AIRPORT ACCESS

AND

TRAVEL TIME UNCERTAINTY

by

ROBIN TAYLOR B.Sc. (Hons), M.Sc., MCIT

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Loughborough University of Technology

Department of Aeronautical and Automotive

Engineering and Transport Studies

Supervisor: Dr. R.E. Caves Ph.D., MRAeS, MCIT, C.Eng.

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Dedication

To my family and friends

Abstract

The implications of travel time uncertainty on the operational efficiency of airport terminals have until now not been examined. With the forecast growth in congestion levels predicted for all modes of transport, not only will travel time uncertainty increase but its impact may increase also.

The first part of this thesis covers the analysis of two passenger surveys conducted at Manchester Airport and Birmingham Airport. These surveys had the objective of providing evidence to support or dispute the belief that air travellers react to travel time uncertainty. The research identifies that passengers do react by allowing margins of safety for their access journeys, and that this change in behaviour will modify the arrival distribution patterns at airports. The second part of this thesis examines how airport passenger flows could be altered by a change in the arrival distribution of originating passengers at airport terminals. Three airports - Manchester, Birmingham and East Midlands International - are modelled using a simulation tool and tested to assess how a shift in arrival distribution affects queuing and peak passenger volumes within the airport terminal.

The findings of this thesis show that airport passenger terminal operational efficiency is affected by access journey time uncertainty. It also identifies that passenger decision making can only be explained by various combinations of factors. Possible methods of minimising the effects of travel time uncertainty are considered. The advantages and disadvantages of access journey time uncertainty for airports and airlines are discussed. It concludes that, to be successful in overcoming negative aspects, both parties must provide a service that results in customer satisfaction. This is the only sure way to maintain their respective revenue levels and secure their future in what is becoming an increasingly competitive industry.

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1. Introduction

With the continuing trend of growth in air transport, a great deal of investment is required in all areas of the industry on a global scale. Investment will include the expansion of existing airports and construction of new airports. Heathrow's Terminal 5, the new Chek Lap Kok Airport (Hong Kong) and Kuala Lumpur International Airport (Malaysia) are just a few of the many airport projects planned and under development.

Ground based modes of transport are also experiencing growth in demand for capacity. Investment in ground transport infrastructure is not easy to attract compared with the air industry, where the financial benefits of investment are easier to discern. With the increasing disparity between the capacity and demand for the ground transport infrastructure, problems will inevitably ensue. One such problem is the reduction in the consistency, and therefore predictability, of journey times.

Because most air travellers access originating airports by ground transport, a change in predictability of journey time is likely to have some impact on air travellers. This thesis examines the argument that if the access journey time is uncertain, passengers will modify their behaviour to increase the probability of catching a flight. The thesis focuses on passenger behaviour to first determine if passengers react to uncertainty, then, the nature of any reaction, and finally, if the reaction could have an impact on airport efficiency.

The research begins by reviewing explanations for travel time uncertainty. Although considerable research has been undertaken in this area, this is the first piece of work to address the air traveller specifically. The work proceeds by using primary data collected specially for this research but supplemented by data from other sources, to assess how passenger behaviour might change as uncertainty of ground access journey time increases. It continues by examining what effects the resulting behavioural changes have on passenger arrival patterns and, by using simulation techniques, assessing the effectiveness of existing terminal design and management standards to cope with such changes.

A number of models of airport passenger flows are developed and tested under a number of scenarios, building upon previous simulation experience [Taylor, 1991]. Each scenario represents a change in the arrival distribution caused by access journey time uncertainty. The aim of the simulation exercise is to identify significant impacts on passenger flows, impacts that are attributable to access journey time uncertainty. The results of the simulation exercise are discussed and conclusions drawn. Possible airport operational and design changes to alleviate problems caused by access journey time uncertainty are also considered. The thesis concludes with an overall evaluation of the research undertaken and its findings.

2. Thesis Objective and Structure

2.1 Thesis Objective

The objective of this thesis to investigate the hypothesis that:

With an increase in ground access journey time uncertainty there is an impact on traveller behaviour, and the resulting behavioural change will alter arrival patterns at and affect passenger flows within airport terminals.

The subject of airport access journey time uncertainty and its consequential impacts on air traveller behavioural change has not previously been considered in any detail. This research therefore examines this subject to assess in particular if there are impacts associated with journey time uncertainty. It also identifies possible problem areas and potential benefits that could result.

If the findings of any research suggest that existing designs and operating practice are not sufficient to manage effectively the operation of an airport, then there is likely to be a need for change. The importance of this research becomes clearer when the level of investment required to build and modify airport facilities are considered. However, it is the aim of this work to draw attention to rather than attempt to solve the possible problems that the industry could face in the future.

2.2 Thesis Structure

This thesis is divided into six main parts:

1. An introduction to airport access;
2. Related and relevant research;
3. A methodology for testing the general hypothesis;
4. Survey analysis and simulation, including the presentation of results;
5. An evaluation of the results in the light of the general hypothesis; and
6. Discussion and recommendations

With this structure it is possible to follow the progression of the research and develop an understanding of why the research followed its course. The constraints and obstacles that the author faced during the course of the research are identified, along with the reasoning for choosing a particular course of action to overcome them.

To assist this understanding further, supporting information is provided in appendices. For reasons of confidentiality and practicality it is not possible to include all the raw data associated with this research; consequently, the appendices contain typical data collected and used for this research.

3. Introduction to Airport Access

3.1 General Introduction

Ashford et al [1991] describe the function of an airport as 'either an intermediate or terminal operating point of an aircraft on the air portion of a trip'. Although a limited number of an airport's passengers will be transfer passengers, arriving and departing aboard aircraft, the remainder will arrive or depart by some means of ground transportation. This ground transportation could involve other individuals, such as well-wishers or greeters, who will also need to arrive at and depart from the airport.

Modern airports have developed beyond these basic functions to include the provision of secondary or related services. Effective execution of these services relies on a substantial labour force that, like passengers, also has the need for ground access to and from the airport.

The airport's ability to function depends on people's ability to access it. Therefore an airport authority should assist in providing an access infrastructure appropriate for the expected volumes of traffic.

When considering an air traveller's journey, three stages can usually be identified:

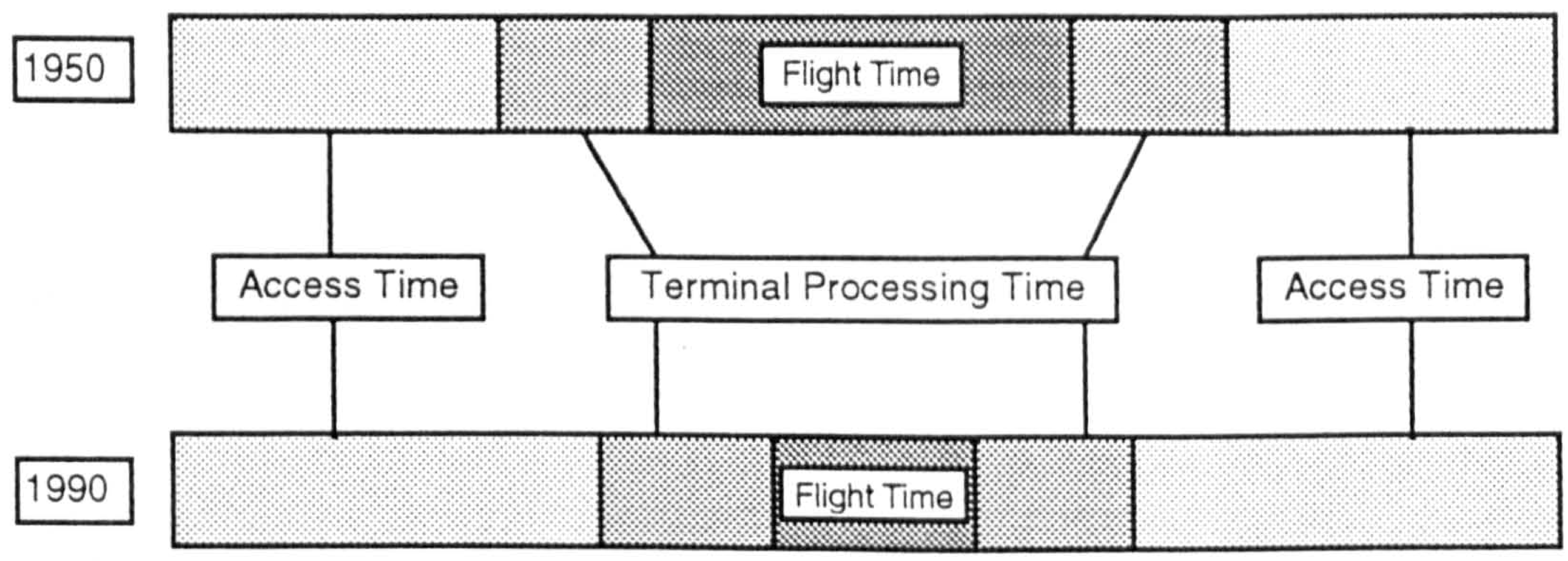
a) ground transportation to the origin airport,

b) the flight between two or more airports, and

c) ground transportation from the destination airport.

Today, by comparison with previous decades, international travel times have been reduced significantly. With an ever increasing number of people using all available modes of transport, the perception is that even relatively short distance ground based journeys generally appear to be taking longer than before. The irony is that it is these short distance journeys which typify airport access journeys, resulting in the reduction of the net benefit of the reduced air travel times. This argument is supported by Ashford and Wright [1992] who compared the scale of changes in first-origin to final-destination times for a short haul trip over the last 40 years. Figure 1 is a visual representation of their view.

Figure 1 Comparison of short-haul city-centre to city-centre travel, 1950-1990



Source: Airport Engineering, Ashford and Wright 1992

This view of the land versus air travel has also been identified by de Neufville [1971] who stated that 'the airport access problem is widely perceived.... as a gross imbalance between the relative ease with which it is possible to traverse long distances by air and the great congestion that often exists on the ground'.

The effect of the air industry's success and image has been to show up the failings of the ground transportation systems. Improvements made to the airport access systems are counter balanced by:

a) the growth in the volume of originating and terminating air travellers;

b) new airports such as Munich, Kuala Lumpur and Seoul are located farther away from the population they serve compared with their predecessors;

c) the peaked nature of traffic, both within and beyond the airport boundary.

The net result is that it takes proportionally longer to get to airports now than it has done in the past. This factor alone suggests that airport planners should be taking an active role in the planning of the ground transportation infrastructure, with thought given to the networks to existing and potential catchment areas. With the changing nature of the airport business, airports are now competing for passengers to increase revenue.

With accessibility becoming an ever increasing decision factor for travellers, a change in the perceived accessibility of an airport will change an airport's catchment area. Ultimately, airport users demand convenience. Inefficient access routes to an airport or better access routes to rival airports could lead to the loss of custom and associated reduction in revenue.

This increased competition between airports and the escalation in the numbers of people travelling by air and other modes of transport, has generated a requirement for improvement in airport ground access networks.

Because of the scale of investment required for ground infrastructure projects the responsibility for them generally falls to Central and Local Government organisations. These organisations by their nature and their budgetary restrictions tend to be reactive and minimalist, acting with short-term remedies to long-term problems. Adopting this policy often means that problems deteriorate further before the implementation of improvements, and the action is too little too late.

In an attempt to ensure that access facilities are suitable, some larger airports are increasing their involvement in transport infrastructure planning. Pilling [1993] outlines three rail projects at Stockholm Arlanda, London Heathrow and Dusseldorf airports for which private financiers are being sought. If these projects are successful they will set the precedent for future investment.

This approach is possible for two main reasons. Firstly, there are a number of organisations looking to invest in such projects because of the industry's perceived stability, and an associated demand base with the prospect of steady income. Secondly, it is more attractive for Governments to provide finance and consent to projects funded jointly with other parties. The larger airports, such as Arlanda and Heathrow, with the security of a large demand base, are more likely to be able to attract private funding.

Regional airports, on the other hand, cannot claim this same demand and as a result often need support from local government. Local governments generally support such projects, funds being available because of the benefits for the local economy of a strong regional airport. Manchester Airport is a typical regional airport. Its new rail link, a $43 million project, was funded by the Greater Manchester Passenger Transport Authority and Regional Railways. Both these are publicly owned organisations [Pilling, 1993]. For years to come, public finance is likely to remain the main source of funding for regional airport access projects.

Airports which can attract private money will possess the ability, and therefore the advantage, to react to changes in demand, by building in anticipation of demand rather than in response to deterioration or failure.

3.2 The Ground Access Network

By defining the airport population as 'the people present within an airport's boundary', the airport population therefore includes travellers and airport workers. At any one time the airport population consists of people who are familiar with the airport environment and others to whom the airport and surrounding region is a new or rare experience.

The ground access network consists of several modes of transport. Ashford [1991] outlined a number of these modes such as the private car, taxis, a variety of bus types and rail options. The private car is probably the most frequently utilised of all modes of transport, especially in the USA and Europe. However, with a significant proportion of any country's resident population and visitors not owning a car, no single ground transport mode is ubiquitously available and ideal for everybody, therefore other modal options are crucial.

In the past, possible solutions to the problems of airport access considered included specialised modes of transport. The viability of access modes, such as vertical take-off and landing aircraft (VTOL), monorails, air cushion vehicles and gravity vacuum systems were discussed by de Neufville [1971]. His conclusion was that these options would for the foreseeable future be too expensive to be viable solutions to the problem. Ostensibly airport authorities need to provide or encourage other organisations to provide ground transportation modes that are both accessible and affordable to the people that need them. There are several ground access modes available to transport people to airports.

Using the example of Heathrow Airport, the statistics shown in Table 1 indicate how Heathrow's departing passengers made use of the available ground access modes to reach the airport [BAA, 1993].

Table 1 Mode of Transport into Heathrow Airport 1992/93	
Mode of Transport	**Percentage**
Private car	38.3
Underground	19.1
Taxi	19.8
Public Bus/Coach/Charter Bus/Hotel Courtesy Coach	15.5
Chauffeur Driver Car	3.9
Hire Car	4

Heathrow Airport's access modes are by no means representative of all airports; additional modes are available at other airports. For example, conventional rail is not currently available at Heathrow Airport, a situation that will change with the introduction of the Heathrow Express rail link. This will offer an additional option to passengers. It is hoped that the link may encourage more travellers to use Heathrow Airport.

Generally the modal access can be split into two categories: Road based and Rail based modes. These are discussed in subsequent sections of this chapter.

3.2.1 Road Transport

The private car, hire car, taxi, coach and bus are typical examples of road based transport used to access airports.

Road networks can be described as being more flexible than the rail networks. Typically, if the road network has blocked section(s) there are generally other routes available to the road user, an option that is not available to the rail user. The road based transport category also contains the mode that is most controllable by the traveller, the car. The traveller driving the car has the highest level of control, making journey decisions based on personal and environmental factors.

With the other road based modes, such as taxi, bus and coach, the traveller is dependent on the decisions made by others, the vehicle's owner and its driver. The drivers of such vehicles are generally professional. Professional drivers are likely to have greater experience of driving and traffic conditions. With this experience, these drivers should be better equipped to deal with difficulties or adverse conditions that could be encountered on the journey. Using this advantage over the private car user, these drivers should be able to provide a more reliable service to their customers by identifying possible problems and limiting their effects.

To serve their purpose effectively airports have to be located in proximity to the population that they serve. Heathrow Airport, which ostensibly serves London, was originally located on the periphery of London. However, over time London's urban area has grown, people have relocated and businesses have grown in number. This growth has been exaggerated in the Heathrow area because air transport has become indispensable. Locations around the airport have become prime targets for development. With this demand for the airport and its services, the airport has expanded rapidly. In 1972 Heathrow had 18.3 million terminal passengers. By 1992/93 this number had risen to 45.5 million [BAA, 1993].

The growth of Heathrow Airport and related industries, in the vicinity of the airport, and the overall expansion of the city has increased the demands on the transport infrastructure. Infrastructure enhancements have not kept pace with the growth in road traffic volumes. Heathrow Airport and its surrounding area consequently suffers with the traffic conditions associated with major urban areas, including periods of severe road congestion. This situation is not unique to London. The phenomenon is being replicated world-wide.

Road congestion is detrimental and costly. It occurs as an indirect result of either under funding, poor planning or inadequate development of transportation networks. As demands on a transportation infrastructure grow due to increased economic activity, failure to provide the required capacity for the increasing traffic volumes, will result in congestion. The Institute of Civil Engineers [1989] identifies that it is not a problem that can be easily rectified. This is because typically the planning and construction cycle of infrastructure in most countries is in the range of 10-15 years. In consequence, conditions are often more likely to deteriorate in the short term and may not improve in the long term.

Congestion to a certain degree should be 'self regulating'. Business and commercial operations generally require accessibility; congestion is therefore a factor that would not be favourable to these types of operations. However, when industries are dependent on a major airport for their business, congestion becomes increasingly inevitable and somehow accepted. New transport schemes can be implemented and not always with the anticipated results. The M25 is an example of a scheme that was arguably too successful. In 1989, traffic flows over some sections of the M25 that had been open since 1980 were on average 70% above that originally forecast [DoT, 1989]. Congestion continues to be a problem for all travellers on the M25.

Travel time can be defined as consisting of the total of the congestion free travel time plus any delay caused by external factors. Congestion can cause variability in the access time taken to reach the traveller's destination. The nature of traffic flow along routes is to a certain extent 'random' and accurate prediction of delay is not therefore possible. The delay experienced is dependent on the time of day, road characteristics and environmental conditions, inferring that although delays cannot be predicted accurately they can be expected. Examples of predictable delays are 'rush hour' traffic and 'holiday traffic'. 'Rush hour' traffic occurs regularly because of the large numbers of vehicles using the roads transporting people to and from work, school and the like. These periods of the day are when peaks in demand for transport arise and volume of vehicles is therefore at its greatest. The 'holiday traffic' phenomenon occurs on national holidays and during the summer months; travellers all sharing the common desire to migrate, cause a massive peak in the demand for road space.

Travellers perceive congestion when 'there are delays which add significant time to their reasonable expectations of how long it should take to complete their journeys, or they experience an untoward degree of overcrowding and discomfort in the course of travel' [ICE, 1989]. The effects of this perception of congestion and its effects on traveller behaviour will be discussed in later sections of this thesis.

3.2.2 Rail Transportation

The alternative to the road network, in terms of capacity, is the rail network. The rail network offers a scheduled service for which a user can use in return for the purchase of a ticket. This transport mode is probably the least flexible, which is underlined by the fact that rail stations, route origins and destinations of the system, are fixed.

There can only be a limited number of people for whom the stations are suitably located. To use rail transport, travellers often have to use other additional modes of transport to reach an appropriate rail station. Furthermore, it is possible that the chosen airport is not served by a rail station. In this case the traveller would have to resort to another transport mode to reach the airport.

Furthermore, the route required is not always provided as a direct service, more often than not there will be a change of train at some stage of the journey. This would not normally present too much of a problem but for the fully laden air traveller with luggage it is not quite so simple. The more transfers that the passenger has to make the more undesirable the mode. Research suggests that rail interchange has a probable fixed disutility associated with the inconvenience of having to transfer and the traveller cannot avoid the scheduled gap between arriving and departing services [MVA, 1987].

These factors combined with rail services operating to a timetable means that 'rail systems often give relatively poor overall access time in spite of good line speeds' [Ashford and Wright, 1992].

Like the road network, the rail networks also experience congestion. Hours of peak demand cause large numbers of travellers to congregate in and around stations and connecting pedestrian walkways, which affects the traveller's perceived level of comfort. If this reaches unacceptable levels this experience will influence future decisions regarding modal choice.

Travellers also must make an assessment of the reliability of the rail service at achieving its scheduled arrival and departure times. Passengers will be influenced by the perception of a service running to schedule.

Rail services are affected by elements that include: signalling faults, weather conditions, and industrial disputes. These elements will influence the traveller's perceived reliability of the service.

This perception of reliability will affect modal choice. If rail is the mode chosen, the traveller's perception will continue to influence decision making by determining which train service is caught. As a result the selected service may well not be the most time efficient as the traveller has to reconcile the objective of arriving in time and limiting the amount of idle time spent at the airport.

3.3 The Role of Cost and Reliability in the Choice of Mode into Airports

Air travel requires travellers not only to arrive at the airport before the departure of the booked flight, but with enough time to allow for necessary airline and airport processing activities. These activities will differ according to the type of flight to be taken. An international traveller will have to pass through certain processing requirements that a domestic traveller will not, such as passport control and immigration. As a result of the different processing requirements, the domestic traveller total processing time is less than for the international traveller. Furthermore, the size of aircraft used for international flights reflects the low frequency high volume nature of international travel, compared with high frequency low volume flights that characterise the domestic travel markets. The number of passengers to be checked in per flight is therefore potentially greater for international flights.

The large volume of passengers for international flights, often with luggage, take the airlines longer to process, which extends still further the time taken to pass through the terminal. This is reflected in typical airline check-in times for international flights of 2 hours prior to flight departure, compared with 1 hour for domestic flights. The result of the different processing time is that the latest feasible arrival time for catching a flight for the international traveller is earlier than that for the domestic traveller. This difference will influence the planning of the journey to the airport. For example, a traveller has more scope to arrive at the airport late and still catch a shuttle flight than a charter flight scheduled with the same departure time. This example is possibly too simplistic as other issues come into play, such as the shuttle traveller by arriving too late runs the risk of getting 'bumped off' if the flight is full.

The relative importance of the flight to the individual, and the associated importance of arriving at the airport on time, will affect the travel planning decisions. Travellers with different travel purposes will have different perceptions of the importance of arriving on time and different availability of time.

As discussed earlier there are a number of access modes available to gain access to airports; however, not all are available to every traveller. For example, the use of the private car is limited to those that have access to a car. Similarly, rail services might not operate at the time needed to achieve a suitable arrival time at the airport. Therefore, for a particular individual at any given time, only a limited number of transport modes are suitable options. The transport options are further reduced when the individual considers the budget for and reliability of each mode.

Considering firstly cost, each travelling individual possesses a perception of the importance of time to them. This perception affects travel decisions, such as the choice of ground mode to be utilised. The greater the value of time to the individual, the larger the cost the individual is prepared to pay to 'save' time. For example, a business executive can hire a chauffeur driven limousine maintaining the executive's ability to work while travelling. Practicality and economics dictate that it is not prudent for the business executive to waste time driving and parking a car when his or her time could be better spent on other preferred activities. Access modes have a price structure that reflects the assets of speed, reliability and comfort. The increase in any of these assets results in an associated increase in price. Individuals with a perceived high value of time can exploit faster more expensive modes of transport.

This now raises the issue of traveller perception. Most air travellers would argue that it is important for them to catch a particular flight. However, the importance of the flight is not derived from the flight itself but rather the activity that catching the flight facilitates. This can be illustrated by considering a business executive and a charter traveller.

Governed by a business schedule the business executive cannot afford to be extravagant in allocating time for reaching an airport. However, travelling to catch a scheduled flight the business executive may be able to take other flights should the booked flight is missed.

In contrast the charter traveller's flight will probably be the main focus of the day with the ground access journey reflecting this fact. The traveller may allow ample journey time for a number of reasons. Firstly, being a charter flight the ticket is probably valid for the one flight, and is often part of a package which includes a holiday. Secondly, travelling for leisure the traveller probably may have the luxury of more time with which to make this journey time allowance. Thirdly, the charter passenger, unless he or she is a regular flier, is less likely to be familiar with the journey to the airport. This feature is highlighted by the results of the 1987 CAA Origin-Destination survey. An average business person makes 15 flights per year from Heathrow Airport compared with 1.4 flights per year for an average leisure traveller [CAA, 1989].

Unfamiliarity or uncertainty of the access journey leads into the next area for discussion, that of travel time uncertainty. All travellers will have a degree of uncertainty about the length of time it will take to reach their destination, in this case the originating airport. This confidence of the traveller in the travel time will depend on previous experience of the airport access journey.

Furthermore, it is important to realise that travel time uncertainty is not necessarily something that will gradually change over time, it may occur suddenly without warning and/or be temporary. To illustrate this point, in 1995 when part of the Heathrow Express tunnel collapsed, the underground line to the four Heathrow terminals was temporarily closed. Coaches were laid on to ferry passengers from Hatton Cross, the last available underground station, to the passenger terminals. The inconvenience of the collapse went on for some weeks, affecting the traffic in and around the airport. During this period, travellers' uncertainty of their journey time caused problems for the airport operator. Once the tunnel was reopened normal operations resumed.

The above example shows how a spontaneous event can be the cause of short-term travel time uncertainty. If the growth in traffic volumes continues as anticipated, travel time uncertainty is likely to increase. Therefore, researchers need to identify what the effects will be on travel dependent facilities such as airports' functional efficiency.

3.4 Conclusion

Having introduced the subject of airport access and established that there is a need to investigate further, the next step is to identify and evaluate relevant previous research. This is the focus of the next chapter, the literature review.

4. Literature Review

4.1 Introduction

A search of published reference material has revealed work that addresses the issues of travel time uncertainty. However, as will be shown, none of it focuses specifically on this issue and its effects on ground access journeys of air travellers.

Vandebona and Allen [1993] developed a number of descriptive and other models for arrival distributions at airports, for the purposes of terminal size estimation and design of road access networks. However, their work does not address the issue of travel time uncertainty.

Senna [1994] identified two approaches to studies into the area of travel time variability, engineering and socio-economic. These two strategies approach the issue from two angles. The engineering studies look into the effects on the speed of travel (variability). The socio-economic studies examine the traveller behaviour that occurs as a consequence of variability in journey time.

Pas [1987] identified two types of journey time variability: explained and unexplained. This is just one of a number of studies that have identified a number of types of journey time variability. The observations of Pas are supported by the work of Huff and Hanson [1986] and Jones and Clark [1988].

Bates, Dix and May [1987] developed three categorises of variability which are outlined below:

a) 'Inter-vehicular' variability: Vehicles travelling at the same time experience different types of delay factors (traffic signals and driving style) and hence have different average speeds.

b) 'Inter-period' variability: The vehicle speeds for a journey at different times vary according to separate factors (traffic densities, daylight and incidents).

c) 'Inter-day' variability: Journey times vary due to traffic densities experienced on a daily basis (weekday/weekend/public holiday).

Travellers make assumptions about expected traffic conditions based on these three forms of travel time variability. It is the traveller's perception of these facets of variability and not the causes of the variability that is under consideration in this research.

Hendrickson and Plank [1984] identified three factors which influence departure time decisions. These factors are:

a) Congestion avoidance - travelling in the off-peak reduces the probability of delay due to congestion.

b) Schedule delay/service reliability - early or late arrival could be dependent on other parties and schedules.

c) Peak/off-peak periods and parking availability - financial influences due to charges associated with travelling and peak and off-peak periods.

If a traveller wants to use other transport modes then restricting factors are introduced such as timetabled arrival time and the reliability of the service. The 'timetabled' traveller is required to make a personal judgement on the journey time. The decision is more restricted with the departure time structured rather than on a continuum as is the case with a car.

Starkie [1971] concluded that a traveller, delayed because of scheduling problems which prevents arrival as desired, experiences 'schedule delay'. If an arrival deadline exists, travellers often catch earlier services to prevent schedule delay, causing in effect a schedule surplus time. Therefore a lack of confidence in a transport mode will often cause excessive margins of safety and will result in a premature arrival at the destination.

Pells [1987] in research investigating work access travel found that travellers base the departure time decision on previous experience of their journeys to work. Typically such journey decisions are constrained especially when it comes to departure time choice. Furthermore, such journeys are characteristically of a fixed length and travelled regularly, characteristics that are not necessarily associated with airport ground access journeys.

Ben-Akiva and De Palma [1987] identified that decisions regarding departure time and route choice are affected by:

a) information provided by third parties (e.g. work colleagues or TV/radio broadcasts).

b) day to day factors such as weather conditions and accidents.

c) past experiences and individual habits.

Chang and Mahmassani [1988] studied the mechanics of planned arrival times and anticipated arrival times. Their work concluded that both early and late arrivals affect future prediction of arrival time. It also found that recent experience has greatest influence on traveller perceptions of expected travel time. The importance of arriving on time to the individual is now brought into question.

Paine [1976] concluded that for a given journey, the average time and the cost of the journey are not as important as the ability to accurately predict arrival time. For a journey from point A to point B it is possible to take two different routes, or travel the same route at different times of the day. The journeys may have similar mean journey times but very different standard deviations. It is easier to predict the time for a journey if the standard deviation is small. So a journey with a smaller standard deviation would be preferable even if the mean journey time and cost are greater. However, not all travellers have enough experience to make such judgements.

Hall [1983] identified that 'Travellers do not know what the performance of the (transport) system will be. They do not know exactly how long it will take to reach their destinations, or whether they will arrive on time'. Travellers might adopt other techniques, such as allowing extra time or margins of safety for their journey. The size of margin of safety will relate to the significance, or the uncertainty, of the arrival time at the destination.

The margin of safety can be defined as:

$$\text{Margin Of Safety} = \text{Planned Arrival Time} - (\text{Departure Time} + \text{Expected Travel Time}) \quad \text{(EQ 1)}$$

The size of the Safety Margin allocated will be dependent on the variability in the travel time previously experienced and the importance of arriving at the destination on time.

Bates et al. [1988] expressed that 'Drivers who depart at clearly sub-optimal times are not acting irrationally..' but, 'opt, by choice or obligation, for activity schedules in which the often conflicting demands and constraints....all have to be reconciled'. Which supports the view that some travellers do not have the luxury of surplus time with which to 'construct' an effective margin of safety and therefore achieve the best they can within the prevailing constraints to arrive on time.

Knight [1974] identified that a traveller will try to reduce the margin of safety's size to an optimum level. With knowledge of a journey the traveller can assess with greater accuracy the implications of the variability of travel times around the mean travel time. This can be developed so that the safety margin becomes more 'consistent'. The experienced traveller, assuming he or she is in full control over the departure time, will be able to adjust the departure time in a way that will not increase the probability of being late. If this is achieved then the margin of safety can be said to have been optimised. It can be argued that the level of margin of safety allocated reflects the confidence of the traveller in predicting the journey time.

Pells [1987] expressed the finding that the benefit "to the individual of being able to transfer time from leisure activities at the work place to leisure activities at the origin" can be expressed as a value per minute. Using stated preference techniques SPT this work ascertained that if travel time variability is reduced, the margin of safety allowed by the traveller is reduced accordingly. Individuals' displayed a preference to spend their leisure time at home rather than at work. This was shown by an average perceived benefit of 1.5 pence per minute, compared with a 'value of lateness' in the region of 7 pence per minute. This suggests that people would rather arrive early to work than late. The value of lateness for an air traveller is not currently available; although it could be expected to be higher than of the work journey. Furthermore, the value of lateness would be dependent on the type and importance of the flight to the individual.

Lisco [1974] identified that there are numerous problems associated by attempting to attach values to people's time, which are a 'direct result of travel time value concept and measurement problems'. Expanding these points Lisco asks 'can time have a value since it is never sold?' Lisco goes on to ask 'whether travel time saving is a sensible notion given that time passes at a uniform rate and cannot be kept for use in a future period'. The measurement of travel time values is difficult because 'values for time per se cannot be established' and 'difficulties associated with attempting to measure a "pure" opportunity cost of time'.

European Conference of Ministers of Transport (ECMT) [1976] support the opinion that the value of time concept is problematic. They concluded that 'The evaluation of travel time savings in terms of money units is a hazardous procedure and it is debatable whether, everything considered, it would not be better to measure time in minutes'. In addition, 'in the final analysis, money is the determining factor....it is useful to present the various factors in terms of a common denominator and to avoid the juxtaposition of disparate elements'.

If there is a level of uncertainty of arrival time, for whatever reason, a behaviour change is likely. Car drivers possess the freedom to select their own departure time. Travellers can prepare for uncertainty by starting their journey earlier than under 'normal' conditions. An earlier departure, especially if caused by uncertainty of congestion, will broaden the period of peak demand on the roads.

Cheung [1989], in work involving revealed preference and stated preference studies into urban travel, found "a wide range of variability in people's valuation of travel time savings". This work supports the view that personal circumstance and individual perception will affect modal choice and that there are a limited number of modes that any particular individual will use. The choice will ultimately depend up three factors: the modes available, the journey cost and the journey time reliability. The evidence from such work indicates that people are prepared to pay different amounts for different modes depending on the journey's importance and probable duration.

4.2 Literature Review Implications for Research into Air Traveller Travel Behaviour

There are three factors specific to the air traveller that require comment at this stage. These are:

1. Constrained journey arrival time
2. Experience
3. Variability

4.2.1 Constrained Journey Arrival Time

Considering the first factor, an air traveller's journey is more constrained than, for example, a standard journey to work which is typical of the studies outlined in the literature review. A traveller going to work can be late and incur a penalty in the form of, for example, a reprimand. If an air traveller is late for a flight the penalty can be more severe, ranging from not getting a choice of seat to missing the desired flight altogether. The air traveller is more likely to be prepared to incur greater costs to access the airport, compared with accessing a work place, if it increases the probability of catching the flight.

4.2.2 Experience

In contrast to air travellers, people travelling to work or on other frequently travelled route have a good knowledge of the journey taken. Unless carried out by a member of the airport staff or a regular commuter, an airport journey is relatively unknown to the majority of travellers. East Midlands International Airport [1992] reported 42% of its passengers had flown once in the previous year (a further 20% had flown only twice). Heathrow Airport statistics shown in Table 2 highlight the difference between the number of flights a business traveller makes compared with a holiday traveller.

Table 2 Frequency of Heathrow Use by Traveller Type 1987	
Passenger Category	**Mean Trips**
UK Business	15.0
Foreign Business	2.0
UK Leisure	1.4
Foreign Leisure	1.3

Source CAA [1987]

Clearly there is a difference between business and leisure air travellers in terms of journey experience. This fact could have implications for the design of airports. An airport with a passenger bias towards charter travellers might offer more space for 'novice' travellers compared with an airport with a business traveller bias. An example of this is London City Airport, which provides limited check-in space on the assumption that travellers are knowledgeable of the access and check-in system and will arrive just prior to plane departure time. This is shown effectively if a comparison is drawn between the design standards for East Midlands International Airport, which is a regional airport, and London City Airport. These airports' design standards are given in Table 3.

