT GRADE PERMANENT WAY COSTS
PER KM
PWTUNMIN! = 45.78: PWTUNMAX! = 54.5         'PERMANENT WAY IN TUNNEL PER KM
PWELEMIN! = 10.9:  PWELEMAX! = 17.44        'PERMANENT WAY ELEVATED PER KM
PWCCMIN! = 21.8:   PWCCMAX! = 54.5          'PERMANENT WAY CUT AND COVER
PER KM
STATMIN! = 7.63:   STATMAX! = 9.047         'AT GRADE STATION COSTS PER
STATION
STUGMIN! = 15.26:  STUGMAX! = 32.7          'UNDER-GROUND STATION COSTS PER
                                                   'STATION
STELEMIN! = 2.83:  STELEMAX! = 10.03        'ELEVATED STATION COST PER
STATION
TRSUPMIN! = .763:  TRSUPMAX! = 1.308        'TRACK SUPER STRUCTURE COSTS
PER KM
PSMIN! = .981:     PSMAX! = 2.398           'POWER SUPPLY EQUIPMENT COSTS
PER KM
CONCOMMIN! = .872: CONCOMMAX! = 3.488       'CONTROLS AND COMMUNICATIONS
COSTS
                                                   'PER KM
VEHMIN! = .436:    VEHMAX! = .872           'VEHICLE COSTS PER VEH
GARMIN! = .218:    GARMAX! = .654           'GARAGE AND MAINTENANCE COSTS
PER VEH
'
'*************************************************************************
'                  EFFECTIVE INTEREST RATE CALCULATIONS
```

```
'**********************************************************************
'
LOCATE 17, 67: PRINT "7%"
LOCATE 17, 17: INPUT "3. Interest Rate(%)                    = ", INR!
        IF INR! = 0 THEN INR! = 7!
LOCATE 19, 67: PRINT "3%"
LOCATE 19, 17: INPUT "4. Inflation Rate(%)                   = ", IFR!
        IF IFR! = 0 THEN IFR! = 3!
INR! = INR! * .01
IFR! = IFR! * .01
EFR! = (INR! + 1!) * (IFR! + 1!) - 1!
'
'*********************************************************************
'              LIFE OF COMPONENTS AND COST RECOVERY FACTORS
'*********************************************************************
'
ROFWAYLIFE% = 200
CALL EMPTY(4, 22)
 CALL box(13, 10, 18, 69)
 LOCATE 15, 11: PRINT "   Do you want to input the expected lives of "
LOCATE 16, 17: PRINT "          components of the system (Y/N)"
LOCATE 17, 15: PRINT "(If entered 'No' the model assumes default
values)"
LOCATE 16, 57: INPUT y$
IF (y$ = "y" OR y$ = "Y") THEN
        CALL EMPTY(4, 22)
        CALL inbox(6, 10, 21, 74)
        COLOR 8
        LOCATE 7, 15: PRINT "Expected Life of Components of System in
Years"
        COLOR 15
        LOCATE 9, 68: PRINT "30"
        LOCATE 9, 14: INPUT "1. Life of Permanent way At-Grade          =
", PWATLIFE%
'
        LOCATE 10, 67: PRINT "100 "
        LOCATE 10, 14: PRINT "2. Life of Tunnel/Elevated Construction /"
        LOCATE 11, 19: INPUT "Cut and Cover construction           = ",
PWTULIFE%
'
        LOCATE 12, 68: PRINT "[illegible]"
        LOCATE 12, 14: INPUT "3. Life of At-Grade Stations
= ", STATLIFE%
'
        LOCATE 13, 67: PRINT "100"
        LOCATE 13, 14: INPUT "4. Life of Underground Stations
= ", STUGLIFE%
'
        LOCATE 14, 68: PRINT "30"
        LOCATE 14, 14: INPUT "5. Life of Track Structure
= ", TRSTLIFE%
'
        LOCATE 15, 68: PRINT "30";
        LOCATE 15, 14: PRINT "6. Life of Power Supply and Distribution
System"
```

```
        LOCATE 16, 19: INPUT "                                          = ",
POWRLIFE%
'
        LOCATE 17, 68: PRINT "25"
        LOCATE 17, 14: PRINT "7. Life of Control and Communications
Systems"
        LOCATE 18, 19: INPUT "                                          = ",
PWLIFE%
'
        LOCATE 19, 68: PRINT "25"
        LOCATE 19, 14: INPUT "8. Life of Vehicles
= ", VEHLIFE%
'
        LOCATE 20, 68: PRINT "50"
        LOCATE 20, 14: INPUT "9. Life of Maintenance Storage Facilities
= ", GARALIFE%

   ELSE
        GOTO 100
END IF
100  IF PWATLIFE% = 0 THEN PWATLIFE% = 30       'DEFAULTS
     IF PWTULIFE% = 0 THEN PWTULIFE% = 100
     IF STATLIFE% = 0 THEN STATLIFE% = 50
     IF STUGLIFE% = 0 THEN STUGLIFE% = 100
     IF TRSTLIFE% = 0 THEN TRSTLIFE% = 30
     IF POWERLIFE% = 0 THEN POWERLIFE% = 30
     IF CONLIFE% = 0 THEN CONLIFE% = 25
     IF VEHLIFE% = 0 THEN VEHLIFE% = 25
     IF GARALIFE% = 0 THEN GARALIFE% = 50

'                    COST RECOVERY FACTORS
'
CALL CRF(ROFWAYLIFE%, EFR!, F10!)
CALL CRF(PWATLIFE%, EFR!, F11!)
CALL CRF(PWTULIFE%, EFR!, F12!)
CALL CRF(STATLIFE%, EFR!, F13!)
CALL CRF(STUGLIFE%, EFR!, F14!)
CALL CRF(TRSTLIFE%, EFR!, F15!)
CALL CRF(POWERLIFE%, EFR!, F16!)
CALL CRF(CONLIFE%, EFR!, F17!)
CALL CRF(VEHLIFE%, EFR!, F18!)
CALL CRF(GARALIFE%, EFR!, F19!)
'
'                    EQUIVALENT ANNUAL COSTS
'
ACROFWAY! = ROFWAY! * F10!
'
ACPWATL! = PWATMIN! * F11!
ACPWATU! = PWATMAX! * F11!          'FOR PERMANENT WAY AT-GRADE
'
ACPWTUL! = PWTUNMIN! * F12!
ACPWTUU! = PWTUNMAX! * F12!         'FOR PERMANENT WAY IN TUNNEL
'
ACPWELL! = PWELEMIN! * F12!
ACPWELU! = PWELEMAX! * F12!         'FOR ELEVATED CONSTRUCTION
```

```
'
ACPWCCL! = PWCCMIN! * F12!
ACPWCCU! = PWCCMAX! * F12!          'FOR CUT AND COVER CONSTRUCTION
'
ACSTATL! = STATMIN! * F13!
ACSTATU! = STATMAX! * F13!          'FOR STATIONS AT GRADE
'
ACSTSTUGL! = STUGMIN! * F14!
ACSTSTUGU! = STUGMAX! * F14!        'FOR STATIONS UNDERGROUND
'
ACSTELEL! = STELEMIN! * F14!
ACSTELEU! = STELEMAX! * F14         'ELEVATED STATIONS
'
ACTRSUPL! = TRSUPMIN! * F15!
ACTRSUPU! = TRSUPMAX! * F15!        'FOR TRACK SUPERSTRUCTURE
'
ACPSL! = PSMIN! * F16!
ACPSU! = PSMAX! * F16!              'FOR POWER SUPPLY EQUIPMENT
'
ACCONCOML! = CONCOMMIN! * F17!
ACCONCOMU! = CONCOMMAX! * F17!      'FOR CONTROLS AND COMMUNICATIONS

'              INPUT OF CONSTRUCTION DETAILS
'
CALL EMPTY(4, 22)
PRINT CHR$(7)
CALL inbox(7, 8, 18, 73)
COLOR 8
 LOCATE 8, 20: PRINT "      CONSTRUCTION DETAILS"
COLOR 15
    LOCATE 11, 68: PRINT "0%"
LOCATE 11, 10: INPUT "1. Tunnel Construction in Percent of New Line  =
", T!
'
    LOCATE 13, 68: PRINT "0%"
LOCATE 13, 10: INPUT "2. Elevated Construction in Percent of New Line=
", E!
'
    LOCATE 15, 68: PRINT "0%"
LOCATE 15, 10: PRINT "3. Cut and Cover Construction in Percent of "
        LOCATE 16, 25: INPUT "                          New Line     = ", C!
'
N2% = INT(((T! + C!) * .01) * NST%): N3% = INT((E! * .01) * NST%)
N1% = NST% - N2% - N3!

TCCOSTL1! = LENGTH! * ((PWATMIN! + ROFWAY!) * (1! - (T! * .01)) +
PWTUNMIN! * (T! * .01) + PWELEMIN! * (E! * .01) + PWCCMIN! * (C! * .01)
+ TRSUPMIN! + PSMIN! + CONCOMMIN!) + N1% * STATMIN! + N2% * STUGMIN! +
N3% * STELEMIN!
TCCOSTU1! = LENGTH! * ((PWATMAX! + ROFWAY!) * (1! - (T! * .01)) +
PWTUNMAX! * (T! * .01) + PWELEMAX! * (E! * .01) + PWCCMAX! * (C! * .01)
+ TRSUPMAX! + PSMAX! + CONCOMMAX!) + N1% * STATMAX! + N2% * STUGMAX! +
N3% * STELEMAX!
'
'*******************************************************************
```

```
' EQUIVALENT ANNUAL COST OF CONSTRUCTION EXCEPT VEHICLES AND GARAGE
'*****************************************************************
'
ACCOSTL! = LENGTH! * ((ACPWATL! + ACROFWAY!) * (1! - T! * .01) +
ACPWTUL! * (T! * .01) + ACPWELL! * (E! * .01) + ACPWCCL! * (C! * .01) +
ACTRSUPL! + ACPSL! + ACCONCOML!) + N1% * ACSTATL! + N2% * ACSTSTUGL! +
N3% * ACSTELEL!
ACCOSTU! = LENGTH! * ((ACPWATU! + ACROFWAY!) * (1! - T! * .01) +
ACPWTUU! * (T! * .01) + ACPWELU! * (E! * .01) + ACPWCCU! * (C! * .01) +
ACTRSUPU! + ACPSU! + ACCONCOMU!) + N1% * ACSTATU! + N2% * ACSTSTUGU! +
N3% * ACSTELEU!
'
'******************************************************************-
'ANNUAL COST FOR VEHICLES AND GARAGE
'******************************************************************-
'
CALL NVEH(PKFT%)
TCVEHL! = VEHMIN! * PKFT%: TCVEHU! = VEHMIN! * PKFT%
   ACVEHL! = TCVEHL! * F18!: ACVEHU! = TCVEHU! * F18!
TCGARL! = GARMIN! * PKFT%: TCGARU! = GARMAX! * PKFT%
   ACGAR1! = TCGARL! * F19!: ACGARU! = TCGARU! * F19!
ANCOSTL! = ACCOSTL! + ACVEHL! + ACGAR1!
ANCOSTU! = ACCOSTU! + ACVEHU! + ACGARU!
'
TCCOSTL! = TCCOSTL1! + TCVEHL! + TCGARL!
TCCOSTU! = TCCOSTU1! + TCVEHU! + TCGARU!
TCOST! = (TCCOSTL! + TCCOSTU!) / 2! * 1.25        '25% extra
'*****************************************************************
'              ANNUAL MAINTENANCE COST CALCULATIONS
'*****************************************************************
'
CALL EMPTY(4, 23)
PRINT CHR$(7)
CALL inbox(9, 11, 17, 72)
COLOR 5
LOCATE 10, 21: PRINT "   *** OPERATIONAL DETAILS ***"
COLOR 15

        LOCATE 12, 67: PRINT "4"
        LOCATE 13, 13: PRINT "(eg:2 hrs during am peak + 2 hrs during pm
peak)"
LOCATE 12, 13: INPUT "1. Peak Hour Operation in Hours       = ", DURPK!
'
        IF DURPK! = 0 THEN DURPK! = 4!
        LOCATE 15, 66: PRINT "16"
LOCATE 15, 13: INPUT "2. Off-Peak Hour Operation in hours   = ",
DUROFPK!
'
        IF DUROFPK! = 0 THEN DUROFPK! = 16!
'
' CALCULATION OF CAR.KM PER DAY AND PER YEAR
'
CARKMd& = LENGTH! * (NOCARPERTRAIN% * DURPK! * 120! / PKHW% +
NOCAROFFPERTRAIN% * DUROFPK! * 120! / OFPKHW%)
CARHRd& = (DURPK! * PKNOCARS% + DUROFPK! * OFPKNOCARS%)
```

```
CARKMd1& = LENGTH! * (NOCAROFFPERTRAIN% * 20 * 120! / RDTRIPTIME%)
CARHRd1& = (20 * OFFPKNOCARS%)
CARKMy& = CARKMd& * 52 * 5 / 1000 + CARKMd1& * 52 * 2 / 1000
CARHRy& = CARHRd& * 52 * 5 + CARHRd1& * 52 * 2
ANMAINT! = 2.4 * CARKMy& / 1000
NETANCL! = ANMAINT! + ANCOSTL!
NETANCU! = ANMAINT! + ANCOSTU!
'
'    OUTPUT OF OPERATIONAL DETAILS
'
CALL EMPTY(4, 23)
CALL outbox(4, 10, 19, 73)
COLOR 5
LOCATE 5, 24: PRINT " *** OUTPUT OF OPERATIONAL DETAILS ***"
COLOR 15
LOCATE 7, 13: PRINT "1. Length of New Line (km)                         ="
        LOCATE 7, 64: PRINT USING "###.#"; LENGTH!
LOCATE 8, 13: PRINT "2. Length of Tunnel Construction (km)              ="
        LOCATE 8, 65: PRINT USING "##.#"; LENGTH! * T! * .01
LOCATE 9, 13: PRINT "3. Length of Elevated Construction (km)            ="
        LOCATE 9, 65: PRINT USING "##.#"; LENGTH! * E! * .01
LOCATE 10, 13: PRINT "4. Length of Cut & Cover Construction (km)         ="
        LOCATE 10, 65: PRINT USING "##.#"; LENGTH! * C! * .01
LOCATE 11, 13: PRINT "5. Round Trip time (minutes)                       ="
        LOCATE 11, 66: PRINT USING "###"; RDTRIPTIME%
LOCATE 12, 13: PRINT "6. Number of Trains Required for Peak Hour
Operation="
       LOCATE 12, 66: PRINT USING "###"; PKTRAIN%
LOCATE 13, 13: PRINT "                              for Off-Peak
Operation="
       LOCATE 13, 66: PRINT USING "###"; OFFPKTRAIN%
LOCATE 14, 13: PRINT "7. Number of Cars per Train During Peak Hour
="
       LOCATE 14, 67: PRINT USING "##"; NOCARPERTRAIN%
LOCATE 15, 13: PRINT "                             During Off-Peak Hour
="
       LOCATE 15, 67: PRINT USING "##"; NOCAROFFPERTRAIN%
LOCATE 16, 13: PRINT "8. Number of Cars Required for Operation           ="
        LOCATE 16, 65: PRINT USING "####"; PKNOCARS%
LOCATE 17, 13: PRINT "9. Number of Car Kilometres per day                = "
       LOCATE 17, 62: PRINT USING "#######"; CARKMd&
LOCATE 18, 12: PRINT "10. Number of Car Hours per day                    ="
       LOCATE 18, 62: PRINT USING "#######"; CARHRd&
'
LOCATE 20, 13: INPUT "         Press ENTER to continue   ", D$
ANNPAX! = NPAX& * 52! * (5! + .3 * 2!) / 1000!
COSTPERPAX! = (NETANCL! + NETANCU!) / 2! / ANNPAX!
'
CALL EMPTY(4, 23)
CALL outbox(4, 11, 17, 73)
COLOR 5
LOCATE 5, 24: PRINT " *** OUTPUT OF COST DETAILS ***"
COLOR 15
LOCATE 7, 13: PRINT "1. Annual passengers (millions)                   ="
        LOCATE 7, 65: PRINT USING "####.##"; ANNPAX!
```

```
LOCATE 9, 13: PRINT "2. Total Capital Cost of System             = M
$"
       LOCATE 9, 64: PRINT USING "#####.##"; TCOST!
LOCATE 11, 13: PRINT "3. Annual Operating and Maintenance Cost      = M
$"
       LOCATE 11, 66: PRINT USING "###.##"; ANMAINT!
LOCATE 13, 13: PRINT "4. Equivalent Annual Cost of the System       = M
$"
       LOCATE 13, 65: PRINT USING "####.##"; (NETANCL! + NETANCU!) / 2!
LOCATE 15, 13: PRINT "5. Average Cost per Passenger                 =
$"
       LOCATE 15, 66: PRINT USING "###.##"; COSTPERPAX!


