Airport Ground Access: Rail Transit Alternatives

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Because of the increase in congestion in ground access at many airports, rail transit alternatives are getting increased attention. During the conceptual planning phase, it is useful to know the relative attractiveness of such alternatives over other modes. In this research, three concepts are examined: (*a*) an exclusive rail link from the city center, (*b*) an extension of an existing rail line to the airport, and (*c*) an automated people mover or shuttle bus connection linking the terminal area to a station on a nearby rail line. The concepts were evaluated using multicriteria analysis. Quantifiable criteria such as travel time and cost and nonquantifiable criteria such as accessibility, reliability, baggage convenience, and parking convenience were considered in the evaluation. Computer models were developed to determine quantifiable criteria values, and fuzzy ratings were used for nonquantifiable criteria. Passenger demands at which airport rail alternatives become attractive were identified for three usage levels of business passengers and vacationers. The effect of baggage-handling facilities at rail stations on service attractiveness is also presented.

Getting to the airport has become one of the biggest headaches for travelers today. Twenty years ago the solution would have been simply to add more highway lanes to the airport and provide more parking. However, many airports cannot utilize such options because of land resources and environmental concerns; as a result, rail transit options are being considered. Because of the large number of trips by air passengers, employees, and visitors to and from large airports, fixed-rail transit may have potential applications. The following sections summarize the research undertaken to study rail transit attributes and user characteristics. The information is then evaluated to assess the potential for airport fixed-rail service and determine what levels of demand are required for such service to be viable.

AIRPORT RAIL TRANSIT

Three basic categories of fixed-rail transit for airports were examined: conventional railway, urban rail rapid transit, and exclusive service (*1*).

Conventional Railway

The use of conventional intercity or commuter railway lines is common at several European airports. These access links consist of special-purpose spur lines that are connected to the existing rail network. As a result, conventional railway access can be relatively inexpensive because airport trains share lines with other rail services over much of the route. Conventional railway systems are usually oriented to a main station in the central city, and, although they will serve this destination very well, one must remember that in many cities most travelers do not have a city center destination.

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Urban Rail Rapid Transit

Some airports have direct access to the metropolitan urban rail rapid transit system in the airport terminal. This type of access has several significant advantages. Usually, the rapid transit system is a coordinated part of the overall metropolitan transit system, giving air passengers and airport employees reasonable access to a large portion of the urban area. Because the rail rapid transit line operates on a reserved right-of-way, fairly reliable service is available.

In airports where rail rapid transit links have been built, these links have typically been short extensions to existing systems. The airport station is one stop on the network, and on many systems it is an end station on a line. Because most rapid transit systems are radial, airport lines tend to serve the central city best, and because trains must make frequent stops en route, high overall trip times are common. As with conventional railway systems, the greatest difficulty is the mixing of baggage-laden air passengers with other passengers, especially during peak periods. Typically, stations have not been designed for passengers with baggage and so travelers experience problems when stations are crowded.

Exclusive Service

One of the most significant technological advances to capture the public imagination in recent years has been the concept of a high-speed, nonstop train that transports passengers from the airport to the city center. Many such trains have been suggested and investigated all over the world but none have been built. The disadvantages of such a system are the high costs, and the fact that only a portion of the airport traffic will want to travel between the airport and the city center.

EXISTING AIRPORT RAIL SERVICES

Table 1 lists world airports that are directly served by a fixed-rail transit line in which a station has been incorporated in or near the passenger terminal. More information is available in the literature. (*1,2*).

In the United States, eight airports have airport rail service. At Atlanta Hartsfield, Chicago Midway, Chicago O'Hare, Cleveland Hopkins, and Washington National airports, the transit line is part of the metropolitan rail rapid transit network, which provides travelers with access to many destinations in the urban area. In

TABLE 1 Airports with Rail Transit Service

United States	
Atlanta Hartsfield	Philadelphia
Chicago Midway	St. Louis Lambert
Chicago O'Hare	South Bend, Indiana
Cleveland Hopkins	Washington National
Other World Airports	
Amsterdam Schipol	London Stansted
Barcelona	Mexico City
Berlin - Schonefeld	Munich 2
Birmingham, U.K.	Paris Charles de Gaulle
Brussels	Paris Orly
Dusseldorf	Rome - Fiumicino
Frankfurt - Main	Tokyo Haneda
Geneva Cointrin	Tokyo Narita
London Gatwick	Vienna
London Heathrow	Zurich

Philadelphia, the airport line is a commuter rail service that links the airport with Penn Center in downtown Philadelphia. In South Bend, Indiana, the Michiana Regional Transportation Center is a multimodal center serving air, rail, and bus. St. Louis Lambert International, the most recent airport station to be added to this list, was opened in 1994 on the St. Louis Metrolink light rail transit network. There are also several airports in the United States in which express or shuttle buses link the airport with the nearest rapid transit station.