Table 3 Airport Design Standards		
Facility	**East Midlands International**	**London City**
Check-in area	2.5 sq.m	1.25 sq.m
International Lounge	1.5 sq.m	1.75 sq.m

The design standards used at East Midlands International Airport are 2.5 square metres per passenger in the check-in areas and 1.5 square metres per passenger in the international lounge. East Midlands International Airport caters for a significant level of charter traffic, with a high proportion of first time travellers. In contrast, the design standards for London City Airport are 1.25 square metres per passenger in the check-in areas and 1.75 square metres per passenger in the international lounge. The low check-in area design standard at London City is such that it is less than that afforded to passengers in the international lounge. The London City international lounge is designed for the business executive, with individual leather seating for passengers, which, compared with the standard airport seating systems, is very space intensive. The lack of large suitcases, which is a feature of leisure travel, also helps to keep the check-in space requirement low.

4.2.3 Variability

A weakness in the comparison between airport access and commuter journeys becomes apparent when the subject of travel time variability is raised. Travel time variability was the focus of much of the work conducted to date and featured in the literature review. It covers the elements of the journey's duration; it does by definition imply previous experience of the journey. Evidence would suggest that a significant number of travellers have limited experience of their airport ground access journeys. For example, for the year 1992/93 Heathrow's first time user proportion was 34.2% of passengers; the next highest category was 1-3 flights in the previous twelve months which constituted 32.6%. It is important to note that the category with 1-3 flights in the previous twelve months may be limited in that their access trips may have had different origins. For this reason this thesis will no longer refer to travel time variability. It will use a more appropriate term of Journey Time Uncertainty.

4.3 Conclusion

From the literature review a number of aspects become clear. The first is that this research is novel. Secondly, journey time uncertainty affects traveller behaviour for commuter journeys and therefore can be expected to affect airport access journeys. Thirdly, previous research of commuter behaviour should provide a suitable foundation from which to develop an appreciation of a number of the possible factors which may feature and influence air traveller ground access decision making.

Having established that this research is novel, the following chapter outlines the research that was undertaken to investigate airport access and journey time uncertainty.

5. The Research

The previous chapter examined the existing research or more accurately the lack of research into airport access journey decision making. The remainder of this thesis seeks to resolve this problem by aiming to provide an understanding of the issues associated with airport access and journey time uncertainty.

This thesis will therefore examine how the uncertainty of the arrival time at an airport for travellers using ground transport modes currently affects the operation of airports. More importantly it examines how, with the current trends identified by Ashford and Wright [1992] and the M25 Review [1989] of increasing congestion, passenger behavioural changes will affect the functional efficiency of existing airport designs and practices.

Airports are important for both regional and national economies. It is therefore in the interests of national and local government, airport operators and the public at large, to make airports as effective and profitable as possible. To achieve these goals airport operators must ensure their airports can perform all the functions expected of a modern airport.

This thesis will attempt to identify ways to avoid airport terminal system failures similar to those experienced on the roads. This will be achieved by identifying the likely outcomes of increased journey time uncertainty for airport operators and identifying possible solutions that can be developed for the mutual benefit of all parties involved.

5.1 Sources of Information

The first step of the research was to identify possible sources of relevant information. The major sources that were identified included airports, Government agencies and air travellers.

Considering the first category, airports, limited co-operation from the industry was anticipated. This is due to the commercial and political sensitivity of the congestion associated with airports. Airports looking to expand to handle more passengers are notoriously sensitive. Support in the form of information came from three airports in the UK - Manchester, Birmingham and East Midlands International - support that was gratefully accepted and acknowledged. The information supplied by these airports was vital to prosecution and validity of this research.

The second source of information identified for this research came from the UK Civil Aviation Authority (CAA). The CAA is an advisor to the Government on matters relating to airport policy. In 1987 it undertook a large scale origin-destination survey of passengers using the airports in the South East of England and Manchester. The surveys aimed to maintain the up-to-date information available to the CAA. In 1987 the surveyed airports handled "66 million passengers, 77% of the total UK market" [CAA, 1989].

Data tapes containing a copy of the CAA survey data were supplied to the Department of Transport Technology at Loughborough University of Technology. The tapes provide the capacity to analyse each individual trip record obtained by the CAA.

CAA origin destination data tapes were converted into files onto Loughborough University's mainframe computers. The data were collected through surveys conducted at Heathrow, Gatwick, Stansted, Luton and Manchester airports. Initial data analysis provided information relating to the origin and destination of passengers surveyed. These data provided vital background information for this research, however, its use was limited in that access journey planning had not been effectively addressed in the surveys.

Access journey questions contained in the surveys were limited to origin and mode of transport used to access the airport. Other aspects such as expected length of time to reach the airports were not included in the surveys. This weakness of the CAA's surveys increased the need to conduct a survey as part of this research, with the objective of ascertaining more detailed information about air travellers' journey planning.

Air traveller surveys conducted to address this weakness form the third source of data for this research. These surveys were designed to take into account access journey decision making. The structure of the surveys are discussed in the first section of the Research Methodology which is outlined in the following chapter.

6. Methodology

The methodology used to complete this thesis is outlined in the following two sections. The first section addresses the methodology used to survey air travellers. The second section addresses the development of a methodology for the simulation of airport terminal passenger flows. The methodology is designed specifically to ensure that the simulation addresses the issue of the affect of a change in ground access arrival distributions on passenger terminals.

6.1 Air Traveller Survey

The methodology developed for this section of the research had the objective of examining the decision making process of travellers with special attention placed on the journey to the airport. The purpose of this methodology is to establish a foundation of understanding through evaluating what factors which influence traveller behaviour.

Following the example of the CAA origin destination surveys, the chosen method for collecting valid and reliable data was a 'one to one' passenger survey.

The dominant factor in this decision was the need to survey people who have recently experienced the need to make a journey to an airport to catch a flight. The most logical method for accomplishing this goal is to survey departing air travellers as they arrived at an airport. The main reason for surveying air travellers in this way is that the journey undertaken is still fresh in the minds of the traveller. As a result recollection is simpler and travellers can also remain anonymous, which can often improve responses.

The airport based survey also has the benefit of being cost effective. It is possible to survey a large number of people in a relatively short period of time. This is because the proportion of departing air travellers in a passenger terminal is likely to be significantly higher than most other possible surveying locations.

The ideal location for surveying departing passengers would be the departure lounge. Conducting this type of survey within the departure lounges would allow access to the full spectrum of travelling passengers, including late arriving passengers and executives. Another reason why lounge based surveys would probably be more productive is that having completed the necessary check-in and other processing requirements, passengers should be more relaxed and therefore responsive to questioning.

However, the use of departure lounges faced a number of obstacles that prevented this particular location from being used. The main obstacle comes as a result of the recent increase in the level of security at airports. This change has meant that departure lounges are not generally accessible to the non-travelling public unless they are airport based employees.

Having identified that departure lounges are inaccessible the next most suitable locations for passenger surveys are the check-in areas of the passenger terminals.

There are drawbacks associated with surveying in check-in areas. Higher numbers of passengers refuse to complete surveys and not being able to survey late arriving passengers are two such drawbacks.

Any survey of this nature has another principle weakness, in that it is human nature that in their responses people may want to appear successful in the eyes of other human beings. Knowing this, it is often useful not to reveal the true objective of the survey and to avoid leading questions. To clarify this point, a question asking "How accurately did you predict your journey to the airport?" is likely to bias responses towards high prediction accuracy. It is possible to find out the same information by asking two separated questions, such as "What time did you plan to arrive?" and later "What time did you arrive?". Using this method not only reduces the personal assessment aspect of the survey, but also allows for further analysis of the journey decision making to be made.

Other options for obtaining suitable information were also considered, such as the use of postal surveys and diaries. A summary of the advantages and disadvantages of the methods considered can be seen in Table 4.

Table 4 Considered Options for the Air Traveller Survey		
Option	**Advantages**	**Disadvantages**
Departure Survey	• Large selection of possible respondents • Range of passenger categories • Large number of responses in a short period of time • Recent experience of access journey • Anonymity	• Restricted Access to airports • Survey Team Required • Traveller anxiety • Hard to identify passenger category prior to survey
Arrival Survey	• Range of passenger categories • Large number of responses in a short period of time • Anonymity • Identify Passenger category prior to survey	• Restricted Access to airports • Survey Team Required • Forgotten key details about their originating access journey
Postal Response survey	• Range of passenger categories • Low anxiety	• Restricted Access to airports • Hard to identify passenger category • Risk of people forgetting to complete the survey • Risk of people forgetting to return the survey • Not possible to chase missing questionnaires • Expense of post (International postage) • Not ideal for non-UK respondents • Slow return of surveys • Hard to identify passenger category prior to survey
Diary	• Detailed journey information provided • Structured sample	• Risk of people forgetting to complete the diary • Limited respondents • Not ideal for non-UK respondents

		• Risk of people forgetting to return the diary • Expense of post (International postage) • Change in behaviour thorough being more self conscious

6.1.1 Sampling

Cohen and Holliday [1982] identify the strengths and weaknesses of sampling techniques. Considering the needs of this research the use of a traveller survey offered the best method for obtaining the required information. Sampling techniques remain the most productive method of obtaining the required data when total population sampling is not possible or practical.

Clearly, for financial and logistical reasons it is impossible to survey all departing passengers at all airports, therefore it is necessary to survey a representative sample of departing passengers. In this research representative sample of the total population would comprise a number of passengers from a number of different airports.

6.1.2 Data Analysis

The questionnaire, as can be seen in Appendix 1, was designed with data preparation coding in mind. This allows straightforward entry of data into a database. So after the surveys have been completed the questionnaires are ready for data preparation into a data file. Once the data file has been completed and checked it is ready for analysis. This analysis examines the data by category using techniques, such as correlation, to identify any significant relationships between different categories. One of the methods of evaluating correlation between such categories is the Scheffé S Test. An outline of this test can be seen in Appendix 4 to this document. This analysis was conducted to identify factors that affect the arrival patterns of travellers at airports.

The survey data are also suitable for producing arrival distributions for the passengers at the specific airports selected for the surveys. The arrival distributions from the surveys form the link with the second phase of the research - that of passenger flow modelling.

6.2 Passenger Flow Modelling

The second section of this methodology builds on the knowledge collected in the first section. The objective of this section is to develop a series of models to simulate the affects on airport passenger terminals of changes in departing travellers' behaviour because of journey time uncertainty.

As the purpose of this research is to investigate phenomena that are by their nature not normal, it is not possible to obtain the relevant information simply by monitoring existing behaviour patterns. It is therefore necessary to use the technique of simulation to develop a perception of how systems (passenger terminals) will operate with a change in inputs (passenger arrival patterns).

As with surveying it is not practical to develop large numbers of airport simulation models. So, the decision was taken to develop a total of five passenger terminals based on three chosen airports. For convenience the terminal models were based on the airports which featured in the passenger surveys. The models were developed using information gathered from the first section of this research and supplied directly by the airports being modelled.

The simulations conducted for the research are based on six different scenarios which represent a range of arrival patterns. By running a sufficient number of iterations to calculate a valid mean result for each scenario it hopefully will be possible to identify trends that occur within and between the scenarios.

Six scenarios was felt to ensure an appropriate balance between scenarios and iterations to achieve effective results within the time available. Because of time constraints conducting more than six scenarios would have required the number of iterations for each scenario to be reduced. Reducing the number of scenarios would have decreased the validity of the results obtained.

√ The tool selected for simulating passenger flows was the Norr Airport Planning Associates (NAPA) Terminal Planning Model. The logic behind the choice of this tool is, firstly, that the software is relatively accessible through an agreement with the University and NAPA; and secondly, that it is designed specifically for analysing passenger flows within a terminal. It must be noted that it was not designed specifically for assessing the affects of a change in arrival distributions, but nevertheless it is possible to use this software to model a change in arrival patterns.

Because the software was designed for modelling passenger terminal flows, it is more or less straight forward to use. It is relatively easy, although time consuming, to build each model and validate it. Each model is set-up as a series of facilities. On completion of an iteration it is possible to record the peak number of people for each facility. These results can be entered into a database for later analysis. The last significant factor in choosing simulation as a method of research is the author's previous experience of using other simulation packages as part of other research studies [Taylor, 1991].

There are a number of other simulation tools, for example, that of the Preston Group. However, the research constraints of cost, time and resources, plus the fact that the NAPA software was adequate for the task prevented the pursuit, use or development of alternative software packages.

The case against simulation as a method of research, although considered not significant enough to prevent the study, still needs to be outlined. Simulation is a tool that is not designed to be an answer in itself, but rather to support (or discredit) an argument by providing evidence based on the best possible information. The results cannot be said to be definitively accurate because it is more or less impossible to build a model that can predict each individual's responses to a variety of factors. To put this point into context, a passenger who flies from the same airport every week might one week buy a tie from a shop within the terminal. Unless the model includes a variable for how often passengers buy ties, it is unlikely to predict this activity. Even if it was possible to create an 'individual sensitive model', owing to the nature of airports, such a model would require millions of different profiles for each potential passenger. This level of detail within a simulation model is clearly impractical.

Simulation is therefore not something that produces right or wrong answers, but is designed to provide a representation of a real system. Unfortunately it is not possible to collect data freely at an airport because of security restrictions as discussed earlier in this chapter. Therefore the models produced for this research are based on data collected by others and accepted in good faith as being realistic.

A number of concerns remained on commencement of work. These were that the software was to be used for a task that was not its primary function, and that one is not fully aware of a software's weaknesses until having used it extensively.

6.3 Constraints

The constraints which influenced the course of this research and the scale of the research most significantly are time, finance and resources. These three factors play a major part in any research project. If these factors were available in larger quantities, the size of the project might have been a great deal larger, but most significantly the methodology would not have been different to that which was conducted. Even with an endless supply of these ingredients, it would still have been necessary to (a) monitor actual passenger behaviour; and (b) simulate the affect of changes in arrival patterns. In short, faced with researching this area without the prevailing constraints that this study endured, the methodology that would have been adopted would have been very similar, if not identical to that outlined above.

In summary the methodology used for this research has two sections. The first section has the objective of discovering the motives and rationale behind departing passengers' behaviour and decision making processes for the ground access journey to the airport. Specifically, to identify how passengers react to uncertainty of their journey's travel time. The second section seeks to identify the impacts of the changes in passenger behaviour that are attributable to the increased uncertainty of the journey time to the airport.

7. The Air Traveller Survey

This chapter addresses the first part of the research, the air traveller survey. The objective of the survey was along the same lines as the 1987 CAA surveys, but with greater emphasis on the access journey to the airport. Therefore in addition to general questions relating to the profile of the traveller (purpose of the flight), a number of other questions focused on the timing of the journey to the airport, namely:

1. What time did you leave home?
2. What time were you asked to check-in?
3. What time did you arrive at the airport?
4. What time did you expect to arrive at the airport?

Having asked these journey specific questions the collected data can be used to generate:

1. Arrival distributions - using the start of check-in proceedings as a common reference point for each individual journey,
2. Expected journey time,
3. Actual journey time,
4. Accuracy of prediction of the journey time.
5. Planned arrival time in relation to start of check-in proceedings.

These calculated values can then be correlated with traveller's profile to ascertain if there are significant relationships between the traveller's characteristics and the resulting journey. The analysis of these surveys will give an indication of how different passenger types plan, in particular what planning allowance is made for their lack of knowledge or uncertainty of their respective journeys.

As outlined in Chapter 5, the first phase of this research addresses the issue of the air traveller. It draws on primary and secondary data, in an attempt to identify critical factors that influence the behaviour of air travellers. The initial discussion of the passenger surveys deals with the individual airports separately. An overall comparison of the results is followed by more detailed investigations, such as statistical correlation. This involves the analysis of the data gathered and significance tested to identify factors that are significant to at least 95% (if not 99%) confidence limits.

7.1 The Airport Questionnaire

The Airport questionnaire was very simple. Its purpose was assist in the formation of a theory of how decisions relating to departure time from the ground origin are made. To meet this objective the questionnaire posed very general questions. The key areas for information gathering included:

a) Destination airport of first sector to be flown

b) Mode of transport utilised on access journey

c) Start point of ground access journey

d) Flight number

e) Purpose of journey

f) Number in group

g) Frequency of case airport use

h) Recommended check-in time

i) Ground origin departure time

j) Actual arrival time at airport

k) Expected airport arrival time

l) Cause of difference in expected and actual arrival time

m) Time allowed as safety margin

Note was also made of the following information:

a) Gender of traveller

b) Time of day

c) Day of week

d) Airport survey location

The questionnaires were designed so that they could be easily decoded into a data file by Loughborough University's Data Preparation Service. A copy of the questionnaire can be seen in Appendix 1. Having created a data file it is then possible to commence analysing the data.

7.2 Manchester Airport

Manchester Airport was the first airport selected for a ground access survey. Over a period of two days a team of four and five surveyors aimed to interview 500 travelling passengers as they arrived at Manchester Airport bound for the departure concourse. The surveys were conducted in Manchester Airport's two terminals.

At Manchester Airport, Terminal 1 handles both domestic and international flights, whereas Terminal 2's operations focus on international flights, the majority of which are long haul. Passengers who had arrived at the airport by ground access modes with the objective of flying on that day were surveyed. A total of 591 valid Manchester Airport based surveys were conducted and data processed for this research.

7.2.1 Last Mode of Transport into Manchester Airport

Table 5 provides a breakdown of the last mode of transport used by the passengers to access Manchester Airport. The most frequently reported mode of transport was the private car, with 64.64% of the individuals surveyed driving or being driven to the airport by private car. A further 3.5% indicated a preference of the private car as a normal mode of access to the airport. The second most popular mode of transport was taxi with 18.95% of the survey population. The third most popular mode was rail, utilising the recently opened rail station at the airport. The percentage of individuals using this option amounted to 5.58% of the population questioned.

Table 5 Last Mode of Transport into Manchester Airport

Mode	Observations	Percentage
Private Car	382	64.64%
Chauffeur Driven	1	0.17%
Rental Car	14	2.37%
Taxi/Minicab	112	18.95%
Charter Bus/Coach	22	3.72%
Public Bus/Coach	4	0.68%
Hotel Courtesy Coach	10	1.69%
Rail	33	5.58%
Other	3	0.51%
Not Recorded	10	1.69%
Total	591	100.00%

7.2.2 Purpose of Journey

Unfortunately only a limited number of business travellers were surveyed which is partly due to the prevention of access to departure lounges by Manchester Airport. Lounge based surveying may have increased this proportion by surveying individuals in a calmer environment, with all processing functions such as check-in completed. Business travellers were not widely available to receptive to questioning. The low number of business travellers surveyed this produced a high proportion of passengers travelling for holiday or leisure purposes. The complete breakdown can be seen in Table 6.

Table 6 Purpose of Journey

Purpose	Observations	Percentage
Business	30	5.08%
Package Tour Holiday	309	52.28%
Package Tour	13	2.20%
Visiting Friends and Relatives	138	23.35%
Other non-business	101	17.09%
Not Recorded	0	0.00%
Total	591	100.00%

7.2.3 Number of People Flying in the Group

The most commonly occurring group size revealed by the survey was two, with 44.16% of the survey population being accompanied by a fellow traveller; 23.0% of the sample were travelling alone. Those travelling in groups of three or four individuals comprised samples of 12.69% and 13.03% respectively. A surprising number of individuals were travelling in groups of nine or more, with 2.54% of the survey population. This is due to people arriving at the airport and surveyed separately and yet flying together in a large group. Table 7 provides this summary of the figures obtained in the Manchester Airport survey.

Table 7 Number of People Flying in the Group

Group Size	Observations	Percentage
1	136	23.01%
2	261	44.16%
3	75	12.69%
4	77	13.03%
5	18	3.05%
6	4	0.68%
7	1	0.17%
8	4	0.68%
+9	15	2.54%
Not Recorded	0	0.00%
Total	591	100.00%

7.2.4 Origin Location

The vast majority (86.46%) of the survey population began the journey from home. A lower than expected 2.03% of the survey population began their journey from a place of work. This result highlights the point that of the business travellers (5.08% of the total survey population) more than half started their trip to Manchester Airport from a location other than their place of work. The 'Other' category comprised 11.51% of the responses provided, of which hotels and guest houses were the major constituent. The results are provided in Table 8.

Table 8 Origin Location

Origin	Observations	Percentage
Work	12	2.03%
Home	511	86.46%
Other	68	11.51%
Not Recorded	0	0.00%
Total	591	100.00%

7.2.5 Margins of Safety in Journey Times

The next section of the questionnaire related to the margin of safety planned for the journeys. It revealed a large number of people (28.76%) who stated that they had allowed no time for unexpected delays on their ground access journey. This figure was higher than anticipated, however, the security requirements for some flights, especially those going to North America, requested passengers check-in up to four hours before departure. Some respondents did not see the need to add further time to their journey in addition to what appeared to be an excessively early arrival at the airport.

Most people allowed broad bands of safety margin, for example the most commonly occurring safety margins quoted were 0,15,30 and 60 minutes, 28.76%, 7.11%, 24.2% and 25.89% of the survey population respectively. The results for the margin of safety allocated by the Manchester Airport survey respondents can be seen in Table 9.

Table 9 Margins of Safety in Journey Times

Margin (min)	Observations	Percentage
0	170	28.76%
1-15	42	7.11%
16-30	143	24.20%
31-60	153	25.89%
61-120	72	12.18%
+121	11	1.86%
Not Recorded	0	0.00%
Total	591	100.00%

7.2.6 Flights per Year

The survey results for the travellers' frequency of flying from Manchester Airport in the last twelve months are shown in Table 10. The traveller survey revealed that a large number of people were using Manchester Airport for the first time. Just over 10% of the survey sample had used the Manchester Airport on more than three occasions over the last twelve months. These figures support the profile anticipated with a large constituent of leisure travellers.

Table 10 Flights per Year

Flights/Year	Observations	Percentage
1	391	66.16%
2	109	18.44%
3	31	5.25%
4-5	18	3.05%
6-9	21	3.55%
+10	21	3.55%
Not Recorded	0	0.00%
Total	591	100.00%

7.2.7 Global Destination

Table 11 shows the survey results for the global destinations of Manchester Airport's customers. The survey was split into four categories: Domestic, Europe, N. America and the Rest of the World. The survey revealed a relatively high number of European and N. American passengers. This proportion is exaggerated by the disappointing low number of domestic travellers in the survey sample.

Table 11 Global Destination

Destination	Observations	Percentage
Domestic	20	3.38%
European	336	56.85%
North America	150	25.38%
Rest of the World	85	14.38%
Not Recorded	0	0.00%
Total	591	100.00%

As indicated earlier, access to the departure lounges was restricted. This limited the survey team to the terminal concourse and check-in areas. The domestic category size is relatively small for a number of reasons. The domestic flights are only available from Manchester Airport's Terminal 1, which was scheduled for one day of surveying. Furthermore, a large number of the domestic travellers were business travellers and were not disposed to being surveyed. However, the long haul and European travellers were more co-operative and as a result formed a greater proportion of the sample population. A proportion of the passengers surveyed were starting the first segment of a multi-segment flight.

7.2.8 Gender

The last category to be reviewed in this manner for Manchester Airport was the gender of the respondent. The survey revealed a dominance of male individuals travelling from Manchester Airport, shown in Table 12. This predominance of male travellers is a trait that is common to most airports around the world.

Table 12 Gender

Gender	Observations	Percentage
Female	259	43.82%
Male	320	54.15%
Not Recorded	12	2.03%
Total	591	100.00%

Further results from the Manchester Airport will be provided in section 7.4, which follows the Birmingham Airport Survey results.

7.3 Birmingham Airport

Birmingham Airport was the second airport selected for the airport access air traveller surveys. Birmingham Airport staff kindly conducted 294 surveys on behalf of Loughborough University. They used the same questionnaire used at Manchester Airport. The majority of the surveys were conducted in Birmingham Airport's Eurohub.

7.3.1 Last Mode of Transport into Birmingham Airport

Using the same format as the Manchester Airport results, the first subject for review is the last mode of ground transport used to access Birmingham Airport. The most frequently reported mode of transport, as at Manchester Airport, was the private car, with 59.0% of the individuals surveyed driving or being driven to the airport in a private car. The second most popular mode of transport was the taxi which was utilised by 13.56% of the survey population. The third most popular mode was rail, with 11.53% of the population surveyed; it might well be higher too because 6.78% reported using modes which includes including the Maglev. It is possible that a number of people surveyed used rail transport prior to using the Maglev. The rail utilisation at Birmingham Airport is far higher than at Manchester Airport. Rail transport at Birmingham Airport has been available for a longer period of time and has the benefit of being a main line station. The results are shown in Table 13.

Table 13 Last Mode of Transport into Birmingham Airport

Mode	Observations	Percentage
Private Car	174	58.98%
Chauffeur Driven	2	0.68%
Rental Car	0	0.00%
Taxi/Minicab	40	13.56%
Charter Bus/Coach	0	0.00%
Public Bus/Coach	3	1.02%
Hotel Courtesy Coach	3	1.02%
Rail	34	11.53%
Other (e.g. Maglev)	20	6.78%
Not Recorded	19	6.44%
Total	295	100.00%

7.3.2 Purpose of Journey

The number of business travellers surveyed at Birmingham Airport was far greater than the Manchester Airport survey. Surveying business passengers at Birmingham Airport was easier because the surveys were conducted by Birmingham Airport's own market research team, which had access to key airport facilities for surveying purposes. The breakdown of the results is shown in Table 14. It is important to observe that 64.07% of travellers surveyed were travelling on business. The proportions of holiday and leisure travellers were low by comparison, reflecting Eurohub's operation of scheduled intra-European and non-charter traffic.

Table 14 Purpose of Journey

Purpose	Observations	Percentage
Business	189	64.07%
Conference/Trade fair	29	9.83%
Package Tour Holiday	7	2.37%
Package Tour	2	0.68%
Visiting Friends and Relatives	35	11.86%
other non-business	22	7.46%
Not Recorded	11	3.73%
Total	295	100.00%

7.3.3 Number of People Flying in the Group

The most common travelling group size revealed by the survey, as at Manchester Airport, was two, with 60.0% of the survey population. Unaccompanied travellers comprised 24.07% of the sample population. The proportions of groups of three or four travellers were 9.49% and 4.07% of the total population respectively. The data reveals a tendency towards people travelling in small groups. This is a typical result for a survey population with few travelling families, a characteristic that typifies business dominated travel. Table 15 gives a summary of the figures obtained at Birmingham Airport.

Table 15 Number of People Flying in the Group

Group Size	Observations	Percentage
1	71	24.07%
2	177	60.00%
3	28	9.49%
4	12	4.07%
5	3	1.02%
6	1	0.34%
7	2	0.68%
8	0	0.00%
+9	1	0.34%
Not Recorded	0	0.00%
Total	295	100.00%

7.3.4 Origin Location

The proportion of people travelling on work related activities was higher than at Manchester Airport for the reasons outlined earlier. However, only 17.29% of the surveyed population started their journey from their place of work; over half the individuals surveyed began their journeys from home. A total of 31.19% began their journeys from elsewhere. These individuals mainly started their journeys from hotels and the National Exhibition Centre in Birmingham, where a trade fair was held on the day of the survey. A breakdown of the results can be seen in Table 16.

Table 16 Origin Location

Origin	Observations	Percentage
Work	51	17.29%
Home	150	50.85%
Other	92	31.19%
Not Recorded	2	0.68%
Total	295	100.00%

7.3.5 Margins of Safety in Journey Times

Table 17 addresses the results obtained for the margin of safety allowed by travellers in the planning of their journeys. These results reveal that a large proportion of passengers (36.95%) had not allowed any time for unexpected delays during their ground access journey. This higher risk approach could be the result of many factors relating to the business travellers, including:

1. they do not possess large amounts of time to make extravagant allowances;
2. they have more experience of the ground access journey to the airport (relative to the holiday making counterpart);
3. they are on the whole more at ease with the air transport procedures through greater experience;
4. the implications of a missed flight would be less severe than the loss of a holiday flight.

Most people allowed bands of time a safety margin. The most commonly occurring margins were 0,15,30 and 60 minutes; the respective breakdown being 36.95%, 21.69%, 24.41% and 11.86%.

Table 17 Margins of Safety in Journey Times

Margin (min)	Observations	Percentage
0	109	36.95%
1-15	64	21.69%
16-30	72	24.41%
31-60	35	11.86%
61-120	14	4.75%
+121	1	0.34%
Not Recorded	0	0.00%
Total	295	100.00%

7.3.6 Flights per Year

The previous experience of Birmingham Airport's travellers are shown in Table 18. The results show the number of flights in the previous twelve months that travellers have made from Birmingham Airport. The results reveal a large number of people that had not used Birmingham Airport in the last twelve months. Unlike the Manchester Airport survey (in which just over 10% had used the Manchester Airport on more than three occasions), 40.34% of the Birmingham Airport survey had used Birmingham Airport at least three times. 15.59% used it on more than 10 times in the preceding twelve months. This last value again underlines the increased experience that business travellers generally have over leisure travellers.

Table 18 Flights per Year

Flights/Year	Observations	Percentage
1	112	37.97%
2	48	16.27%
3	16	5.42%
4-5	30	10.17%
6-9	43	14.58%
+10	46	15.59%
Not Recorded	0	0.00%
Total	295	100.00%

7.3.7 Global Destination

The flight destination for the Birmingham Airport's travellers surveyed is shown in the global destination category. The global destination category was split into four categories: Domestic, Europe, N. America and the Rest of the World. The survey revealed a high number of Domestic and European passengers as one might expect from a facility which generally caters for intra-European travel. A breakdown of the results are given in Table 19.

Table 19 Global Destination

Destination	Observations	Percentage
Domestic	153	51.86%
European	123	41.69%
North America	1	0.34%
Rest of the World	17	5.76%
Not Recorded	1	0.34%
Total	295	100.00%

7.3.8 Gender

The last survey category, shown in Table 20, is that of the gender of the surveyed traveller. The results revealed a dominance of male individuals travelling from Birmingham Airport. The high proportion of male travellers reflects the high proportion of men involved in business. The higher proportion of men than women revealed by this survey is a result typical of most airports. This particular survey, with its high proportion of business travellers would be expected to have a higher proportion of male travellers than a non-business orientated airport.

Table 20 Gender

Gender	Observations	Percentage
Female	70	24.73%
Male	209	73.85%
Not Recorded	4	1.41%
Total	283	100.00%

7.4 Further Analysis of Manchester and Birmingham Survey Data

From the data obtained from the surveys of travellers conducted at Manchester and Birmingham airports it was possible to conduct some simple calculations. From these calculations specific elements such as actual journey time, expected journey time, and the difference between actual and expected journey times could be identified. For example, it is possible to calculate individuals' arrival time in relation to the start of check-in time. Using such relationships it is possible to identify any differences that exist between passenger and flight characteristics, and decisions made by the individuals for the purpose of the ground access journeys to the airport.

A number of these elements were subjected to analysis of variance testing to evaluate the significance of the observed differences for various variables such as global destination. Under normal circumstances a significance test such as the Tukey test would be utilised, however, given the results identified in the earlier sections of this chapter it was necessary to utilise the Scheffé S test. Like the Tukey test, the Scheffé S test is used to identify significant differences between sample means. The Scheffé S test was chosen in preference to the Tukey test because 'it is particularly applicable to groups of unequal sizes.....to compute the limits of a confidence interval for each difference between means.' [Cohen, 1982] The formula and explanation of the Scheffé S test can be seen in Appendix 4.

7.4.1 Arrival distributions by global destination

The first statistical investigation carried out, isolates the characteristic of flight destination. By subtracting the start of flight check-in time from the ground access arrival time it is possible to obtain a simple arrival distribution. Analysis would reveal the importance of arriving at the airport to the passenger using the reference point of the start of the check-in for their flight. It is important to remember there are different check-in periods depending on the destination of the flight. For example, it is common practice for airlines on some domestic routes to check-in passengers from an hour before flight time to just before flight departure. The requirements of international flights for security checks, customs and alike, prevents a similar check-in policy; check-in periods of between three or even four hours are not uncommon.

Domestic and European flights with shorter check-in periods provide passengers with a smaller safety margin at the airport for unexpected access delays. However the flight may be part of a frequent schedule service, with further flights available later in the day. Long haul flights require a longer check-in period. This provides more flexibility for delays in the access journey. Check-in operations for these flights stop earlier because of the logistics of security checks, baggage reconciliation and other activities as highlighted earlier.

Global destination considers four divisions:

1. Domestic
2. European
3. North American
4. Rest of the world

The Manchester Airport results indicate that for Manchester Airport there are significantly different arrival distributions depending on the traveller's destination. All the groups when compared with the remaining three were significantly different, as Table 21 shows. The Scheffé S test for Birmingham Airport revealed that none of the four distributions were significantly different.

Table 21 Scheffé S Test for Global Destination at Manchester Airport (General)

Level of Significance	Difference Between
0.01	Domestic and the remainder of the sampled population
0.01	European and the remainder of the sampled population
0.01	N. America and the remainder of the sampled population
0.05	Rest of the World and the remainder of the sampled population

Comparison between the categories reveals that there is no significant difference between Domestic and European access arrival distributions. Similarly the difference between N. American and the Rest of the World access arrival distributions is not significant. Differences between the arrival distributions of the groupings of short or medium haul and long haul reveal are found to be significant, as Table 22 illustrates.

Table 22 Scheffé S Test for Global Destination at Manchester Airport (Specific)

Level of Significance	Difference Between
0.01	Domestic and N. America
0.01	Domestic and Rest of the World
0.01	European and N. America
0.05	European and Rest of the World

The results suggest that the Domestic and European (short or medium haul) flights have a similar access arrival distribution of passengers, and the North American and Rest of the World (long haul) flights have another.