'************************************************************************

LOCATE 21, 13: PRINT "Do you want Print the Results     (",
LOCATE 21, 52: PRINT ")"
COLOR 4
LOCATE 21, 49: PRINT "Y/N"
COLOR 15
LOCATE 21, 54: INPUT D$
IF (D$ = "Y" OR D$ = "y") THEN
'************************************************************************
LPRINT ; TAB(5); "  ***  COST MODEL FOR RAIL RAPID SYSTEMS  ***"
LPRINT
LPRINT
LPRINT ; TAB(15); "              Input Data"
LPRINT
LPRINT ; TAB(8); "A. GENERAL INFORMATION  "
LPRINT
LPRINT ; TAB(10); " 1. Length of New Line(in kilometres) = ", LENGTH!
LPRINT
LPRINT ; TAB(10); " 2. Number of Stations Planned/Calc.  = ", NST%
LPRINT
LPRINT ; TAB(10); " 3. Interest Rate(%)                  = ", INR! * 100
LPRINT
LPRINT ; TAB(10); " 4. Inflation Rate(%)                 = ", IFR! * 100
LPRINT
LPRINT ; TAB(10); " 5. Tunnel Construction (%)           = ", T!
LPRINT
LPRINT ; TAB(10); " 6. Elevated Construction (%)         = ", E!
LPRINT
LPRINT ; TAB(10); " 7. Cut and Cover Construction (%)    = ", C!
LPRINT
LPRINT ; TAB(8); "B. OPERATIONAL CHARACTERISTICS "
LPRINT
LPRINT
LPRINT ; TAB(10); " 1. Number of Passengers in Both Directions"
LPRINT ; TAB(10); "       on an Average  Weekday  in  THOUSANDS = ";
NPAX&
LPRINT
LPRINT ; TAB(10); " 2. Percent of Average Week day Passengers"
LPRINT ; TAB(10); "                             During Peak Hour = ";
.HP!
```

```
LPRINT ; TAB(10); " 3. Peak Hour Operation in Hours              = ";
DURPK!
LPRINT
LPRINT ; TAB(10); " 4. Off-Peak Hour Operation in hours          = ";
DUROFPK!
LPRINT
LPRINT ; TAB(10); " 5. Headway During Peak Hour in Minutes       = ";
PKHW%
LPRINT
LPRINT ; TAB(10); " 6. Headway During Off-Peak Hour in Minutes   = ";
OFPKHW%
LPRINT CHR$(12)
LPRINT
LPRINT TAB(15); "              Output of the Model"
LPRINT
LPRINT
LPRINT TAB(8); "A. OUTPUT OF OPERATIONAL CHARACTERISTICS "
LPRINT
LPRINT
LPRINT ; TAB(10); " 1. Length of New Line (km)                        =";
USING "###.#"; LENGTH!
LPRINT
LPRINT ; TAB(10); " 2. Length of Tunnel Construction (km)             =";
USING "##.#"; LENGTH! * T! * .01
LPRINT
LPRINT ; TAB(10); " 3. Length of Elevated Construction (km)           =";
USING "##.#"; LENGTH! * E! * .01
LPRINT
LPRINT ; TAB(10); " 4. Length of Cut & Cover Construction (km)        =";
USING "##.#"; LENGTH! * C! * .01
LPRINT
LPRINT ; TAB(10); " 5. Round Trip time (minutes)                      =";
USING "###"; RDTRIPTIME%
LPRINT
LPRINT ; TAB(10); " 6. Average Operating Speed in kmph                =";
USING "###.#"; ave%

LPRINT ; TAB(10); " 7. Number of Trains Required for Peak Hour Operation
="; USING "####"; PKTRAIN%
LPRINT ; TAB(10); "                                 for Off-Peak Operation
="; USING "####"; OFPKTRAIN%
LPRINT
LPRINT ; TAB(10); " 8. Number of Cars per Train During Peak Hour
="; USING "####"; NOCARPERTRAIN%
LPRINT ; TAB(10); "                               During Off-Peak Hour
="; USING "####"; NOCAROFFPERTRAIN%
LPRINT
LPRINT ; TAB(10); " 9. Number of Cars Required for Operation
="; USING "####"; PKNOCARS%
LPRINT
LPRINT ; TAB(10); "10. Number of Car Kilometres per day
="; USING "#######"; CARKMd&
LPRINT
LPRINT ; TAB(10); "11. Number of Car Hours per day
="; USING "#######"  CARHRd&
```

```
 LPRINT
 LPRINT
 LPRINT ; TAB(8); "B. OUTPUT OF COST DETAILS "
 LPRINT
 LPRINT
 LPRINT ; TAB(10); " 1. Annual passengers (millions)              =
 "; USING "#####.##"; ANNPAX!
 LPRINT
 LPRINT ; TAB(10); " 2. Total Capital Cost of System               = M
 $"; USING "#####.##"; TCOST!
 LPRINT
 LPRINT ; TAB(10); " 3. Annual Operating and Maintenance Cost      = M
 $"; USING "#####.##"; ANMAINT!
 LPRINT
 LPRINT ; TAB(10); " 4. Equivalent Annual Cost of the System       = M
 $"; USING "#####.##"; (NETANCL! + NETANCU!) / 2!
 LPRINT
 LPRINT ; TAB(10); " 5. Average Cost per Passenger                 =
 $"; USING "#####.##"; COSTPERPAX!

'*********************************************************************
ELSE
END IF
        LOCATE 21, 13: PRINT "Do you want to make another trial (",
        LOCATE 21, 52: PRINT ")"
        COLOR 4
        LOCATE 21, 49: PRINT "Y/N"
        COLOR 15
        LOCATE 21, 54: INPUT dD$

IF (dD$ = "y" OR dD$ = "Y") THEN
        GOTO 200
 COLOR 4
LOCATE 24, 24: PRINT "Terminating the program"
'***************************************
ELSE
END IF

SUB box (rlt%, clt%, rlb%, clb%) STATIC
sthor = 205: botlc = 200: botrc = 188: toplc = 201: toprc = 187
stver = 186: PLUS = 206: TEE = 203: INVTEE = 202: rtee = 204: ltee = 185
'
LOCATE rlt%, clt%: PRINT CHR$(toplc);
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
LOCATE , clb%: PRINT CHR$(toprc);
'
FOR I = rlt% + 1 TO rlb% - 1
    LOCATE I, clt%: PRINT CHR$(stver);
    LOCATE , clb%: PRINT CHR$(stver);
NEXT I
LOCATE rlb%, clt%: PRINT CHR$(botlc);
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
LOCATE , clb%: PRINT CHR$(botrc);
END SUB
```

```
SUB CRF (LIFE%, EFR!, RF!)
REM SUBPROGRAM FOR COST RECOVERY FACTOR
RF! = (EFR! * ((1 + EFR!) ^ LIFE%)) / ((1 + EFR!) ^ LIFE% - 1)
END SUB

SUB EMPTY (S, E)
FOR I = S TO E
    LOCATE I, 2: PRINT "                                                  "
    LOCATE I, 40: PRINT "                                                 ";
NEXT I
END SUB

SUB inbox (rlt%, clt%, rlb%, clb%) STATIC
'
COLOR 8
LOCATE rlt% + 1, clb% - 9: PRINT "Defaults"
COLOR 1
CALL box(rlt%, cl?t%, rlb%, clb%)
LOCATE rlt% + 2, clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor))
'
FOR I = rlt% + 1 TO rlb% - 1
    LOCATE I, clb% - 11: PRINT CHR$(stver)
NEXT I
LOCATE rlt%, clb% - 11: PRINT CHR$(TEE)
LOCATE rlt% + 2, clb% - 11: PRINT CHR$(PLUS)
'
LOCATE rlb%, clb% - 11: PRINT CHR$(INVTEE)
LOCATE rlt% + 2, clt%: PRINT CHR$(rtee)
LOCATE rlt% + 2, clb%: PRINT CHR$(ltee)
E   SUB

SUB NVEH (PKFT%)

'*********************************************************
'            SUB-PROGRAM FOR FLEET CALCULATION
'*********************************************************
'
CALL EMPTY(4, 22)
PRINT CHR$(7)
 CALL inbox(8, 9, 23, 73)
 COLOR 8
LOCATE 9, 20: PRINT "   *** OPERATIONAL DETAILS ***"
COLOR 15
'   .
LOCATE 11, 66: PRINT "None"
LOCATE 11, 11: PRINT "1. Number of Passengers in Both Directions on"
10  LOCATE 12, 14: INPUT "    an Average Weekday in THOUSANDS       = ",
NPAX&
IF NPAX& = 0 THEN
PRINT CHR$(7)
GOTO 10
ELSE
END IF
'
LOCATE 13, 67: PRINT "10%";
```

```
LOCATE 13, 11: PRINT "2. Percent of Average Week day Passengers During"
  LOCATE 14, 14: INPUT "                              Peak Hour      = ",
PHF!
'
IF PHF! = 0 THEN PHF! = 10!
'
LOCATE 15, 67: PRINT "15";
LOCATE 15, 11: INPUT "3. Headway During Peak Hour in Minutes      = ",
PKHW%
  LOCATE 16, 19: PRINT ""
'
IF PKHW% = 0 THEN PKHW% = 15
'
LOCATE 17, 67: PRINT "30";
LOCATE 17, 11: INPUT "4. Headway During Off-Peak Hour in Minutes  = ",
OFPKHW%
  LOCATE 18, 19: PRINT ""
'
  IF OFPKHW% = 0 THEN OFPKHW% = 30
'
'**********************************************
'                 PEAK HOUR CALCULATIONS
'**********************************************
'
PKHRCAP! = CINT((PHF! * .01) * NPAX& * 1000 * .6 / .9) 'ASSUMES 60
TRAVEL IN PEAK DIRECTION
'
PKNOTR% = CINT(60 / PKHW% + .49)        ' number of trains per hour
'
LOCATE 19, 66: PRINT "120"
LOCATE 19, 11: INPUT "5. Capacity of car   (Passengers/car)       = ",
CAPCAR%
'
IF CAPCAR% = 0 THEN CAPCAR% = 120
NOCARS% = CINT(PKHRCAP! / CAPCAR% + .49)
NOCARPERTRAIN% = CINT((NOCARS% / PKNOTR%) + .49)
IF NOCARPERTRAIN% < 2 THEN NOCARPERTRAIN% = 2
'
LOCATE 22, 15: PRINT "Calculates if entered ZERO"
 LOCATE 21, 66: PRINT "Calc."
LOCATE 21, 11: INPUT "6. Round Trip Time in Minutes               = ",
RDTRIPTIME%
'
IF RDTRIPTIME% < 5 THEN
        CALL oprspeed(LENGTH!, NST%, tt!)
        RDTRIPTIME% = 2 * tt! + 2
     ELSE
END IF
PKTRAIN% = CINT(RDTRIPTIME% / PKHW% + .49)
PKNOCARS% = NOCARPERTRAIN% * PKTRAIN%
PKFT% = PKTRAIN% * NOCARPERTRAIN%
'
'**********************************************
'               OFF-PEAK HOUR CALCULATIONS
'**********************************************
```

```
'
OFPKHRCAP! = CINT((PHF! * .01 * .3 * 1000) * NPAX& / .9)
OFPKNOTR% = CINT(60! / OFPKHW% + .49)
NOCARSOF% = CINT(OFPKHRCAP! / CAPCAR% + .49)
NOCAROFPERTRAIN% = CINT((NOCARSOF% / OFPKNOTR%) + .49)
IF NOCAROFPERTRAIN% < 2 THEN NOCAROFPERTRAIN% = 2
OFPKTRAIN% = CINT(RDTRIPTIME% / OFPKHW% + .49)
OFPKFT% = OFPKTRAIN% * NOCAROFPERTRAIN%
OFPKNOCARS% = NOCAROFPERTRAIN% * OFPKNOTR%
END SUB

SUB oprspeed (LENGTH!, NST%, tt!)
'*********************************************************************
'THIS PROGRAM CALCULATES THE OPERATING SPEED OVER NUMBER OF STOPS
'*********************************************************************
50 CALL EMPTY(4, 23)
PRINT CHR$(7)
CALL inbox(7, 8, 21, 75)
COLOR 8
LOCATE 8, 17: PRINT "        OPERATING CHARACTERISTICS"
COLOR 15
LOCATE 12, 68: PRINT " 30"
20 LOCATE 12, 12: INPUT "1. Dwelling time at each stop in Seconds = ",
DWLTIME!
'
IF (DWLTIME! > 25! AND DWLTIME! <= 120!) GOTO 130
IF DWLTIME! = 0 THEN
        DWLTIME! = 30!
    ELSE
     GOTO 20
END IF
LOCATE 14, 68: PRINT " 80"
130  LOCATE 14, 12: INPUT "2. Maximum Speed in km/hr              = ",
V!
'
IF V! = 0 THEN V! = 80!
V! = V! * 1000! / 3600!
LOCATE 16, 68: PRINT "1.5"
LOCATE 16, 12: INPUT "3. Acceleration rate in m/sec/sec       = ", ACC!
'
IF ACC! = 0 THEN ACC! = 1.5
LOCATE 18, 68: PRINT "1.3"
LOCATE 18, 12: INPUT "4. Deceleration rate in m/sec/sec       = ", DCC!
'
IF DCC! = 0 THEN DCC! = 1.3
s1! = V! ^ 2 / 2! / ACC!
s2! = V! ^ 2 / 2! / DCC!
S! = s1! + s2!
'
l! = LENGTH! / (NST% - 1) * 1000!
'
IF (S! > l!) THEN
        V! = SQR(l! / (1 / 2! / ACC! + 1 / 2! / DCC!))
        t1! = V! / ACC!
        t2! = V! / DCC!
```

```
         T! = t1! + t2!

      ELSE
         s3! = l! - S!
         t3! = s3! / V!
         t1! = V! / ACC!
         t2! = V! / DCC!
         T! = t1! + t2! + t3!
END IF
'
T! = (NST% - 1) * T! + (NST% - 2) * DWLTIME!
avsp! = LENGTH! / T! * 3600
avs% = FIX(avsp!)
tt! = CINT(T! / 60! * 10) / 10
'
CALL EMPTY(4, 23)
CALL outbox(9, 8, 17, 73)
COLOR 15
LOCATE 10, 19: PRINT "** OUTPUT OF OPERATIONAL CHARACTERISTICS **"
LOCATE 13, 12: PRINT "1. Travel Time for single trip in minutes =", tt!
LOCATE 15, 12: PRINT "2. Average Operating Speed in kmph        = ",
avs%
LOCATE 18, 12: INPUT "           Press ENTER to continue   ", C$
END SUB

SUB outbox (rlt%, clt%, rlb%, clb%) STATIC
'
COLOR 1
CALL box(rlt%, clt%, rlb%, clb%)
LOCATE rlt% + 2, clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor))
LOCATE rlt% + 2, clt%: PRINT CHR$(rtee)
LOCATE rlt% + 2, clb%: PRINT CHR$(ltee)

END SUB

SUB TITLE

COLOR 7
CALL outbox(1, 1, 24, 80)
LINE (8, 7)-(632, 12), 8, BF
LINE (8, 28)-(632, 33), 8, BF
COLOR 14
LOCATE 2, 10: PRINT "     ***     COST MODEL FOR RAIL RAPID TRANSIT
SYSTEMS      ***"
COLOR 6
LOCATE 4, 18: PRINT "A PLANNING MODEL TO ESTIMATE COST AND OPER    :IAL"
LOCATE 5, 22: PRINT "REQUIREMENTS OF RAIL RAPID TRANSIT SYSTEMS"
COLOR 5
LOCATE 6, 12: PRINT "Developed By Srinivasa R. Mandalapu at University
of Alberta"
END SUB
```

## B.2 Listing of APM Cost Model

The APM Cost Model has similar structure that of RRT Cost Model. The differences and the features are explained in Section 4.3. The following is the listing of the model.