The use of fixed-rail systems for airport access is more common in Europe, where intercity trains and commuter-type connections to a central city rail station are used. British Rail's service to London's Gatwick and Stansted airports, Frankfurt's S-Bahn service to the Frankfurt-Main Airport, or the Munich S-Bahn service to the new Munich airport are a few examples of this type of service. The Amsterdam (Schipol), Geneva (Cointrin), and Zurich airports are examples in which the airport is one station on an extensive intercity rail network. The airport link with the London Underground at London's Heathrow Airport is an excellent example of a well-planned access connection. The new Chek Lap Lok Airport in Hong Kong is planning a fixed-rail service as a vital link in its development.

EVALUATION

Evaluating airport access alternatives is quite complex because planners must consider several factors or criteria. Some criteria, such as travel time and cost, can be quantified; others, such as convenience, reliability, and environmental effects, are not as easily quantified.

For this research, a hierarchical analysis proposed by L. Thomas Saaty in the early 1980s (*3*) was used. Saaty developed this evaluation theory and technique while working on contingency planning problems for the U.S. Department of Defense in the 1970s. Since then, his approach has been used in resource allocation, planning of public and private projects, and construction management (*4*).

The first step in the analysis is to identify the criteria. The second step is to develop a pairwise comparison matrix and determine the criteria weights. The pairwise comparison is done by comparing each criterion with others and assigning fuzzy values. Saaty examined and tested various scales and adopted a scale of 1–9 to reflect the human cognitive process. For example, when Criterion A is compared with Criterion B, a value of 1 is assigned if both criteria are considered equally important. A value of 9 is assigned if A is absolutely more important than B.

The values of pairwise comparison are represented in a matrix form as shown in Matrix 1. This is a reciprocal matrix ($a_{ij} = 1/a_{ij}$) with a unit diagonal indicating that a criterion is equally important to the same criterion. The pairwise comparison matrices could be developed at an individual airport using market surveys of user preferences.

MATRIX 1 PAIRWISE COMPARISON OF CRITERIA

$$
\begin{array}{r}
\\ C_1 \\ C_2 \\ [\mathrm{PWC}] = C_3 \\ . \\ C_n
\end{array}
\begin{array}{ccccc}
C_1 & C_2 & C_3 & \ldots\ldots & C_n \\
\hline
\end{array}
$$

$$
\begin{array}{r|ccccc|}
 & C_1 & C_2 & C_3 & \ldots\ldots & C_n \\
C_1 & 1 & b_{12} & b_{13} & \ldots. & b_{1n} \\
C_2 & 1/b_{12} & 1 & b_{23} & \ldots & b_{2n} \\
[\mathrm{PWC}] = C_3 & 1/b_{13} & 1/b_{23} & 1 & \ldots. & b_{3n} \\
. & \ldots & \ldots. & \ldots. & \ldots & . \\
C_n & 1/b_{1n} & 1/b_{2n} & 1/b_{3n} & & 1
\end{array}
$$

b_{ij} = the fuzzy value for importance of Criterion i when compared with Criterion j
C_i = Criterion i
n = number of criteria

The eigenvector (CW) corresponding to the largest eigenvalue of the matrix [PWC] represents the weights of criteria (W_i). 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 consistent pairwise comparison matrix, the largest eigenvalue would be equal to the size of the matrix, other eigenvalues would be zero, and the sum of all the eigenvalues would be equal to the largest eigenvalue. Small perturbations of the entries in a positive reciprocal matrix imply small perturbations in the eigenvalues. The consistency of comparison can be checked by using a consistency index, which represents the average deviation of other eigenvalues from the sum of all the eigenvalues of a consistent case.

The third step is to evaluate alternatives with respect to each criterion. For nonquantifiable criteria, the procedure is similar to the pairwise comparison described previously. Each alternative is compared with all other alternatives with respect to the criterion in question, and fuzzy values are assigned. The eigenvector corresponding to the 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.