Conclusion: At Manchester Airport the final destination to which passengers are flying, defined as either short haul or long haul, causes significant difference in the arrival distributions experienced.

7.4.2 Distance and predictability

From the questionnaires it is possible to calculate both the expected journey time and the actual journey time for each individual. By taking the actual arrival time from the expected arrival time it is possible to calculate an accuracy value. This can be used to compare the accuracy of prediction against the length of the access journey. This analysis is entirely dependent on the stated perceptions of the individuals surveyed.

It was anticipated that a proportion of the passengers surveyed would want to give the impression of correctly predicting the access journey time, while others would not have scheduled a specific access arrival time. These two factors could cause an effect in the results. However, these characteristics and therefore the effects can be assumed to occur evenly within each of the groups and would therefore not affect the testing significantly.

The length of journey was divided into the following expected journey time categories:

a) < 1 hour c) 2-3 hours

b) 1-2 hours d) > 3 hours

As with the previous analysis the Scheffé S test was used to determine significant difference. Manchester Airport provided three significant results in terms of the 'accuracy' of journey time prediction as shown in Table 23. No significant difference for the Birmingham Airport survey data was found.

Table 23 Scheffé S Test for Distance and Predictability at Manchester Airport

Level of Significance	Difference Between
0.01	< 1 hour journey and the remainder of the sampled population
0.01	2 - 3 hours journey and the remainder of the sampled population
0.01	>3 hours journey and the remainder of the sampled population

Conclusion: At Manchester Airport, a passenger's accuracy of the prediction of journey time can be said to be dependent on the distance to be travelled to the airport.

7.4.3 Analysis of prediction accuracy by frequency of travel

Another factor that was believed to influence the prediction of journey time to the airport was investigated. The travellers surveyed were asked how many times they had flown from the survey airport in the previous year. Using the accuracy score from the preceding investigation, with the same limitations, it is possible to compare the accuracy of access journey time and the frequency of travel to the airport. The following frequency categories were used:

a) First time

b) 1-3 times in the previous year

c) 4-5 times in the previous year

d) ≥6 times in the previous year

The results obtained and displayed in Table 24 for the Scheffé S test were relatively disappointing. Only one group, those that had used Birmingham Airport for four or five times previously in the previous year, was found to be significantly different. Passengers using Birmingham Airport more than six times were very close to being significantly different from the remainder of the sample population.

Table 24 Scheffé S Test for Frequency and Predictability at Birmingham Airport

Level of Significance	Difference Between
0.05	4-5 trips per annum and the remainder of the sampled population

It is of interest that poor prediction of access journey time does not appear to be affected by the frequency of use of the airport. One might expect those people who regularly use an airport to have a greater knowledge of the journey time. With this greater knowledge regular travellers might adopt tighter time schedules for which unexpected hold-ups have a greater impact.

Conclusion: The prediction accuracy of access journey times for both airports surveyed is not dependent on previous experience, except for Birmingham Airport passengers with 4 or 5 previous trips in the previous year. This group was significantly better at predicting their access journey time than the rest of the population.

7.4.4 Margin of safety allocated by frequency of travel

The next area for investigation was the margin of safety allocated by travellers compared with frequency of use of an airport. The only result that proved to be significant was the category of first time users of Manchester Airport who had a larger margin of safety that other travellers as shown in Table 25. It appears that with experience of an access journey to an airport, travellers reduce their margin of safety, reflecting a level of confidence in their journey. However, the level of confidence does not continue to reduce the margin of safety as the traveller becomes more knowledgeable about the airport access journey.

Table 25 Scheffé S Test for Frequency and Margin of Safety at Manchester Airport

Level of Significance	Difference Between
0.05	First time users and the remainder of the sampled population

Conclusion: At Manchester Airport first time users had significantly larger margins of safety than passengers with more experience.

7.4.5 Purpose of trip

Evaluating the differences between reported expected arrival time and the start of flight check-in procedures, it was hoped would provide an insight into the planning decisions made by different categories of passengers. Three distinct categories from the questionnaire were selected for the purpose of this analysis:

a) Business and Conference, Trade Fair or Exhibition

b) Package tour holiday and Package Tour flight

c) Visiting friends and relatives and other non-business

The selected groups were tested for relationships between the expected time of arrival and the start of flight check-in time. The Scheffé S test results revealed that none of the groups were significantly different at Manchester or Birmingham Airports.

Conclusion: The purpose of the journey does not cause any significant change in the planned access arrival time for travellers using Manchester and Birmingham Airports.

7.4.6 Journey time to the airport

The explanation for the difference between the Manchester Airport and the Birmingham Airport samples could simply be a reflection of the flight categories that each airport supports. Manchester Airport's survey population, consisting of predominantly charter and holiday traffic is likely to be travelling significantly farther than Birmingham Airport's population. This is because more often than not the departure airport is not entirely at the discretion of the individual traveller. In contrast, scheduled flights are generally more widely available, except for some specific long haul flights. As a simple test of this belief the mean access journey times for both airports were calculated. The results are shown in Table 26.

Table 26 Mean Ground Access Journey Time

Airport	Mean Journey Time
Manchester	86.4 Minutes
Birmingham	59.6 Minutes

The results show that the Manchester Airport's surveyed travellers on average will travel approximately 25 minutes longer than Birmingham Airport's travellers. The difference between these mean times of 25 minutes equates to 25 miles at an assumed average speed of 60 m.p.h. This result supports the view that the airport access journey distance will be dependent on the type of flights operating at an airport.

7.5 Arrival Distributions at Manchester and Birmingham Airports

For the purposes of the second part of this research it is important to identify actual arrival distributions at both Manchester and Birmingham Airports. From the Scheffé S test results outlined earlier it has been shown that different arrival distributions exist between the two airports and between certain categories. Figure 2 presents the cumulative frequency of access arrivals for both airports. The results are shown in relation to the start of check-in procedures. The start of check-in procedures indicates the time that airlines requested passengers to arrive at the airport prior to the scheduled time of departure (STD) of the flight. For example, Domestic = 30 minutes prior to STD, European = 60 minutes prior to STD.

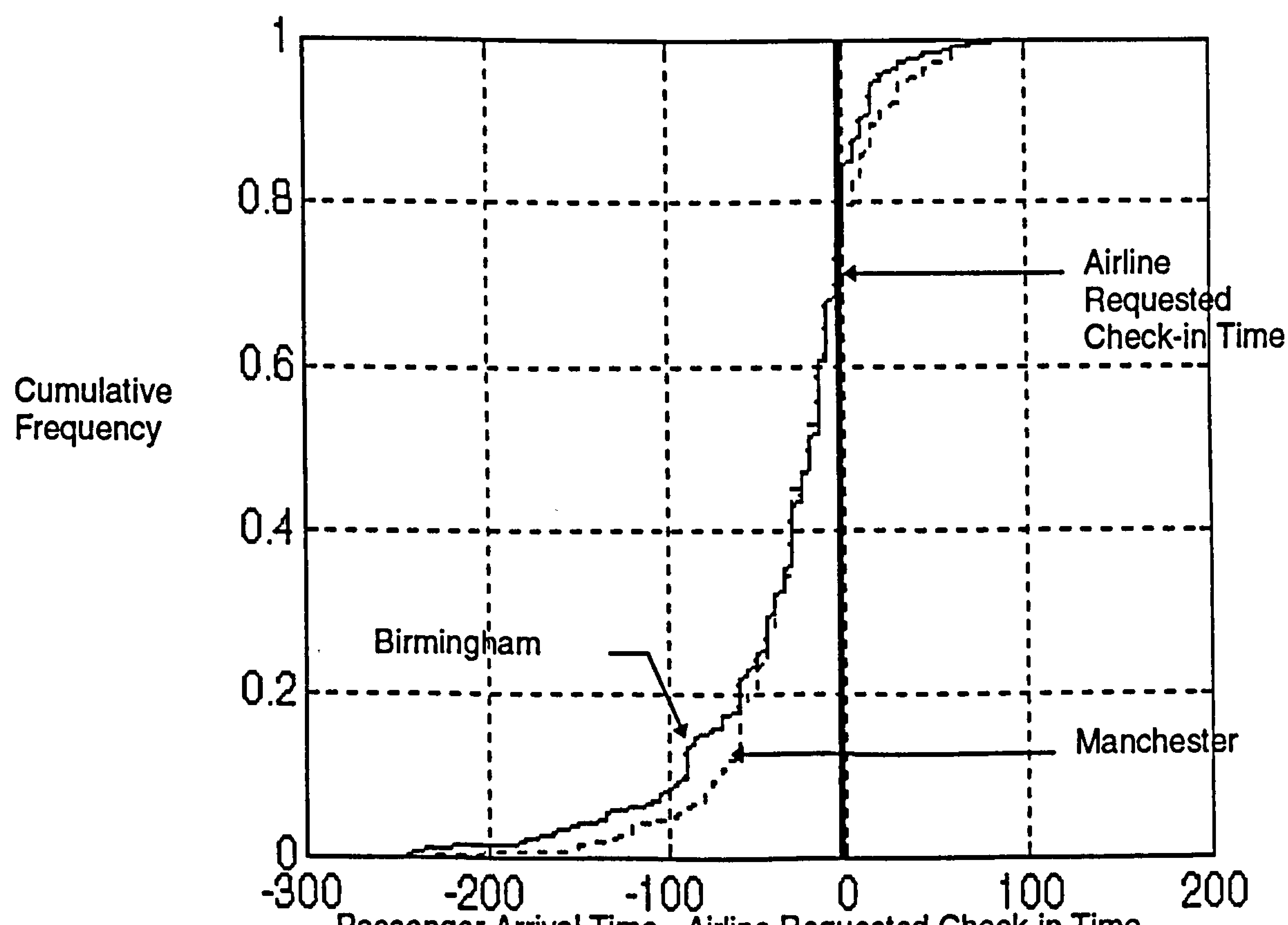


Figure 2 Passenger Arrivals at Manchester and Birmingham Airports

The figure shows that Manchester and Birmingham airports have similar arrival distributions. Birmingham Airport receives a larger proportion of early arrivals; Manchester Airport's rate of arrivals increases about an hour before check-in facilities open. This rate then slows, with approximately 20% of Manchester Airport's passengers arriving up to 90 minutes after check-in desks are available. This compares with approximately 15% of Birmingham Airport passenger arrivals for the same period. These points are made clearer by frequency histograms for the two airports, which are given in Figure 3 and Figure 4 which follow.

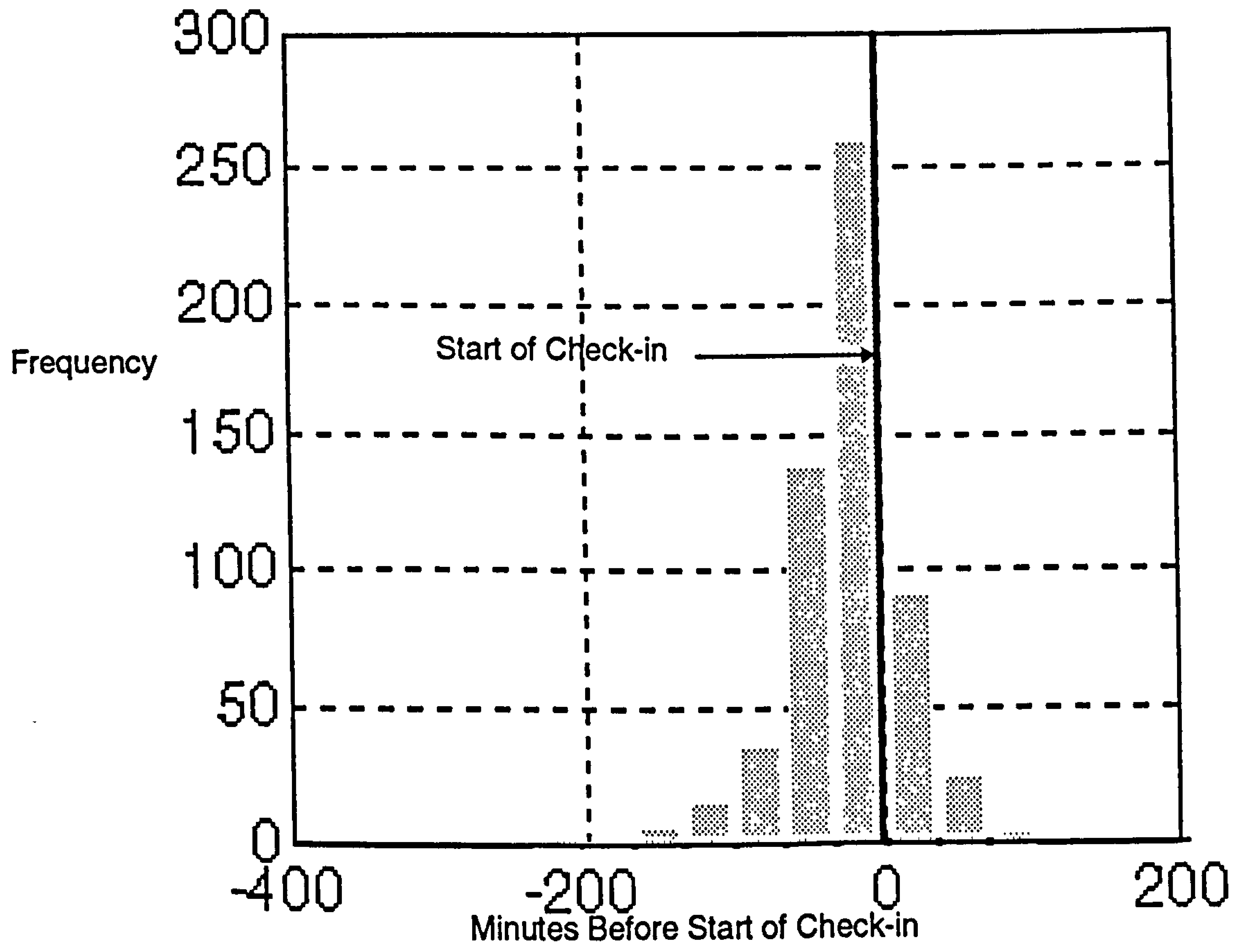


Figure 3 Arrival Distribution in Relation to Start of Check-in at Manchester Airport

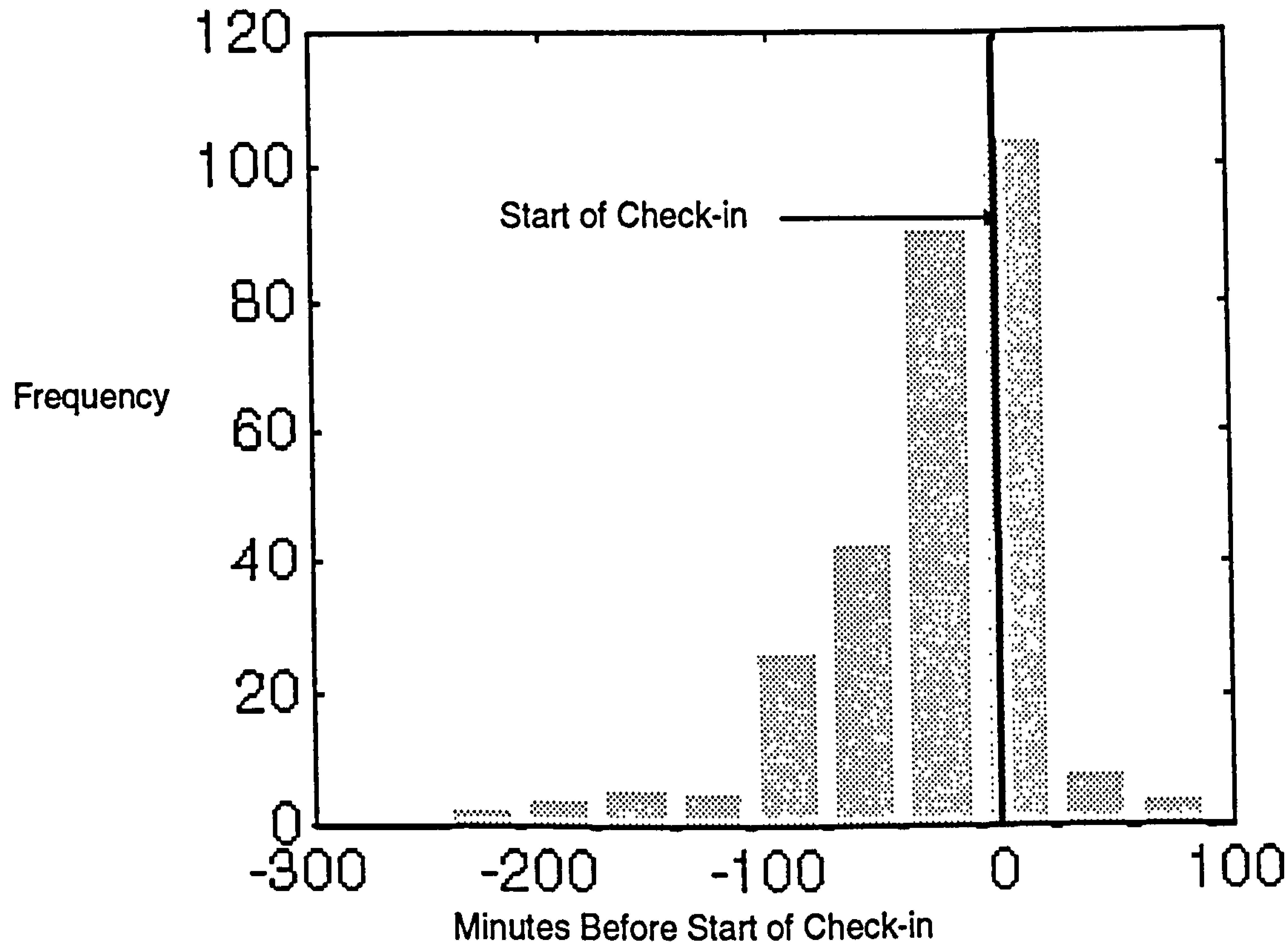


Figure 4 Arrival Distribution in Relation to Start of Check-in at Birmingham Airport

7.5.1 Domestic Ground Access Arrivals at Manchester Airport

The distribution domestic ground access arrivals at Manchester Airport are shown in Figure 5. It reveals an increase in the number of ground access arrivals up to a peak before start of check-in time proceedings. In all probability the results are unrealistic because people arrive after the start of check-in proceedings, however, with the short amount of time available travellers are less likely to stop to speak to the survey team.

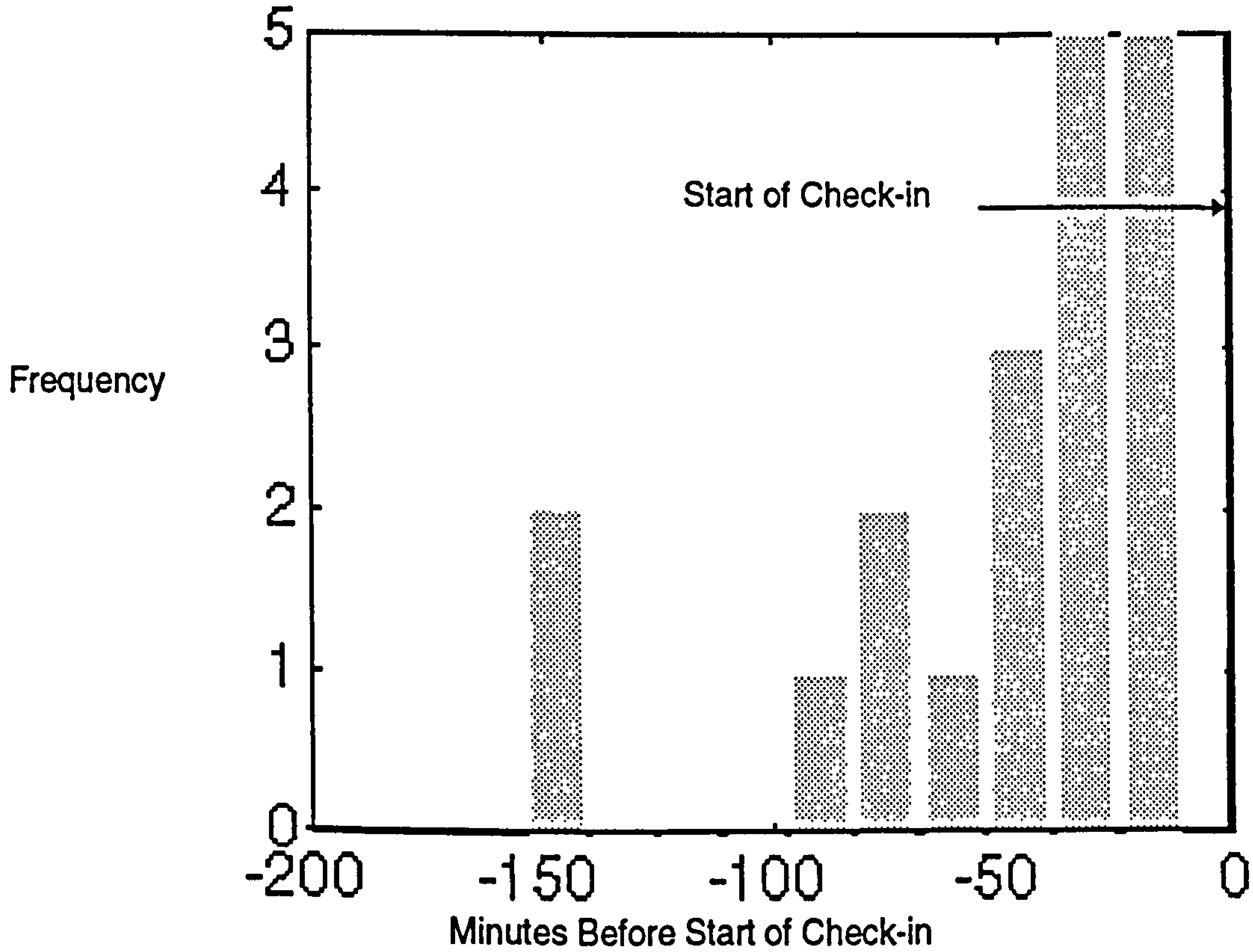


Figure 5 Histogram of Domestic Ground Access Arrivals at Manchester Airport

7.5.2 European Ground Access Arrivals at Manchester Airport

The European ground access arrivals at Manchester Airport are shown in Figure 6. The results show the number of arrivals increasing as check-in facilities prepare to open. Travellers continue to arrive at Manchester Airport after airlines have started to check-in flights. This greater period of check-in time associated with the European category compared with the domestic results seems to affect the shape of the arrival distributions.

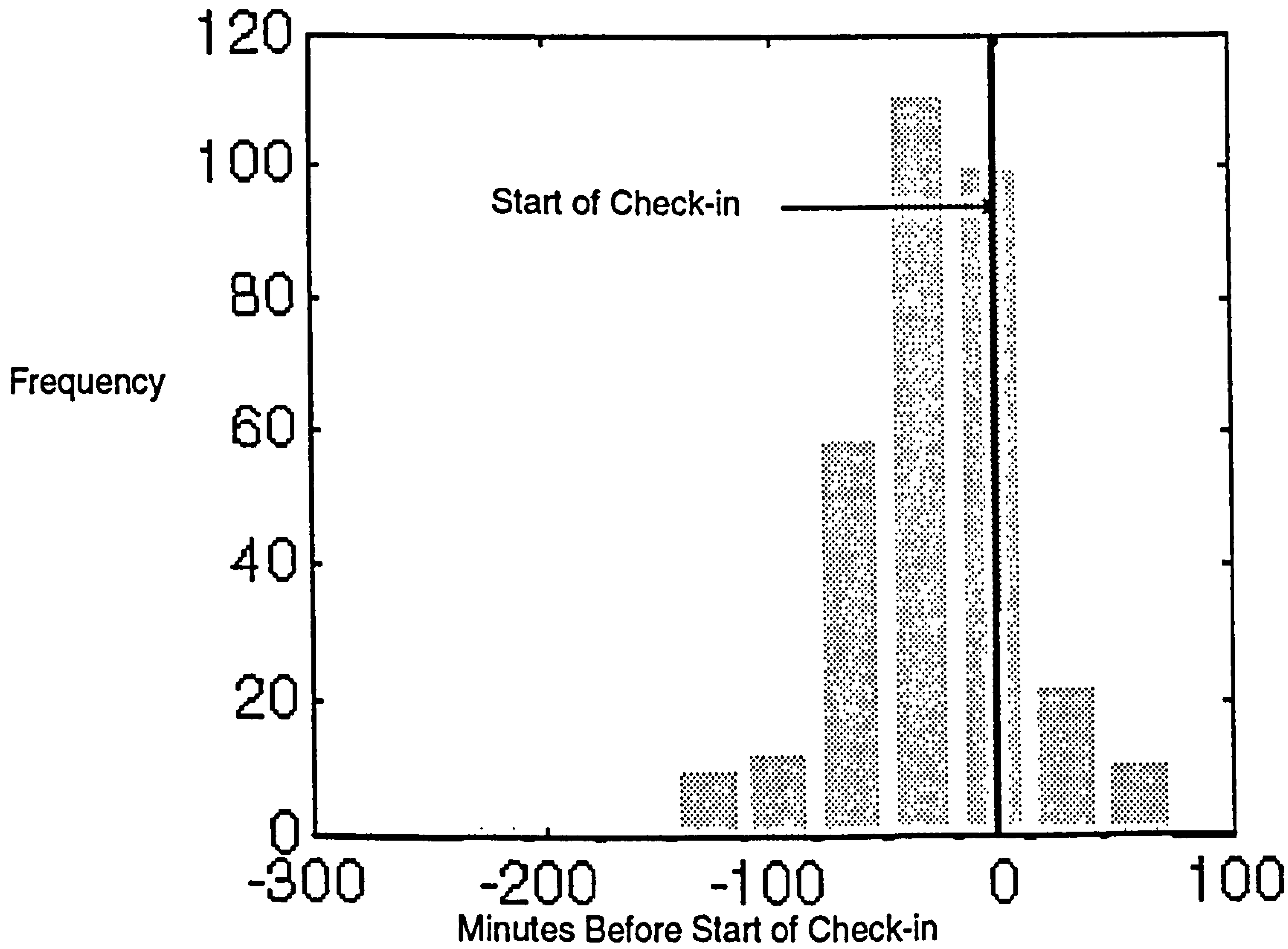


Figure 6 Histogram of European Ground Access Arrivals at Manchester Airport

7.5.3 N. American Ground Access Arrivals at Manchester Airport

Figure 7 below shows the arrival distribution for check-in for North American flights. The histogram reveals a much more balanced distribution with a greater proportion arriving after the start of check-in proceedings, when compared with the previous histograms. The reason for this lies in longer check-in periods for flights some of which were recorded as being between 3 and 4 hours. This longer period of time before STD clearly affects travellers' decisions and more importantly the observed arrival distribution. Some travellers surveyed felt that it was unnecessary to have such a long period for check-in and deliberately arrived after the start of check-in. Others aimed to get to the airport for the start of check-in as would be done for any 'normal' flight with standard check-in periods.

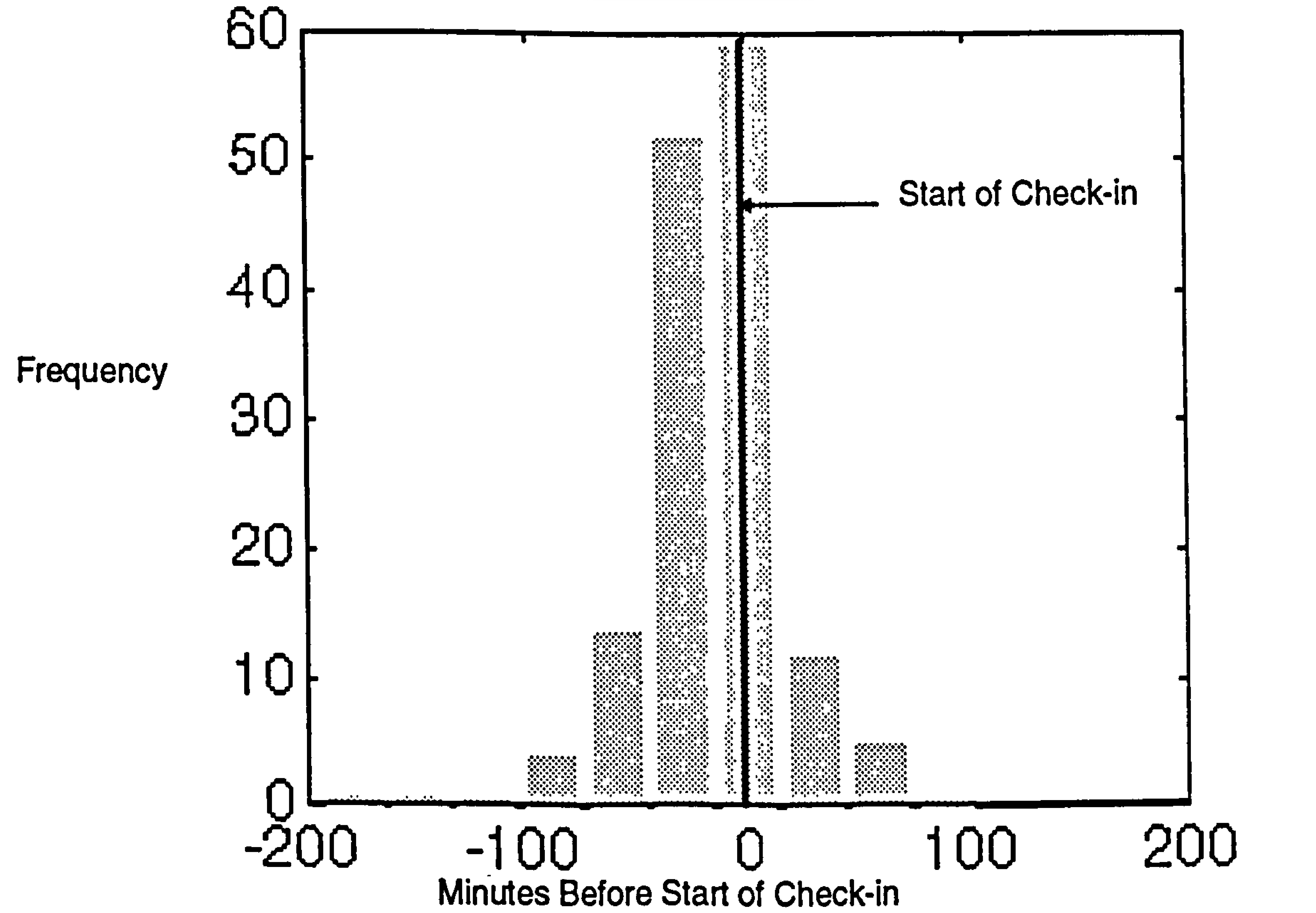


Figure 7 Histogram of N. American Ground Access Arrivals at Manchester Airport

7.5.4 Rest of the World Ground Access Arrivals at Manchester Airport

Figure 8 reflects the arrival distribution for the Rest of the World flights at Manchester Airport. The distribution reflects a similar trend observed for the N. American flights with a large number of travellers arriving at the airport before the flights have begun to check-in. However, more people arrive after the start of check-in compared with the other distributions. No one reason appears to explain this difference, but it could be due to the long check-in time combined with other factors. Although not surveyed, it is possible that some travellers returning home to foreign countries might act as though using their home airport. Other airports may have different access and processing characteristics compared to Manchester Airport.

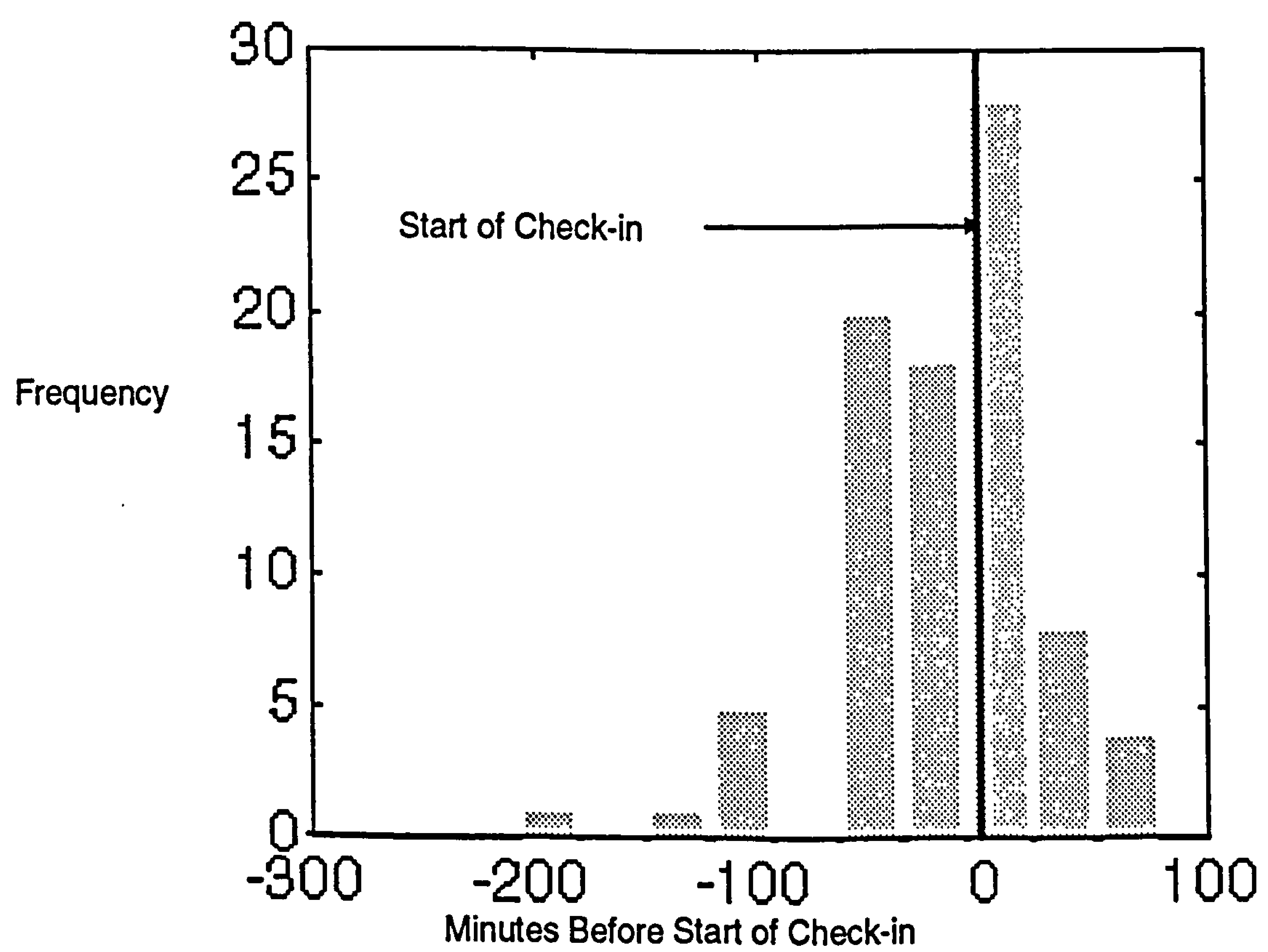


Figure 8 Histogram of Rest of the World Ground Access Arrivals at Manchester Airport

7.6 General Observations

The overall view of the arrival distributions at Manchester Airport is that people tend to arrive before check-in proceedings have commenced. The mean arrival time for Manchester Airport from the survey is 27 minutes before the start of check-in proceedings. This aspect has implications for the operation of the terminal if the trend of the arrival distributions was to shift further away from the start of check-in proceedings, or if check-in periods were lengthened. Birmingham Airport survey population produced an even more extreme figure at 33 minutes before the initiation of check-in procedures.