```
DECLARE SUB box (rlt%, clt%, rlb%, clb%)
DECLARE SUB oprspeed (LENGTH!, NST%, tt!)
DECLARE SUB TITLE ()
DECLARE SUB EMPTY (S, E)
DECLARE SUB NVEH (PKFT%)
DECLARE SUB CRF (LIFE%, EFR!, RF!)
DECLARE SUB inbox (rlt%, clt%, rlb%, clb%)
DECLARE SUB outbox (rlt%, clt%, rlb%, clb%)
COMMON SHARED RDTRIPTIME!, PHF!, PKFT%, OFPKFT%, PKNOCARS%, OFPKNOCARS%,
NOCARPERTRAIN%, PKTRAIN%, NOCAROFFPERTRAIN%, OFPKTRAIN%, NPAX&, LENGTH!,
NST%, tt!, PKHW%, OFPKHW%, avs%
COMMON SHARED sthor, rtee, ltee, stver, PLUS, TEE, INVTEE, EFR!
' botlc, botrc, toplc, toprc,
'************************************************************************

SCREEN 9
COLOR 8, 3
200 CALL EMPTY(4, 23)
CALL TITLE
CLEAR a - z
CALL inbox(10, 11, 21, 72)
COLOR 8
LOCATE 11, 25: PRINT "  ** General Information **   "
COLOR 15
'************************************************************************
*****
'   CALCULATION EQUIVALENT ANNUAL COST OF RAIL RAPID TRANSIT PROJECT
'************************************************************************

'LENGTH OF NEW LINE
'
LOCATE 13, 65: PRINT "None"
30 LOCATE 13, 15: INPUT "1. Length of APM Line (kilometres)  = ",
LENGTH!
IF (LENGTH! <= 0! OR LENGTH > 120!) THEN GOTO 30

'                  NUMBER OF STATIONS PLANNED
'

LOCATE 15, 67: PRINT "2"
LOCATE 15, 15: INPUT "2. Number of Stations Planned       = ", NST%
IF NST% = 0 THEN NST% = 2

'************************************************************************
```

```
'  MINIMUM AND MAXIMUM COSTS OF COMPONENTS OF RAIL TRANSIT SYSTEM
'**********************************************************************
ROFWAY! = 5.22        'RIGHT OF WAY COST PER KM
PWAT! = 1.22          'AT GRADE PERMANENT WAY COSTS PER KM
PWTUN! = 7.41         'PERMANENT WAY BELOW GRADE PER KM
PWELE! = 3.2          'PERMANENT WAY ELEVATED PER KM
STAT! = .25           'AT GRADE STATION COSTS PER STATION
STUG! = 1.23          'UNDER-GROUND STATION COSTS PER STATION
STELE! = .38          'ELEVATED STATION COST PER STATION
PS! = 1.25            'POWER SUPPLY EQUIPMENT COSTS PER KM
CONCOM! = 2.45        'CONTROLS AND COMMUNICATIONS COSTS PER KM
VEH! = .7             'VEHICLE COSTS PER VEH
GAR!·= .17            'GARAGE AND MAINTENANCE COSTS PER VEH
'SOURCE FOR THESE COSTS "UMTA REPORT #MA-06-0039-83-3, PLANNING  FOR
DOWNTOWN
'CICULATION SYSTEMS:ANALYSIS TECHNIQUES, VOL 2, 1983
'**********************************************************************
'       EFFECTIVE INTEREST RATE CALCULATIONS
'**********************************************************************
LOCATE 17, 67: PRINT "7%"
LOCATE 17, 15: INPUT "3. Interest Rate(%)                    = ", INR!
        IF INR! = 0 THEN INR! = 7!
'
LOCATE 19, 67: PRINT "3%"
LOCATE 19, 15: INPUT "4. Inflation Rate(%)                   = ", IFR!
        IF IFR! = 0 THEN IFR! = 3!
'
INR! = INR! * .01
IFR! = IFR! * .01
EFR! = (INR! + 1!) * (IFR! + 1!) - 1!
'**********************************************************************
'       LIFE OF COMPONENTS AND COST RECOVERY FACTORS
'**********************************************************************
ROFWAYLIFE% = 200
 CALL EMPTY(4, 23)
 COLOR 8
 CALL box(13, 10, 18, 69)
 COLOR 15
 LOCATE 15, 11: PRINT "    Do you want to input the expected lives of "
LOCATE 16, 17: PRINT "          components of the system (Y/N)"
LOCATE 17, 15: PRINT "(If entered 'No' the model assumes default
values)"
LOCATE 16, 57: INPUT y$
IF (y$ = "y" OR y$ = "Y") THEN
        CALL EMPTY(4, 23)
'        COLOR 8
        CALL inbox(4, 10, 23, 74)
        COLOR 5
        LOCATE 5, 15: PRINT "Expected Life of Components of System in
Years"
        COLOR 15
        LOCATE 7, 68: PRINT "30"
        LOCATE 7, 14: INPUT "1. Life of Guideway At-Grade             =
", PWATLIFE%
'
```

```
        LOCATE 9, 67: PRINT "100 "
        LOCATE 9, 14: INPUT "2. Life of Guideway Elevated/Below Grade  =
", PWTULIFE%
'
        LOCATE 11, 68: PRINT "50"
        LOCATE 11, 14: INPUT "3. Life of At-Grade Stations
= ", STATLIFE%
'
        LOCATE 13, 67: PRINT "100"
        LOCATE 13, 14: INPUT "4. Life of Underground/Elevated Stations
= ", STUGLIFE%
'
        LOCATE 15, 68: PRINT "30";
        LOCATE 15, 14: INPUT "5. Life of Power Supply & Distn. Systems
= ", POWRLIFE%
'
        LOCATE 17, 68: PRINT "25"
        LOCATE 17, 14: INPUT "6. Life of Control & Commun. Systems
= ", PWLIFE%
'
        LOCATE 19, 68: PRINT "25"
        LOCATE 19, 14: INPUT "7. Life of Vehicles in Years
= ", VEHLIFE%
'
        LOCATE 21, 68: PRINT "50"
        LOCATE 21, 14: INPUT "8. Life of Maintenance Support Facilities
= ", GARALIFE%
   ELSE
        GOTO 100
END IF
100  IF PWATLIFE% = 0 THEN PWATLIFE% = 30
  IF PWTULIFE% = 0 THEN PWTULIFE% = 100
  IF STATLIFE% = 0 THEN STATLIFE% = 50
  IF STUGLIFE% = 0 THEN STUGLIFE% = 100
  IF POWERLIFE% = 0 THEN POWERLIFE% = 30
  IF CONLIFE% = 0 THEN CONLIFE% = 25
  IF VEHLIFE% = 0 THEN VEHLIFE% = 25
  IF GARALIFE% = 0 THEN GARALIFE% = 50

'                     COST RECOVERY FACTORS
'
CALL CRF(ROFWAYLIFE%, EFR!, F10!)
CALL CRF(PWATLIFE%, EFR!, F11!)
CALL CRF(PWTULIFE%, EFR!, F12!)
CALL CRF(STATLIFE%, EFR!, F13!)
CALL CRF(STUGLIFE%, EFR!, F14!)
CALL CRF(POWERLIFE%, EFR!, F16!)
CALL CRF(CONLIFE%, EFR!, F17!)
CALL CRF(VEHLIFE%, EFR!, F18!)
CALL CRF(GARALIFE%, EFR!, F19!)
'
'                      EQUIVALENT ANNUAL COSTS
'
ACROFWAY! = ROFWAY! * F10!
ACPWATL! = PWAT! * F11!        'FOR PERMANENT WAY AT-GRADE
```

```
ACPWTUL! = PWTUN! * F12!          'FOR PERMANENT WAY IN TUNNEL
ACPWELL! = PWELE! * F12!          'FOR ELEVATED CONSTRUCTION
ACPWCCL! = PWCC! * F12!           'FOR CUT AND COVER CONSTRUCTION
ACSTATL! = STAT! * F13!           'FOR STATIONS AT GRADE
ACSTSTUGL! = STUG! * F14!         'FOR STATIONS UNDER -GROUND
ACSTELEL! = STELE! * F14!         'ELEVATED STATIONS
ACPSL! = PS! * F16!               'FOR POWER SUPPLY EQUIPMENT
ACCONCOML! = CONCOM! * F17!       'FOR CONTROLS AND COMMUNICATIONS

'
CALL EMPTY(4, 23)

CALL inbox(9, 8, 18, 73)
COLOR 5
LOCATE 10, 20: PRINT "      CONSTRUCTION DETAILS"
COLOR 15
    LOCATE 13, 68: PRINT "0%"
LOCATE 13, 12: INPUT "1. Percent of Guideway Below Grade      = ", T!
'
    LOCATE 15, 68: PRINT "0%"
LOCATE 15, 12: INPUT "2. Percent of Guideway Elevated         = ", E!
'
    LOCATE 15, 68: PRINT "0%"
N2% = INT((T! * .01) * NST%): N3% = INT((E! * .01) * NST%)
N1% = NST% - N2% - N3%

'
'*******************************************************************
' EQUIVALENT ANNUAL COST OF CONSTRUCTION EXCEPT VEHICLES AND GARAGE
'*******************************************************************
 CALL NVEH(PKFT%)
  IF PKTRAIN% < 2 THEN
        TYPE$ = "Shuttle (Single Guideway)"
        LENGTH1! = LENGTH!
      ELSE
       IF PKTRAIN% = 2 THEN
        LENGTH1! = LENGTH! * 2
        TYPE$ = "Double Shuttle/Loop (Dual Guideway)"
       ELSE
         LENGTH1! = LENGTH! * 2
         TYPE$ = "Loop (Dual Guideway)"
       END IF
  END IF
TCCOSTL1! = LENGTH1! * ((PWAT! + ROFWAY!) * (1! - (T! * .01)) + PWTUN! *
(T! * .01) + PWELE! * (E! * .01) + PS! + CONCOM!) + N1% * STAT! + N2% *
STUG! + N3% * STELE!
ACCOSTL! = LENGTH1! * ((ACPWATL! + ACROFWAY!) * (1! - T! * .01) +
ACPWTUL! * (T! * .01) + ACPWELL! * (E! * .01) + ACPSL! + ACCONCOML!) +
N1% * ACSTATL! + N2% * ACSTSTUGL! + N3% * ACSTELEL!
'*******************************************************************-
'            ANNUAL COST FOR VEHICLES AND GARAGE
'*******************************************************************-

TCVEHL! = VEH! * PKFT%
   ACVEHL! = TCVEHL! * F18!
```

```
TCGARL! = GAR! * PKFT%
   ACGAR1! = TCGARL! * F19!
ANCOSTL! = ACCOSTL! + ACVEHL! + ACGAR1!
'
TCCOSTL! = TCCOSTL1! + TCVEHL! + TCGARL!

'******************************************************************
'ANNUAL MAINTENANCE COST CALCULATIONS
'******************************************************************
CALL EMPTY(4, 23)
CALL inbox(9, 11, 17, 72)
 COLOR 5
LOCATE 10, 21: PRINT "   *** OPERATIONAL DETAILS ***"
COLOR 15
LOCATE 12, 67: PRINT "4"
LOCATE 13, 13: PRINT "(eg:2 hrs during am peak + 2 hrs during pm peak)"
LOCATE 12, 13: INPUT "1. Peak Hour Operation in Hours     = ", DURPK!
        IF DURPK! = 0 THEN DURPK! = 4!
LOCATE 15, 66: PRINT "16"
LOCATE 15, 13: INPUT "2. Off-Peak Hour Operation in hours = ", DUROFPK!
        IF DUROFPK! = 0 THEN DUROFPK! = 16!
'
' CAR.KM PER DAY
'
CARKMd& = LENGTH! * (NOCARPERTRAIN% * DURPK! * 120! / PKHW% +
NOCAROFFPERTRAIN% * DUROFPK! * 120! / OFPKHW%)
CARHRd& = (DURPK! * PKNOCARS% + DUROFPK! * OFPKNOCARS%)
CARKMd1& = LENGTH! * (20 * 120! / OFPKHW%)
CARHRd1& = (20 * OFPKNOCARS%)
'
CARKMy& = CARKMd& * 52 * 5 / 1000 + CARKMd1& * 52 * 2 / 1000
CARHRy& = CARHRd& * 52 * 5 + CARHRd1& * 52 * 2
'
ANMAINT! = 1.16 * CARKMy& / 1000
'
NETANCL! = ANMAINT! + ANCOSTL!
CALL EMPTY(4, 23)
CALL outbox(5, 10, 20, 73)
COLOR 5
LOCATE 6, 24: PRINT " *** OUTPUT OF OPERATIONAL DETAILS ***"
COLOR 15
LOCATE 8, 13: PRINT "   Type of Operation   ="
        LOCATE 8, 38: PRINT TYPE$
LOCATE 9, 13: PRINT "1. Length of Guideway (lane.km)                 ="
        LOCATE 9, 64: PRINT USING "###.#"; LENGTH1!
LOCATE 10, 13: PRINT "2. Length of Guideway below grade (lane.km)   ="
        LOCATE 10, 65: PRINT USING "##.#"; LENGTH1! * T! * .01
LOCATE 11, 13: PRINT "3. Length of Guideway Elevated (lane.km)      ="
        LOCATE 11, 65: PRINT USING "##.#"; LENGTH1! * E! * .01
LOCATE 12, 13: PRINT "4. Round Trip time (minutes)                  ="
        LOCATE 12, 64: PRINT USING "###.#"; FIX(RDTRIPTIME!)
LOCATE 13, 13: PRINT "5. Number of Trains Required for Peak Hour
Operation="
       LOCATE 13, 66: PRINT USING "###"; PKTRAIN%
```

```
LOCATE 14, 13: PRINT "                                        for Off-Peak
Operation="
       LOCATE 14, 66: PRINT USING "###"; OFPKTRAIN%
LOCATE 15, 13: PRINT "6. Number of Cars per Train During Peak Hour
="
       LOCATE 15, 67: PRINT USING "##"; NOCARPERTRAIN%
LOCATE 16, 13: PRINT "                                  During Off-Peak Hour
="
       LOCATE 16, 67: PRINT USING "##"; NOCAROFPERTRAIN%
LOCATE 17, 13: PRINT "7. Number of Cars Required for Operation       ="
        LOCATE 17, 65: PRINT USING "####"; PKNOCARS%
LOCATE 18, 13: PRINT "8. Number of Car Kilometres per day            = "
       LOCATE 18, 62: PRINT USING "#######"; CARKMd&
LOCATE 19, 12: PRINT " 9. Number of Car Hours per day                ="
       LOCATE 19, 62: PRINT USING "#######"; CARHRd&
'
LOCATE 22, 13: INPUT "Press ENTER to continue"; D$
ANNPAX! = NPAX& * 52! * (5! + .3 * 2!) / 1000!
'
COSTPERPAX! = NETANCL! / ANNPAX!
'
CALL EMPTY(4, 23)
CALL outbox(6, 11, 19, 73)
 COLOR 5
LOCATE 7, 24: PRINT " *** OUTPUT OF COST DETAILS ***"
COLOR 15
LOCATE 9, 13: PRINT "1. Annual passengers (millions)             ="
       LOCATE 9, 65: PRINT USING "####.##"; ANNPAX!
LOCATE 11, 13: PRINT "2. Total Capital Cost of System               = M
$"
       LOCATE 11, 65: PRINT USING "####.##"; TCCOSTL!
LOCA"E 13, 13: PRINT "3. Annual Operating and Maintenance Cost      = M
$"
       LOCATE 13, 66: PRINT USING "###.##"; ANMAINT!
LOCATE 15, 13: PRINT "4. Equivalent Annual Cost of the System       = M
$"
       LOCATE 15, 65: PRINT USING "####.##"; NETANCL!
LOCATE 17, 13: PRINT "5. Average Cost per Passenger                 =
$"
       LOCATE 17, 66: PRINT USING "###.##"; COSTPERPAX!'