Because the basic idea of the pairwise comparison matrix is to obtain the weights to be used in a 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.

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

MATRIX 2 CRITERIA VALUES FOR ALTERNATIVES

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

c_{ij} = Value of alternative i with respect to criterion j
C_i = Criterion i
A, B, C, D = alternatives

The final step is to multiply the matrix of criterion values [CV] by the criterion weights [CW] to get the final weights of alternatives. These final values reflect all the criteria in proportion to their importance and can be used to rank the alternatives. The values might be treated as attractiveness measured on a relative scale.

FIXED-RAIL CONCEPTS

Three basic rail system concepts were examined (S.R. Mandalapu, unpublished Ph.D. dissertation, 1994):

- Concept A—A dedicated or exclusive line between the airport and city center. The service would provide express nonstop service. The airport station would be located in the terminal.
- Concept B—An extension of an existing fixed-rail line to the airport. The airport station would be located in the terminal.
- Concept C—An airport station would be located on a rail line that passes the airport. A shuttle bus or automated people mover system (APM) would link this station with the airport terminal(s).

The concepts were compared with auto, bus, and taxi service using the Saaty hierarchical analysis technique (S.R. Mandalapu, unpublished Ph.D. dissertation, 1994). A range of distances, average daily demands, number of business and vacation travelers, and baggage-handling facilities were examined. The criteria considered for the analysis included travel time, cost, reliability, baggage convenience, accessibility, and parking. Travel times and costs for a single-user trip were calculated using computer models developed for rail and bus systems, automobiles, and taxis.

Because the relative attractiveness of an alternative depends on the criteria considered, weights were given to each criteria. It was also realized that the importance of a particular criterion for a business traveler would be different for a vacationer, and as a result, weights were varied with the level of usage of business passengers and vacationers. Three levels of usage were considered: (*a*) more business passengers (90 percent), for which time is more important than cost; (*b*) an equal number of business and vacation passengers, for which time is as important as cost; and (*c*) more vacationers (90 percent), for which cost is more important than time.

Evaluation of Concept A: Dedicated or Exclusive Airport Fixed-Rail Link

This concept is for airports that are proposing a new fixed-rail link between the airport and the city center. The competing modes were automobile, taxi, and bus, and the evaluation criteria included travel time, trip reliability, mode accessibility, cost, baggage convenience, and parking.

In each case of level of usage by business passengers and vacationers, the multicriteria analysis is performed for various route lengths of 10 to 50 km with an increment of 5 km, and a minimum demand required for the rail alternative to be attractive is identified. The results of the analysis, presented in Figure 1, indicate that if only vacationers use the airport, exclusive rail links would be attractive when the rail transit passenger demand exceeds 50,000 per day. Few airports have such activity.

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

This concept is for airports that are proposing an extension of an existing fixed-rail line from its present location to the airport. Good station access and good service information are assumed. The competing modes considered in the research are the automobile, taxi,

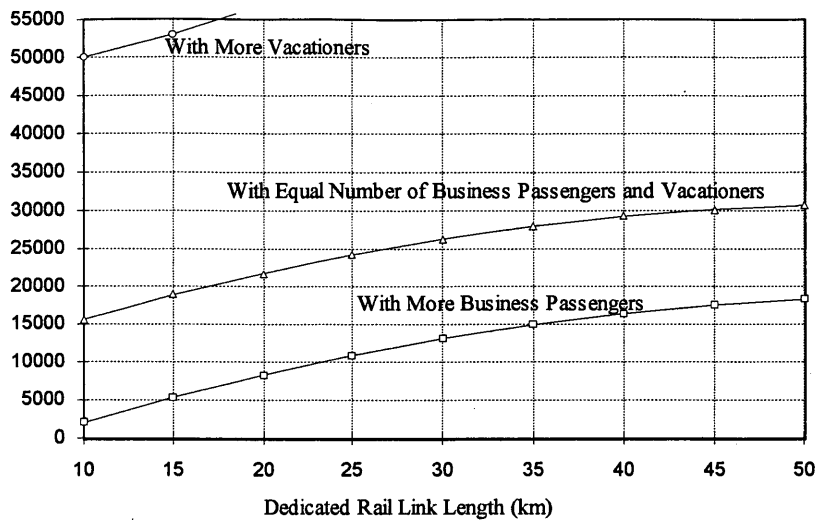

FIGURE 1 Variation of minimum passenger demand with route length for direct rail link (Concept A) to airports to be attractive for various demand levels.

and bus. The evaluation criteria included travel time, trip reliability, mode accessibility, cost, baggage convenience, and parking.