The only real caution in drawing this conclusion is that the sample may be skewed. A possible bias could exist through not surveying travellers that arrive very close to their flight departure time. As was pointed out earlier, these travellers are not inclined to participate in such surveys because of the limited time they have available to complete the remaining processes before the departure of their flights.

7.7 Summary

The air traveller survey was conducted mainly to discover if some highly significant factors have previously been overlooked which affect traveller decision making. It turns out there are lessons to be learned from the traveller survey. For example, travellers tend to allocate margins of safety in blocks of time, such as 15 or 30 minutes. This suggests that travellers are not trying to plan their arrival to a specific time, but to a time frame. The survey also underlined the feature that not all airports experience the same arrival patterns. The arrival patterns observed will reflect the flight mix that each airport supports. These facts will be carried into the next part of the research, that of simulating the affects of changing arrival distributions on a number of airports.

8. The Simulation of Passenger Flows

This chapter marks the start of the second part of this thesis.

8.1 The Case for Modelling Passenger Flows

A probable outcome of increased ground access congestion will be a change in trip duration and consistency of individuals' travel times to airports. As has been explained in earlier chapters, these changes will be exaggerated because of the perceived importance of arriving at the airport on time. This importance has been revealed to be extremely high for airport access journeys. Some travellers surveyed were prepared to arrive over six hours prior to flight departure [Manchester Airport Survey, 1993].

Planners and operations staff at airports should be aware how travellers' uncertainty of the access journey influence arrival patterns and what causes this uncertainty. Even more crucial is that these people have an understanding of how the changes in arrival will affect the functional efficiency of their airport terminals. The consequences of a change in arrival distributions will potentially affect the facility requirements in terms of capacity, allocation of space and the type of the activities conducted within the terminal by travellers.

If traveller habits, such as retail purchases and lounge dwell times, change significantly current management philosophy should be reviewed. If there was a reduction of amount of time travellers have available for non-essential activities because of arriving closer to flight departure time there might be an affect on retail purchases.

The income generated by retail outlets is currently a prospering revenue area for most airports. Therefore any change in the consumer spending in the retail outlets will have a knock-on effect on the airport operator. A reduction in revenue would have a large impact on those airports geared towards retail income, such as Heathrow Airport in London. Alternatively, if the availability of time to travellers in the terminal areas increased, travellers may demand a greater variety of retail facilities. Ostensibly this might appear to be ideal for the airport, but the fact that people are spending more time in the terminal has its drawbacks. It causes an increase in the number of travellers within the terminal. This will increase in the demand for floor space within the terminal area. The end result of travellers spending more time in the terminal will be that the travellers and the facilities they demand both require valuable floor space. The result is a dilemma for the airport authority of finding a balance between meeting desired levels of comfort for travellers while at the same time maximising revenue.

It is therefore necessary to develop an appreciation of what the impacts will occur as a result of a change in arrival patterns for airports. To achieve this objective, the first step is to develop a representative model of an airport terminal and its passenger flows. The next step is to discover what changes occur to the passenger flows as a direct result of modified the arrival patterns. This chapter discusses the role of simulation and reasons for conducting airport modelling.

8.2 The Role of Simulation

Simulation supports three main functions:

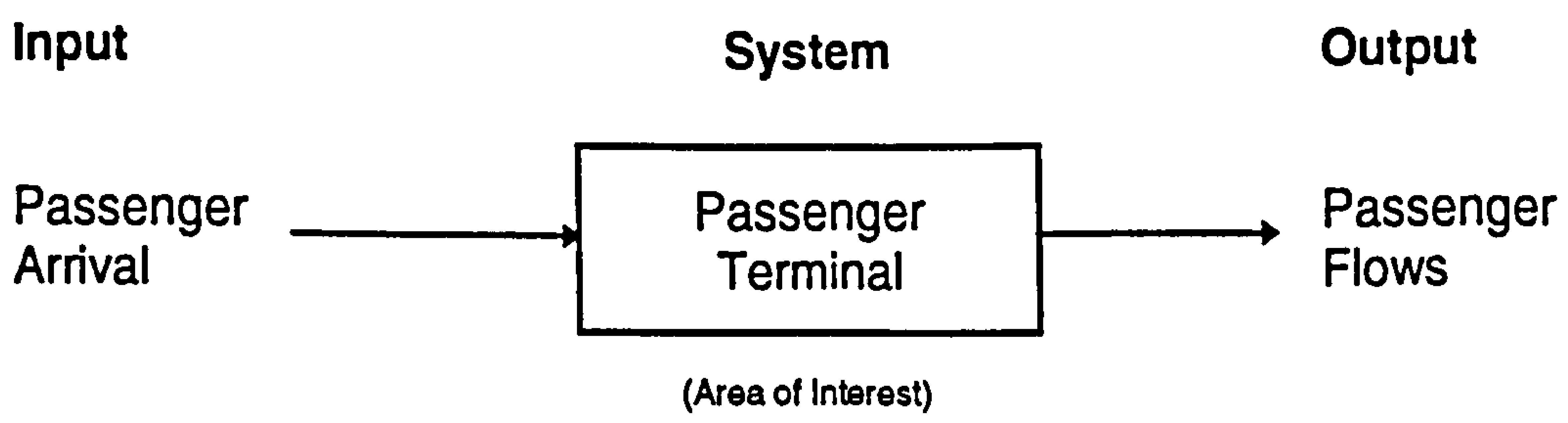
a) Tractability:- when real system observation is either too time consuming, too expensive or still at the planning stage.

b) Training purposes: - to provide experience without the risks, for example, flight simulators for pilots and business games for managers.

c) Understanding the unknown:- to provide an insight into a poorly understood system.

The purpose of simulation is to discover how an existing system will function given a change in input characteristics and what effect, if any, this will have on the output of the system. In this research the system under consideration is the airport terminal. The system inputs are the passenger arrival distributions and system outputs are the passenger flows within the terminal that result, as shown in Figure 9.

Figure 9 A Simple Simulation Model



Although simulation is a powerful tool it is important to remember it is not easy or cheap to apply correctly. 'The basic ideas of simulation are simple and straight forward, and as a proposal for analysis might appear attractive. However, it is all too easy to underestimate the amount of time required to collect and compute results' [Taylor, 1991].

It is important to emphasise that simulation is not a stand alone problem solving tool. It is used to assist in the solving of problems by showing what the outcome might be under a certain number of preconditions. Unlike linear programming and similar techniques it will not produce an answer showing the best method for conducting a project. Simulation results therefore provide outcomes that must be evaluated and applied by the user, who must keep in mind the simulation conditions that were established.

The purpose of using airport planning models in this research is to learn what the potential outcomes may be of a change in the arrival pattern of passengers. The results from the simulation modelling will be assessed for evidence of trends and identification of possible impacts on the airport terminal. Although the results produced may not be an accurate prediction of capacity requirements and possible queue lengths, they will identify strengths and weaknesses of existing terminal design and operation at the airports modelled.

8.3 The Modelling of Airports

Airport modelling tools have the primary objective of providing planners with a means of assessing what the effects might be of making modifications to an airport. The benefits to planners of modelling are in saving time and money. It offers the ability to study the effects of change without external expenditure and in a relatively short period of time. It is therefore a cost effective solution.

Airport developments are extraordinarily costly. BAA have revised their plans for Terminal 5 at Heathrow Airport. They now estimate that construction costs will be in the region of £800 million. The final cost could exceed £1 billion.

By modelling a proposed layout errors in design can be corrected and alterations made before any structural work commences. The long term implication for the airport industry of improvements in simulation skills and software is that planners will increasingly be able to produce more successful designs, while at the same time reducing the number of expensive errors. The simulation modelling capability is becoming increasingly more sophisticated with enhancements in Information Technology (IT), however, there are limitations to this technological solution.

Probably the most significant factor is that assumptions have to be made for any simulation exercise. For example, assumptions must be made about passenger behaviour within the terminal. Making assumptions is necessary to achieve any significant results but it is far from ideal.

Another problem for airport planners is that it is not possible to predict future changes to international regulations and guidelines. For example, some US airports have been forced to alter their terminals dramatically with the introduction of stricter security regulations to counter terrorism and other security hazards. Airports such as Kansas City Airport, which had been designed with the objective of minimal walking distances for passengers, had to be modified to meet the new security regulations. The changes fundamentally affected the flows of passengers within the airport's 'horseshoe' shaped terminals.

Planners should anticipate the need for modifications to their designs. The simulation capability can be used both to assist in optimising the modifications and minimising the operational impacts during the implementation phase of modifications.

9. The NAPA Terminal Flow Model

The main model selected for this part of the research is the NAPA Terminal Flow Model. This chapter will outline the model and how it operates to illustrate its suitability for modelling changes in arrival distributions. To achieve this objective, a guide to the structure and processes which support the operation software package follows.

The NAPA model operates using a simulation language called GPSS. This language is complex and to avoid airport planners having to be literate in GPSS the software writers produced a 'front-end', or pseudo compiler to allow for 'easier' operation. The pseudo compiler provides a template for data entry into the terminal flow model. The product of successfully entering the correct data is a simulation model. This model produces volumes for static facilities and queuing levels for dynamic facilities. These features combine to represent the flows that occur within an airport terminal.

The pseudo compiler takes a series of tables completed by the modeller and converts them into GPSS coding (ASCII standard text format) for simulation. After the simulation iteration has been completed the results can be read by an extraction program.

To successfully construct a model the pseudo compiler requires a series of tables to be completed correctly before it will run effectively and correctly. The tables required for the simulation of departing passengers are as follows:

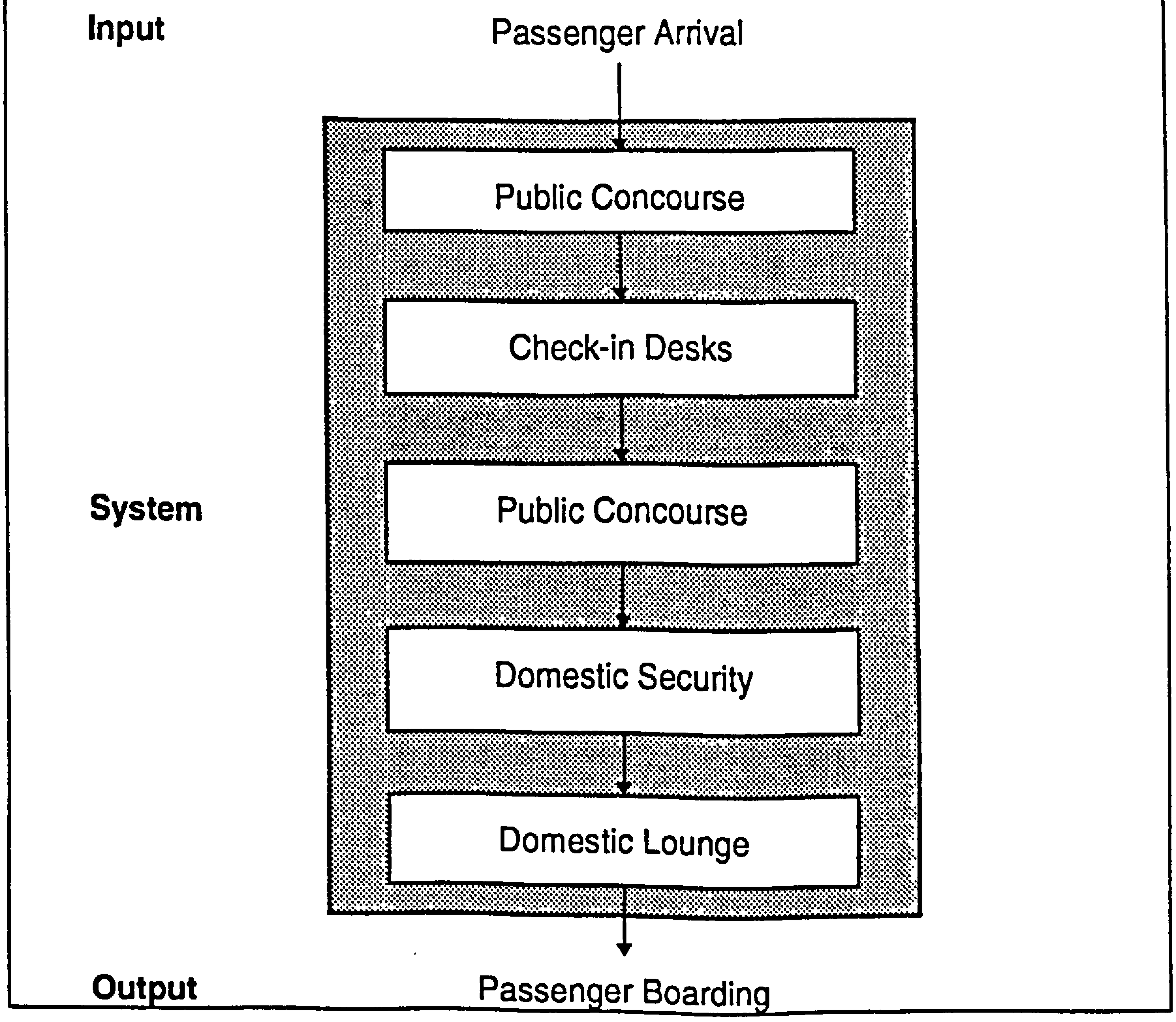
1. Facility Table
2. Precedence Table
3. Function Table
4. Variable Table
5. Check-in Table
6. Departure Scenario Table
7. Arrival Pattern Table

These tables are used to enter process specific information and data which is used during simulation to control the movement of passengers. The end result is a representation of the passenger flows through an airport terminal. An example of a typical flow diagram for such a process can be seen in Figure 10.

An important aspect to appreciate is that passengers are restricted to a single direction through the model and therefore cannot revisit a facility. Also there is the restriction of model development is restricted to seven stages (facilities or processes) because of the graphical limitations of the software.

To examine how such a flow diagram is turned into a model within the GPSS software it is necessary to discuss the role and structure of the various tables which make up the pseudo compiler individually. Each of the tables is essentially a database that is used by the program to build an ASCII file. This file sets the parameters and variables with which the GPSS software will operate. Each data entry within the tables has a specific and unique record number. The pseudo compiler tables are outlined in the following sections. Examples of the pseudo compiler tables used for this simulation research can be seen in Appendix 3.

Figure 10 Typical Passenger Flow Diagram for a Domestic Terminal



9.1 The Precedence Table

The Precedence Table consists of a number of uniquely named entries. Each entry relates to a facility to be modelled. The table is then used to set the order in which passengers encounter facilities as they pass through the model. The user must specify the preceding and following facilities for each facility entered.

The Precedence Table is used to set passenger flows which must satisfy various specified constraints. The constraints are established for a number of features that must be satisfied before a flow can be modelled. Until the constraints are satisfied the simulation program will continue searching for a satisfactory match. It is possible to establish flows which can either apply to the total passenger flow or to specific target groups or categories. The latter is achieved by entry in relevant columns that classify the passenger flows in greater detail.

The categorisation of the flows can be classified by:

1. **Sector:** Passengers grouped with similar attributes e.g. Destination or charter flight
2. **Agent:** Ground handling agent
3. **Airline:** Flight operator

The flows can be controlled by further restrictions or specifications entered in the precedence table. It is possible to control the time at which a flow can occur. If the modeller wanted to have a facility that was opened for a limited period of time it is possible to establish a start time and end time for which a particular flow can occur.

Not every facility will have the total specified passengers passing through it, for example not all passengers will have their bags searched as they pass through a security channel. It is therefore possible to specify a probability of a passenger experiencing each facility.

Unique to dynamic facilities such as security channels and passport controls, there is a column in which it is possible to establish the number of 'servers' or channels available in a facility. There is one exception to this 'dynamic facility' rule, which is the check-in facility. The check-in facility possesses its own table in which parameters such as the numbers of desks are set. This table will be reviewed later in this chapter.

Not all people that enter passenger terminals are passengers, the terminal also supports people sending or greeting passengers. Within the precedence table it is possible to specify whether or not non-passengers are allowed access to a particular facility by using the 'visitor' column. The entry of 'Y' (Yes) or 'N' (No) in this column establishes whether access to a facility is possible for non-passengers.

9.2 The Facility Table

The role of the Facility Table is to define further each facility that appears in the Precedence Table. A facility can take one of the following forms:

1. **Static:** A facility term that is used to identify areas which have the function of containing passengers. A facility categorised as static is expressed as a volume, such as a public concourse or departure lounge.
2. **Check-in:** This is a very specific facility term reserved for identifying check-in facilities.
3. **Dynamic:** This term identifies process related facilities that will change in size due to the number of passengers passing through it, such as security and passport control.
4. **Baggage:** This facility is specified solely for baggage reclaim devices for deplaning passengers. It is not required in this work but is included in this list for completeness.

The flow from or through each facility is controlled by either a function, a variable or a number. Within the facility table each facility is allocated a 'type of advance' label. This is used to direct the program to the correct table (Function or Variable). Having identified the desired table for the program to view the next stage is to specify an 'advance value'. In the case of functions and variables this takes the form of a unique name for a function in the function table or variable in the variable table. If a number is required an integer is simply entered into the table.

There is a display column in the Facility Table that can be used to indicate facilities which operate simultaneously or within the same area of the terminal. This is used for reviewing results in a clear and structured manner. An example would be to set two departure lounges with the same display number so their performance can be compared easily when viewing the results.

9.3 The Function Table

The program is directed to the Function Table by the Facility Table entry. It selects the relevant information for the required function. Each function has a unique name and form. A function can take one of a number forms:

1. **User defined** function
2. **Erlang** function
3. **Normal** function

The User Defined function, regardless of whether or not it is discrete or continuous, requires specific values to be established. These values are the minimum, the maximum and the mean. The number of data points to be entered by the modeller for the function is also required. The modeller then must enter data corresponding to the number of points as indicated in the previous task. The program checks the points entered for the function against the mean value entered. If the mean value reflects the data entered then the entry can be saved. However if this not the case, a warning message appears on the screen providing an accurate mean reading for the data points entered. The modeller then has the option to either enter new data points in an attempt to match the desired mean or change the mean value to match the data points that were previously entered. It is worth noting that the greater the number of data points entered the smoother the distribution will be. An example of a User Defined function would be the number of 'well-wishers' accompanying a passenger. The function would specify the minimum, maximum and mean number of 'well-wishers'. These values can be calculated to reflect the probability for each number of 'well-wishers' to be modelled. The function would produce a number of 'well-wishers' for individual passengers.

The Erlang Function is a continuous distribution, a form of Gamma function, chosen to reflect service times of dynamic and queue processes within the airport. The key entry values relate to the minimum, maximum and mean, with an additional 'K' value that alters the shape of the distribution; a step size is also entered which affects the smoothness of the distribution. The smaller the step size, the greater number of data points the smoother the resulting distribution.

A truncated normal distribution with a mean of 1 can be achieved by entering a 'Tnorm' function into the table. This can obviously be used when "modelling a 'population' with similar characteristics within a range" [NAPA, 1992]

9.4 The Variable Table

Performing a similar task to the Function Table the Variable Table is used to define the variables for facilities contained in the Facility Table.

The format for the Variable Table is such that the modeller enters the unique variable name, the variable type and the variable definition. The variable name reflects the variable name as entered in the Facility Table. The variable type can take one of two forms VAR or FVAR. The VAR variable is designed for Boolean operations, with the aim of producing either the value 1 or 0. In the variable model, it is used to evaluate whether an equation is true or false. For example, if VAR variable X1 is expressed as:

$$(\text{Flight Time} - 30) > \text{Current Time} \qquad \text{(EQ 2)}$$

The outcome depending on the flight time and the current time will either be true or false. If the answer is true the variable X1 will take the value 1, if false X1 will take the value 0. This could then be used to calculate an FVAR, which returns a true arithmetic answer, which can then be used in the simulation process. For example, if FVAR variable Holdtime is expressed as:

$$X1\ (\text{Flight Time} - 30) - \text{Current Time} \qquad \text{(EQ 3)}$$

If X1 is true, X1=1 therefore Holdtime will have a positive value. It will cause a delay in a facility equal to the value of Holdtime. If X1 is false, X1=0 therefore Holdtime=0. This causes the 'passenger' to move onto the next facility. An FVAR variable can be made up of numerous VAR variables, which allows the modeller to construct models as detailed and sophisticated as required.

9.5 The Check-in Table

This table identifies the processes of the airlines and handling agents checking-in passengers. The facility name is the first entry in the table. The name relates to the name given in both the Precedence and Facility tables.

The objective of the Check-in Table is to define certain criteria. The first is the number of desks used by the airline or handling agent. This of course may vary with the number of passengers checking-in for different flights. The second is the opening of the check-in desks prior to the scheduled time of flight departure.

Data are entered into the series of columns of the table. The main columns of the table are: minimum number of passengers, maximum number of passengers and a number of desks column. This allows the modeller to establish the number of desks that would be opened for different numbers of passengers (or aircraft size) . An example is shown in Table 27.

Table 27 Example Check-in Desk Table

Min.	Max.	Desks
0	100	2
101	999	3

The above example indicates that an airline operates 2 desks for flights with passengers of 100 or less, or 3 for any flights greater than 100.

A further column headed 'Open At' is used to set the number of minutes before the scheduled time of departure of the flight that the allocated number of check-in desks will open.

9.6 The Scenario Tables

The purpose of the scenario tables is to allow the modeller to set the number of people accompanying passengers within the terminal. There are two scenario tables, one for enplaning and deplaning scenarios. As this research is focused on the enplaning (departing) activities of passengers the Deplaning Scenario Table will not be discussed.

Different types of flight will result with different levels of accompaniment. A shuttle flight will probably have a minimal number of 'well-wishers'. Some long haul flights to particular regions of the world, such as Asia, are prone to generating large numbers of 'well-wishers'.

Obviously such occurrences can greatly affect the volumes of people within areas such as public concourses, and therefore running models that reflect these trends are required. The limits for 'well-wisher' numbers can be specified for individual flights. This is achieved through the definitions entered in the Enplaning Scenario Table.

The Enplaning Scenario Table can be used to specify the relevant function from the Function Table that reflects the numbers of 'well-wishers' expected, as well as identifying the sector to which these levels are applicable. Further details can be introduced to identify specific flights. Details such as the airlines or handling agents responsible for a flight or the start and finish time that the function is valid. It is therefore possible to associate 'well-wisher' functions with all flights or to target specific flights, the level of detail is at the discretion of the modeller.

9.7 The Arrival Pattern Table

The Arrival Pattern Table is used to regulate the passengers entry into the model. This table, like the Scenario Table, can be very detailed. The modeller can define the periods when distributions apply as well as defining the distribution variation by sector, airline or handling agent.

The distributions themselves are a series of five points expressed in minutes prior to departure. Associated with each point is a value. The value represents the percentage of the distribution that lies between each of the five points. Therefore four percentage values have to be entered into the table. 'Passengers' will then be generated by the program to reflect the distribution entered by the modeller.

The Arrival Pattern Table is fundamental to the research, because this table will be varied while other aspects of the model will remain unchanged. This approach allows for the evaluation of the impact of changes in arrival distributions to be made. This research is particularly interested in the performance of the facilities and processes in the terminal.

9.8 Data Requirements

In order to build and validate a model, a significant amount of information and data are required about the selected airport. An outline of the data required to construct and run the NAPA models are given in Table 28.

Table 28 Data Requirements for the NAPA models

Data Category	Data type
Flight Schedule	Airline name Airline code Handling Agent Destination/Origin airport Flight number Day ETA/ETD Aircraft Seats Load factor Number of transfer passengers Type of flight (originating/terminating/turn or through) Gate Numbers of Well-wishers/Greeters Dates for schedule is representative
Gate Information	Restrictions (aircraft size) Adjacent gates effected Gate preferences(airline/agent) Buffer time (between aircraft on a gate) Towing operation (time) Maximum gate occupation time before towing commences
Aircraft used	Airlines Seating capacity
Terminal plan	Identify facilities and holding areas (e.g. Concourses) Passenger capacity 'Walking times'
Handling agents	

Sectors: Origin/Destination categories	
Check-in desks	Agent Service times Desks per flight
Security Channels	Number Service times
Baggage Devices	Number Service times
Passport Control	Number Service times
Customs	Number Service times
Concourses	Type Capacity Number
Lounges	Type Capacity Number
Walkways	Walking times

The data requirements for the NAPA models conclude this chapter on passenger flow modelling and the NAPA models. The next chapter examines the process of developing models and details the models that were developed for this research.

10. Passenger Flow Modelling

Having discussed the purpose of modelling and outlined the NAPA modelling tool, the next step is to develop the models. However, before developing effective models it is necessary to prepare correctly. The preparation for such an exercise involves, setting objectives, addressing the modelling limitations and making a number of assumptions. These preparatory activities are reviewed in the following section. The subsequent sections provide detail of how each model was developed.

10.1 Modelling Objectives

To achieve suitable results for this research it is necessary to establish a set of objectives for the modelling process. The six objectives set for this research were as follows:

1. to model three UK airports in terms of passenger flows, as closely to reality as permitted by available data.
2. to conduct 6 scenarios for each model, each scenario reflecting a shift in arrival distribution of passengers.
3. to conduct sufficient iterations to reduce the element chance.
4. to show impacts of a change in arrival patterns on the passenger flows experienced within an airport's passenger terminal.
5. to draw conclusions on any observed trends revealed by the models.
6. to complete the entire modelling process within research deadlines.

To meet the first of these objectives three airports - Manchester, Birmingham and East Midlands International - were selected for modelling. The overall strategic objective of the modelling process was to examine the impacts of changes in the arrival distribution patterns on passenger flows within each airport's terminals.

10.2 Modelling Limitations

As with any project that deals with modelling, there are limitations to the level of sophistication that can be built into a model. The most important limitation on this project is time. Time pressures restrict the amount of detail that can be entered into the model. Model development time is further eroded because the acquisition of relevant data from external sources is time consuming and unpredictable.

The process of building and running a NAPA Terminal model can be broken down into the following stages:

1. Input of terminal schedule (and editing)
2. Allocation of gates
3. Entry of the pseudo compiler tables
4. Simulation
5. Retrieving results
6. Data entry into spreadsheets
7. Analysis
8. Reporting

The tasks outlined above are affected by other factors such as computer speed. The computer speed affects the amount of time taken to complete a simulation iteration. A total of 600 iterations had to be conducted for this project. Unfortunately, the NAPA software results facility is not a flexible tool; it turned out to be quicker to manually record the results. To print the results of an iteration takes longer than the completion of the simulation iteration itself! Manual extraction of results from the NAPA software proved to be the most effective, economical and 'environmentally friendly' method of recording the results.

Another limitation of this project is the so called 'commercial sensitivity' of the information provided by the airports to the researcher. This meant that certain information would not be made available for modelling purposes. Consequently it was necessary to make assumptions to complete the models. The assumptions made were based on information from other airports and personal experience of departmental staff.

Another limitation identified relates to the availability of people with experience of using the NAPA software. The available NAPA software support was based in Canada, and was therefore generally not as effective as perhaps it might have been had it been based in the UK. The skills required to operate the software were acquired gradually through practical experience. One of the hardest aspects of the software to grasp was the use of protocols used to define variables. The use of Boolean equations and the structure of the protocols required particular attention.

The software also has its own limitations, such as the model size, which is restricted by the software's capacity to display the results using its on-screen animation facility. Although the animation facility was not required, it is not possible to develop a model that extends beyond the constraints established by the software's producers. For this reason large areas had to be grouped together and the end results tend to reflect a general, rather than a detailed picture of passenger flows. Other restrictions included the unidirectional flow of passengers; having passed through a facility passenger cannot return to it. This restriction prevents the detailed simulation of activities such as shopping within a terminal concourse.

Any simulation modelling requires a number of assumptions to be made and modelling passenger behaviour within terminals is no exception. This limits the human factor element achievable within the model's processing. For example, when simulating a queue, the software uses a 'first in first out' rule, which in reality is not necessarily realistic. A passenger screaming "I am going to miss my flight" and dashing to the front of the queue may be allowed entry ahead of those waiting in the queue. People will also act differently depending on what they see. Passengers may alter their behaviour simply because there is a queue for a facility, joining the queue earlier than they might otherwise have done. This sort of behaviour is hard to accurately replicate using this software.

The software also assumes that all flights leave on time, which seldom occurs in reality. Therefore the holding areas represented in the models, such as the departure lounges do not experience the higher passenger volumes that would occur through flight delays. Other aspects that cannot be reproduced in the models include the airlines' ability to temporarily hold a flight departure, in order to allow a group of inbound passengers to catch their connecting outbound flight.

Using variables and functions to control the flow of passengers assumes that all passengers will react in the same way. However, the variables and functions adopted for a model can never truly reflect the 'real world' situation. This must therefore be acknowledged to be a limitation of this technique. For example it is not possible to reflect personal preference for retail facilities within the terminal.

The schedules used in the models are for a single day and therefore the simulation results are only a 'snap-shot'. Ideally for the model to achieve 'realism' it should be run to represent a longer period of time and iterated to a greater extent. Due to the limitations of information provided by the airports and the time available this was not a possible.

For the purpose of experimental correctness each scenario was iterated twenty times. This was done to minimise as far as possible random values that can occur when simulating within the time constraints of the project. A figure of higher than twenty iterations would have further reduced the element of chance in the results. However, with consideration of the research's assumptions and time constraints, twenty iterations was deemed to be appropriate.

These identified limitations are not significant enough to negate the validity of the modelling process. In order to minimise impact of these limitations, and produce a working model it is necessary to make some assumptions. The assumptions made for the models contained in this thesis are provided in the next section.

10.3 Assumptions

As was indicated earlier, limitations in the available data require modellers to make assumptions to achieve working models. The assumptions made for the purposes of this research were:

1. A single day was chosen from a peak month to reflect higher levels of passenger flows expected during this time of the year.
2. Service times and dwell times were synthesised if no data were available.
3. The flow of passengers is unidirectional through the terminal facilities.
4. Passengers within each category would act similarly.
5. All aircraft depart on time.
6. The five models built should contain different passenger mixes to reflect the unique traffic mixes of the terminals on which each model was based.
7. Passengers have the same knowledge.
8. The five models should each experience the same changes to the passenger arrival patterns.
9. Passengers will have an associated 'well-wisher' function.