'**********************************************************************

LOCATE 21, 13: PRINT "Do you want Print the Results     (",
LOCATE 21, 52: PRINT ")"
COLOR 4
LOCATE 21, 49: PRINT "Y/N"
COLOR 15
LOCATE 21, 54: INPUT D$
IF (D$ = "Y" OR D$ = "y") THEN
'**********************************************************************


LPRINT ; TAB(5); "  ***  COST MODEL FOR AUTOMATED PEOPLE MOVER SYSTEMS
***"
```

```
LPRINT
LPRINT ; TAB(15); " Input Data"
LPRINT
LPRINT ; TAB(8); "A. GENERAL INFORMATION  "
LPRINT ;
LPRINT ; TAB(10); " 1. Length of APM Line (kilometres)   = ", USING
"##.#"; LENGTH!
LPRINT ; TAB(10); " 2. Number of Stations Planned/Calc.  = ", USING
"##"; NST%
LPRINT ; TAB(10); " 3. Interest Rate(%)                  = ", USING
"##"; INR! * 100
LPRINT ; TAB(10); " 4. Inflation Rate(%)                 = ", USING
"##"; IFR! * 100
LPRINT ; TAB(10); " 5. Guideway Below Grade (%)          = ", T!
LPRINT ; TAB(10); " 6. Guideway Elevated (%)             = ", E!
LPRINT
LPRINT ; TAB(8); "B. OPERATIONAL CHARACTERISTICS "
LPRINT
LPRINT ; TAB(10); " 1. Number of Passengers in Both Directions"
LPRINT ; TAB(10); "       on an Average  Weekday  in  THOUSANDS = ";
NPAX&
LPRINT ; TAB(10); " 2. Percent of Average Week day Passengers"
LPRINT ; TAB(10); "                              During Peak Hour = ";
PHF!
LPRINT ; TAB(10); " 3. Peak Hour Operation in Hours            = ";
DURPK!
LPRINT ; TAB(10); " 4. Off-Peak Hour Operation in hours        = ";
DUROFPK!
LPRINT ; TAB(10); " 5. Headway During Peak Hour in Minutes     = ";
PKHW%
LPRINT ; TAB(10); " 6. Headway During Off-Peak Hour in Minutes  = ";
OFPKHW%
LPRINT
LPRINT TAB(15); "  Output of the Model"
LPRINT
LPRINT TAB(8); "A. OUTPUT OF OPERATIONAL CHARACTERISTICS "
LPRINT
LPRINT ; TAB(10); " 1. Type of Operation  = "; TYPE$
LPRINT ; TAB(10); " 2. Length of Guideway (lane.km)              =";
USING "###.#"; LENGTH1!
LPRINT ; TAB(10); " 3. Length of Guideway below grade (lane.km)  =";
USING "##.#"; LENGTH1! * T! * .01
LPRINT ; TAB(10); " 4. Length of Guideway Elevated (lane.km)     =";
USING "##.#"; LENGTH1! * E! * .01
LPRINT ; TAB(10); " 5. Round Trip time (minutes)                 =";
USING "###"; FIX(RDTRIPTIME!)
LPRINT ; TAB(10); " 6. Average Operating Speed in kmph           = ";
USING "##.#"; ave%
LPRINT ; TAB(10); " 7. Number of Trains Required for Peak Hour Operation
="; USING "####"; PKTRAIN%
LPRINT ; TAB(10); "                              for Off-Peak Operation
="; USING "####"; OFPKTRAIN%
LPRINT ; TAB(10); " 8. Number of Cars per Train During Peak Hour
="; USING "####"; NOCARPERTRAIN%
```

```
LPRINT ; TAB(10); "                                    During Off-Peak Hour
="; USING "####"; NOCAROFFPERTRAIN%
LPRINT ; TAB(10); " 9. Number of Cars Required for Operation
="; USING "####"; PKNOCARS%
LPRINT ; TAB(10); "10. Number of Car Kilometres per day
="; USING "#######"; CARKMd&
LPRINT ; TAB(10); "11. Number of Car Hours per day
="; USING "#######"; CARHRd&
LPRINT
LPRINT ; TAB(8); "B. OUTPUT OF COST DETAILS "
LPRINT
LPRINT ; TAB(10); " 1. Annual passengers (millions)              =
"; USING "#####.##"; ANNPAX!
LPRINT ; TAB(10); " 2. Total Capital Cost of System              = M
$"; USING "#####.##"; TCOST!
LPRINT ; TAB(10); " 3. Annual Operating and Maintenance Cost     = M
$"; USING "#####.##"; ANMAINT!
LPRINT ; TAB(10); " 4. Equivalent Annual Cost of the System      = M
$"; USING "#####.##"; (NETANCL! + NETANCU!) / 2!
LPRINT ; TAB(10); " 5. Average Cost per Passenger                =
$"; USING "#####.##"; COSTPERPAX!

'************************************************************************

ELSE
END IF
        LOCATE 21, 13: PRINT "Do you want to make another trial (",
        LOCATE 21, 52: PRINT ")"
        COLOR 4
        LOCATE 21, 49: PRINT "Y/N"
        COLOR 15
        LOCATE 21, 54: INPUT dD$

IF (dD$ = "y" OR dD$ = "Y") THEN
        GOTO 200
 COLOR 4
LOCATE 24, 24: PRINT "Terminating the program"
'****************************************
ELSE
END IF

SUB box (rlt%, clt%, rlb%, clb%) STATIC
sthor = 205: botlc = 200: botrc = 188: toplc = 201: toprc = 187
stver = 186: PLUS = 206: TEE = 203: INVTEE = 202: rtee = 204: ltee = 185
'
LOCATE rlt%, clt%: PRINT CHR$(toplc);
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
LOCATE , clb%: PRINT CHR$(toprc);
'
FOR I = rlt% + 1 TO rlb% - 1
    LOCATE I, clt%: PRINT CHR$(stver);
    LOCATE , clb%: PRINT CHR$(stver);
NEXT I
LOCATE rlb%, clt%: PRINT CHR$(botlc);
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
```

```
LOCATE , clb%: PRINT CHR$(botrc);

END SUB

SUB CRF (LIFE%, EFR!, RF!)
REM SUBPROGRAM FOR COST RECOVERY FACTOR
RF! = (EFR! * ((1 + EFR!) ^ LIFE%)) / ((1 + EFR!) ^ LIFE% - 1)
END SUB

SUB EMPTY (S, E)
FOR I = S TO E
    LOCATE I, 2: PRINT "                                              "
    LOCATE I, 40: PRINT "                                           ";
NEXT I
END SUB

SUB inbox (rlt%, clt%, rlb%, clb%) ' STATIC
'
COLOR 8
LOCATE rlt% + 1, clb% - 9: PRINT "Defaults";
COLOR 1
CALL box(rlt%, clt%, rlb%, clb%)
LOCATE rlt% + 2, clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
'
FOR I = rlt% + 1 TO rlb% - 1
LOCATE I, clb% - 11: PRINT CHR$(stver);
NEXT I
LOCATE rlt%, clb% - 11: PRINT CHR$(TEE)
LOCATE rlt% + 2, clb% - 11: PRINT CHR$(PLUS)
'
LOCATE rlb%, clb% - 11: PRINT CHR$(INVTEE)
LOCATE rlt% + 2, clt%: PRINT CHR$(rtee)
LOCATE rlt% + 2, clb%: PRINT CHR$(ltee)
END SUB

SUB NVEH (PKPT%)
'
'*******************************************************
'SUB-PROGRAM FOR FLEET CALCULATION
'*******************************************************
REM
CALL EMPTY(4, 23)
COLOR 8

 CALL inbox(8, 9, 23, 73)
 COLOR 5
LOCATE 9, 20: PRINT "   *** OPERATIONAL DETAILS ***"
COLOR 15

LOCATE 11, 66: PRINT "None"
LOCATE 11, 11: PRINT "1. Number of Passengers in Both Directions on"
10  LOCATE 12, 14: INPUT "    an Average Weekday in THOUSANDS       = ",
NPAX&

IF NPAX& = 0 GOTO 10
```

```
LOCATE 13, 67: PRINT "10%";
LOCATE 13, 11: PRINT "2. Percent of Average Week day Passengers During"
  LOCATE 14, 14: INPUT "                                    Peak Hour      = ",
PHF!
'
IF PHF! = 0 THEN PHF! = 10!

LOCATE 15, 67: PRINT " 5"
LOCATE 15, 11: INPUT "3. Headway During Peak Hour in Minutes      = ",
PKHW%
  LOCATE 16, 19: PRINT ""
'
IF PKHW% = 0 THEN PKHW% = 5

LOCATE 17, 67: PRINT "10";
LOCATE 17, 11: INPUT "4. Headway During Off-Peak Hour in Minutes  = ",
OFPKHW%
  LOCATE 18, 19: PRINT ""
'
  IF OFPKHW% = 0 THEN OFPKHW% = 10
'**********************************************
'                     PEAK HOUR CALCULATIONS
'**********************************************
PKHRCAP! = CINT((PHF! * .01) * NPAX& * 1000 * .6 / .9) 'ASSUMES 60
TRAVEL IN PEAK DIRECTION
'
PKNOTR% = 60 / PKHW%            ' number of trains per hour
'
LOCATE 19, 66: PRINT " 80"
LOCATE 19, 11: INPUT "5. Capacity of car   (Passengers/car)       =  ",
CAPCAR%
'
IF CAPCAR% = 0 THEN CAPCAR% = 80
nocars% = CINT(PKHRCAP! / CAPCAR% + .49)
NOCARPERTRAIN% = CINT((nocars% / PKNOTR%) + .49)
IF NOCARPERTRAIN% < 1 THEN NOCARPERTRAIN% = 1

 '
 '
LOCATE 21, 66: PRINT "Calc."
LOCATE 22, 15: PRINT "Calculates if entered ZERO"
LOCATE 21, 11: INPUT "6. Round Trip Time in Minutes                = ",
RDTRIPTIME!
'
IF RDTRIPTIME! = 0 THEN
        CALL oprspeed(LENGTH!, NST%, tt!)
        RDTRIPTIME! = 2 * tt! + 1
    ELSE
END IF
PKTRAIN% = CINT(RDTRIPTIME! / PKHW% + .49)

PKNOCARS% = NOCARPERTRAIN% * PKTRAIN%
NOCARSPERPKHR% = PKTRAIN% * NOCARPERTRAIN%
'
```

```
'**********************************************
'                   OFF-PEAK HOUR CALCULATIONS
'**********************************************

OFPKHRCAP! = CINT((PHF! * .01 * .3 * 1000) * NPAX& / .9)
OFPKNOTR% = CINT(60 / OFPKHW%)
NOCARSOF% = CINT(OFPKHRCAP! / CAPCAR% + .49)
NOCAROFPERTRAIN% = CINT((NOCARSOF% / OFPKNOTR%) + .49)
IF NOCAROFPERTRAIN% < 1 THEN NOCAROFPERTRAIN% = 1
 OFPKTRAIN% = CINT(RDTRIPTIME! / OFPKHW% + .49)

NOCARSPEROFPKHR% = OFPKTRAIN% * NOCAROFPERTRAIN%
PKFT% = NOCARSPERPKHR%
OFPKFT% = NOCARSOFPERPKHR%
OFPKNOCARS% = NOCAROFPERTRAIN% * OFPKNOTR%
END SUB

SUB oprspeed (LENGTH!, NST%, tt!)
'*****************************************************************
'THIS PROGRAM CALCULATES THE OPERATING SPEED OVER NUMBER OF STOPS
'*****************************************************************
50 CALL EMPTY(4, 23)
CALL inbox(7, 8, 21, 75)
'
LOCATE 8, 17: PRINT "       OPERATING CHARACTERISTICS"
COLOR 15
20 LOCATE 12, 68: PRINT " 30"
LOCATE 12, 12: INPUT "1. Dwelling time at each stop in Seconds = ",
dwltime!
'
IF (dwltime! > 25! AND dwltime! <= 120!) GOTO 130
IF dwltime! = 0 THEN
        dwltime! = 30!
    ELSE
     GOTO 20
END IF
130  LOCATE 14, 68: PRINT " 42"
LOCATE 14, 12: INPUT "2. Maximum Speed in km/hr                = ", v!
'
IF v! = 0 THEN v! = 42!
v! = v! * 1000! / 3600!
LOCATE 16, 68: PRINT "1.1"
LOCATE 16, 12: INPUT "3. Acceleration rate in m/sec/sec        = ", acc!
IF acc! = 0 THEN acc! = 1.1
'
LOCATE 18, 68: PRINT "1.1"
LOCATE 18, 12: INPUT "4. Deceleration rate in m/sec/sec        = ", dcc!
IF dcc! = 0 THEN dcc! = 1.1
s1! = v! ^ 2 / 2! / acc!
s2! = v! ^ 2 / 2! / dcc!
S! = s1! + s2!
l! = LENGTH! / (NST% - 1) * 1000!
IF (S! > l!) THEN
        v! = SQR(l! / (1 / 2! / acc! + 1 / 2! / dcc!))
        t1! = v! / acc!
```

```
         t2! = v! / dcc!
         T! = t1! + t2!

      ELSE
         s3! = l! - S!
         t3! = s3! / v!
         t1! = v! / acc!
         t2! = v! / dcc!
         T! = t1! + t2! + t3!
END IF
T! = (NST% - 1) * T! + (NST% - 2) * dwltime!
avsp! = LENGTH! / T!   3600
avs% = FIX(avsp!)
tt! = CINT(T! / 60! * 10) / 10!
CALL EMPTY(4, 23)
CALL outbox(9, 8, 17, 73)
COLOR 15
LOCATE 10, 19: PRINT "** OUTPUT OF OPERATIONAL CHARACTERISTICS **"
LOCATE 13, 12: PRINT "1. Travel Time for single trip in minutes =", tt!
LOCATE 15, 12: PRINT "2. Average Operating Speed in kmph         = ",
avs%
LOCATE 18, 12: INPUT "          Press enter to continue  ", C$
END SUB

SUB outbox (rlt%, clt%, rlb%, clb%) STATIC
'
COLOR 1
CALL box(rlt%, clt%, rlb%, clb%)
LOCATE rlt% + 2, clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
'
LOCATE rlt% + 2, clt%: PRINT CHR$(rtee)
LOCATE rlt% + 2, clb%: PRINT CHR$(ltee)

END SUB

SUB TITLE

'COLOR 7

CALL outbox(1, 1, 24, 80)

LINE (8, 7)-(632, 12), 8, BF
LINE (8, 28)-(632, 33), 8, BF
COLOR 14
LOCATE 2, 8: PRINT "     ***     COST MODEL FOR AUTOMATED PEOPLE MOVER
SYSTEMS      ***"
COLOR 6
LOCATE 4, 18: PRINT "A PLANNING MODEL TO ESTIMATE COST AND OPERATIONAL"
LOCATE 5, 20: PRINT "REQUIREMENTS OF AUTOMATED PEOPLE MOVER SYSTEMS"
COLOR 5
LOCATE 6, 12: PRINT "Developed By Srinivasa R. Mandalapu at University
of Alberta"
END SUB
```

## B.3 Listing of Bus Cost Model

The Bus Cost Model has similar structure that of RRT Cost Model and APM Cost Model. The differences and the features are explained in Section 4.4. The following is the listing of the model.