Multicriteria analysis was performed for total route lengths of 15, 20, 25, and 30 km. The extensions analyzed are from 2.5 km to 50 percent of the total route length with 2.5-km increments. For example, 2.5-, 5-, and 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 the fare on the existing line. Minimum demands required for the rail extension to be attractive were 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, a 2.5-km extension of 15-km total route length, a 2.5-km extension of 20-km route length, and so on. The averages of the results for the three cases are presented in Figure 2. The results suggest that if more vacationers use the airport, rail extensions beyond 10 km are not feasible for an airport. In such cases the system must attract more than 37,000 passengers per day.

Evaluation of Concept C: Rail Transit Station Near Airport with Shuttle Bus or APM System Connections

This concept may be applied to airports that use shuttle buses or an APM system to connect the airport terminal area to a station on a nearby rail line. The rail line may be an intercity or commuter rail line, or a rail rapid transit line.

The competing modes considered for evaluation of this fixed-rail concept are automobile, taxi, and express bus from the city center. These competing modes are compared with a rail service on the existing link with a shuttle bus service, or a rail service on the existing line with an APM link. Modal attraction is added to the previ-

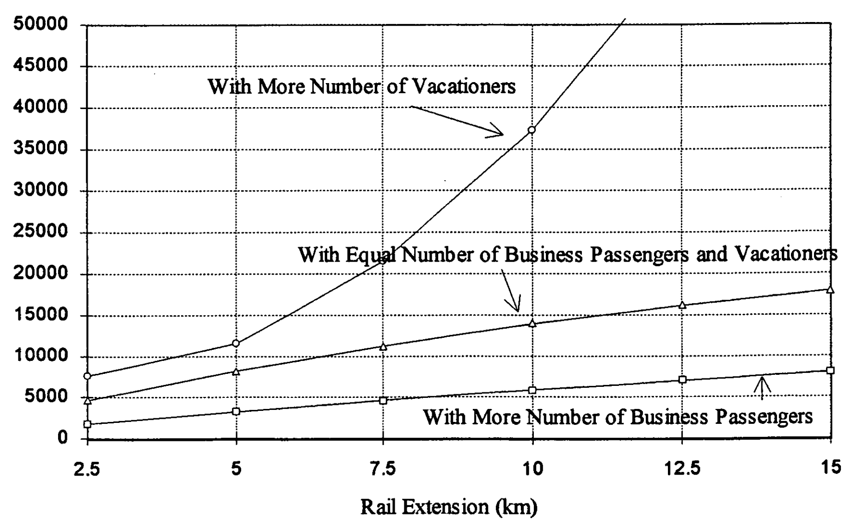

FIGURE 2 Minimum additional demand required for rail extensions to airport (Concept B) to be attractive for various passenger demand levels.

ous criteria: travel time, reliability, accessibility, cost, baggage convenience, and parking convenience.

Travel times for the rail plus shuttle bus and the rail plus APM alternatives are determined by adding the travel time on the existing rail link using the rail rapid transit model; the travel times on the connections are calculated using the shuttle bus model and the APM model. A transfer time from rail to the connection is added to the actual travel time.

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 an elevated guideway. The total cost of a trip from the city center to the airport is calculated by adding the cost of a trip on the connection and the basic fare on the rail link. The evaluation of each case with the criteria was performed for total route lengths (including connections) of 15, 20, 25, and 30 km. The connecting lengths considered are 0.5, 1.0, 1.5, 2.0, 2.5, 5.0, 7.5, and 10.0 km. For example, for a route length of 20 km the combinations examined are 19.5 km of existing rail link plus a 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 indicated that there is no considerable difference between the route lengths for the same connecting length. 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 3.

INFLUENCE OF BAGGAGE CHECK-IN FACILITIES AT STATIONS

Baggage convenience is one of the key factors that influence the selection of airport access mode. Most vacationers have considerable baggage, whereas business travelers have few bags that are checked. If special baggage-handling facilities are provided, the influence on the modal attraction changes depending on the composition of passengers with the two basic journey purposes. To study the effects, baggage check-in facilities were examined for the concepts using the multicriteria analysis.