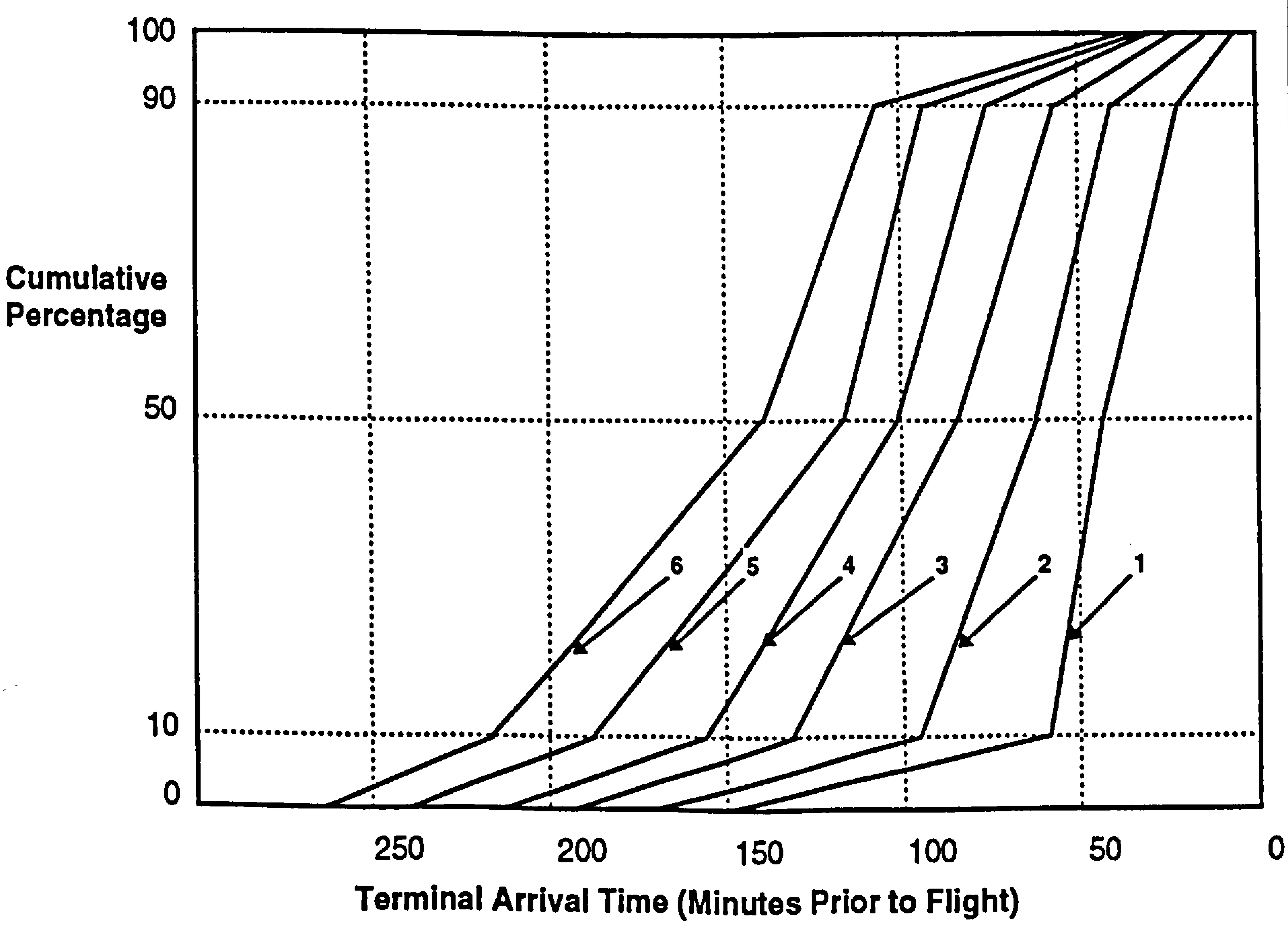
As long as the results and conclusions drawn from the modelling process take account the outlined limitations and assumptions, this methodology remains valid and therefore can be used for this research.

10.4 The Six Scenarios

For each model developed for this research arrival distributions are used to control the arrival patterns of passengers at the terminal. In order to appreciate the affects of a change in arrival distributions the decision was taken to conduct simulations using an even range of six arrival distributions.

The six arrival distributions were created from distributions either provided directly by the relevant airport or calculated from the surveys conducted in part 1 of this research. These distributions were plotted onto a single graph. From this graph it was possible to select the steepest and shallowest arrival patterns. The steepest distribution was the domestic sector arrival pattern for Manchester Airport and the shallowest was the European sector arrival pattern for Birmingham Airport. These extreme patterns were used to set the limits for a series of evenly spaced curves ranging from one extreme to another. Four curves were drawn between these extremes at equal intervals until a total of six curves had been plotted. These six curves can be seen in Figure 11.

Figure 11 Six Arrival Distributions for Terminal Passenger Flow Simulation



These six curves were used to produce the 'mixes' of arrival distributions for the models under consideration. Using another of the NAPA models, the SCIM model, it was possible to evaluate from each airport's schedule the proportion of passengers for each sector or flight category. In accordance with the proportions calculated, each sector's arrival pattern was weighted and compared to the six new curves. With these proportions and weightings it is possible to calculate synthesised arrival distributions for each sector that when combined provide an arrival distribution that matches the desired scenario curve. Each set of synthesised arrival patterns (six in all) form the input for one scenario. Each model can then be tested to see how it would be affected by the shift in arrival patterns.

It was identified earlier in this that given a greater uncertainty of arrival time that passengers may use a margin of safety in their journey planning. Assuming the availability of time with which to make this allowance, the greater the uncertainty the greater the margin of safety that can be anticipated. The use of a range of arrival patterns was chosen because it is possible that passengers might arrive at the airport a great deal later than they anticipate which may also affect passenger flows. It may also produce trends that can be used in the analysis of shift in arrival distributions. It is important to remember that observed arrival patterns were used to set the boundaries for the six arrival patterns.

Each of the five airport models was allocated its set of six arrival patterns. For each of the scenarios the airport model's arrival pattern file was modified to take into account a set of these arrival patterns. The aim of the scenarios is to assess how airport terminal flows are affected by a change in arrival patterns. Scenarios 1 to 6 reflect a range of arrival patterns. Scenario 1 reflects a distribution with a high proportion of passengers arriving at the airport terminal relatively close to the scheduled time of departure. Scenario 6 on the other hand reflects passengers arriving gradually over a longer period of time.

11. The Five Models of Terminal Passenger Flow

Descriptions and visual representations of the models produced for this research are given in the following sections. Due to an agreement with the airports the models and subsequent results are not allowed to be used without written consent. It is also important to note that at the time of this research high security was required for N. Ireland flights. It is to be hoped that the need for this country specific security will be reduced in the future.

11.1 East Midlands International Airport

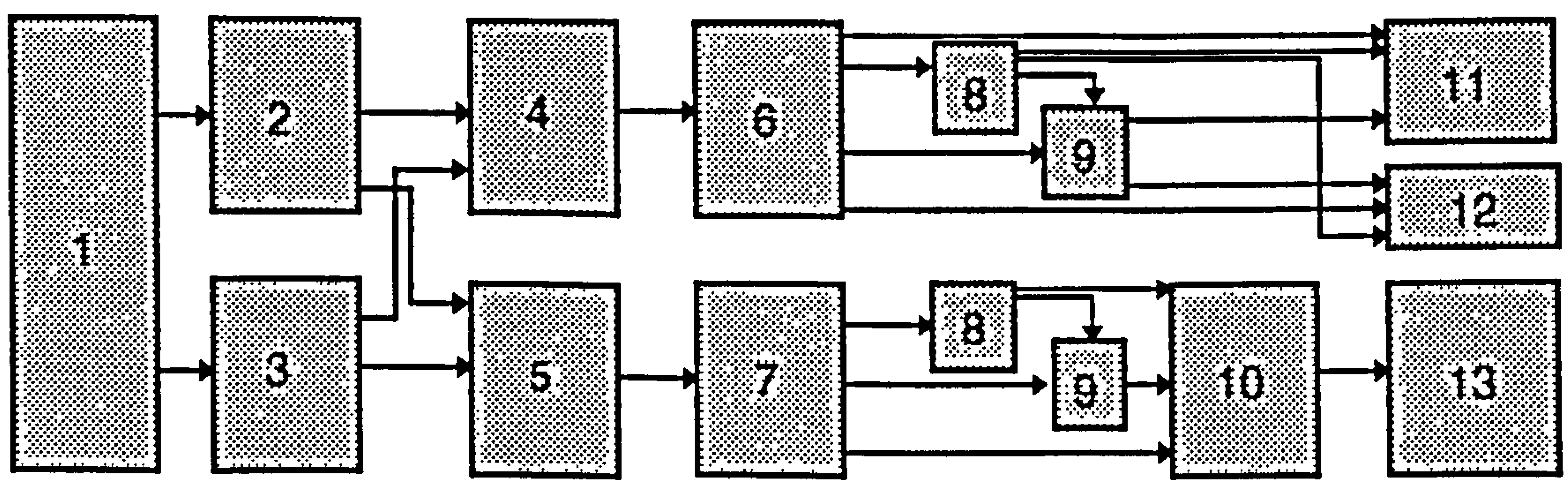
A visual representation of the East Midlands International Airport (EMIA) model is shown in Figure 12. Passengers are generated in a public concourse, where they congregate until the check-in desks open. There are two check-in desk areas run by two different handling agents. The handling agents deal with both domestic and international flights.

Having passed through the check-in facilities the passengers return to the public concourse, where all the passengers can freely mix. In this model the public concourse is identified by two public concourses numbered 1 and 2. The reason for this is due to the requirement for each facility to have a unique name, and with flow being unidirectional it is necessary to have a different name for the pre and post-check-in facilities. The difference between the two post-check-in facilities is that 1 identifies domestic passengers and 2 identifies international passengers. It is important to remember that the three public concourses are in reality one, and passenger volume for the passenger concourse is therefore the total of all three.

From the public concourse the passengers then move to a security facility. Depending on the destination of the passengers, they either enter the international security facility or the domestic security facility. During security processing it is also possible that passengers may experience a frisk (body search) and/or a bag search. For this model there are three international security channels and a single domestic security channel. The probability associated with the frisk and bag search facilities are low, but for some categories of flight the probability is higher, such as flights to N. Ireland.

After clearing the domestic security area, domestic passengers can either move into the domestic departure lounge or the N. Ireland lounge. International passengers after clearing international security proceed to the passport control facility and from there into the international lounge. Passengers depart from the lounges when their flights are called.

Figure 12 Simplified Flow Diagram for EMIA



1 Public Concourse
2 Agent1 Check-in Desks
3 Agent 2 Check-in Desks
4 Public Concourse 1
5 Public Concourse 2
6 Domestic Security
7 International Security
8 Frisk Facilities
9 Bag Search Facilities
10 Passport Control
11 Domestic Lounge
12 N. Ireland Lounge
13 International Lounge

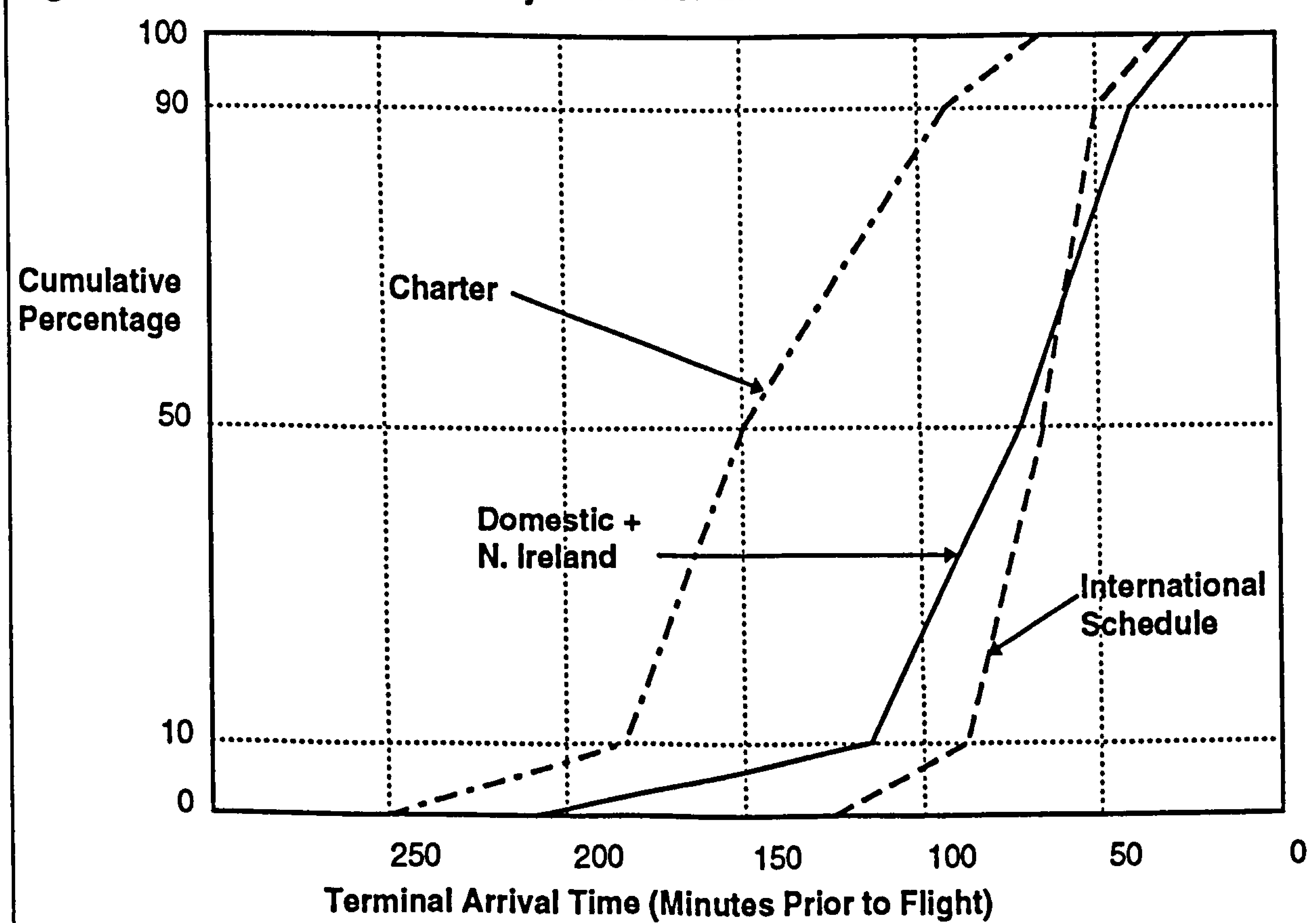
The flows of passengers from each facility are controlled by the following:

Public concourse	This static facility is controlled by a variable designed so that passengers leave the public concourse when the check-in desks open.
Agent1 check-in desks Agent2 check-in desks	These dynamic facilities are controlled by functions created from surveys conducted within the terminal by the airport authority in the past. The check-in desks open 90 minutes prior to the scheduled time of departure (STD) for domestic flights and 120 minutes prior to STD for international flights.
Public concourse 1 Public concourse 2	These static facilities for domestic and international passengers respectively are controlled by variables designed to release passengers at an even rate until a set time before flight time. At this time passengers move through to the next facility.
Domestic security International security	These dynamic facilities are controlled by a function, created from surveys conducted out at the terminal by the airport authority in the past.
Frisk facilities	These dynamic facilities are controlled by functions based on surveys conducted within the airport terminal

	in the past.
Bag search facilities	These dynamic facilities are controlled by functions based on surveys conducted within the airport terminal in the past.
Passport control	This dynamic facility is controlled by a function synthesised from other data.
Domestic lounge N. Ireland lounge International lounge	These static facilities are controlled by variables designed to release passengers at a set time before flight time.

The arrival distributions used for EMIA model were provided by East Midlands International Airport [1992]. The arrival patterns of passengers by sector for this model are shown in Figure 13.

Figure 13 Arrival Distributions by Sector for EMIA



11.2 Birmingham Airport

The Birmingham Airport model represents both of Birmingham Airport's two terminals. The two terminals have been combined within this single model because the schedule provided by the airport covered both terminals. It was not possible to split the schedule without significantly delaying the research. It was decided that combining the two terminals into a single model offered no real drawbacks as the passenger flows for the two terminals would remain unconnected. For simplicity the description of the model addresses the two terminals (Part 1 and Part 2) separately. The plans of the model can be seen in Figure 14.

11.2.1 Part 1

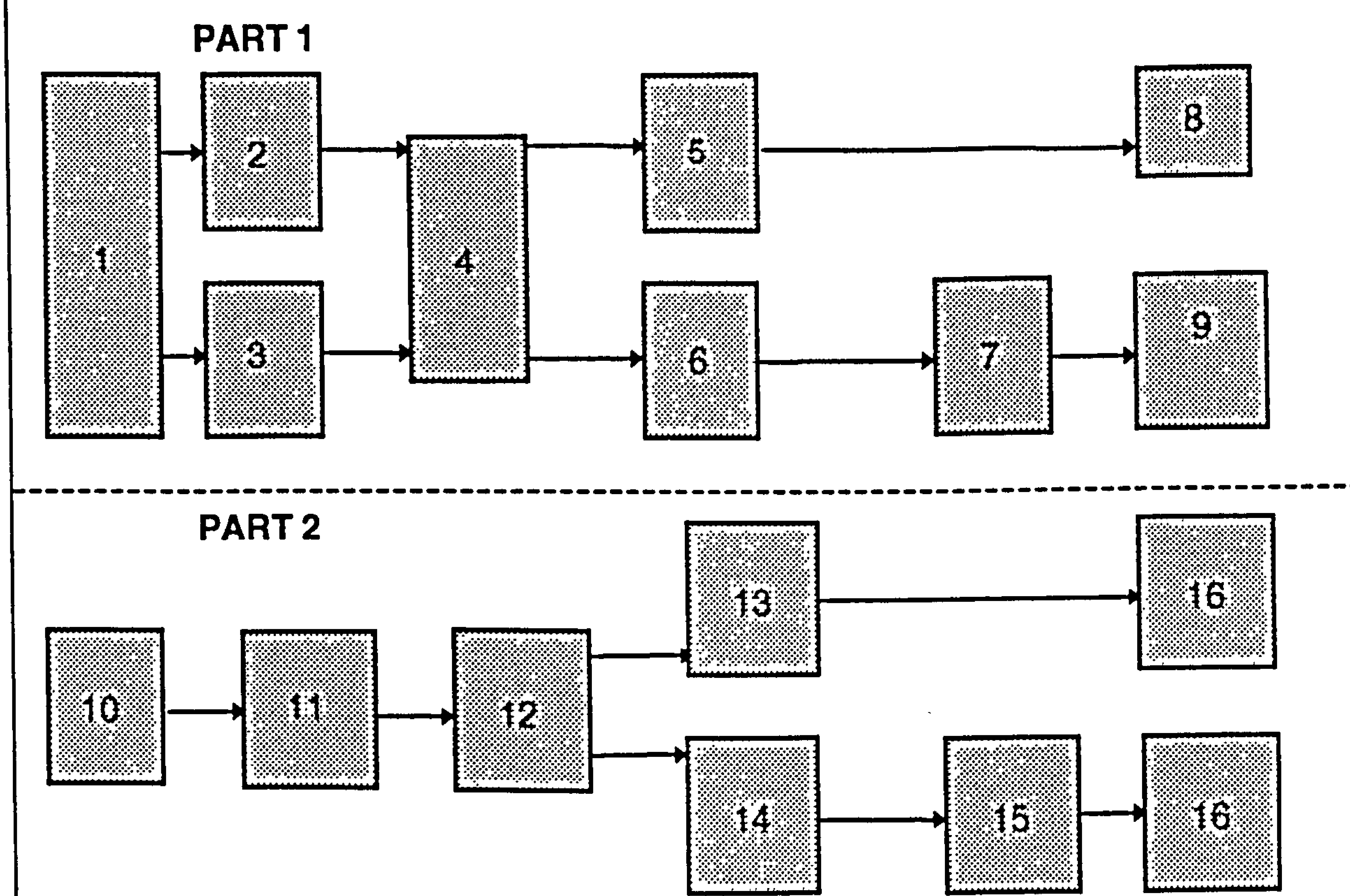
Passengers are generated in the passenger concourse which is the first facility in this model. They remain in this area until the check-in desks for the relevant flight open. As in the first model, there are two separate handling agents operating both domestic and international flights.

From the check-in desks the passengers move into an area that includes concession facilities. From here the passengers move through to the security section. Unlike the EMIA model there is no separation of the frisk and bag search facilities. Although these activities do occur, the service times allocated to the security function reflect times for all security activities. After completing passage through security, the passengers can either move into either the domestic lounge or the passport control facility depending on the flight category. For passengers leaving the passport control facility the next facility is the international departure lounge.

11.2.2 Part 2

The second terminal experiences the same pattern of flows as part 1, the only difference is that the second terminal is operated by a single handling agent that operates in this terminal exclusively.

Figure 14 Simplified Flow Diagram for Birmingham Airport



1 Public Concourse 1	7 Passport Control 1	13 Domestic Security 2
2 Agent1 Check-in Desks	8 Domestic Lounge 1	14 International Security 2
3 Agent 2 Check-in Desks	9 International Lounge 1	15 Passport Control 2
4 Retail 1	10 Public Concourse 2	16 Domestic Lounge 2
5 Domestic Security	11 Agent 3 Check-in Desks	17 International Lounge 2
6 International Security 1	12 Retail 2	

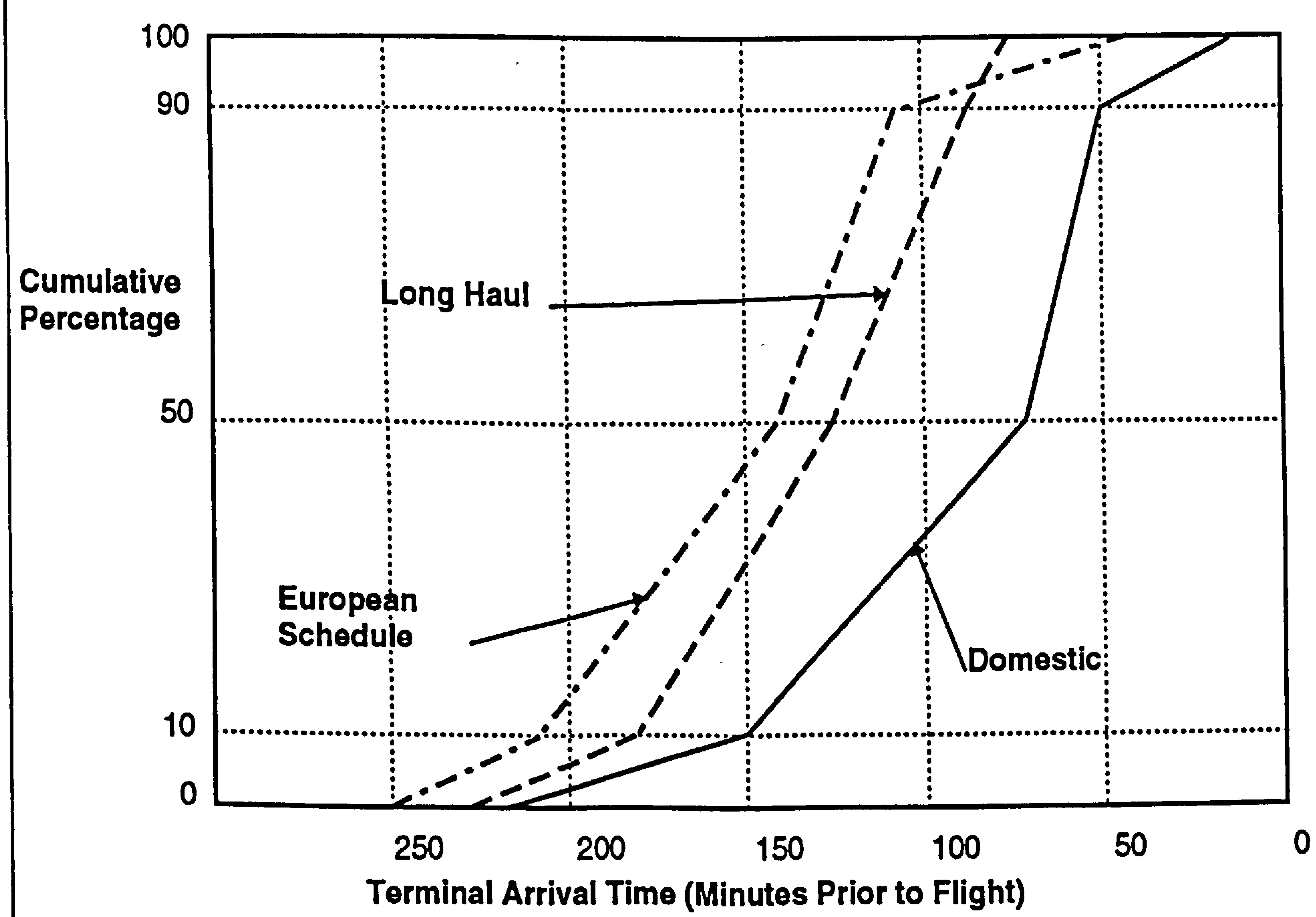
The flows of passengers from each facility are controlled by the following:

Public concourse 1 Public concourse 2	These static facilities are controlled by a variable designed so that passengers leave the public concourses when the check-in desks open.
Agent1 check-in desks Agent2 check-in desks Agent3 check-in desks	These dynamic facilities are controlled by functions created from standards supplied by the airport. The desks open 120 minutes prior to STD for domestic flights and 150 minutes prior to STD for international flights.
Retail 1 Retail 2	These static facilities for domestic and international passengers are controlled by a variable designed to release passengers after 15 minutes, until a set time before flight time. At this time passengers move through to the next facility.
Domestic security 1	These dynamic facilities are controlled by a function,

Domestic security 2 International security 1 International security 2	created from standards issued by the airport.
Passport control 1 Passport control 2	These dynamic facilities are controlled by a function based on standards issued by the airport.
Domestic lounge 1 Domestic lounge 2 International lounge 1 International lounge 2	These static facilities are controlled by variables designed to release passengers at a set time before flight time.

The arrival patterns of passengers by sector for the Birmingham Airport model are shown in Figure 15.

Figure 15 Arrival Distributions by Sector for Birmingham Airport

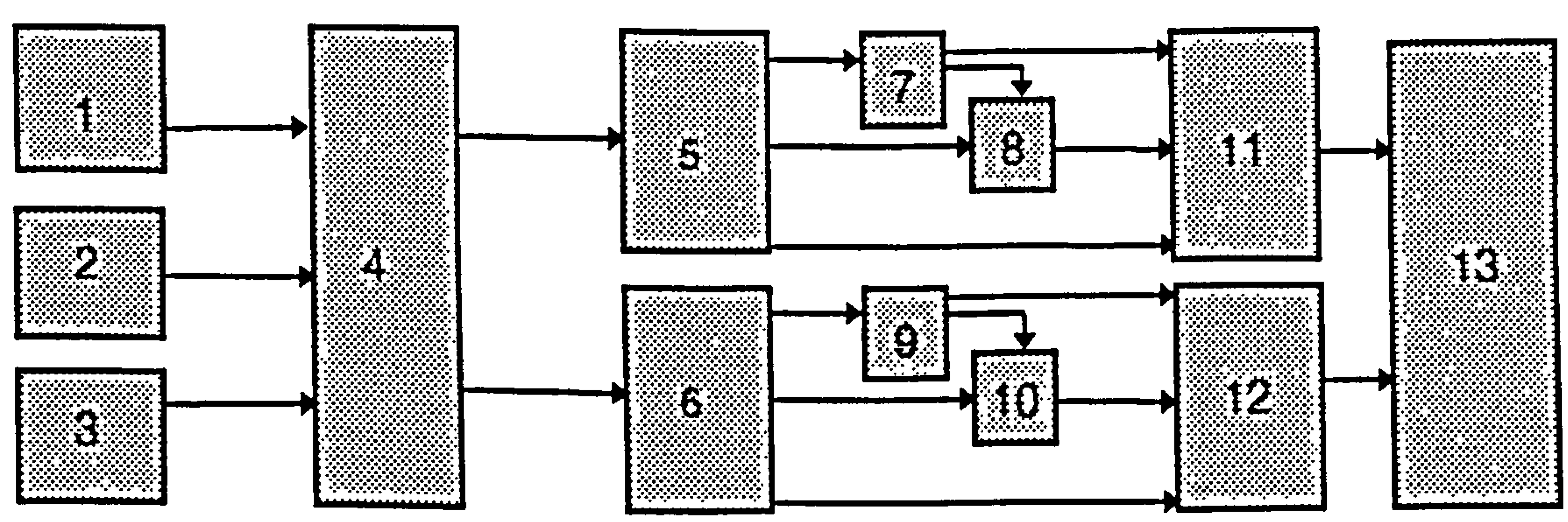


11.3 Manchester Airport Model 1

Manchester Airport Model 1 concentrates on the international movements within Manchester Airport's Terminal 1. A plan of this model can be seen in Figure 16.

Passengers appear in the model at the check-in stage of processing. There are three handling agents operating within the terminal. Having checked-in for their flight, the passengers then move into the public concourse area. From the public concourse, the passengers then split into either International or Common Travel Area (CTA). The paths through the model for both categories are parallel. Passengers pass through security and passport control before the two flows join again at the international lounge. The security checks in this model may involve the separate frisk and bag search facilities.

Figure 16 Simplified Flow Diagram for Manchester Airport Model 1



1 Agent 1 Check-in
2 Agent 2 Check-in
3 Agent 3 Check-in
4 Public Concourse
5 Security (CTA)
6 International Security
7 Frisk Facility (CTA)
8 Bag Search Facility (CTA)
9 Frisk Facility
10 Bag Search Facility
11 Passport Control (CTA)
12 Passport Control
13 International Lounge

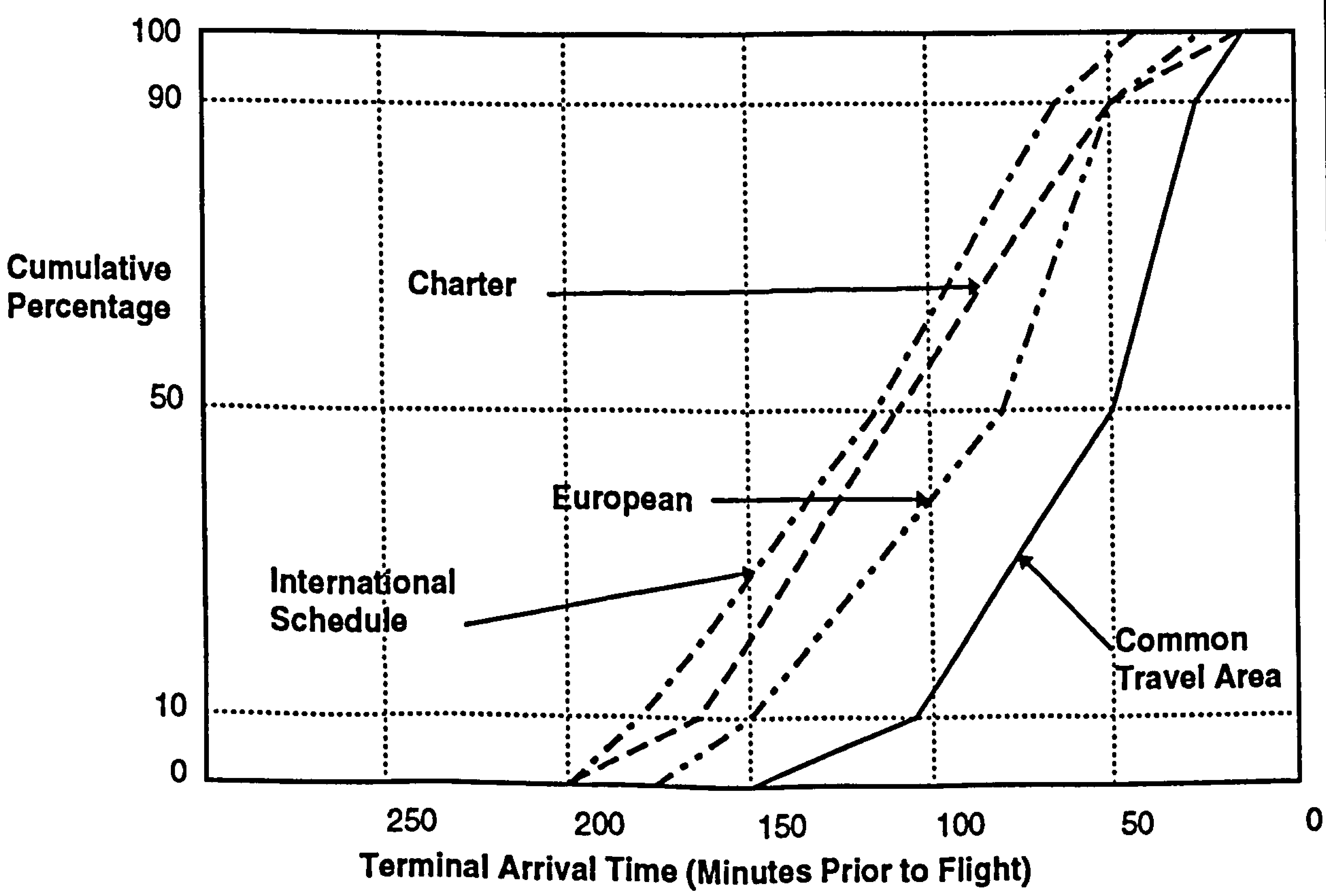
The flows of passengers from each facility are controlled by the following:

Agent1 check-in desks Agent2 check-in desks Agent3 check-in desks	These dynamic facilities are controlled by functions based on information supplied by the airport. The check-in desks open 150 minutes before the STD of the respective flight.
Public concourse	This static facility is controlled by a variable designed to release passengers at a rate controlled by a distribution and in relation to time before flight, based of information provided by the airport.

Security (CTA)	This dynamic facility is controlled by a function based on data provided by the airport.
International security	This dynamic facility is controlled by a function based on data provided by the airport.
Frisk (CTA)	This dynamic facility is controlled by a function based on data provided by the airport.
Bag search (CTA)	This dynamic facility is controlled by a function based on data provided by the airport.
Passport control (CTA)	This dynamic facility is controlled by a function based on data provided by the airport.
Frisk	This dynamic facility is controlled by a function based on data provided by the airport.
Bag search	This dynamic facility is controlled by a function based on data provided by the airport.
Passport control	This dynamic facility is controlled by a function based on data provided by the airport.
Boarding lounge	This static facility is controlled by a variable designed to release passengers at a set rate after a certain time before flight time.

The arrival patterns of passengers by sector for Manchester Airport Model 1 are shown in Figure 17.