```
DECLARE SUB box (rlt%, clt%, rlb%, clb%)
DECLARE SUB oprspeed (LENGTH!, NST%, tt!)
DECLARE SUB TITLE1 ()
DECLARE SUB TITLE ()
DECLARE SUB EMPTY (S, E)
DECLARE SUB NVEH (PKFT%)
DECLARE SUB CRF (LIFE%, EFR!, RF!)
DECLARE SUB inbox (rlt%, clt%, rlb%, clb%)
DECLARE SUB outbox (rlt%, clt%, rlb%, clb%)
COMMON SHARED PKHW!, OFFPKHW!, RDTRIPTIME!, PHF!, avs%, PKNOBUS%,
OFFPKNOBUS%, NPAX&, LENGTH!, NST%, tt!
COMMON SHARED sthor, botlc, botrc, toplc, toprc, stver, PLUS, TEE,
INVTEE, rtee, ltee
'***********************************************************************

SCREEN 9
200 CALL EMPTY(4, 23)
CLEAR a - z
COLOR 8, 3
CALL inbox(10, 11, 21, 72)
COLOR 5
CALL TITLE
COLOR 8
LOCATE 11, 25: PRINT "  ** General Information **    "
COLOR 15
'***********************************************************************

'    CALCULATION EQUIVALENT ANNUAL COST OF BUS SYSTEM'S COMPONENTS
'***********************************************************************

'
LOCATE 13, 65: PRINT "None"
30 LOCATE 13, 15: INPUT "1. Length of Shuttle Bus Route (km)      = ",
LENGTH!
IF (LENGTH! <= 0! OR LENGTH > 120!) THEN GOTO 30

'                    NUMBER OF STATIONS PLANNED
'
 LOCATE 15, 67: PRINT "0"
 LOCATE 15, 15: INPUT "2. Number of Enroute Stops Planned       = ",
NST%
 NST% = NST% + 2
```

```
'*************************************************************************
'MINIMUM AND MAXIMUM COSTS OF COMPONENTS OF BUS TRANSIT SYSTEM
'*************************************************************************

STAT! = .0575        'BUS STATION COSTS PER STATION
VEH! = .2             'VEHICLE COSTS PER VEH
GAR! = .05           'GARAGE AND MAINTENANCE COSTS PER VEH

'SOURCE FOR THESE COSTS "UMTA REPORT #MA-06-0039-83-3,
'
'*************************************************************************
'         EFFECTIVE INTEREST RATE CALCULATIONS
'*************************************************************************

LOCATE 17, 67: PRINT "7%"
LOCATE 17, 15: INPUT "3. Interest Rate(%)                        = ", INR!
       IF INR! = 0 THEN INR! = 7!
'
LOCATE 19, 67: PRINT "3%"
LOCATE 19, 15: INPUT "4. Inflation Rate(%)                       = ", IFR!
       IF IFR! = 0 THEN IFR! = 3!
'
INR! = INR! * .01
IFR! = IFR! * .01
EFR! = (INR! + 1!) * (IFR! + 1!) - 1!
'*************************************************************************
'          LIFE OF COMPONENTS AND COST RECOVERY FACTORS
'*************************************************************************

 CALL EMPTY(4, 23)
 COLOR 8
 CALL box(13, 10, 18, 69)
 COLOR 15
 LOCATE 15, 11: PRINT "    Do you want to input the expected lives of "
 LOCATE 16, 17: PRINT "            components of the system (Y/N)"
 LOCATE 17, 15: PRINT "(If entered 'No' the model assumes default
values)"
 LOCATE 16, 57: INPUT y$
 IF (y$ = "y" OR y$ = "Y") THEN
        CALL EMPTY(4, 23)
        COLOR 8
        CALL inbox(7, 10, 17, 74)
        COLOR 5
        LOCATE 8, 15: PRINT "Expected Life of Components of System in
Years"
        COLOR 15
        LOCATE 11, 68: PRINT "40"

        LOCATE 11, 14: INPUT "1. Life of Bus Stop/Stations
= ", STATLIFE%
'
```

```
        LOCATE 13, 68: PRINT "12"

        LOCATE 13, 14: INPUT "2. Life of Bus
= ", VEHLIFE%
'
        LOCATE 15, 68: PRINT "40"

        LOCATE 15, 14: INPUT "3. Life of Maintenance Support Facilities
= ", GARALIFE%
   ELSE
        GOTO 100
END IF
100 IF STATLIFE% = 0 THEN STATLIFE% = 40
  IF VEHLIFE% = 0 THEN VEHLIFE% = 12
  IF GARALIFE% = 0 THEN GARALIFE% = 40
'
'                    COST RECOVERY FACTORS
'
CALL CRF(STATLIFE%, EFR!, F13!)
CALL CRF(VEHLIFE%, EFR!, F18!)
CALL CRF(GARALIFE%, EFR!, F19!)
'
'                     EQUIVALENT ANNUAL COSTS
'
ACSTATL! = STAT! * F13!        'FOR STATIONS AT GRADE

'*******************************************************************
' EQUIVALENT ANNUAL COST OF CONSTRUCTION EXCEPT VEHICLES AND GARAGE
'*******************************************************************
 CALL NVEH(PKFT%)
 TCCOSTL1! = NST% * STAT!
 ACCOSTL! = NST% * ACSTATL!
'*******************************************************************-
'ANNUAL COST FOR VEHICLES AND GARAGE
'*******************************************************************-

TCVEHL! = VEH! * PKNOBUS%
   ACVEHL! = TCVEHL! * F18!
TCGARL! = GAR! * PKNOBUS%
   ACGARl! = TCGARL! * F19!
ANCOSTL! = ACCOSTL! + ACVEHL! + ACGARl!
'
TCCOSTL! = TCCOSTL1! + TCVEHL! + TCGARL!
'
'*******************************************************************
'ANNUAL MAINTENANCE COST CALCULATIONS
'*******************************************************************
 CALL EMPTY(4, 23)
 COLOR 4

 CALL inbox(9, 11, 17, 72)
 COLOR 5
LOCATE 10, 21: PRINT "   *** OPERATIONAL DETAILS ***"
COLOR 15
 '
```

```
LOCATE 12, 67: PRINT "4"
LOCATE 13, 13: PRINT "(eg:2 hrs during am peak + 2 hrs during pm peak)"
LOCATE 12, 13: INPUT "1. Peak Hour Operation in Hours         = ",
DURPK!
IF DURPK! = 0 THEN DURPK! = 4!
'
LOCATE 15, 66: PRINT "16"
LOCATE 15, 13: INPUT "2. Off-Peak Hour Operation in hours      = ",
DUROFPK!
IF DUROFPK! = 0 THEN DUROFPK! = 16!
'
' Bus.KM PER DAY
'
BUSKMd& = LENGTH! * (DURPK! * 120! / PKHW! + DUROFPK! * 120! / OFPKHW!)
BUSHRd& = (DURPK! * PKNOBUS% + DUROFPK! * OFPKNOBUS%)
BusKMd1& = LENGTH! * (20 * 120! / OFPKHW!)
BUSHRd1& = (20 * OFPKNOBUS%)
'
BusKMy& = BUSKMd& * 52 * 5 / 1000 + BusKMd1& * 52 * 2 / 1000
BUSHRy& = BUSHRd& * 52   5 + BUSHRd1& * 52 * 2     '
ANMAINT! = 1.94 * BusKMy& / 1000
'
NETANCL! = ANMAINT! + ANCOSTL!
CALL EMPTY(4, 23)

CALL outbox(6, 10, 21, 73)
COLOR 5
LOCATE 7, 24: PRINT " *** OUTPUT OF OPERATIONAL DETAILS ***"
COLOR 15
LOCATE 9, 13: PRINT "1. Length of Shuttle Bus Route (km)          ="
        LOCATE 9, 64: PRINT USING "###.#"; LENGTH!
LOCATE 11, 13: PRINT "2. Round Trip time (minutes)                  ="
        LOCATE 11, 64: PRINT USING "###.#"; RDTRIPTIME!
LOCATE 13, 13: PRINT "3. Number of Buses Required for Peak Hour
Operation ="
       LOCATE 13, 66: PRINT USING "###"; PKNOBUS%
LOCATE 14, 13: PRINT "                             for Off-Peak
Operation ="
       LOCATE 14, 66: PRINT USING "###"; OFPKNOBUS%
LOCATE 16, 13: PRINT "4. Headway in minutes during Peak Hour        ="
        LOCATE 16, 65: PRINT USING "##.#"; PKHW!
LOCATE 17, 13: PRINT "                             Off-Peak Hour    ="
        LOCATE 17, 65: PRINT USING "##.#"; OFPKHW!
LOCATE 18, 13: PRINT "5. Number of Bus Kilometres per day           = "
       LOCATE 18, 62: PRINT USING "#######"; BUSKMd&
LOCATE 20, 13: PRINT "6. Number of Bus Hours per day                ="
       LOCATE 20, 62: PRINT USING "#######"; BUSHRd&
'
LOCATE 23, 13: INPUT "    Press ENTER to continue      ", D$
ANNPAX! = NPAX& * 52! * (5! + .3 * 2!) / 1000!
'
COSTPERPAX! = NETANCL! / ANNPAX!
'
CALL EMPTY(4, 23)
COLOR 4
```

```
CALL outbox(4, 11, 17, 73)
COLOR 5
LOCATE 5, 24: PRINT " *** OUTPUT OF COST DETAILS ***"
COLOR 15
LOCATE 7, 13: PRINT "  1. Annual passengers (millions)          ="
        LOCATE 7, 63: PRINT USING "####.##"; ANNPAX!
LOCATE 9, 13: PRINT "  2. Total Capital Cost of System          = M
$"
       LOCATE 9, 64: PRINT USING "###.##"; TCCOSTL!
       LOCATE 11, 13: PRINT "  3. Annual Operating and Maintenance Cost
= M $"
       LOCATE 11, 64: PRINT USING "###.##"; ANNMAINT!
LOCATE 13, 13: PRINT "  4. Equivalent Annual Cost of the System    = M
$"
       LOCATE 13, 64: PRINT USING "###.##"; NETANCL!
LOCATE 15, 13: PRINT "  5. Average Cost per Passenger              =
$"
       LOCATE 15, 64: PRINT USING "###.##"; COSTPERPAX!


'*************************************************************************


LOCATE 21, 13: PRINT "Do you want Print the Results     (",
LOCATE 21, 52: PRINT ")"
COLOR 4
LOCATE 21, 49: PRINT "Y/N"
COLOR 15
LOCATE 21, 54: INPUT D$
IF (D$ = "Y" OR D$ = "y") THEN
'*************************************************************************

LPRINT ; TAB(5); "  ***  COST MODEL FOR SHUTTLE BUS SYSTEMS  ***"
LPRINT
LPRINT
LPRINT ; TAB(15); "              Input Data"
LPRINT
LPRINT ; TAB(8); "A. GENERAL INFORMATION  "
LPRINT
LPRINT ; TAB(10); " 1. Length of Shuttle Bus Route(km)   = ", LENGTH!
LPRINT
LPRINT ; TAB(10); " 2. Number of Enroute Stops Planned   = ", NST%
LPRINT
LPRINT ; TAB(10); " 3. Interest Rate(%)                  = ", INR! * 100
LPRINT
LPRINT ; TAB(10); " 4. Inflation Rate(%)                 = ", IFR! * 100
LPRINT
LPRINT
LPRINT ; TAB(8); "B. OPERATIONAL CHARACTERISTICS "
LPRINT
LPRINT
LPRINT ; TAB(10); " 1. Number of Passengers in Both Directions"
LPRINT ; TAB(10); "       on an Average  Weekday  in  THOUSANDS = ";
NPAX&
```

```
LPRINT
LPRINT ; TAB(10); " 2. Percent of Average Week day Passengers"
LPRINT ; TAB(10); "                                      During Peak Hour = ";
PHF!
LPRINT
LPRINT ; TAB(10); " 3. Peak Hour Operation in Hours              = ";
DURPK!
LPRINT
LPRINT ; TAB(10); " 4. Off-Peak Hour Operation in hours          = ";
DUROFPK!
LPRINT
LPRINT ; TAB(10); " 5. Headway During Peak Hour in Minutes       = ";
PKHW!
LPRINT
LPRINT ; TAB(10); " 6. Headway During Off-Peak Hour in Minutes   = ";
OFPKHW!
LPRINT CHR$(12)
LPRINT
LPRINT TAB(15); "               Output of the Model"
LPRINT
LPRINT
LPRINT TAB(8); "A. OUTPUT OF OPERATIONAL CHARACTERISTICS "
LPRINT
LPRINT
LPRINT ; TAB(10); " 1. Length of Shuttle Bus Route (km)            =";
USING "###.#"; LENGTH!
LPRINT
LPRINT ; TAB(10); " 2. Round Trip time (minutes)                   =";
USING "###"; RDTRIPTIME!
LPRINT
LPRINT ; TAB(10); " 3. Average Operating Speed in kmph             =";
USING "###.#"; avs%
LPRINT
LPRINT ; TAB(10); " 4. Number of Buses Required for Peak Hour Operation
="; USING "####"; PKNOBUS%
LPRINT ; TAB(10); "                                  for Off-Peak Operation
="; USING "####"; OFPKNOBUS%
LPRINT
LPRINT ; TAB(10); " 5. Number of Bus Kilometres per day
="; USING "#######"; BUSKMd&
LPRINT
LPRINT ; TAB(10); " 6. Number of Bus Hours per day
="; USING "#######"; BUSHRd&
LPRINT
LPRINT
LPRINT ; TAB(8); "B. OUTPUT OF COST DETAILS "
LPRINT
LPRINT
LPRINT ; TAB(10); " 1. Annual passengers (millions)               =
"; USING "#####.##"; ANNPAX!
LPRINT
LPRINT ; TAB(10); " 2. Total Capital Cost of System               = M
$"; USING "#####.##"; TCCOSTL!
LPRINT
```

```
LPRINT ; TAB(10); " 3. Annual Operating and Maintenance Cost      = M
$"; USING "#####.##"; ANMAINT!
LPRINT
LPRINT ; TAB(10); " 4. Equivalent Annual Cost of the System       = M
$"; USING "#####.##"; (NETANCL! + NETANCU!) / 2!
LPRINT
LPRINT ; TAB(10); " 5. Average Cost per Passenger                 =
$"; USING "#####.##"; COSTPERPAX!

'*************************************************************************

ELSE
END IF
        LOCATE 22, 13: PRINT "Do you want to make another trial (",
        LOCATE 22, 52: PRINT ")"
        COLOR 4
        LOCATE 22, 49: PRINT "Y/N"
        COLOR 15
        LOCATE 22, 54: INPUT dD$

IF (dD$ = "y" OR dD$ = "Y") THEN
        GOTO 200
 COLOR 4
LOCATE 24, 24: PRINT "Terminating the program"
'***************************************
ELSE
END IF

SUB box (rlt%, clt%, rlb%, clb%) STATIC
sthor = 205: botlc = 200: botrc = 188: toplc = 201: toprc = 187
stver = 186: PLUS = 206: TEE = 203: INVTEE = 202: rtee = 204: ltee = 185
'
LOCATE rlt%, clt%: PRINT CHR$(toplc);
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
LOCATE , clb%: PRINT CHR$(toprc);
'
FOR I = rlt% + 1 TO rlb% - 1
    LOCATE I, clt%: PRINT CHR$(stver);
    LOCATE , clb%: PRINT CHR$(stver);
NEXT I
LOCATE rlb%, clt%: PRINT CHR$(botlc);
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
LOCATE , clb%: PRINT CHR$(botrc);
'
END SUB

SUB CRF (LIFE%, EFR!, RF!)
'       SUBPROGRAM FOR COST RECOVERY FACTOR
RF! = (EFR! * ((1 + EFR!) ^ LIFE%)) / ((1 + EFR!) ^ LIFE% - 1)
END SUB

SUB EMPTY (S, E)
FOR I = S TO E
    LOCATE I, 2: PRINT "                                     "
    LOCATE I, 40: PRINT "                                   ";
```

```
NEXT I
END SUB

SUB inbox (rlt%, clt%, rlb%, clb%) STATIC
'
COLOR 8
LOCATE rlt% + 1, clb% - 9: PRINT "Defaults";
COLOR 1
CALL box(rlt%, clt%, rlb%, clb%)
LOCATE rlt% + 2, clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
'
FOR I = rlt% + 1 TO rlb% - 1
      LOCATE I, clb% - 11: PRINT CHR$(stver);
NEXT I
LOCATE rlt%, clb% - 11: PRINT CHR$(TEE)
LOCATE rlt% + 2, clb% - 11: PRINT CHR$(PLUS)
'
LOCATE rlb%, clb% - 11: PRINT CHR$(INVTEE)
LOCATE rlt% + 2, clt%: PRINT CHR$(rtee)
LOCATE rlt% + 2, clb%: PRINT CHR$(ltee)
END SUB

SUB NVEH (PKFT%)
'
'*******************************************************
'   SUB-PROGRAM FOR FLEET CALCULATION
'*******************************************************
CALL EMPTY(4, 23)
COLOR 4

COLOR 8

 CALL inbox(8, 9, 21, 73)
 COLOR 5
LOCATE 9, 20: PRINT "   *** OPERATIONAL DETAILS ***"
COLOR 15

LOCATE 11, 66: PRINT "None"
LOCATE 11, 11: PRINT "1. Number of Passengers in Both Directions on"
10  LOCATE 12, 14: INPUT "    an Average Weekday in THOUSANDS      = ",
NPAX&
IF NPAX& <= 0 GOTO 10

LOCATE 14, 67: PRINT "10%";
LOCATE 14, 11: PRINT "2. Percent of Average Week day Passengers During"
  LOCATE 15, 14: INPUT "                              Peak Hour      = ",
PHF!

IF PHF! <= 0 THEN PHF! = 10!