For the case in which baggage check-in facilities are provided at stations, the baggage can be checked in at the rail station(s), shipped to the airport, and loaded onto the respective airplanes. The responsibility for the baggage lies with the airline or the airline agent. There will be an additional cost involved for the airline to set up such facilities. Passengers must take the risk that their baggage may not travel with them on their flight. The penalty for baggage convenience on fixed-rail options is reduced to reflect the convenience of having the facility at stations. Even when check-in facilities are provided at stations, rail travel cannot be perceived to be better than automobile or taxi travel because of the risks mentioned earlier. Fuzzy criterion values were chosen to reflect the risks.

The analysis was carried out with a new set of criterion values for baggage convenience; the rest of the criteria are unchanged. The minimum daily passenger demands required for the fixed-rail alternative to be attractive are identified for various route lengths. The minimum passenger demands required for the fixed-rail options to be attractive for various route lengths with baggage check-in facilities at stations are presented in Figures 4–6.

CONCLUSIONS

In this study three concepts for rail transit access were developed and evaluated using multicriteria analysis. The criteria considered in the evaluation are travel time, trip reliability, mode accessibility, cost, baggage convenience, parking, and mode attraction. Passenger demand levels (required for rail alternatives to be more attractive than other conventional modes) were identified. The results are useful in the conceptual planning phase of fixed-rail links to airports from city centers.

The influence of travel time, trip cost, and baggage handling on the attractiveness of fixed-rail alternatives is considerable. The attractiveness of fixed-rail alternatives increases with an increase in demand. The attractiveness also varies with the number of business passengers and vacationers. The rail alternatives are attractive at lower passenger demand levels if more business passengers use the

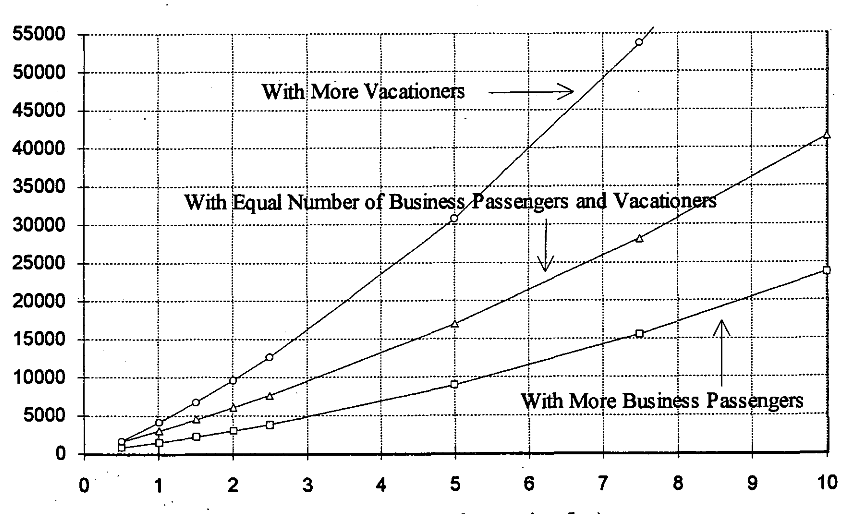

FIGURE 3 Minimum additional demand required for APM connection from rail station to airport (Concept C) to be attractive for various passenger demand levels.

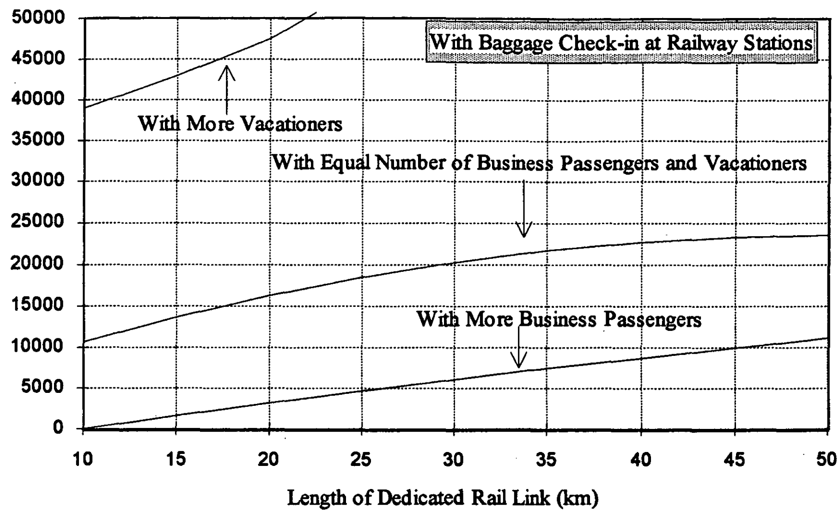

FIGURE 4 Minimum passenger demand required for the exclusive rail links to be attractive if baggage check-in facilities are provided at stations.