Figure 17 Arrival Distributions by Sector for Manchester Airport Model 1

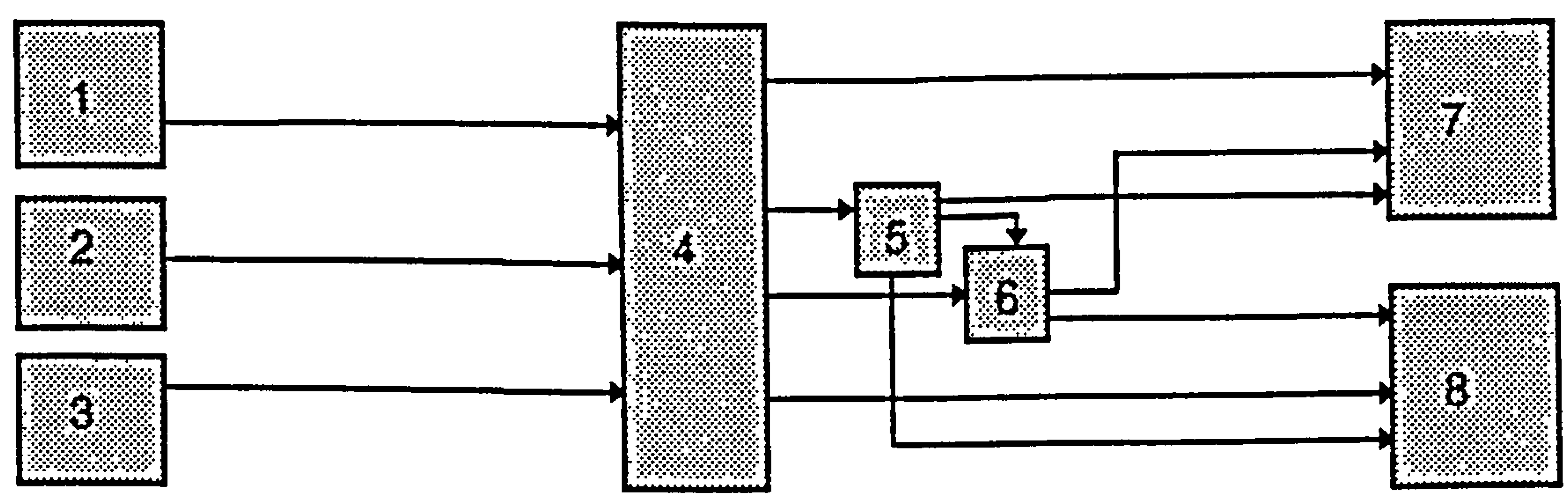


11.4 Manchester Airport Model 2

Manchester Airport Model 2, the second of the three models for the Manchester Airport, concentrates on the domestic movements within Manchester Airport's Terminal 1. A visual representation is given by Figure 18.

Passengers arrive in a concourse and proceed to checking-in facilities run by one of the three handling agents. Having checked-in for a flight the passengers then move to the domestic security facility. Passengers can pass straight through the security facility or encounter frisk and bag searches. Having negotiated the security checks the passengers then move through into the appropriate departure lounge for their flight destination. Flights to N. Ireland will pass into a lounge separate from the rest of the domestic passengers. This is due to the high level of security required for flights to this region of the UK. These lounges form the final stage of this terminal model.

Figure 18 Simplified Flow Diagram for Manchester Airport Model 2



1 Agent1 Check-in Desks
2 Agent 2 Check-in Desks
3 Agent 3 Check-in Desks
4 Domestic Security
5 Frisk Facility
6 Bag Search Facility
7 Domestic Lounge
8 N. Ireland Lounge

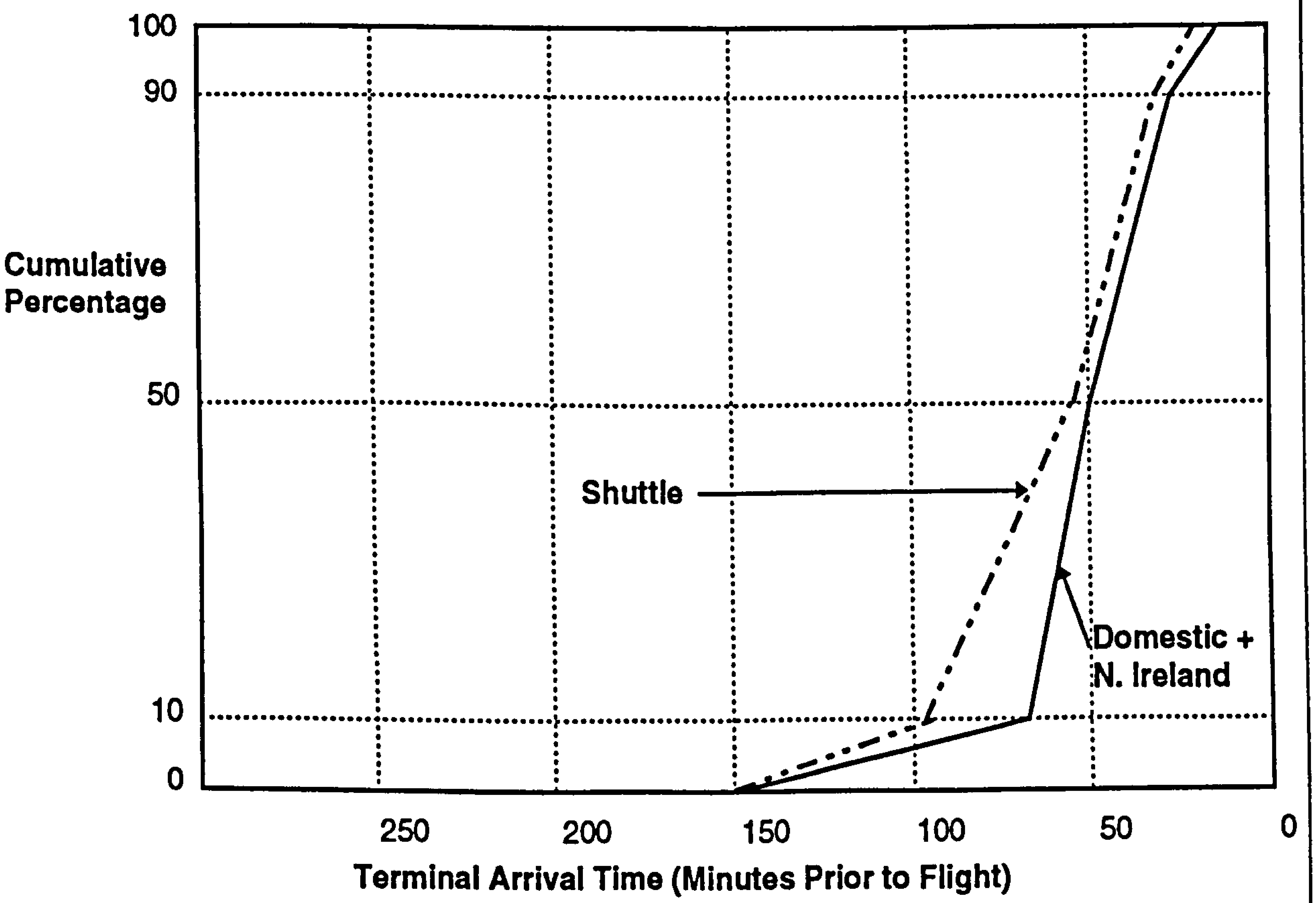
The flows of passengers from each facility are controlled by the following:

Agent1 check-in desks Agent2 check-in desks Agent3 check-in desks	These dynamic facilities are controlled by functions based on information supplied by the airport. The check-in desks open 120 minutes before STD.
Domestic security	This dynamic facility is controlled by a function based on data provided by the airport.
Frisk	This dynamic facility is controlled by a function based on

	data provided by the airport.
Bag search	This dynamic facility is controlled by a function based on data provided by the airport.
Domestic lounge N. Ireland lounge	These static facilities are controlled by variables designed to release passengers at a set rate after a certain time before flight time.

The arrival patterns of passengers by sector for Manchester Airport Model 2 are shown in Figure 19.

Figure 19 Arrival Distributions by Sector for Manchester Airport Model 2

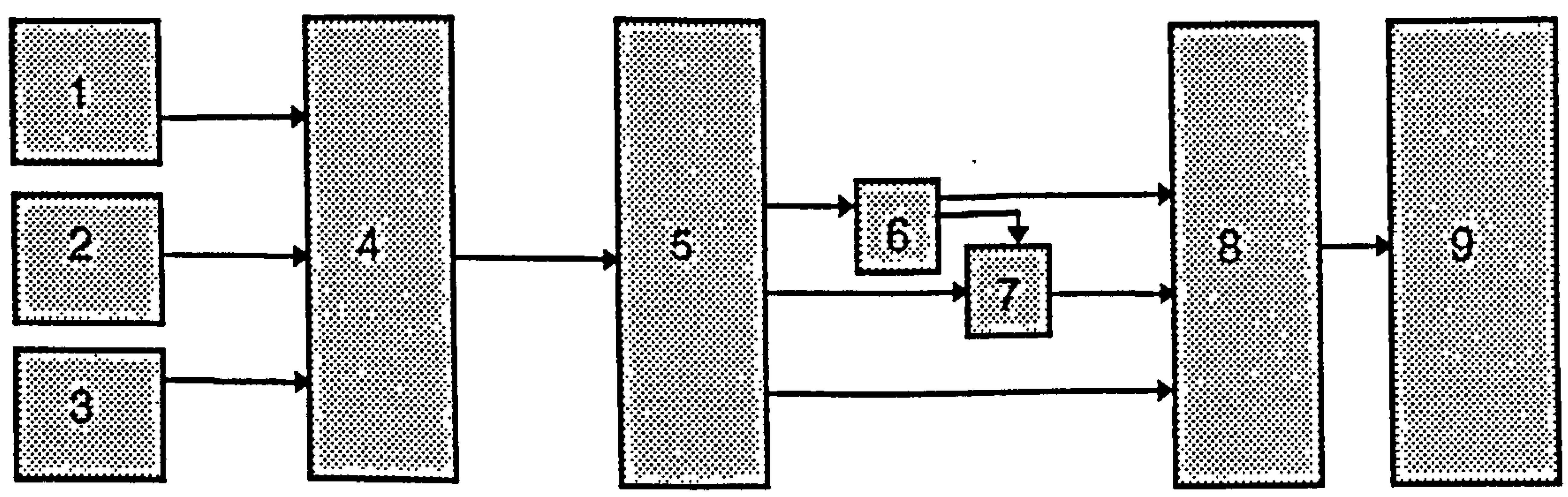


11.5 Manchester Airport Model 3

Manchester Airport Model 3, the third of three models based on the Manchester airport concentrates on the passenger movements within Terminal 2. Figure 20 gives a visual representation of this model.

Passengers enter the model at the checking-in stage of the enplaning process. There are three handling agents that operate within this terminal. After checking-in for their flight, passengers move into a public concourse. From here the passengers move through security area where, as in other models, they may experience a frisk or bag search. After the security check(s) have been completed the passengers then move onto the passport control facility. After this facility is the international lounge which is the last stage of this terminal model.

Figure 20 Simplified Flow Diagram for Manchester Airport Model 3



1 Agent1 Check-in Desks
2 Agent 2 Check-in Desks
3 Agent 3 Check-in Desks
4 Public Concourse
5 International Security
6 Frisk Facility
7 Bag Search Facility
8 Passport Control
9 International Lounge

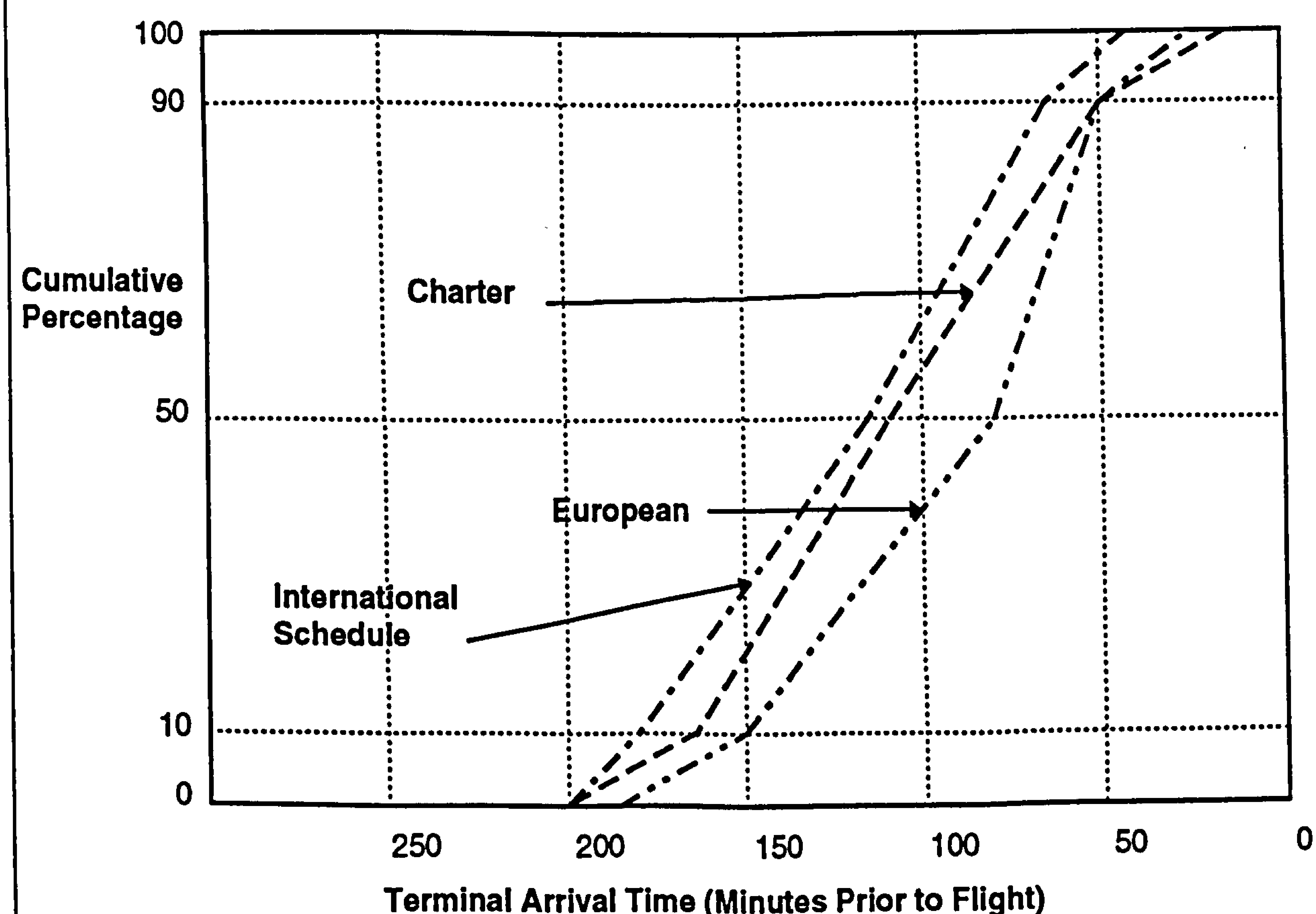
The flows of passengers from each facility are controlled by the following:

Agent1 check-in desks Agent2 check-in desks Agent3 check-in desks	These dynamic facilities are controlled by functions based on information supplied by the airport. The check-in desks open for international flights 150 minutes before STD and 240 minutes before STD for flights to the USA.
Public concourse	This static facility is controlled by a variable designed to release passengers at a rate controlled by a distribution and in relation to time before flight, based of information provided by the airport.
International security	This dynamic facility is controlled by a function based on

	data provided by the airport.
Frisk	This dynamic facility is controlled by a function based on data provided by the airport.
Bag search	This dynamic facility is controlled by a function based on data provided by the airport.
Passport control	This dynamic facility is controlled by a function based on data provided by the airport.
International lounge	This static facility is controlled by a variable designed to release passengers at a set rate after a certain time before flight time.

The arrival patterns of passengers by sector for Manchester Airport Model 3 are given in Figure 21.

Figure 21 Arrival Distributions by Sector for Manchester Airport Model 3



11.6 General Discussion of the Models

As was indicated earlier in this chapter, there are different set-ups for each of the models. The EMIA model is a single terminal airport modelled as a whole. The Birmingham Airport model represents two terminals. Manchester Airport's Models 1, 2 and 3 are different configurations of Manchester Airport's two terminals. From the flow diagrams it is clear that the same general flows exist within the models, although some models show flows in greater detail than others, such as frisking and bag search activities.

The passenger flow through the models is controlled by either releasing passengers from a holding area at a set time prior to flight or after a certain amount of time. The functions used are specific for each model, some functions had to be synthesised due to a lack of real data.

Unique to the EMIA model is an output of check-in queue by agent. This is in contrast to the other models which display check-in queue results by airline carrier.

All the models are restricted to a seven stage design structure. Some models do not have an initial public concourse which can allow for more detailed facility analysis. This does not affect the check-in queues as will be seen from the results that were obtained.

The obvious difference between the models is the mix of flights and consequently the mix of passenger types generated by the flight schedule for each airport. There are also different peak periods and patterns of behaviour relating to the different passenger types for each of the models. The next chapter reviews the results of the simulation part of this research.

12. The Simulation Results

The results from the 600 iterations conducted for this research are outlined in this chapter. The results take the form of graphs with a verbal description and explanation. The chapter is split into six sections. The first five sections address the results for each model in turn. These sections end with an overview of the major findings of each model. The final section draws conclusions from the simulation results from the five models.

The graphs contained in the following sections show passenger numbers (Peak Volume or Peak Queue Length) on the 'Y' axis and Arrival Distribution Scenario Curve on the 'X' axis. Scenario 1 represents passengers arriving at the airport terminal over a short period of time close to the scheduled time of departure. Scenario 6 represents passengers arriving over a longer period of time prior to the scheduled time of departure. Scenarios 2 to 5 represent evenly spaced arrival distributions between Scenario 1 and Scenario 6.

12.1 East Midlands International Airport

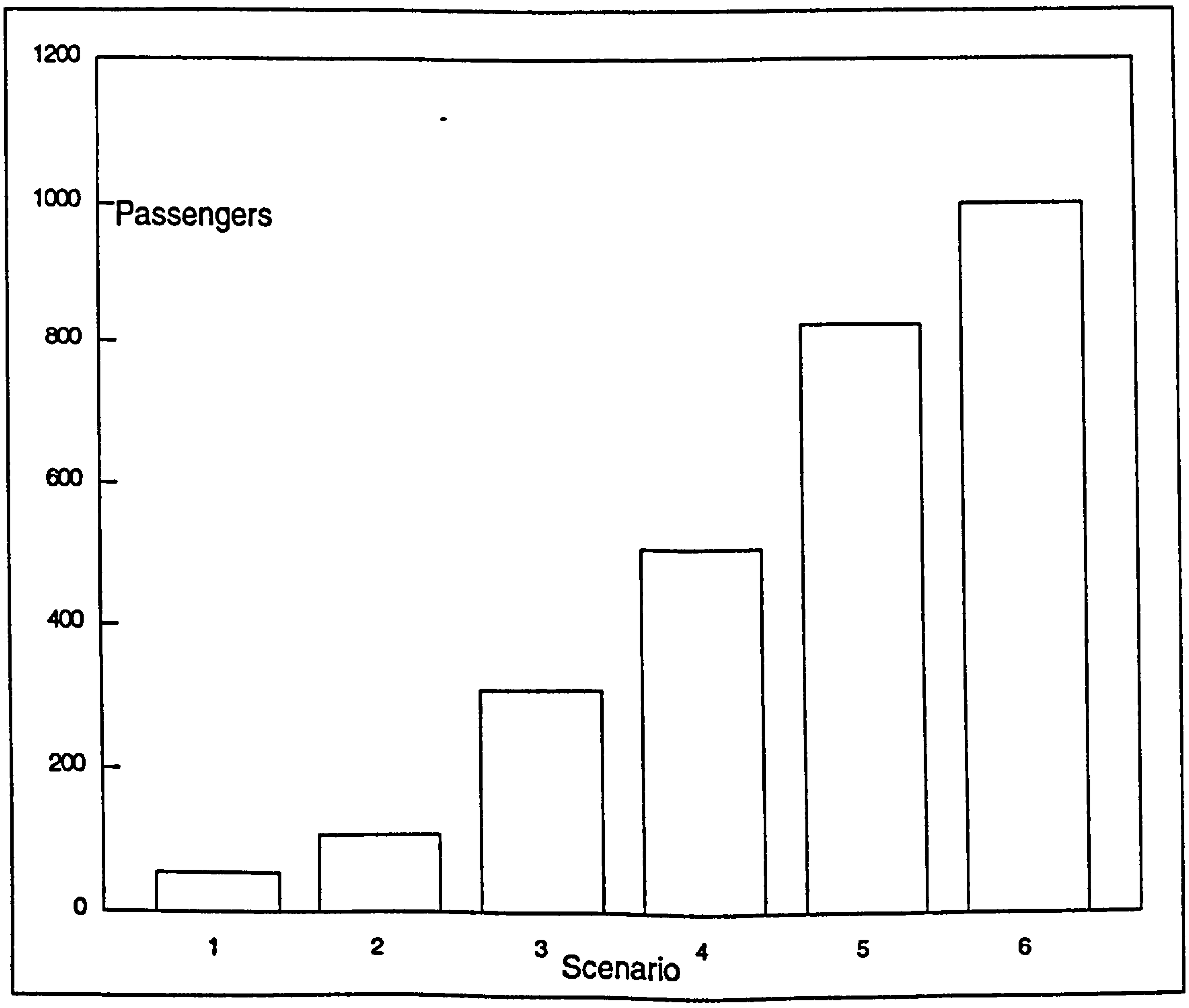
This section addresses the results obtained for the iterations that were conducted based on EMIA. The EMIA model has a single terminal layout, which supports both domestic and international flights. A plan of this model can be seen in Figure 12.

12.1.1 Peak Pre-Check-in Passenger Volume

There is a steady rise in the recorded peak volume of passengers in the public concourse, as the arrival pattern shifts from Scenario 1 to Scenario 6. This trend is presented in Figure 22. The higher levels are caused by earlier passenger arrival at the terminal. These passengers are spending longer periods of time in the terminal waiting for the check-in desks to open.

This result has implications for the provision of facilities for travellers within this area. There may be a demand for more entertainment and comfortable facilities as more travellers congregate in these areas.

Figure 22 Peak Pre-Check-in Passenger Volume

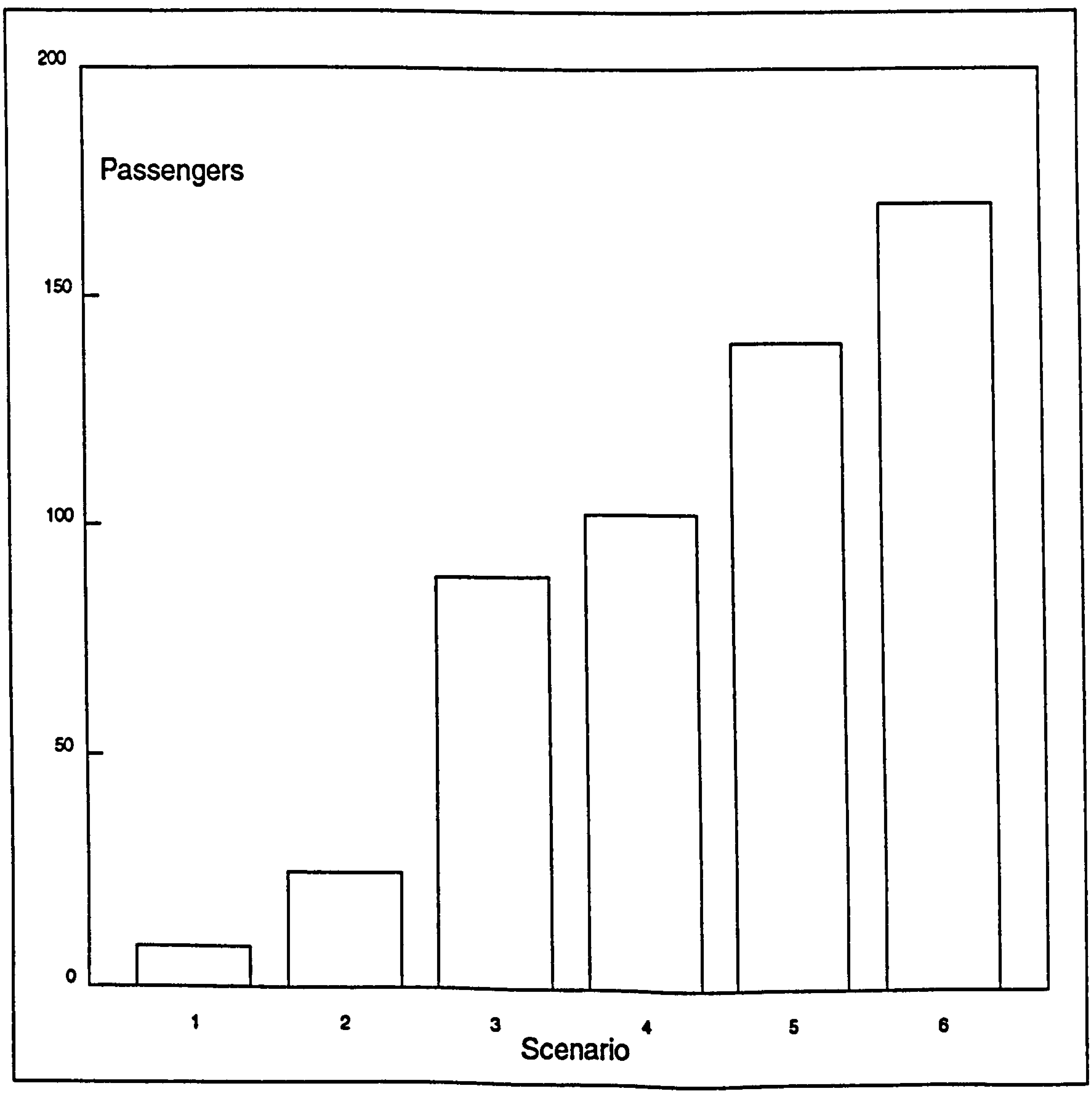


12.1.2 Maximum Check-in Queue Length Agent 1

The results displayed in Figure 23 show an incremental trend. With a shift in the arrival pattern from Scenario 1 to Scenario 6 there is an increase in the maximum queue length. Although the increase appears similar to that in Figure 26, those passengers entering the queues associated with Agent 1 are only a subset of the total passengers in the terminal. These results are for a dynamic facility and will not necessarily reflect the exact trend observed for the pre-check-in area, which is a holding facility. The indication is that with passengers arriving earlier at the airport there is a knock on effect on the queues encountered at check-in desks.

These results may have implications for either the space allocation, desk opening and or passenger processing strategies adopted by handling agents at EMIA.

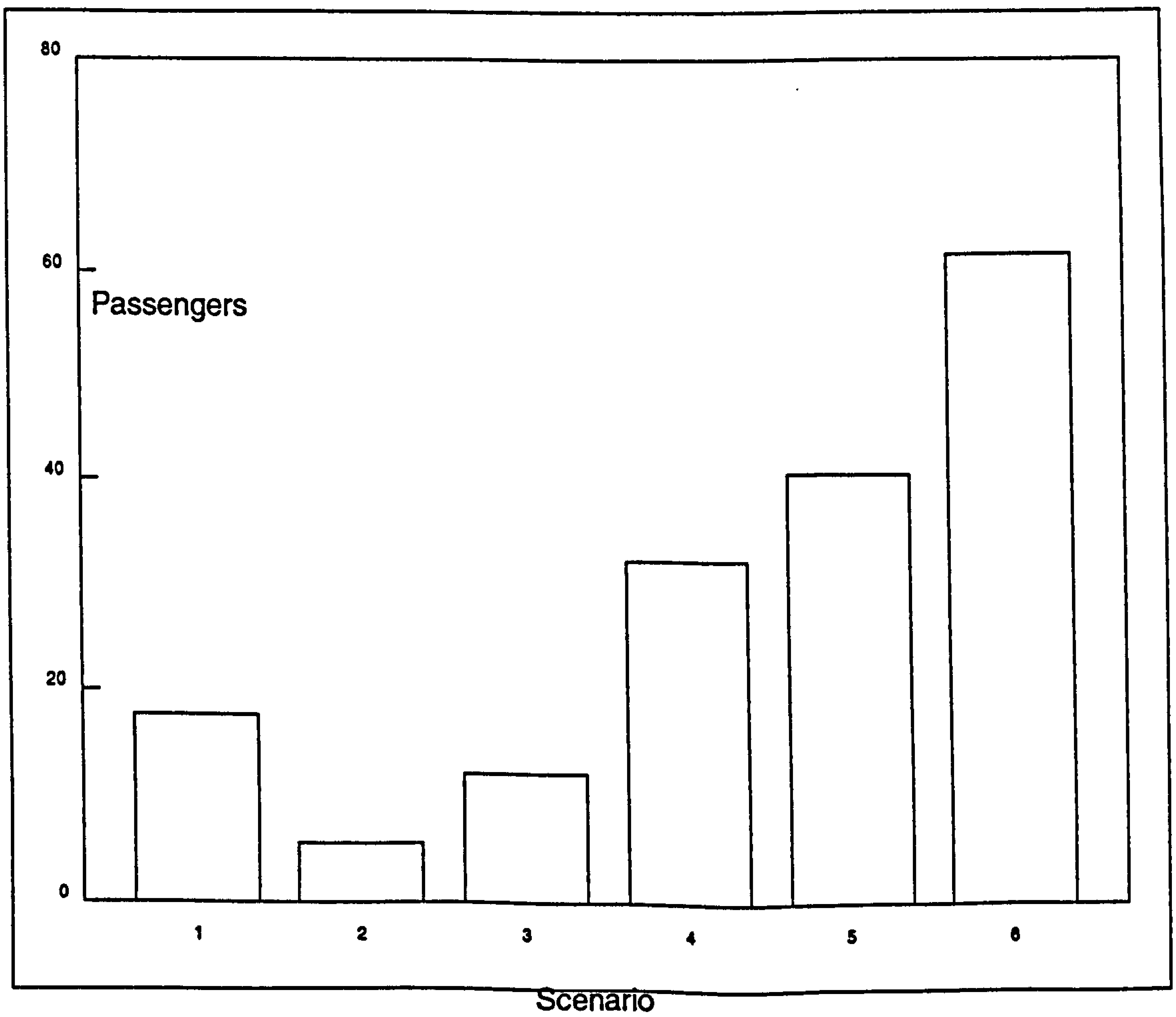
Figure 23 Maximum Check-in Queue Length Agent 1



12.1.3 Maximum Check-in Queue Length Agent 2

The observed results for the second agent, Agent 2, shown in Figure 24, are slightly different to the results for Agent 1. Unlike the steady increment experienced by Agent 1, for Agent 2 the maximum queue length experienced in Scenario 1 is higher than experienced in Scenarios 2 and 3. From Scenario 2 onwards there is a steady increase in the maximum queue length. Agent 2 has a higher proportion of domestic passengers and flights. Therefore, this agent has a larger proportion of its passengers arriving over a short period of time. Without the facilities to process the passengers effectively queues will develop. This could explain the higher passenger numbers experienced in Scenario 1 for this agent. When passengers are not arriving over a short period of time the agent can handle them efficiently as observed for Scenarios 2 and 3. This efficiency is achieved until passengers arrive at the terminal before the check-in desks open, at this point the agent can no longer prevent queues from forming except by opening more facilities and or modifying the check-in desk opening times.

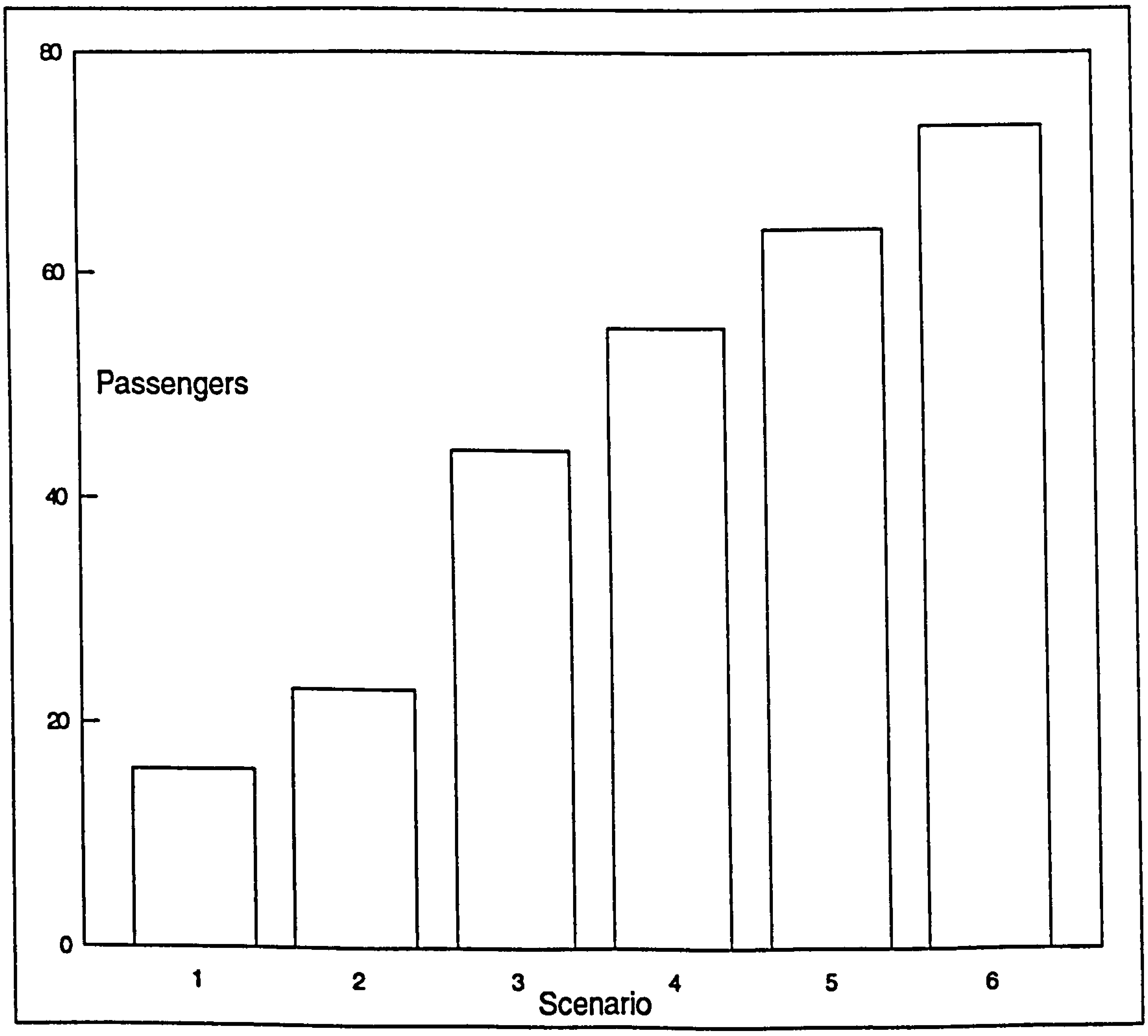
Figure 24 Maximum Check-in Queue Length Agent2



12.1.4 Peak Domestic Passenger Volume Post-Check-in Public Concourse

Figure 25 shows domestic passenger volumes which were observed for the public concourse. There is an increase in observed volumes from Scenario 1 to Scenario 6 corresponding to passengers arriving earlier at the terminal, a result which was expected. It is important to remember that this facility is actually combined with the pre-check-in and International public concourse. This being the case the increase in passenger volumes has even greater influence on the facilities and entertainment and may need to be provided as a consequence of these higher peak passenger volumes.