'**********************************************
'                  PEAK HOUR CALCULATIONS
'**********************************************
PKHRCAP& = CINT((PHF! * .01) * NPAX& * 1000 * .6 / .9)  'ASSUMES 60
TRAVEL IN PEAK DIRECTION
```

```
'
LOCATE 17, 66: PRINT " 40"
LOCATE 17, 11: INPUT "3. Capacity of Bus   (Passengers/Bus)       = ",
CAPBUS%
IF CAPBUS% <= 0 THEN CAPBUS% = 40
NOBUS% = CINT(PKHRCAP& / CAPBUS% + .49)
PKHW! = CINT((60 / NOBUS%) * 10) / 10
 '
 LOCATE 19, 66: PRINT "Calc."
LOCATE 20, 15: PRINT "Calculates if entered ZERO"
LOCATE 19, 11: INPUT "4. Round Trip Time in Minutes                = ",
RDTRIPTIME!
IF RDTRIPTIME! <= 0 THEN
        CALL oprspeed(LENGTH!, NST%, tt!)
        RDTRIPTIME! = 2 * tt! + 2
     ELSE
END IF
PKNOBUS% = CINT(RDTRIPTIME! / PKHW! + .49)
'
'*********************************************
'                  OFF-PEAK HOUR CALCULATIONS
'*********************************************
OFPKHRCAP& = CINT((PHF! * .01 * .3) * NPAX& * 1000 / .9)
NOBUSOF% = CINT((OFPKHRCAP& / CAPBUS%) + .49)
OFPKHW! = CINT(60 / NOBUSOF% + .49)
OFPKNOBUS% = CINT(RDTRIPTIME! / OFPKHW! + .49)
END SUB

SUB oprspeed (LENGTH!, NST%, tt!)
'*******************************************************************
'THIS PROGRAM CALCULATES THE OPERATING SPEED OVER NUMBER OF STOPS
'*******************************************************************
50 CALL EMPTY(4, 23)
COLOR 15
CALL inbox(7, 8, 21, 75)
'
LOCATE 8, 17: PRINT "        OPERATING CHARACTERISTICS"
COLOR 15
LOCATE 12, 68: PRINT " 30"
20 LOCATE 12, 12: INPUT "1. Dwelling time at each stop in Seconds = ",
dwltime!
IF (dwltime! > 25! AND dwltime! <= 120!) GOTO 130
IF dwltime! = 0 THEN
        dwltime! = 30!
    ELSE
     GOTO 20
END IF

LOCATE 14, 68: PRINT " 45"
130  LOCATE 14, 12: INPUT "2. Maximum Speed in km/hr                 = ",
v!
IF v! = 0 THEN v! = 45!
v! = v! * 1000! / 3600!
'
LOCATE 16, 68: PRINT "0.58"
```

```
LOCATE 16, 12: INPUT "3. Acceleration rate in m/sec/sec        = ", acc!
IF acc! = 0 THEN acc! = .58
LOCATE 18, 68: PRINT "1.1"
LOCATE 18, 12: INPUT "4. Deceleration rate in m/sec/sec        = ", dcc!
IF dcc! = 0 THEN dcc! = 1.1
s1! = v! ^ 2 / 2! / acc!
s2! = v! ^ 2 / 2! / dcc!
S! = s1! + s2!
l! = LENGTH! / (NST% - 1) * 1000!
IF (S! > l!) THEN
        v! = SQR(l! / (1 / 2! / acc! + 1 / 2! / dcc!))
        t1! = v! / acc!
        t2! = v! / dcc!
        T! = t1! + t2!

    ELSE
        s3! = l! - S!
        t3! = s3! / v!
        t1! = v! / acc!
        t2! = v! / dcc!
        T! = t1! + t2! + t3!
END IF
T! = (NST% - 1) * T! + (NST% - 2) * dwltime!
avsp! = LENGTH! / T! * 3600
avs% = FIX(avsp!)
tt! = CINT(T! / 60! * 10) / 10!
CALL EMPTY(4, 23)
COLOR 4

CALL outbox(9, 8, 17, 73)
COLOR 15
LOCATE 10, 19: PRINT "** OUTPUT OF OPERATIONAL CHARACTERISTICS **"
LOCATE 13, 12: PRINT "1. Travel Time for single trip in minutes =", tt!
LOCATE 15, 12: PRINT "2. Average Operating Speed in kmph       = ", avs%
LOCATE 18, 12: INPUT "     Press ENTER to continue     ", C$
'
END SUB

SUB outbox (rlt%, clt%, rlb%, clb%) STATIC
'
COLOR 1
CALL.box(rlt%, clt%, rlb%, clb%)
LOCATE rlt% + 2, clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
'
LOCATE rlt% + 2, clt%: PRINT CHR$(rtee)
LOCATE rlt% + 2, clb%: PRINT CHR$(ltee)
'
END SUB

SUB TITLE

COLOR 7
CALL outbox(1, 1, 24, 80)
LINE (8, 7)-(632, 12), 8, BF
LINE (8, 28)-(632, 33), 8, BF
```