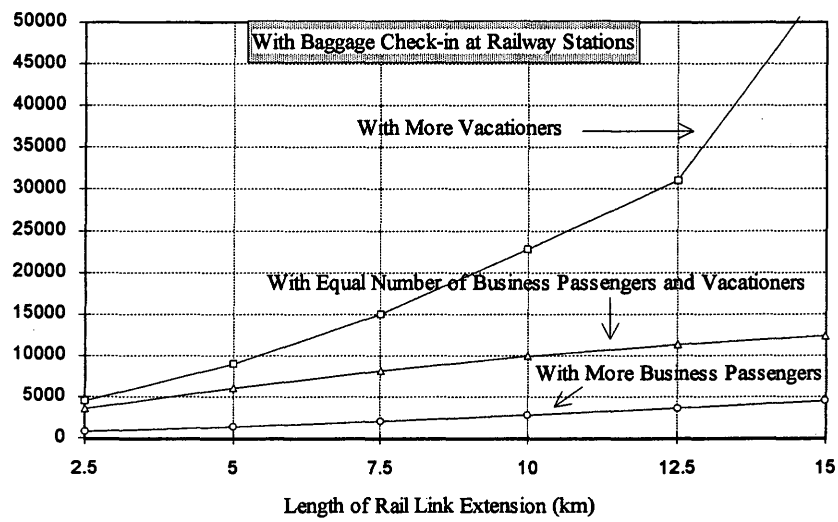

FIGURE 5 Minimum passenger demand required for the extension of rail links to airports to be attractive if baggage check-in facilities are provided at stations.

airport. Rail extensions are more attractive than exclusive links, and shuttle bus systems are more attractive than APM connections to nearby rail stations for short links and low demands.

The following conclusions may be made:

1. If an airport attracts a large number of vacationers, an exclusive rail link is not attractive until the demand is over 50,000 passengers per day.
2. 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 a 10-km distance to over 30,000 passengers per day for a 50-km distance. For a rail extension to be attractive, the demand should be over 5,000 passengers for a 2.5-km extension to over 18,000 passengers per day for a 15-km extension.
3. If an airport is used by more business passengers, exclusive links are attractive at demands of over 2,500 to over 18,000 passengers per day, depending on the distance. Rail extensions are attractive when the demand is over 2,500 to over 7,500 passengers per day, depending on the extension length.

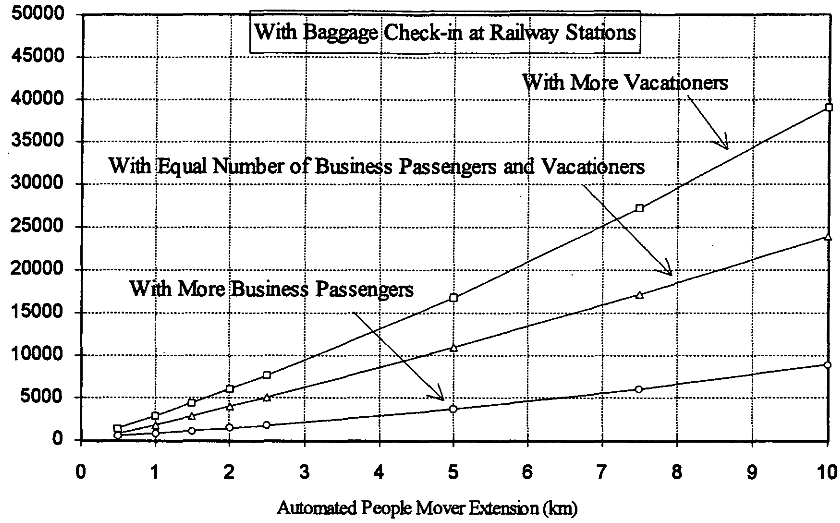

FIGURE 6 Minimum passenger demand required for the APM connection between airport and nearby rail station to be attractive if baggage check-in facilities are provided at stations.

4. Providing baggage check-in facilities at stations makes fixed-rail alternatives more attractive. The demand levels at which fixed-rail alternatives become attractive are 25 to 60 percent lower, depending on the rail concept and distance.

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