Figure 25 Peak Passenger Volume Post-Check-in Public Concourse - Domestic

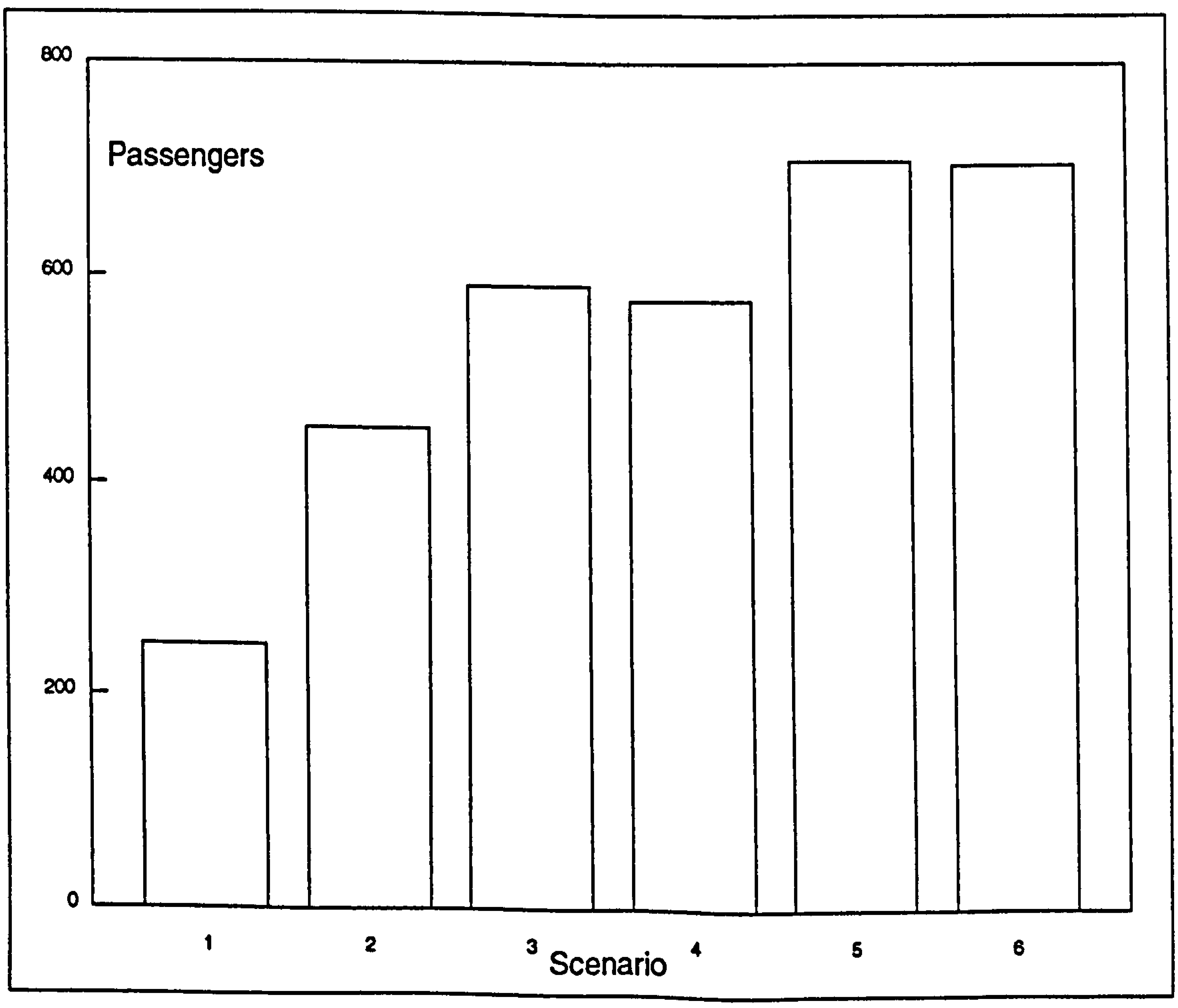


12.1.5 Peak International Passenger Volume Post-Check-in Public Concourse

The results for the volume of international passengers in the public concourse are shown in Figure 26. These reveal an increase in the number of passengers waiting as the arrival pattern shifts from Scenario 1 to Scenario 6. This feature could be caused by the combined effects of increased queuing time at the check-in facilities and the variable used to release passengers onto the next facility. There appears to be a levelling in the number of passengers between Scenario 5 and 6. The character of the EMIA traffic could partly explain this result. EMIA has a large based of charter traffic which tends to operate during set periods of the day. Therefore in the case of Scenario 6, there are no more passengers additional to those observed in Scenario 5 to accommodate in this facility to cause this value to rise further.

The implications of an overall incremental trend in passenger volumes in this area of the terminal has already been addressed in the previous sub-section 11.1.4

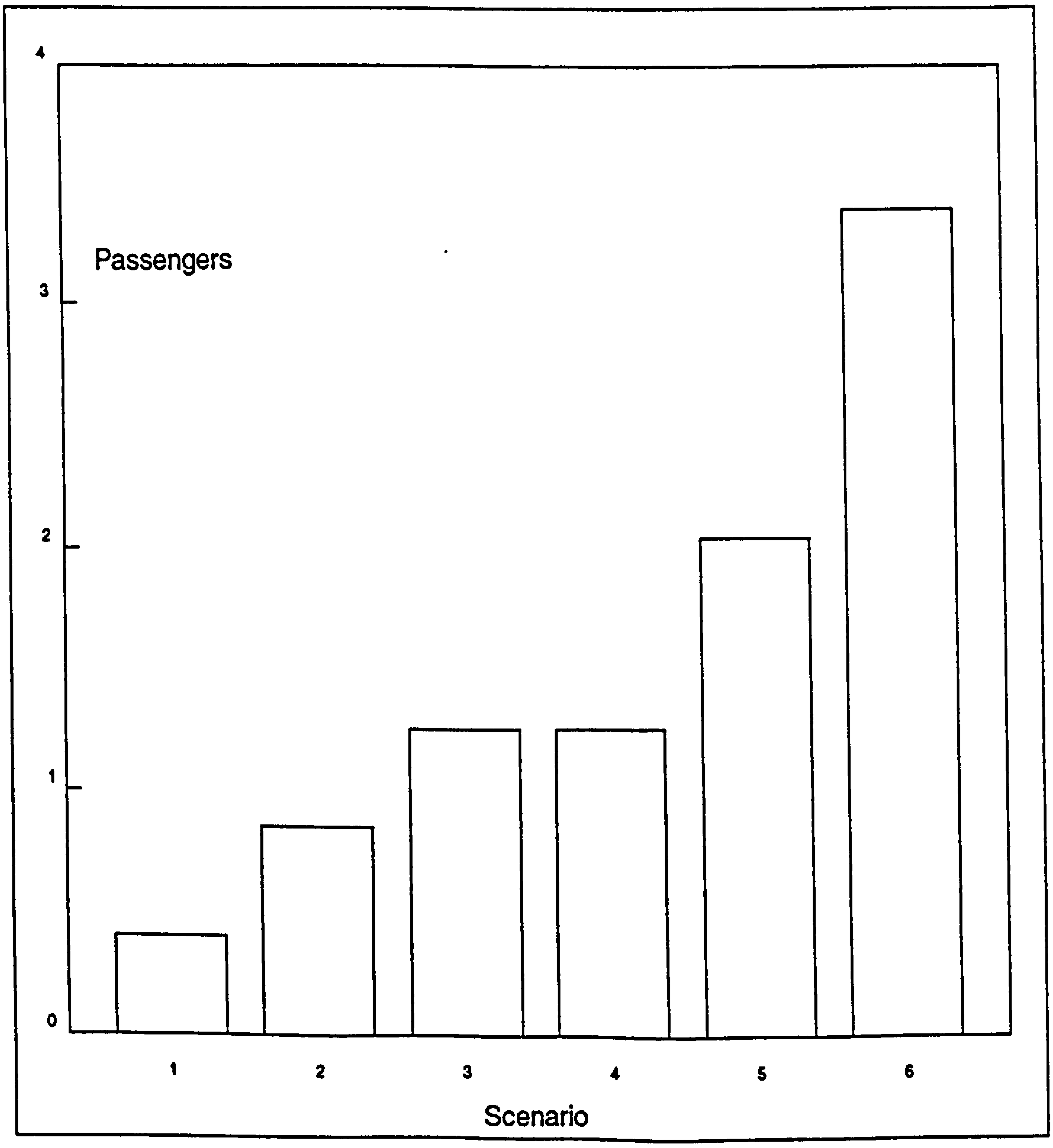
Figure 26 Peak Passenger Volume Post-Check-in Public Concourse - International



12.1.6 Peak Domestic Security Queue Length

The results shown in Figure 27, indicate an increase in the maximum queue length for the domestic security facility as the arrival distributions experienced by the airport terminal shift away from the scheduled time of departure. The trend indicates that the queue would lengthen if the flow of passengers from the public concourse increases significantly. The implications for the domestic security facility are that if passengers arrive earlier at the terminal, there could be an increase in security passenger queue lengths which may require facility modifications or operational changes.

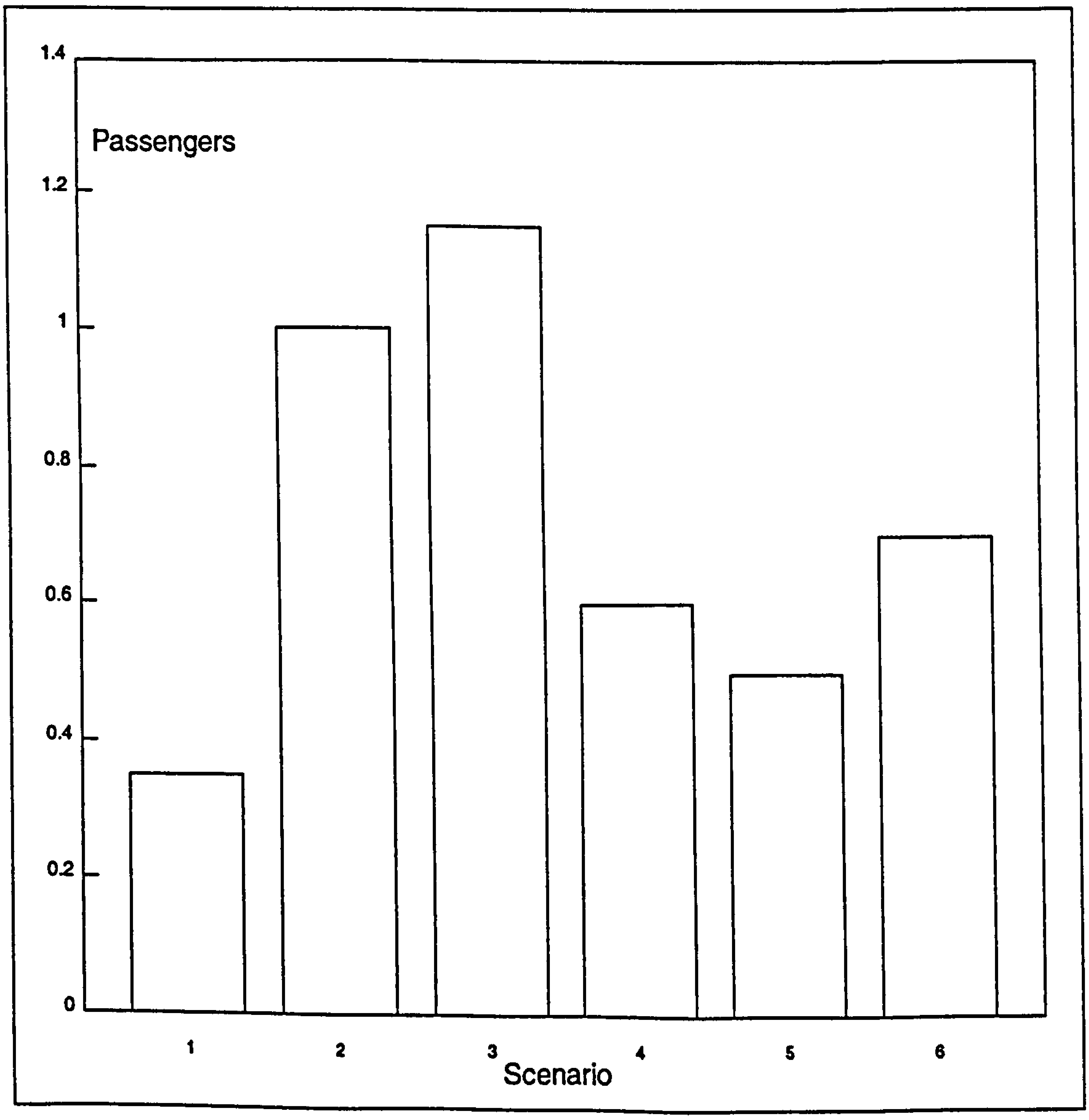
Figure 27 Peak Domestic Security Queue Length



12.1.7 Peak International Security Queue Length

Figure 28 shows the results for the international security facility. No real trend is apparent and Scenarios 2 and 3 seem to be somewhat higher than the others. This could again be due to the nature of EMIA's traffic having a dominant charter bias. The earlier passenger arrivals at the airport may well not affect the flows through the security channels as there would not be a significant change in the flow of passengers to this facility.

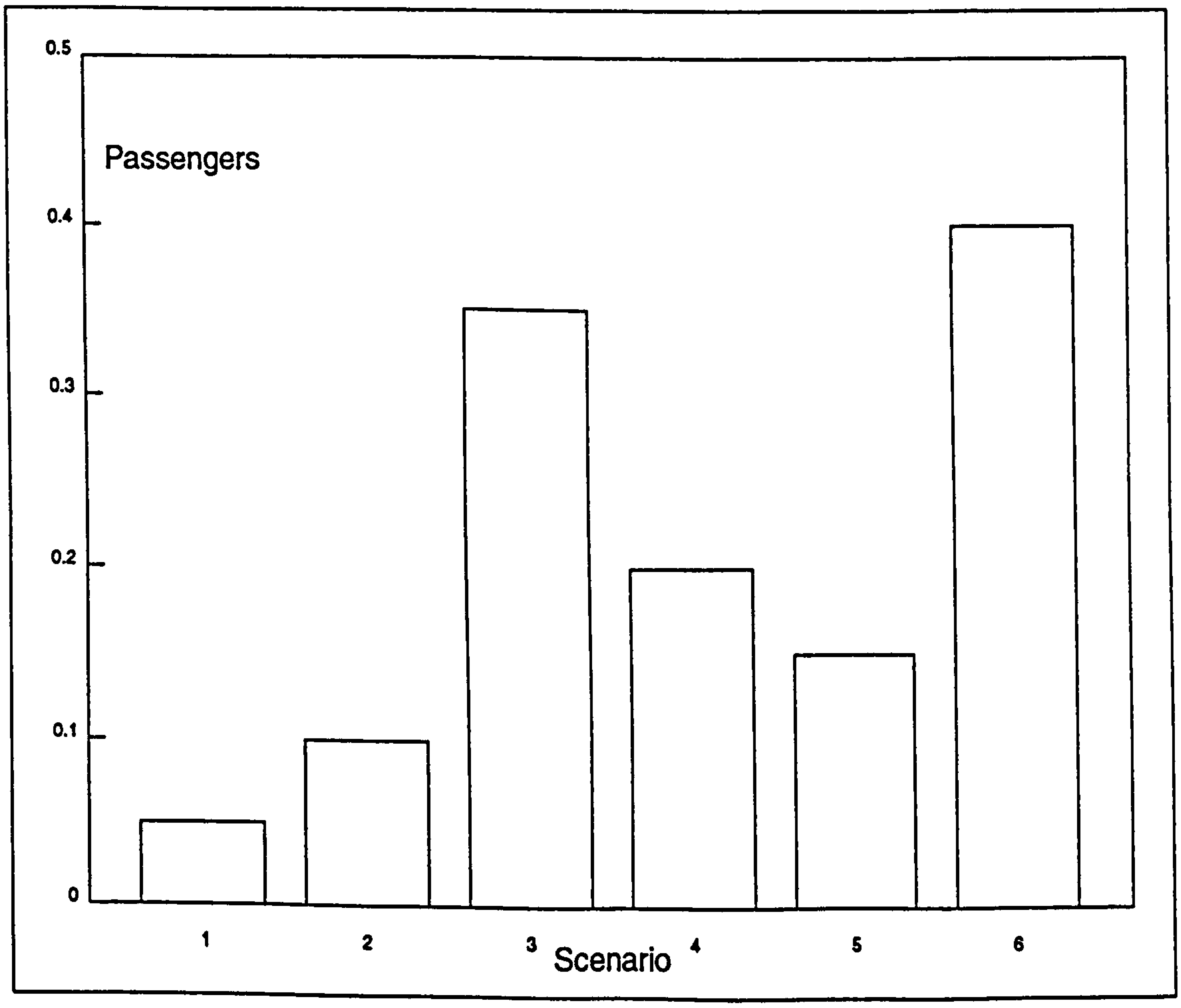
Figure 28 Peak International Security Queue Length



12.1.8 Peak Domestic Frisk Queue Length

The results for the domestic frisk facility are shown in Figure 29. There appears to be no real trend or significant results. This could be caused by the model design and the probability of being selected for 'Frisking'. The proportion for frisking and the time taken to frisk people may be such that the queues that develop are more or less random. The values recorded here may be higher than its international counterpart because of the higher proportion of N. Ireland passengers that must be frisked.

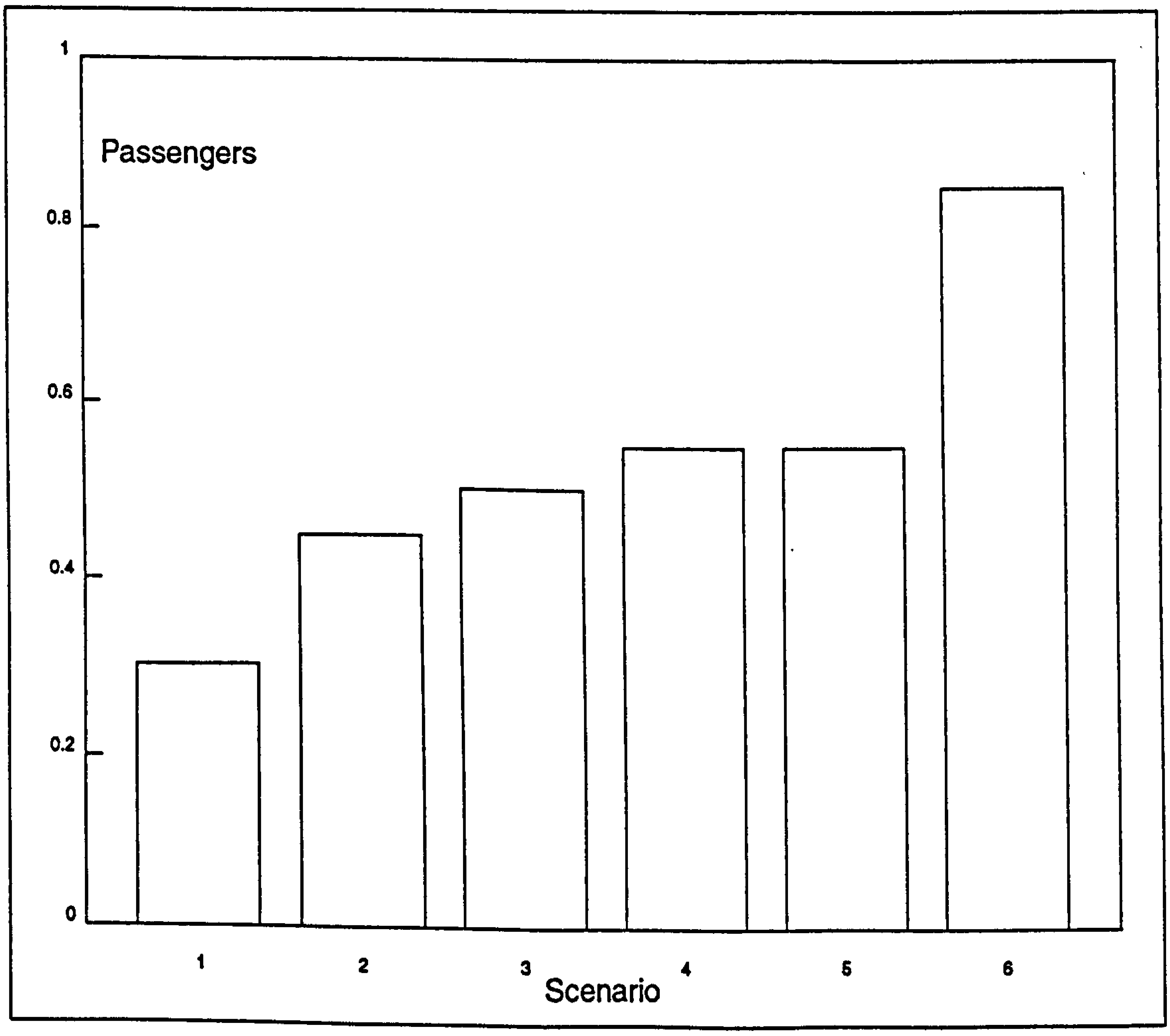
Figure 29 Peak Domestic Frisk Queue Length



12.1.9 Peak Domestic Bag Search Queue Length

The peak volumes of the bag search facility presented in Figure 30, do not vary a great deal. These results are probably influenced by the limited number of N. Ireland flights in the EMIA schedule. There will be a low but stable flow of N. Ireland passengers passing through this facility as N. Ireland passengers are the most prone to bag searches. The result may have been different without the N. Ireland flights.

Figure 30 Peak Domestic Bag Search Queue Length



12.1.10 Peak International Frisk Queue Length

The EMIA model did not produce passenger queues for the international frisk facility in any of the six scenarios. This result does not imply that passengers were not frisked, but that the proportion for frisking and the time taken to frisk people were such that the queues that did not develop.

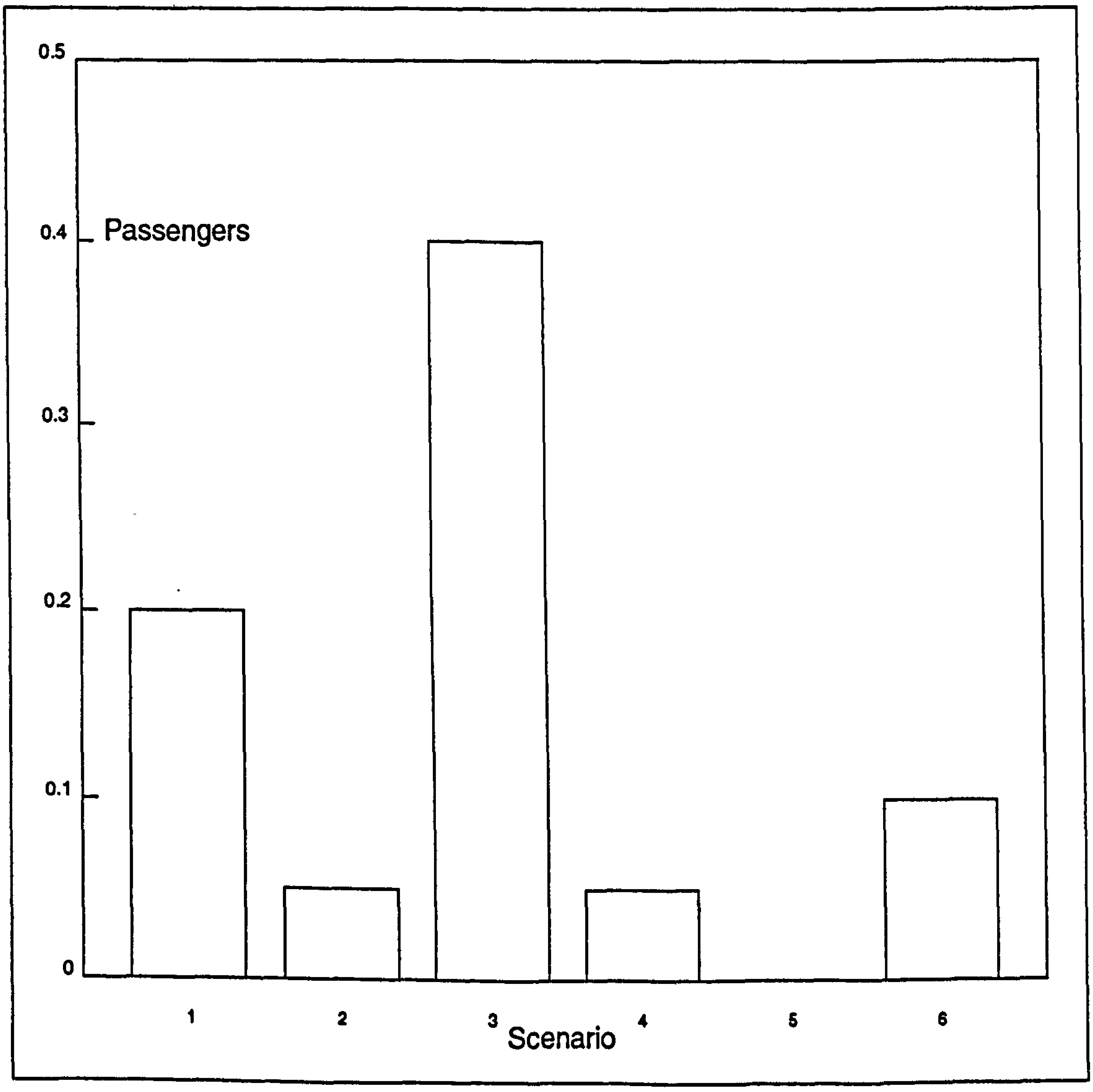
12.1.11 Peak International Bag Search Queue

As with the international frisk facility, the international bag search facility did not develop for any queues for the six scenarios. Again it must be emphasised that this result does not mean that passengers' bags were not simulated as being searched. The proportion for searching and the time taken to search bags was such that the queues that did not develop.

12.1.12 Peak Passport Control Queue Length

The results for the passport control facility shown in Figure 31 reveal no trend that can be directly related to a change in passenger arrival patterns at the airport terminal. The fluctuation in the results obtained show that this particular dynamic facility is not affected by the change in arrival distribution.

Figure 31 Peak Passport Control Queue Length

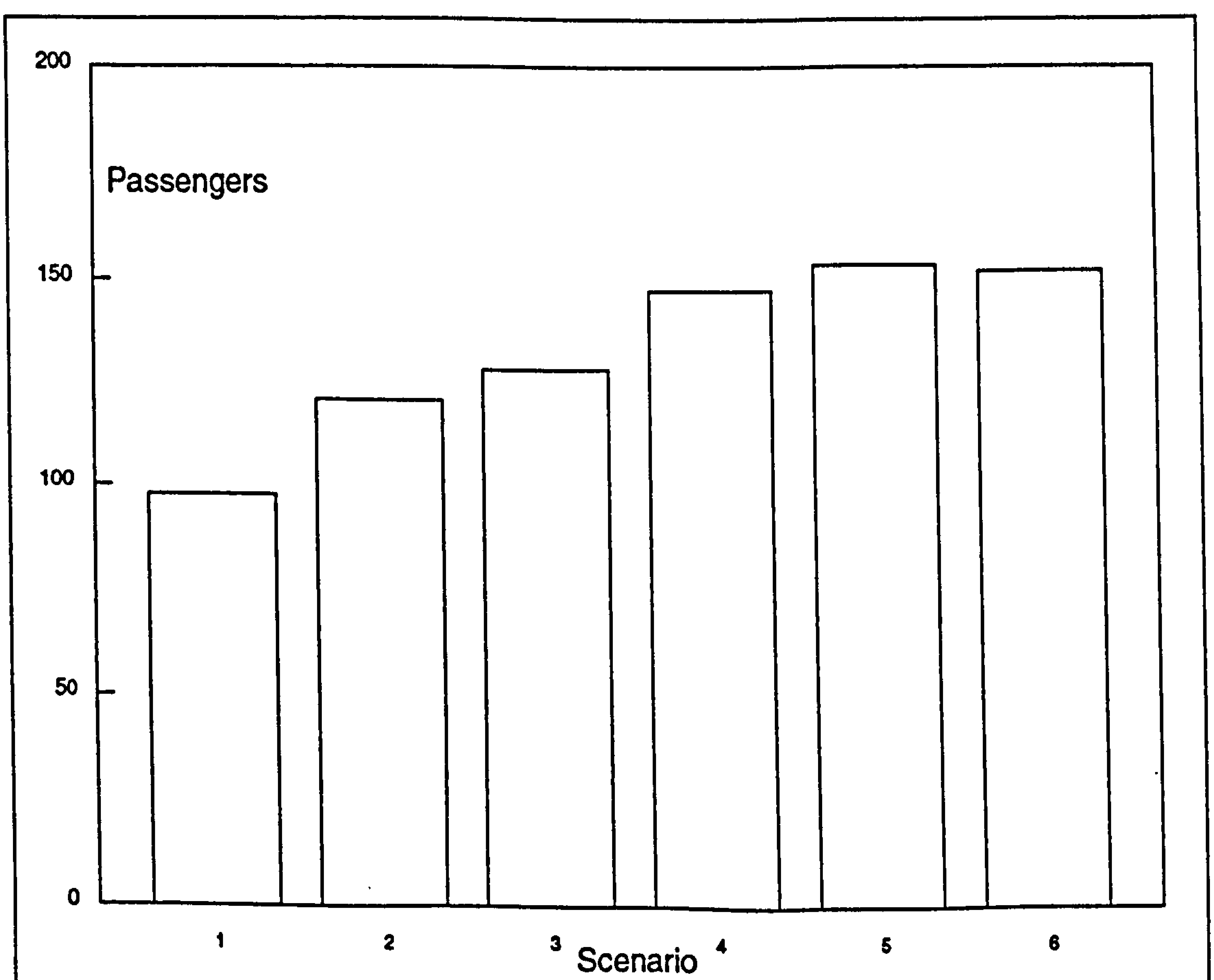


12.1.13 Peak Passenger Volume: Domestic Lounge

The results obtained for the volume of passengers held in the domestic lounge facility shown in Figure 32 reveal a steady increase in volume for the first three scenarios. The peak volume then levels out for Scenarios 4 to 6. The levelling out in the passenger volumes experienced could be explained by the fact that EMIA has a limited amount of domestic traffic. The earlier arrival of passengers at the airport for Scenarios 5 and 6, does not cause higher results than Scenario 4 because there are no more domestic passengers to accommodate than appeared in Scenario 4.

If this trend becomes real then there will obviously be implications for the operators of this airport. These facilities are very rarely designed with 100% occupancy in mind. If passengers are spending increasingly more time in these areas of the terminal, there will be an associated increase in the demand for comfortable fixtures and facilities for passengers in these areas.

Figure 32 Peak Passenger Volume: Domestic Lounge

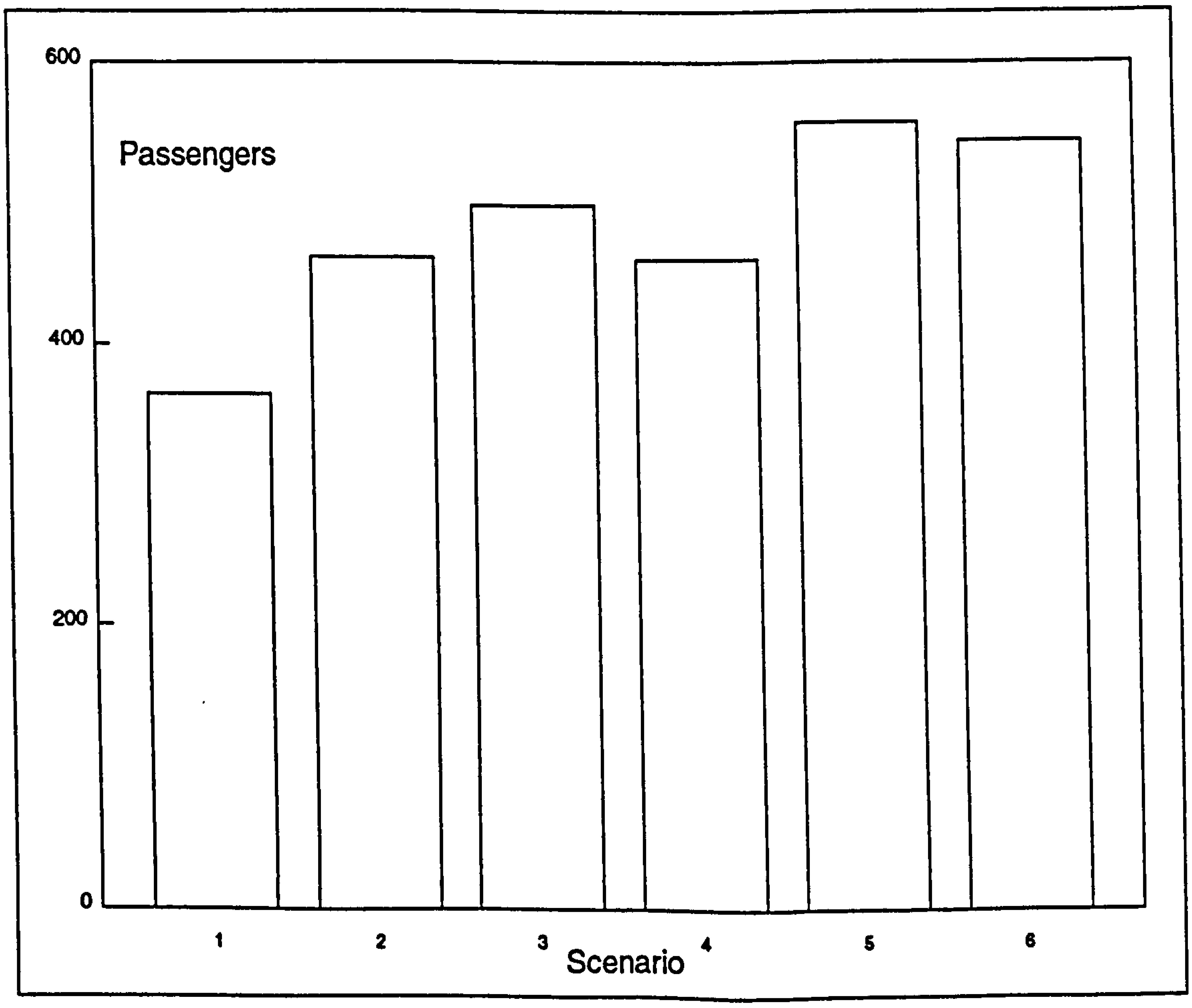


12.1.14 Peak Passenger Volume: International Lounge

Figure 33 shows the results for the volume of passengers held in the internal lounge facility. The results reveal a steady increase in volume for the first three scenarios. The trend is very much the same as for the domestic lounge, except for a slight drop in the peak level for Scenario 4.