```
COLOR 14
LOCATE 2, 8: PRINT "            ***     COST MODEL FOR SHUTTLE BUS
SYSTEMS      ***"
COLOR 6
LOCATE 4, 18: PRINT "A PLANNING MODEL TO ESTIMATE COST AND OPERATIONAL"
LOCATE 5, 20: PRINT "      REQUIREMENTS OF SHUTTLE BUS SYSTEMS"
COLOR 5
LOCATE 6, 12: PRINT "Developed By Srinivasa R. Mandalapu at University
of Alberta"
'
END SUB
```

## APPENDIX C

## C.1 Cost per Passenger Data Used in the Analysis

The following sections present the data developed and used for the analysis of alternatives using the RRT Model, APM Model, and Shuttle Bus Model.

### C.1.1 Cost per Passenger Data Developed from RRT Model

The data presented in Table c.1 is generated using the RRT Model with all the defaults explained in Section B.1.1. The variation of cost per passemger with demand is also presented in Figure C.1. The same data was used in the analysis of alternatives.

Table C.1: Costs per Passenger and Travel Time for New RRT lines for Various Passenger Demands

| Length | Time | Average Daily Passengers (thousands) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | (min) | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 2.0 | 1.8 | 5.00 | 3.34 | 2.50 | 2.00 | 1.67 | 1.43 | 1.30 | 1.15 | 1.04 | 0.98 | 0.89 |
| 4.0 | 4.0 | 8.97 | 5.98 | 4.49 | 3.59 | 2.99 | 2.56 | 2.31 | 2.06 | 1.85 | 1.74 | 1.59 |
| 6.0 | 7.1 | 13.79 | 9.19 | 6.89 | 5.52 | 4.60 | 3.94 | 3.56 | 3.17 | 2.85 | 2.68 | 2.45 |
| 8.0 | 9.3 | 17.73 | 11.82 | 8.86 | 7.09 | 5.91 | 5.06 | 4.57 | 4.07 | 3.66 | 3.43 | 3.15 |
| 10.0 | 11.6 | 21.67 | 14.45 | 10.83 | 8.67 | 7.22 | 6.19 | 5.59 | 4.97 | 4.47 | 4.19 | 3.84 |
| 12.0 | 13.9 | 25.60 | 17.07 | 12.80 | 10.24 | 8.53 | 7.32 | 6.60 | 5.86 | 5.28 | 4.94 | 4.53 |
| 14.0 | 16.9 | 30.43 | 20.29 | 15.21 | 12.17 | 10.14 | 8.69 | 7.85 | 6.98 | 6.28 | 5.88 | 5.39 |
| 16.0 | 19.2 | 34.37 | 22.91 | 17.19 | 13.75 | 11.46 | 9.82 | 8.86 | 7.87 | 7.09 | 6.64 | 6.08 |
| 18.0 | 21.4 | 38.30 | 25.53 | 19.15 | 15.32 | 12.77 | 10.94 | 9.87 | 8.77 | 7.89 | 7.39 | 6.77 |
| 20.0 | 23.7 | 42.40 | 28.27 | 21.20 | 16.96 | 14.13 | 12.11 | 10.94 | 9.72 | 8.75 | 8.20 | 7.52 |
| 22.0 | 26.0 | 46.34 | 30.89 | 23.17 | 18.53 | 15.45 | 13.24 | 11.95 | 10.62 | 9.56 | 8.95 | 8.21 |
| 24.0 | 28.2 | 50.27 | 33.51 | 25.14 | 20.11 | 16.76 | 14.36 | 12.96 | 11.52 | 10.37 | 9.71 | 8.90 |
| 26.0 | 30.5 | 54.37 | 36.24 | 27.18 | 21.75 | 18.12 | 15.53 | 14.03 | 12.47 | 11.22 | 10.52 | 9.64 |
| 28.0 | 32.8 | 58.30 | 38.87 | 29.15 | 23.32 | 19.43 | 16.66 | 15.04 | 13.36 | 12.03 | 11.27 | 10.33 |
| 30.0 | 35.0 | 62.24 | 41.49 | 31.12 | 24.90 | 20.75 | 17.78 | 16.05 | 14.26 | 12.84 | 12.02 | 11.02 |
| 32.0 | 37.3 | 66.33 | 44.22 | 33.17 | 26.53 | 22.11 | 18.95 | 17.11 | 15.21 | 13.69 | 12.83 | 11.76 |
| 34.0 | 39.6 | 70.27 | 46.84 | 35.13 | 28.11 | 23.42 | 20.08 | 18.12 | 16.11 | 14.50 | 13.59 | 12.45 |
| 36.0 | 41.8 | 74.20 | 49.47 | 37.10 | 29.68 | 24.73 | 21.20 | 19.13 | 17.01 | 15.31 | 14.34 | 13.14 |
| 38.0 | 44.1 | 78.14 | 52.09 | 39.07 | 31.25 | 26.05 | 22.32 | 20.14 | 17.91 | 16.11 | 15.09 | 13.83 |
| 40.0 | 46.3 | 82.23 | 54.82 | 41.12 | 32.89 | 27.41 | 23.49 | 21.21 | 18.86 | 16.97 | 15.90 | 14.58 |
| 42.0 | 48.6 | 86.17 | 57.44 | 43.08 | 34.47 | 28.72 | 24.62 | 22.22 | 19.75 | 17.78 | 16.66 | 15.27 |
| 44.0 | 50.9 | 90.10 | 60.07 | 45.05 | 36.04 | 30.03 | 25.74 | 23.23 | 20.65 | 18.58 | 17.41 | 15.96 |
| 46.0 | 52.4 | 93.46 | 62.31 | 46.73 | 37.38 | 31.15 | 26.70 | 24.12 | 21.44 | 19.29 | 18.09 | 16.58 |
| 48.0 | 54.6 | 97.40 | 64.93 | 48.70 | 38.96 | 32.47 | 27.83 | 25.13 | 22.33 | 20.10 | 18.84 | 17.27 |
| 50.0 | 56.9 | 101.33 | 67.55 | 50.66 | 40.53 | 33.78 | 28.95 | 26.14 | 23.23 | 20.91 | 19.59 | 17.96 |

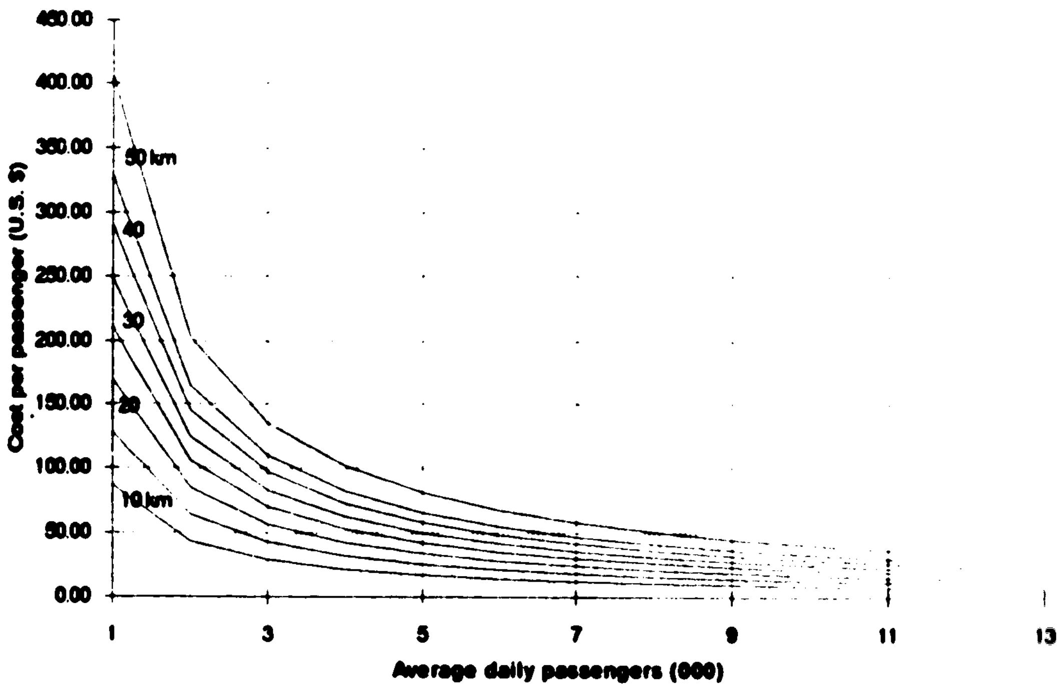



Figure C.1: Variation of Cost per Passenger with Passenger Demand and RRT line Length

### C.1.2 Cost per Passenger Data Developed from APM Model

The data presented in Table c.2 is generated using the APM Model with the following defaults.

Elevated guideway

Non-stop service

Two stations, one at each end of the guideway and

Operational characters as explained in Section 4.3.2

The same data was used in the analysis of the Concept C.

Table C.2: Cost per Passenger and Travel Time for APM Connections for Various Passenger Demands

| Length | Time | Average Daily Passengers (thousands) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | (min) | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 0.5 | 0.9 | 0.79 | 0.53 | 0.39 | 0.32 | 0.26 | 0.23 | 0.23 | 0.20 | 0.18 | 0.17 | 0.15 |
| 1.0 | 1.6 | 1.44 | 0.96 | 0.72 | 0.58 | 0.48 | 0.41 | 0.40 | 0.35 | 0.32 | 0.29 | 0.27 |
| 1.5 | 2.3 | 3.98 | 2.65 | 1.99 | 1.59 | 1.33 | 1.14 | 1.06 | 0.95 | 0.85 | 0.77 | 0.71 |
| 2.0 | 3.0 | 5.23 | 3.49 | 2.61 | 2.09 | 1.74 | 1.49 | 1.39 | 1.23 | 1.11 | 1.01 | 0.92 |
| 2.5 | 3.7 | 6.48 | 4.32 | 3.24 | 2.59 | 2.16 | 1.85 | 1.71 | 1.52 | 1.37 | 1.24 | 1.14 |
| 3.0 | 4.5 | 7.82 | 5.21 | 3.91 | 3.13 | 2.61 | 2.23 | 2.07 | 1.84 | 1.66 | 1.51 | 1.38 |
| 3.5 | 5.2 | 9.07 | 6.04 | 4.53 | 3.63 | 3.02 | 2.59 | 2.39 | 2.13 | 1.92 | 1.74 | 1.60 |
| 4.0 | 5.9 | 10.32 | 6.88 | 5.16 | 4.13 | 3.44 | 2.95 | 2.72 | 2.41 | 2.17 | 1.98 | 1.81 |
| 4.5 | 6.6 | 11.57 | 7.71 | 5.79 | 4.63 | 3.86 | 3.31 | 3.04 | 2.70 | 2.43 | 2.21 | 2.03 |
| 5.0 | 7.3 | 12.91 | 8.60 | 6.45 | 5.16 | 4.30 | 3.69 | 3.40 | 3.02 | 2.72 | 2.47 | 2.27 |
| 5.5 | 8.0 | 14.16 | 9.44 | 7.08 | 5.66 | 4.72 | 4.05 | 3.72 | 3.31 | 2.98 | 2.71 | 2.48 |
| 6.0 | 8.7 | 15.41 | 10.27 | 7.71 | 6.16 | 5.14 | 4.40 | 4.05 | 3.60 | 3.24 | 2.94 | 2.70 |
| 6.5 | 9.5 | 16.74 | 11.16 | 8.37 | 6.70 | 5.58 | 4.78 | 4.41 | 3.92 | 3.53 | 3.21 | 2.94 |
| 7.0 | 10.2 | 18.00 | 12.00 | 9.00 | 7.20 | 6.00 | 5.14 | 4.73 | 4.21 | 3.79 | 3.44 | 3.16 |
| 7.5 | 10.9 | 19.25 | 12.83 | 9.62 | 7.70 | 6.42 | 5.50 | 5.05 | 4.49 | 4.04 | 3.68 | 3.37 |
| 8.0 | 11.6 | 20.50 | 13.67 | 10.25 | 8.20 | 6.83 | 5.86 | 5.38 | 4.78 | 4.30 | 3.91 | 3.58 |
| 8.5 | 12.3 | 21.84 | 14.56 | 10.92 | 8.73 | 7.28 | 6.24 | 5.74 | 5.10 | 4.59 | 4.18 | 3.83 |
| 9.0 | 13.0 | 23.09 | 15.39 | 11.54 | 9.24 | 7.70 | 6.60 | 6.06 | 5.39 | 4.85 | 4.41 | 4.04 |
| 9.5 | 13.7 | 24.34 | 16.23 | 12.17 | 9.74 | 8.11 | 6.95 | 6.39 | 5.68 | 5.11 | 4.64 | 4.26 |
| 10.0 | 14.5 | 25.67 | 17.12 | 12.84 | 10.27 | 8.56 | 7.34 | 6.75 | 6.00 | 5.40 | 4.91 | 4.50 |
| 10.5 | 15.2 | 26.93 | 17.95 | 13.46 | 10.77 | 8.98 | 7.69 | 7.07 | 6.29 | 5.66 | 5.14 | 4.71 |
| 11.0 | 15.9 | 28.18 | 18.79 | 14.09 | 11.27 | 9.39 | 8.05 | 7.39 | 6.57 | 5.92 | 5.38 | 4.93 |
| 11.5 | 16.6 | 29.43 | 19.62 | 14.72 | 11.77 | 9.81 | 8.41 | 7.72 | 6.86 | 6.17 | 5.61 | 5.14 |
| 12.0 | 17.3 | 30.77 | 20.51 | 15.38 | 12.31 | 10.26 | 8.79 | 8.08 | 7.18 | 6.46 | 5.88 | 5.39 |
| 12.5 | 18.0 | 32.02 | 21.35 | 16.01 | 12.81 | 10.67 | 9.15 | 8.40 | 7.47 | 6.72 | 6.11 | 5.60 |
| 13.0 | 18.7 | 33.27 | 22.18 | 16.63 | 13.31 | 11.09 | 9.51 | 8.72 | 7.75 | 6.98 | 6.34 | 5.82 |
| 13.5 | 19.5 | 34.60 | 23.07 | 17.30 | 13.84 | 11.53 | 9.89 | 9.09 | 8.08 | 7.27 | 6.61 | 6.06 |
| 14.0 | 20.2 | 35.86 | 23.90 | 17.93 | 14.34 | 11.95 | 10.24 | 9.41 | 8.36 | 7.53 | 6.84 | 6.27 |
| 14.5 | 20.9 | 37.11 | 24.74 | 18.55 | 14.84 | 12.37 | 10.60 | 9.73 | 8.65 | 7.79 | 7.08 | 6.49 |
| 15.0 | 21.6 | 38.36 | 25.57 | 19.18 | 15.34 | 12.79 | 10.96 | 10.06 | 8.94 | 8.04 | 7.31 | 6.70 |

### C.1.3 Cost per Passenger Data for Direct Bus from CBD Developed from Bus Model

The data presented in Table c.3 is generated using the Shuttle Bus Model with the number of stops and speed presented in Table 5.1. The other defaults used are as explained in Section 4.4.1. The same data was used in the analysis of the concepts.

Table C.3: Cost per Passenger and Travel Time for Direct Bus Service for Various Passenger Demands

| Length | Time | Average Daily Passengers (thousands) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | (min) | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| 10 | 18.1 | 1.32 | 1.24 | 1.07 | 1.08 | 1.09 | 1.06 | 1.09 | 1.00 | 1.06 | 0.99 | 0.94 |
| 12 | 20.5 | 1.56 | 1.46 | 1.28 | 1.28 | 1.31 | 1.27 | 1.30 | 1.19 | 1.26 | 1.17 | 1.12 |
| 14 | 23.5 | 1.84 | 1.71 | 1.49 | 1.50 | 1.51 | 1.47 | 1.51 | 1.38 | 1.47 | 1.37 | 1.30 |
| 16 | 26.5 | 2.06 | 1.95 | 1.69 | 1.70 | 1.72 | 1.68 | 1.72 | 1.57 | 1.67 | 1.56 | 1.48 |
| 18 | 29.5 | 2.35 | 2.20 | 1.90 | 1.92 | 1.94 | 1.88 | 1.93 | 1.76 | 1.87 | 1.75 | 1.66 |
| 20 | 32.5 | 2.57 | 2.41 | 2.10 | 2.12 | 2.15 | 2.09 | 2.14 | 1.96 | 2.08 | 1.94 | 1.84 |
| 22 | 30.7 | 2.81 | 2.64 | 2.28 | 2.30 | 2.33 | 2.26 | 2.32 | 2.12 | 2.25 | 2.10 | 1.99 |
| 24 | 33.1 | 3.03 | 2.85 | 2.48 | 2.50 | 2.53 | 2.46 | 2.53 | 2.30 | 2.46 | 2.29 | 2.17 |
| 26 | 35.5 | 3.25 | 3.10 | 2.69 | 2.70 | 2.74 | 2.66 | 2.74 | 2.50 | 2.66 | 2.47 | 2.34 |
| 28 | 37.9 | 3.54 | 3.34 | 2.87 | 2.92 | 2.95 | 2.86 | 2.94 | 2.69 | 2.85 | 2.66 | 2.52 |
| 30 | 40.3 | 3.76 | 3.55 | 3.07 | 3.12 | 3.15 | 3.06 | 3.15 | 2.87 | 3.06 | 2.85 | 2.70 |
| 32 | 42.7 | 3.98 | 3.80 | 3.28 | 3.32 | 3.35 | 3.27 | 3.35 | 3.06 | 3.26 | 3.04 | 2.88 |
| 34 | 45.1 | 4.26 | 4.01 | 3.48 | 3.53 | 3.57 | 3.46 | 3.56 | 3.25 | 3.46 | 3.22 | 3.05 |
| 36 | 47.5 | 4.48 | 4.26 | 3.69 | 3.73 | 3.77 | 3.67 | 3.76 | 3.44 | 3.66 | 3.41 | 3.23 |
| 38 | 49.9 | 4.70 | 4.47 | 3.87 | 3.93 | 3.98 | 3.86 | 3.97 | 3.63 | 3.86 | 3.60 | 3.41 |
| 40 | 52.3 | 4.98 | 4.72 | 4.08 | 4.13 | 4.19 | 4.07 | 4.18 | 3.81 | 4.06 | 3.78 | 3.58 |
| 42 | 45.4 | 5.17 | 4.88 | 4.23 | 4.28 | 4.33 | 4.20 | 4.33 | 3.94 | 4.20 | 3.91 | 3.70 |
| 44 | 47.3 | 5.39 | 5.13 | 4.44 | 4.48 | 4.53 | 4.41 | 4.53 | 4.12 | 4.40 | 4.09 | 3.87 |
| 46 | 49.1 | 5.61 | 5.34 | 4.62 | 4.68 | 4.74 | 4.60 | 4.73 | 4.31 | 4.60 | 4.28 | 4.05 |
| 48 | 51.0 | 5.83 | 5.59 | 4.82 | 4.88 | 4.94 | 4.80 | 4.93 | 4.50 | 4.79 | 4.46 | 4.22 |
| 50 | 52.8 | 6.11 | 5.80 | 5.01 | 5.08 | 5.14 | 4.99 | 5.14 | 4.68 | 4.99 | 4.64 | 4.39 |

### C.1.4 Cost per Passenger Data for Shuttle Bus System Developed from Bus Model

The data presented in Table c.4 is generated using the Shuttle Bus Model with a speed of 30 kmph and non-stop service . The other defaults used are as explained in Section 4.4.1. The same data was used in the analysis of the Concept C.

Table C.4: Cost per Passenger and Travel Time for Shuttle Bus Service for Various Passenger Demands

| Length | Time | Average Daily Passengers (thousands) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | (min) | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| 0.5 | 1.4 | 0.14 | 0.09 | 0.07 | 0.08 | 0.08 | 0.07 | 0.07 | 0.06 | 0.07 | 0.06 | 0.06 |
| 1.0 | 2.6 | 0.19 | 0.15 | 0.14 | 0.13 | 0.12 | 0.13 | 0.12 | 0.11 | 0.12 | 0.11 | 0.10 |
| 1.5 | 3.8 | 0.25 | 0.20 | 0.19 | 0.17 | 0.18 | 0.17 | 0.18 | 0.16 | 0.17 | 0.16 | 0.16 |
| 2.0 | 5.0 | 0.30 | 0.29 | 0.23 | 0.24 | 0.23 | 0.23 | 0.24 | 0.21 | 0.23 | 0.21 | 0.20 |
| 2.5 | 6.2 | 0.36 | 0.34 | 0.30 | 0.28 | 0.29 | 0.28 | 0.28 | 0.26 | 0.28 | 0.26 | 0.25 |
| 3.0 | 7.4 | 0.41 | 0.39 | 0.34 | 0.35 | 0.35 | 0.33 | 0.34 | 0.31 | 0.33 | 0.31 | 0.29 |
| 3.5 | 8.6 | 0.53 | 0.44 | 0.39 | 0.39 | 0.40 | 0.39 | 0.40 | 0.36 | 0.39 | 0.36 | 0.34 |
| 4.0 | 9.8 | 0.58 | 0.53 | 0.46 | 0.45 | 0.46 | 0.44 | 0.45 | 0.41 | 0.44 | 0.41 | 0.39 |
| 4.5 | 11.0 | 0.64 | 0.58 | 0.50 | 0.50 | 0.50 | 0.49 | 0.51 | 0.46 | 0.49 | 0.46 | 0.43 |
| 5.0 | 12.2 | 0.69 | 0.64 | 0.55 | 0.56 | 0.56 | 0.55 | 0.55 | 0.51 | 0.54 | 0.51 | 0.48 |
| 5.5 | 13.4 | 0.75 | 0.69 | 0.62 | 0.61 | 0.61 | 0.60 | 0.61 | 0.57 | 0.60 | 0.56 | 0.53 |
| 6.0 | 14.6 | 0.81 | 0.77 | 0.66 | 0.67 | 0.67 | 0.65 | 0.67 | 0.61 | 0.65 | 0.60 | 0.58 |
| 6.5 | 15.8 | 0.86 | 0.83 | 0.71 | 0.72 | 0.73 | 0.70 | 0.72 | 0.66 | 0.70 | 0.65 | 0.62 |
| 7.0 | 17.0 | 0.98 | 0.88 | 0.77 | 0.78 | 0.78 | 0.76 | 0.78 | 0.71 | 0.76 | 0.70 | 0.67 |
| 7.5 | 18.2 | 1.03 | 0.93 | 0.82 | 0.83 | 0.84 | 0.81 | 0.83 | 0.76 | 0.81 | 0.75 | 0.72 |
| 8.0 | 19.4 | 1.09 | 0.99 | 0.87 | 0.87 | 0.88 | 0.86 | 0.88 | 0.81 | 0.86 | 0.81 | 0.76 |
| 8.5 | 20.6 | 1.14 | 1.07 | 0.93 | 0.93 | 0.94 | 0.92 | 0.94 | 0.86 | 0.91 | 0.85 | 0.81 |
| 9.0 | 21.8 | 1.20 | 1.13 | 0.98 | 0.98 | 0.99 | 0.96 | 0.99 | 0.91 | 0.97 | 0.90 | 0.86 |
| 9.5 | 23.0 | 1.25 | 1.18 | 1.02 | 1.04 | 1.05 | 1.02 | 1.05 | 0.96 | 1.02 | 0.95 | 0.91 |
| 10.0 | 24.2 | 1.31 | 1.23 | 1.09 | 1.09 | 1.11 | 1.08 | 1.10 | 1.01 | 1.07 | 1.00 | 0.95 |
| 10.5 | 25.4 | 1.36 | 1.32 | 1.14 | 1.15 | 1.16 | 1.12 | 1.15 | 1.06 | 1.13 | 1.05 | 1.00 |
| 11.0 | 26.6 | 1.48 | 1.37 | 1.18 | 1.20 | 1.22 | 1.18 | 1.21 | 1.11 | 1.18 | 1.10 | 1.04 |
| 11.5 | 27.8 | 1.54 | 1.42 | 1.25 | 1.26 | 1.26 | 1.24 | 1.27 | 1.16 | 1.23 | 1.15 | 1.09 |
| 12.0 | 29.0 | 1.59 | 1.48 | 1.29 | 1.31 | 1.32 | 1.28 | 1.32 | 1.21 | 1.28 | 1.19 | 1.14 |
| 12.5 | 30.2 | 1.65 | 1.56 | 1.34 | 1.37 | 1.37 | 1.34 | 1.37 | 1.26 | 1.34 | 1.25 | 1.19 |
| 13.0 | 31.4 | 1.70 | 1.62 | 1.41 | 1.41 | 1.43 | 1.39 | 1.43 | 1.31 | 1.39 | 1.30 | 1.23 |
| 13.5 | 32.6 | 1.76 | 1.67 | 1.45 | 1.48 | 1.49 | 1.44 | 1.48 | 1.36 | 1.44 | 1.35 | 1.28 |
| 14.0 | 33.8 | 1.81 | 1.72 | 1.50 | 1.52 | 1.54 | 1.50 | 1.54 | 1.41 | 1.50 | 1.40 | 1.33 |
| 14.5 | 35.0 | 1.93 | 1.81 | 1.57 | 1.58 | 1.60 | 1.55 | 1.59 | 1.46 | 1.55 | 1.44 | 1.37 |
| 15.0 | 36.2 | 1.98 | 1.86 | 1.61 | 1.63 | 1.64 | 1.60 | 1.64 | 1.51 | 1.60 | 1.49 | 1.42 |

# APPENDIX D

## D.1 Eigenvectors and Eigenvalues

Eigenvectors and eigenvalues are properties of square matrices. Eigenvalues ($\lambda_i$) of a square matrix $A$ of size $n$ are the ones that satisfy the relationship D.1.

$$|A - \lambda I| = 0 \qquad \text{.... D.1}$$

Where

$|A - \lambda I|$ is the determinant of the matrix $(A - \lambda I)$

I is a unit matrix and

$\lambda$ is the eigenvalue

The condition that determinant $|A - \lambda I|$ should equal to zero leads to an $n$th degree equation in $\lambda$, called the characteristic equation of $A$. The roots $\lambda_i$, i = 1, . . ., $n$, of the characteristic equation D.1 are the desired eigenvalues. The eigenvector ($w$) corresponding to each eigenvalue can be obtained by solving the Equation D.2.

$$A\,w = \lambda\,w \quad or\ (A - \lambda I)\,w = 0 \qquad \text{.... D.2}$$

Since the matrix ( $A - \lambda I$ ) is singular, there is dependence between any two rows, hence an arbitrary value has to be assigned to one of the element of the vector and the ratios with the other elements of the vector have to be obtained. The vector may be normalized to make its coefficients sum to unity. The eigenvector corresponding to the largest eigenvalue of pairwise comparison matrix would represent the criterion weights. In this research a numerical method called Power Method (Mathews 1987) is used in the determination of largest eigenvalue and the corresponding eigenvector.

## D.2 Listing of Multiple Criteria Analysis Model

The multicriteria analysis of alternatives using Saaty's approach described in Section 4.6 was translated into a computer program. This program has flexibility of changing criteria preferences and criterion values of alternatives and is written in Quick Basic. The listing is presented as follows:

**Program Listing:**

```
DECLARE SUB BORDER (rlt%, clt%, rlb%, clb%)
DECLARE SUB VECTOR (CRAL!, AX!, A!, CI!)
DECLARE SUB MATMUL (CA!, X!, FW!, A!, C!)
DECLARE SUB EMPTY (S, E)
DECLARE SUB EIGENVECTOR (A!, X!, N!, TEMP!)
DIM SHARED CRAL(10, 10), CA(10, 10), FW(10)
DIM SHARED AT(10, 10), U(10), X(10), AX(10), TEMP, A, CI
COMMON SHARED sthor, botlc, botrc, toplc, toprc, stver, PLUS, TEE,
INVTEE, rtee, ltee

'*** PROGRAM TO EVALUATE ALTERNATIVES USING SATTY'S HIERARCHICAL ***
'                          *** ANALYSIS ***
'---------------------------------------------------------------

TYPE AAA
       FNAME AS STRING * 4
END TYPE
DIM Cr(10) AS AAA
DIM Al(10) AS AAA
CALL EMPTY(5, 23)
SCREEN 9
COLOR 8, 3
CALL BORDER(1, 1, 24, 80)
COLOR 8
case1 = 0
5 LOCATE 8, 20: PRINT "ENTER NUMBER OF ALTERNATIVES    ="
  COLOR 6
  LOCATE 9, 20: PRINT "(Minimum of 2 and Maximum of 7)"
  COLOR 8
  LOCATE 8, 54: INPUT "  ", A
  IF A < 2 THEN GOTO 5
  IF A > 7 THEN GOTO 5
16 LOCATE 10, 20: PRINT "ENTER NUMBER OF CRITERIA      ="
  COLOR 6
  LOCATE 11, 20: PRINT "(Minumum of 2 and Maximum of 7)"
  COLOR 8
  LOCATE 10, 54: INPUT "  ", C
  IF C < 2 THEN GOTO 16
  IF C > 7 THEN GOTO 16
LOCATE 13, 5: PRINT "ENTER SHORT(up to 4 characters) NAMES FOR CRITERIA
AND ALTERNATIVES"
  FOR I = 1 TO C
   LOCATE 14 + I, 10: PRINT "CRITERIA"
   LOCATE 14 + I, 20: PRINT USING "#"; I
   LOCATE 14 + I, 22: PRINT "(C"
   LOCATE 14 + I, 24: PRINT USING "#"; I
   LOCATE 14 + I, 25: PRINT ") = "
   LOCATE 14 + I, 29: INPUT "  ", Cr(I).FNAME
  NEXT I
'***********************************
FOR I = 1 TO A
```

```
   LOCATE 14 + I, 40: PRINT "ALTERNATIVE"
   LOCATE 14 + I, 53: PRINT USING "#"; I
   LOCATE 14 + I, 56: PRINT "(A"
   LOCATE 14 + I, 58: PRINT USING "#"; I
   LOCATE 14 + I, 59: PRINT ") ="
   LOCATE 14 + I, 63: INPUT " ", A1(I).FNAME
NEXT I
300 CALL EMPTY(5, 23)

COLOR 8
LOCATE 7, 15: PRINT "ENTER PAIRWISE IMPORTANCE WEIGHTS(non-zeros) OF
CRITERIA"
FOR J = 1 TO C
   k = J * 7 + 19
   LOCATE 10, k: PRINT Cr(J).FNAME
NEXT J
FOR m = 1 TO C
   N = 11 + m
   LOCATE N, 19: PRINT Cr(m).FNAME
   FOR O = m TO C
     LOCATE N, 18 + O * 7: INPUT "", AT(m, O)
   NEXT O
NEXT m
'
FOR m = 1 TO C
N = 11 + m
FOR O = m TO C
LOCATE N, 18 + O * 7: PRINT USING "#.###"; AT(m, O)
NEXT O
NEXT m
'
LOCATE 21, 10: PRINT "    DO YOU WANT TO CHANGE PREFERENCES (Y/N)"
LOCATE 21, 53: INPUT ABC$
COLOR 8
IF ABC$ = "Y" OR ABC$ = "y" THEN GOTO 300
''''''''''''''''''''''''''''''''''''
CALL EIGENVECTOR(AT, X, C, TEMP)
'********************
 CALL EMPTY(5, 23)
COLOR 8
LOCATE 8, 20: PRINT " RELATIVE WEIGHTS OF CRITERIA  "
Cr(C + 1).FNAME = "Cr.Wt."
FOR J = 1 TO C
k = J * 7 + 14
LOCATE 10, k: PRINT Cr(J).FNAME
NEXT J
LOCATE 10, 24 + C * 7: PRINT Cr(C + 1).FNAME
FOR m = 1 TO C
N = 11 + m
LOCATE N, 11: PRINT Cr(m).FNAME
FOR O = 1 TO C
LOCATE N, 13 + O * 7: PRINT USING "#.###"; AT(m, O)
NEXT O
LOCATE N, 16 + (C + 1) * 7: PRINT USING "##.###"; X(m)
NEXT m
```

```
'
'****************************************************
CIN = ABS(TEMP - C) / (C - 1)
LOCATE 12 + (C + 1), 18: PRINT " Consistancy Index ="
LOCATE 12 + (C + 1), 38: PRINT USING " ##.####"; CIN
'****************************************************
COLOR 6
LOCATE 21, 10: INPUT "    Press  ENTER   to continue    ", ABC$

COLOR 8

CALL EMPTY(5, 23)
 IF case1 = 1 THEN
         GOTO 400
         case1 = 0
      ELSE
 END IF
 ce = C
 cs = 1
700
IF case1 = 2 THEN
 LOCATE 23, 10: PRINT "
"

 LOCATE 23, 16: INPUT "Enter # of Criteria to change preferences    = ",
ce
'
 cs = ce
 case1 = 0
 ELSE
END IF
FOR m = cs TO ce
'
500 CALL EMPTY(5, 23)
    COLOR 8
    LOCATE 7, 15: PRINT "ENTER PAIRWISE COMPARISON VALUES(non-zeros) OF
ALTERNATIVES"
    LOCATE 8, 22: PRINT "WITH RESPECT TO THE CRITERIA ", Cr(m).FNAME
    FOR J = 1 TO A
        k = J * 7 + 19
        LOCATE 10, k: PRINT A1(J).FNAME
    NEXT J
    FOR P = 1 TO A
        N = 11 + P
        LOCATE N, 19: PRINT A1(P).FNAME
        FOR O = P TO A
          LOCATE N, 18 + O * 7: INPUT "", CRAL(P, O)
        NEXT O
    NEXT P
    COLOR 6
    LOCATE 21, 10: INPUT "    DO YOU WANT TO CHANGE VALUES (Y/N) ? ",
ABC$
    COLOR 8
    IF ABC$ = "Y" OR ABC$ = "y" THEN GOTO 500
'
```

```
    FOR P = 1 TO A
        DIAG = CRAL(P, P)
        FOR O = 1 TO A
          CRAL(P, O) = CRAL(P, O) / DIAG
        NEXT O
    NEXT P
    CALL VECTOR(CRAL, AX, A, CI)
    FOR L = 1 TO A
        CA(L, m) = AX(L)
    NEXT L
NEXT m
'
400  CALL EMPTY(5, 23)
COLOR 8
LOCATE 5, 15: PRINT "Weights of Alternatives with respect to Criteria"
FOR I = 1 TO C
        LOCATE 6, 18 + I * 7: PRINT Cr(I).FNAME
NEXT I
FOR m = 1 TO A
   N = 6 + m
   LOCATE N, 18: PRINT Al(m).FNAME
   FOR O = 1 TO C
        LOCATE N, 18 + O * 7: PRINT USING "#.###"; CA(m, O)
   NEXT O
NEXT m
'
'***CALCULATION OF FINAL WEIGHTS (MATRIX MULTIPLICATION)***
FOR I = 1 TO A
   FW(I) = 0!
      FOR k = 1 TO C
           FW(I) = FW(I) + CA(I, k) * X(k)
      NEXT k
NEXT I
'
LOCATE 14, 20: PRINT " The Final Weights of the Alternatives"
LOCATE 15, 30: PRINT "Alt.    Final Wt."
FOR I = 1 TO A
   LOCATE 15 + I, 30: PRINT Al(I).FNAME
   LOCATE 15 + I, 39: PRINT USING "#.###"; FW(I)
NEXT I
COLOR 6
LOCATE 23, 10: PRINT "1 = CRITERIA PREFERENCES"
LOCATE 23, 37: PRINT "2 = CRITERIA VALUES"
LOCATE 23, 59: PRINT "3 = QUIT / PRINT"
LOCATE 19, 55: PRINT "To Change Data"
LOCATE 20, 55: PRINT "or to Quit"
LOCATE 21, 55: INPUT "Enter 1, 2, or 3 = ", CHOICE
COLOR 8
IF CHOICE = 1 THEN
        case1 = 1
        GOTO 300        'FOR PREFERENCES
      ELSEIF CHOICE = 2 THEN
        case1 = 2       'FOR CRITERIA VALUES
        GOTO 700
      ELSE
```

```
        GOTO 200
END IF
200 LOCATE 23, 10: INPUT "        Press 'P' to print results and 'Q' to
quit                ", P$
IF (P$ <> "P" OR P$ <> "p") THEN
LPRINT
 LPRINT ; TAB(5); " MULTIPLE CRITERIA EVALUATION OF ALTERNATIVES"
 LPRINT
 LPRINT
 LPRINT ; TAB(10); "NUMBER OF ALTERNATIVES     =", A
 LPRINT ; TAB(10); "NUMBER OF CRITERIA         =", C
 LPRINT ; ""
  FOR I = 1 TO C
   LPRINT ; TAB(10); "CRITERIA";
   LPRINT ; USING "#"; I;
   LPRINT ; "(C";
   LPRINT ; USING "#"; I;
   LPRINT ; ") = ";
   LPRINT ; Cr(I).FNAME
  NEXT I
LPRINT
FOR I = 1 TO A
   LPRINT ; TAB(10); "ALTERNATIVE";
   LPRINT ; USING "#"; I;
   LPRINT ; "(A";
   LPRINT ; USING "#"; I;
   LPRINT ; ") = ";
   LPRINT ; Al(I).FNAME
NEXT I
LPRINT
LPRINT
LPRINT ; TAB(10); " PAIRWISE IMPORTANCE WEIGHTS OF CRITERIA"
FOR J = 1 TO C
   k = J * 7
    LPRINT ; TAB(k + 10); Cr(J).FNAME;
NEXT J
 LPRINT ; TAB(C * 7 + 15); "    Criteria Wts."
 LPRINT ; TAB(10);
FOR m = 1 TO C
   LPRINT ; USING "&"; Cr(m).FNAME;
   LPRINT ; TAB(15);
   FOR O = 1 TO C
     LPRINT ; TAB(7 * O + 10); USING "#.###"; AT(m, O);
   NEXT O
   LPRINT ; TAB(7 * (C + 2) + 8); USING "##.###"; X(m)
   LPRINT ; TAB(10);
NEXT m
LPRINT
'''''''''''''''    '
    LPRINT ; TAB(10); "PAIRWISE COMPARISON VALUES OF ALTERNATIVES"
    FOR m = 1 TO C
    LPRINT ; TAB(10); "   With Respect to the Criteria", Cr(m).FNAME
    LPRINT
    FOR J = 1 TO A
        LPRINT ; TAB(10 + 7 * J); USING "&"; Al(J).FNAME;
```

```
    NEXT J
    LPRINT ;
    FOR P = 1 TO A

        LPRINT ; TAB(10); USING "&"; Al(P).FNAME;
        FOR O = 1 TO A
          LPRINT ; TAB(10 + 7 * O); USING "#.###"; CRAL(P, O);
        NEXT O
        LPRINT
    NEXT P
    LPRINT
    NEXT m
'''''''''''''''''''''''''
LPRINT
LPRINT ; TAB(10); "Weights of Alternatives with respect to Criteria"
LPRINT ; ""
FOR I = 1 TO C
        LPRINT ; TAB(10 + I * 7); Cr(I).FNAME;
NEXT I
       LPRINT
FOR m = 1 TO A
   LPRINT ; TAB(10); USING "&"; Al(m).FNAME;
   FOR O = 1 TO C
       LPRINT ; TAB(10 + O * 7); USING "#.###"; CA(m, O);
   NEXT O
   LPRINT
NEXT m
LPRINT
LPRINT
LPRINT ; TAB(10); " The Final Weights of the Alternatives"
LPRINT
LPRINT ; TAB(12); "Alternative  Final Wt."
LPRINT
FOR I = 1 TO A
    LPRINT ; TAB(15); USING "&"; Al(I).FNAME;
   LPRINT ; TAB(25); USING "#.###"; FW(I)
NEXT I
ELSE
END IF
55 END

SUB BORDER (rlt%, clt%, rlb%, clb%) STATIC
sthor = 205: botlc = 200: botrc = 188: toplc = 201: toprc = 187
stver = 186: PLUS = 206: TEE = 203: INVTEE = 202: rtee = 204: ltee = 185
'
COLOR 1
LOCATE rlt%, clt%: PRINT CHR$(toplc);
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
LOCATE , clb%: PRINT CHR$(toprc);
'
FOR I = rlt% + 1 TO rlb% - 1
    LOCATE I, clt%: PRINT CHR$(stver);
    LOCATE , clb%: PRINT CHR$(stver);
NEXT I
LOCATE rlb%, clt%: PRINT CHR$(botlc);
```

```
LOCATE , clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
LOCATE , clb%: PRINT CHR$(botrc);
LOCATE rlt% + 3, clt% + 1: PRINT STRING$(clb% - clt%, CHR$(sthor));
'
LOCATE rlt% + 3, clt%: PRINT CHR$(rtee)
LOCATE rlt% + 3, clb%: PRINT CHR$(ltee)
LOCATE 2, 5: PRINT "     *** MODULE FOR MULTIPLE CRITERIA EVALUATION OF
ALTERNATIVES ***"
LOCATE 3, 5: ~RINT "     ***                    USING SAATY'S APPROACH
***"
'
END SUB

SUB EIGENVECTOR (AT, X, N, TEMP)
'
FOR g = 1 TO N
  FOR h = g TO N
  AT(h, g) = 1 / AT(g, h)
   NEXT h
NEXT g
   FOR I = 1 TO N
   U(I) = 1!
   NEXT I
20 FOR k = 1 TO N
   X(k) = 0
    FOR L = 1 TO N
        X(k) = X(k) + AT(k, L) * U(L)
    NEXT L
   NEXT k
'
TEMP = 1000!
 FOR m = 1 TO N
  IF TEMP < X(m) THEN
     GOTO 29
  ELSE
    TEMP = X(m)
  END IF
29  NEXT m
FOR O = 1 TO N
         X(O) = X(O) / TEMP
    NEXT O
FOR P = 1 TO N
  IF ABS(U(P) - X(P)) > .0001 THEN
      GOTO 46
  ELSE
     GOTO 50
  END IF
NEXT P
46  FOR q = 1 TO N
  U(q) = X(q)
  NEXT q
GOTO 20
50 SUM = 0!
 FOR r = 1 TO N
   SUM = SUM + X(r)
```

```
  NEXT r
   FOR S = 1 TO N
     X(S) = X(S) / SUM
   NEXT S
 END SUB

 SUB EMPTY (S, E)
 FOR I = S TO E
     LOCATE I, 2: PRINT "                                              "
     LOCATE I, 40: PRINT "                                           ";
 NEXT I
 END SUB

 SUB VECTOR (CRAL, AX, A, CI)
 FOR g = 1 TO A
   FOR h = g TO A
  CRAL(h, g) = 1 / CRAL(g, h)
 NEXT h
 NEXT g
    FOR I = 1 TO A
    U(I) = 1!
    NEXT I
120 FOR k = 1 TO A
    AX(k) = 0
     FOR L = 1 TO A
         AX(k) = AX(k) + CRAL(k, L) * U(L)
     NEXT L
    NEXT k
'
CI = 1000!
 FOR m = 1 TO A
  IF CI < AX(m) THEN
     GOTO 129
  ELSE
    CI = AX(m)
  END IF
129  NEXT m
FOR O = 1 TO A
            AX(O) = AX(O) / CI
NEXT O
FOR P = 1 TO A
  IF ABS(U(P) - AX(P)) > .0001 THEN
      GOTO 146
  ELSE
     GOTO 150
  END IF
NEXT P
146  FOR q = 1 TO A
  U(q) = AX(q)
  NEXT q
GOTO 120
150 SUM = 0!
 FOR r = 1 TO A
 SUM = SUM + AX(r)
 NEXT r
```

```
  FOR S = 1 TO A
  AX(S) = AX(S) / SUM
  NEXT S
END SUB
```

## D.2 Sample Output of the Model

The sample output of the model for multicriteria evaluation of alternatives is presented in Figure D.1

```
*** MODULE FOR MULTIPLE CRITERIA EVALUATION OF ALTERNATIVES ***
***                  USING SAATY'S APPROACH                  ***

      Weights of Alternatives with respect to Criteria
                Time   Reli   Accb   Cost   Bagg   Park
         Auto   0.241  0.163  0.587  0.357  0.438  0.036
         Taxi   0.241  0.163  0.218  0.104  0.438  0.321
         Bus    0.202  0.092  0.123  0.530  0.063  0.321
         Rail   0.316  0.582  0.072  0.009  0.063  0.321


           The Final Weights of the Alternatives
                   Alt.     Final Wt.
                   Auto     0.288
                   Taxi     0.219
                   Bus      0.208
                   Rail     0.286             To Change Data
                                              or to Quit
                                              Enter 1, 2, or 3 =

 1 = CRITERIA PREFERENCES   2 = CRITERIA VALUES   3 = QUIT / PRINT
```

Figure D.1: Sample Output of Multiple Criteria Evaluation of Alternatives