The levelling out in the passenger volumes experienced as the scenarios progress could be explained by the fact that majority of the airport's international passengers are in the international lounge waiting to depart. No more flights are scheduled that could cause this figure to rise even with passengers arriving earlier. Again if this is the case there will obviously be implications for the operators of this airport. If passengers are spending increasingly more time in this area there will be an associated increase in the demand for comfortable fixtures and facilities for passengers in this area of the terminal.

Figure 33 Peak Passenger Volume: International Lounge

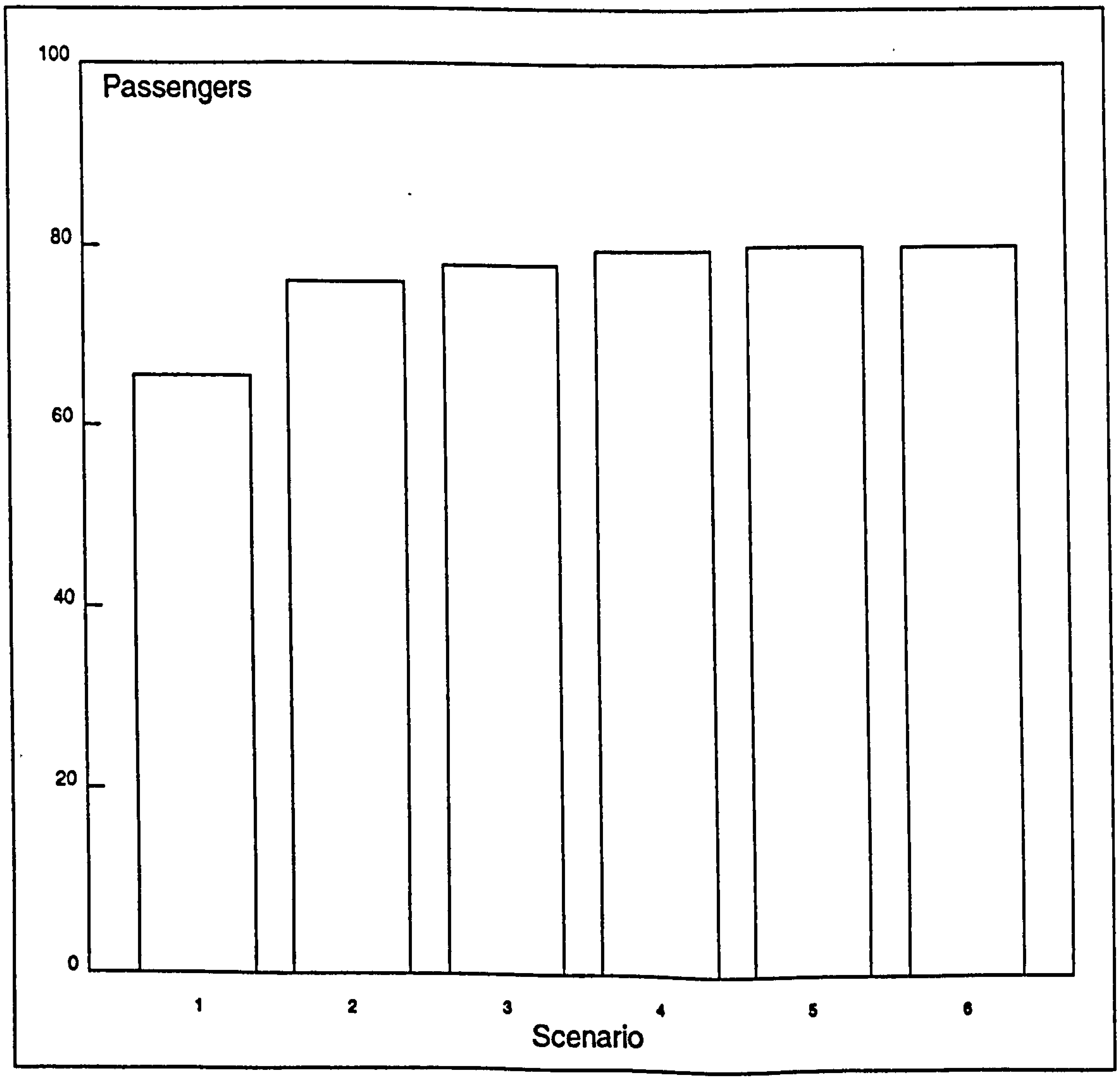


12.1.15 Peak Passenger Volume: N. Ireland Lounge

Figure 34 shows the results for the N. Ireland lounge facility. There is an increase in the volume of passengers for the first two scenarios that then levels out for the remaining scenarios. This feature of the results is due to the frequency of flights to N. Ireland. This lounge is unlikely to have more than one flight waiting at any one time. At the observed peak all the N. Ireland passengers are in the N. Ireland lounge.

As this is a specialised facility there will be limited implications for the operators of this airport. This facility is an under utilised facility due to its dedicated operation, and as such will not have the same facilities that can be found in other areas of the airport. In this case it will be necessary to open this facility at a given time before departure to prevent it having to be staffed unnecessarily and/or upgraded to a higher level of comfort.

Figure 34 Peak Passenger Volume: N. Ireland Lounge

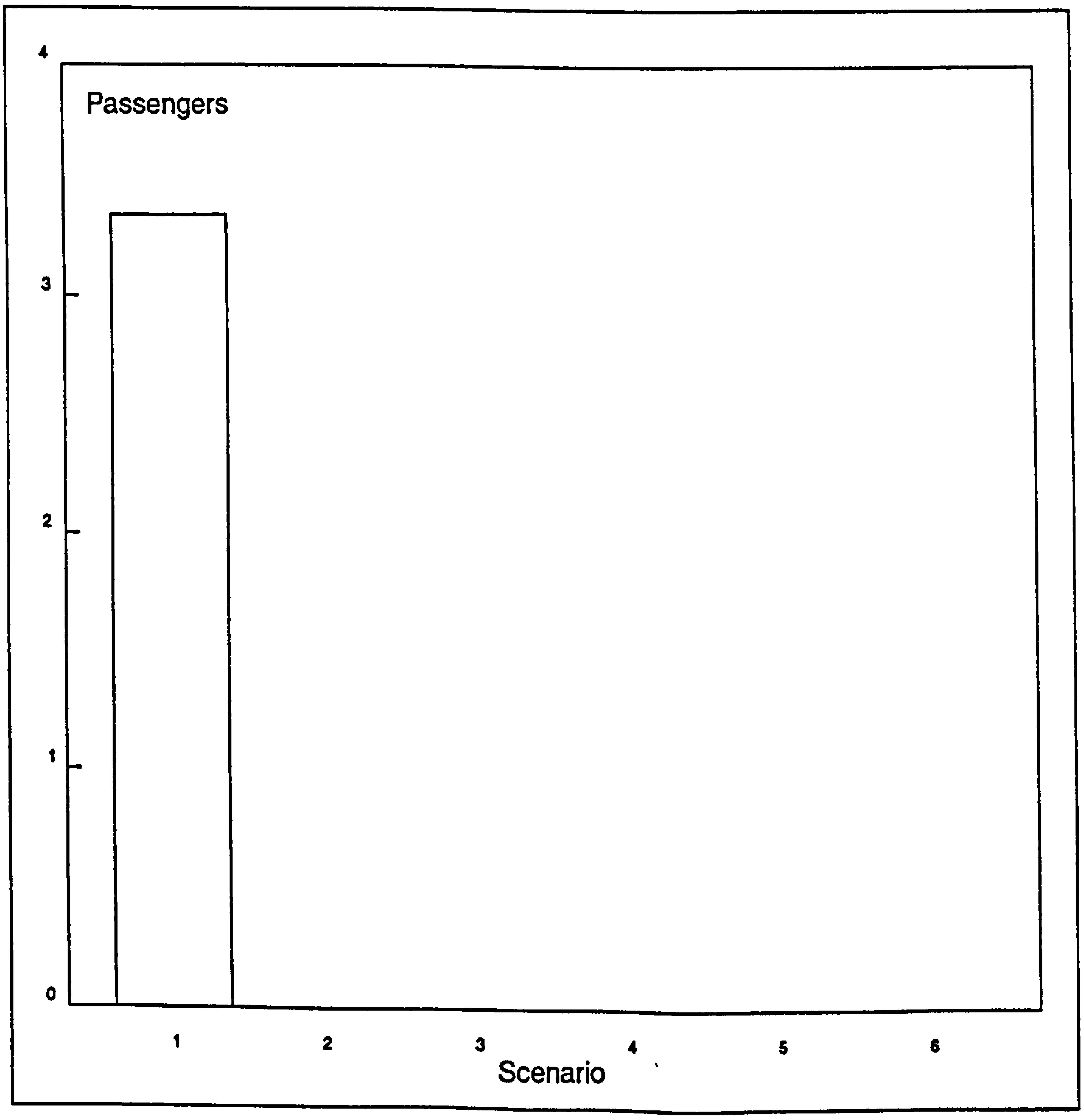


12.1.16 Simulated Missed Flights

The only scenario to record passengers missing flights due to the change in arrival distribution was Scenario 1, as shown in Figure 35. The average number of passengers missing flights for this scenario was less than 4 per iteration.

This comparatively good result could lie in a number of factors that include a high proportion of charter traffic at EMIA or a simpler passenger flow through the terminal. The high performance of the airport as a whole could also be due to the service times presented by the EMIA being collected in a differently to those presented by Birmingham and Manchester Airports.

Figure 35 Simulated Missed Flights



12.1.17 Summary

The results of the 120 iterations conducted for the EMIA model show an impact that tends to be focused very much on the public concourse of the terminal. In this model the pre- and post-check-in public concourse and the check-in queues are all competing for the same valuable space. The results indicate there will be capacity problems at EMIA if there is a shift in arrival distribution away from the scheduled time of departure.

The reason for the concentration of passengers within the concourses is the variable used in the model which releases passengers into the security facilities. This variable releases passengers at a set time before flight, as opposed to a set time after waiting in the public concourse. This variable will have a limited effect on the results.

The results do show that the change in arrival distribution away from the scheduled time of departure has greatest affect of the early stages of the terminal model. Taking the example of the peak passport control queue length, there was little evidence of the shift in arrival distribution compared with the check-in facilities.

There is an impact on the capacity of the departure lounges which is revealed by this simulation. If passenger arrival patterns shift closer to the scheduled time of departure, the spatial demands on the departure lounges are reduced.

12.2 The Birmingham Airport Model: Part 1 and Part 2

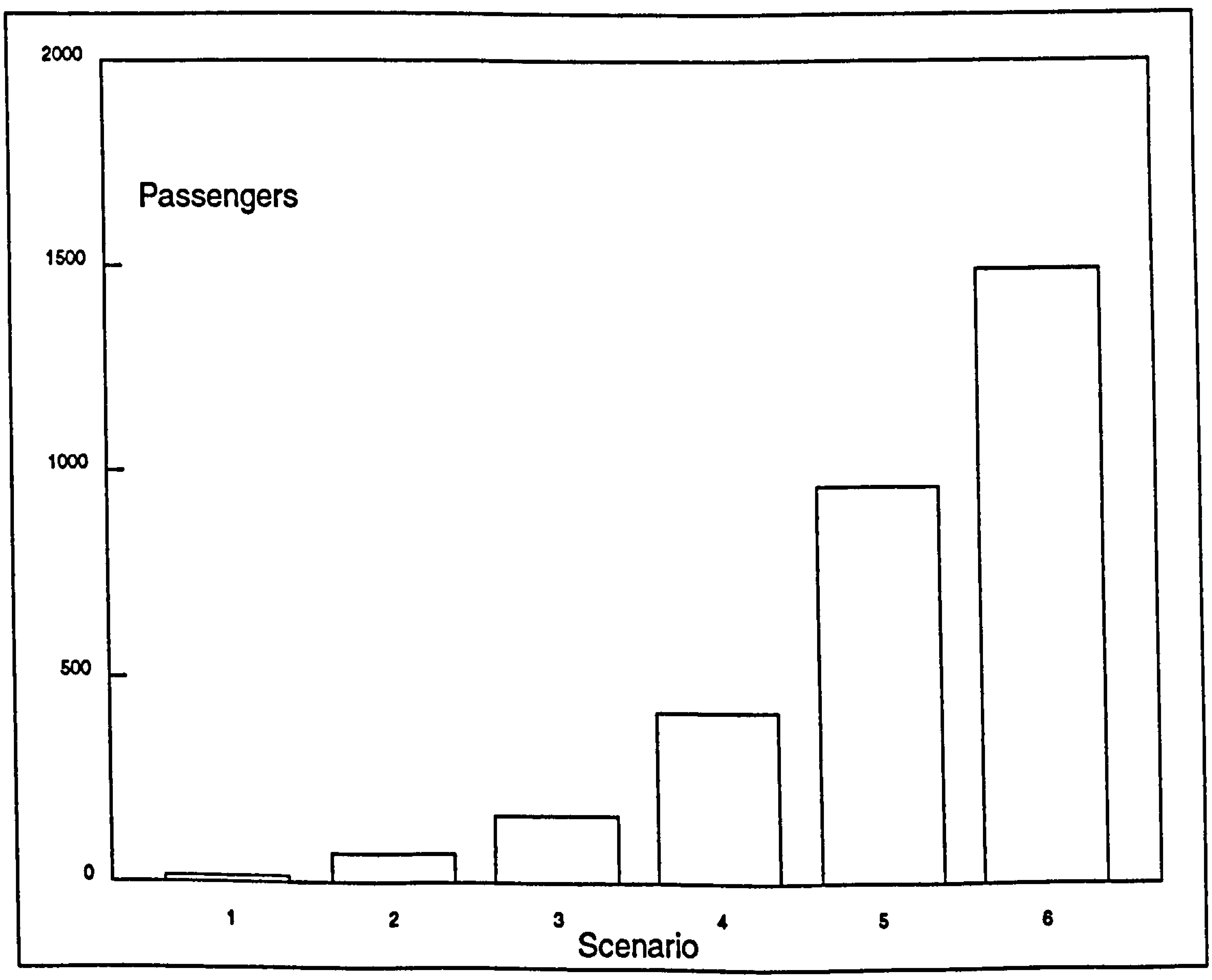
The Birmingham model is based on a two terminal layout. The two terminals support both domestic and international flights. A plan of this model can be seen in Figure 14.

12.2.1 Peak Public Concourse Passenger Volume: Part 1

As can be seen from Figure 36, there is a steady rise in the volume of passengers recorded in the public concourse facility that can be associated with the shift in arrival pattern.

With the shift in arrival patterns away from the scheduled time of departure of their flight passengers are spending more time in this area of the terminal. This will have implications for the airport operator. Attention will have to be given to provision of facilities within this area for both passenger comfort and entertainment.

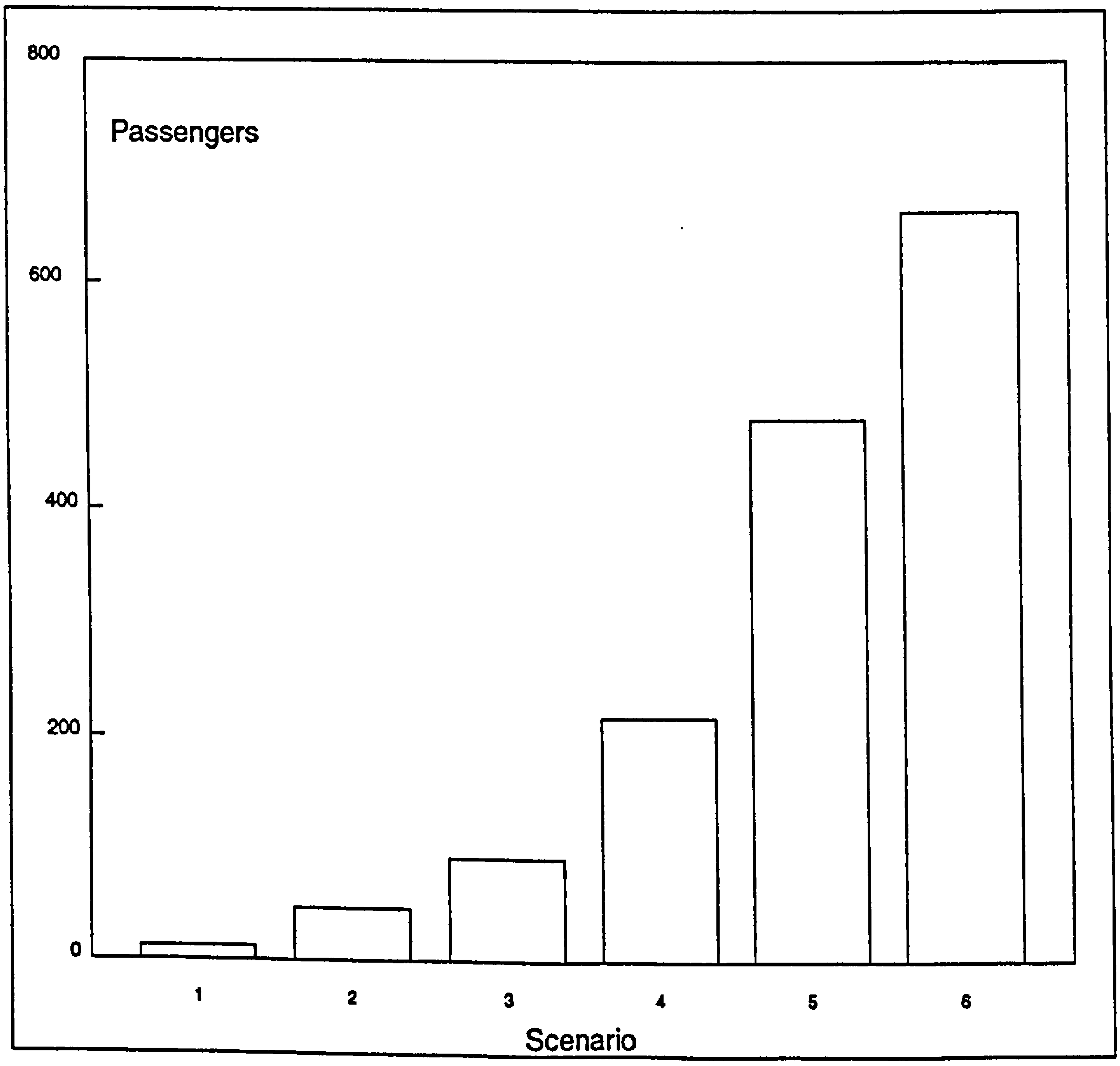
Figure 36 Peak Public Concourse Passenger Volume: Part 1



12.2.2 Peak Public Concourse Passenger Volume: Part 2

Figure 37 shows the results of this separate public concourse facility. Again as the arrival pattern shifts from Scenario 1 to Scenario 6 there is a rise in the peak passenger volume. For the same reason there will be a need to provide facilities within the area for meeting the passengers' demands for comfort and entertainment.

Figure 37 Peak Public Concourse Passenger Volume: Part 2



12.2.3 Maximum Queue Length by Airline: Part 1 and Part 2

Although the passenger flows from the two parts of the models do not mix, the model displays the results of the two parts of the models together in the same terms as the other models. The queues shown in Figure 38 and Figure 39 represent a consistent selection of eight queues from the two parts of the model. However, it is not possible to identify which part of the model the check-in desks originate. This was a limitation of combining the two terminals into the one model.

The results from the various check-in desks queues reveal a common trend, as the arrival pattern shifts from Scenario 1 to Scenario 6, where there is an initial drop in the peak queue length. The trend is then reversed as generally the queue length increases from Scenario 4 onwards. For the first scenario the rate of arrival of passengers is too great for the service times to deal with effectively, and so queues form; the longer queues forming when the arrival rate is highest. The reason for the change in trend for the higher numbered scenarios is that prior to the opening of the check-in desks an ever increasing number of passengers has accumulated in the public concourse. When the check-in desks open these passengers will immediately form a queue. The greater the number of passengers in the public concourse the longer the initial queue length becomes.

The implication for the airport operator is that there needs to be emphasis placed on the processing of passengers should there be a significant shift in passengers to late arrival at the terminal. Likewise there is an implication should the shift be in the opposite direction to change in check-in desk management and/or comfort provision within the terminal. Space allocation, desk opening and passenger processing strategies would have to be reviewed with any significant change in arrival distribution.

Figure 38 Maximum Queue Length by Airline: Part 1 and Part 2 (Queues 1 to 4)

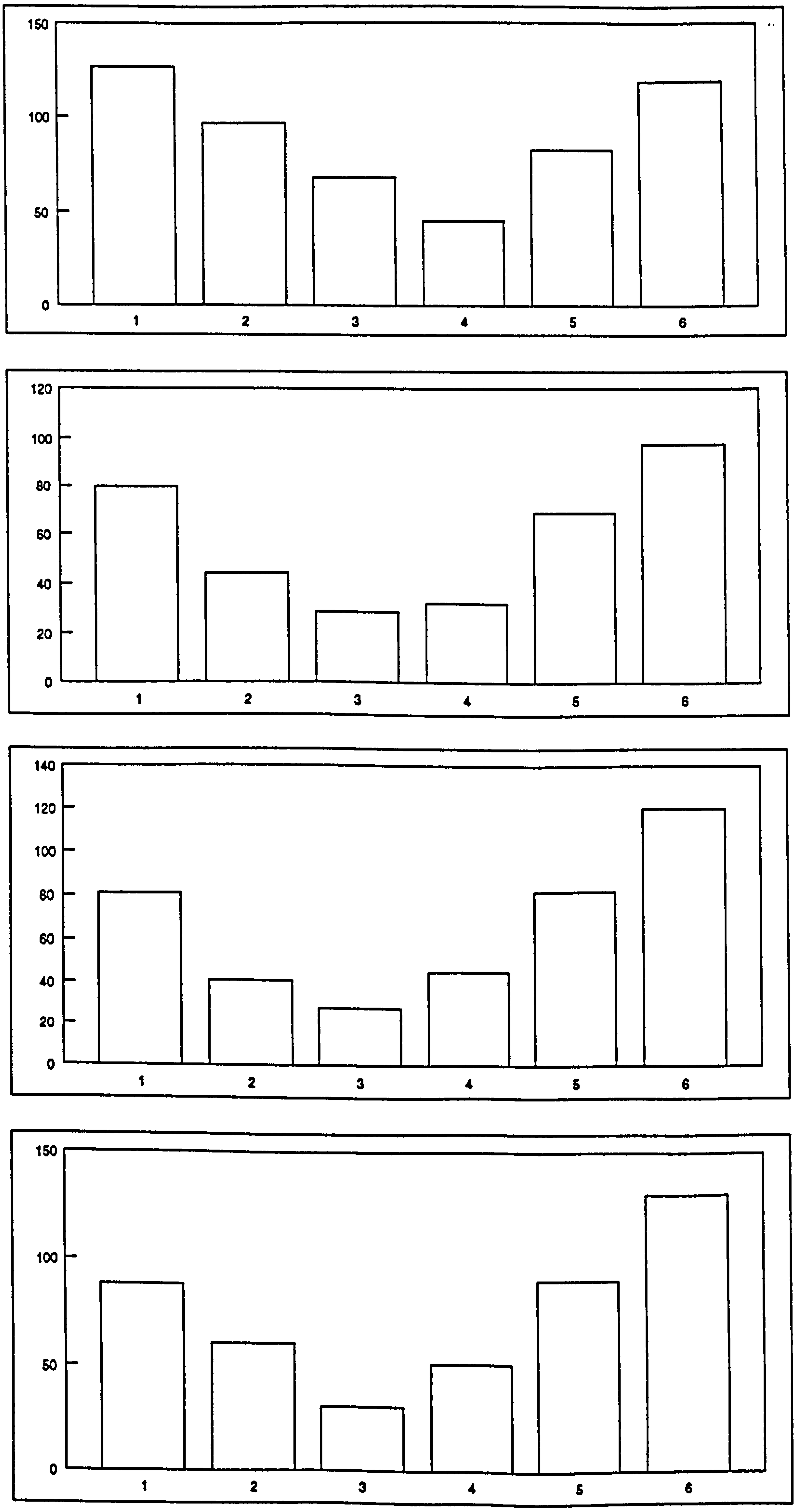
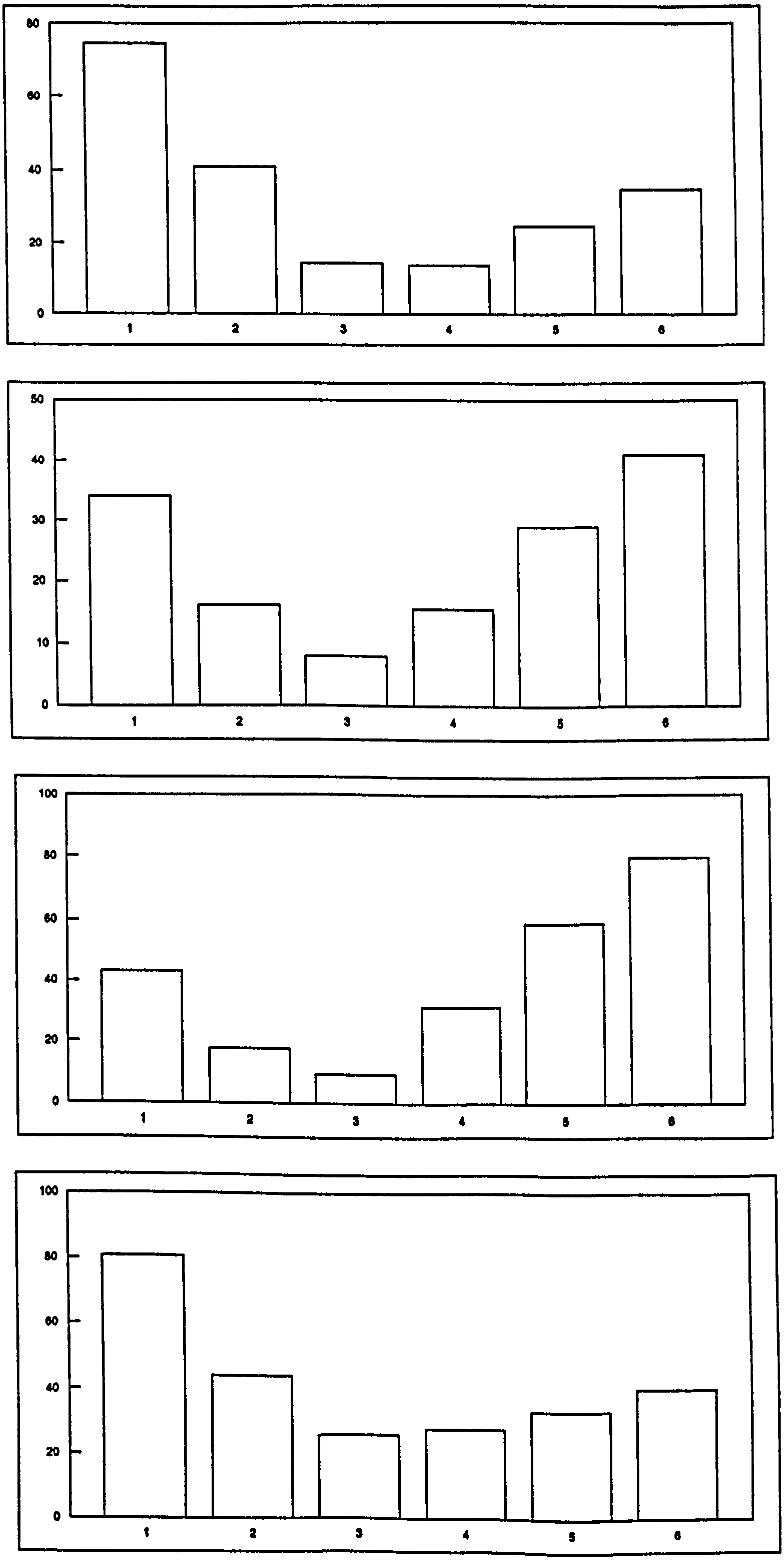


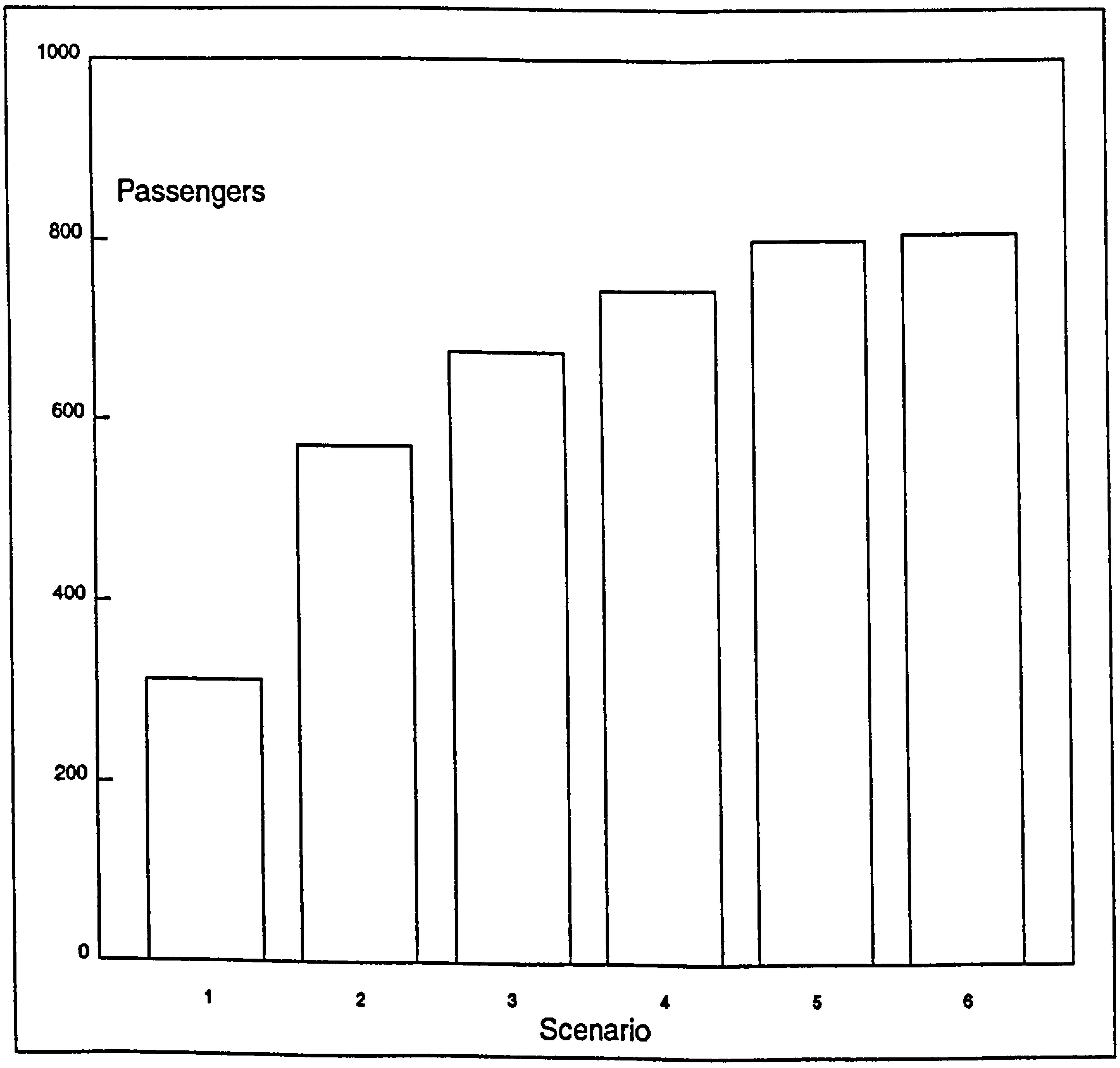
Figure 39 Maximum Queue Length by Airline: Part 1 and Part 2 (Queues 5 to 8)



12.2.4 Peak Passenger Volume Concession Area Part 1

The results of the simulations for the concession area part 1 facility are shown in Figure 40. These reveal an increase in the volume of passengers collecting in the terminal concessions and public areas. The recorded passenger volume increases with the shift in the passenger arrival pattern away from the scheduled time of departure, however, the rate of growth is reduced towards the latter scenarios. Again it is important to remember that this facility is part of the total passenger holding space. As a consequence of these results there may be a need for additional space to support the higher passenger volumes.

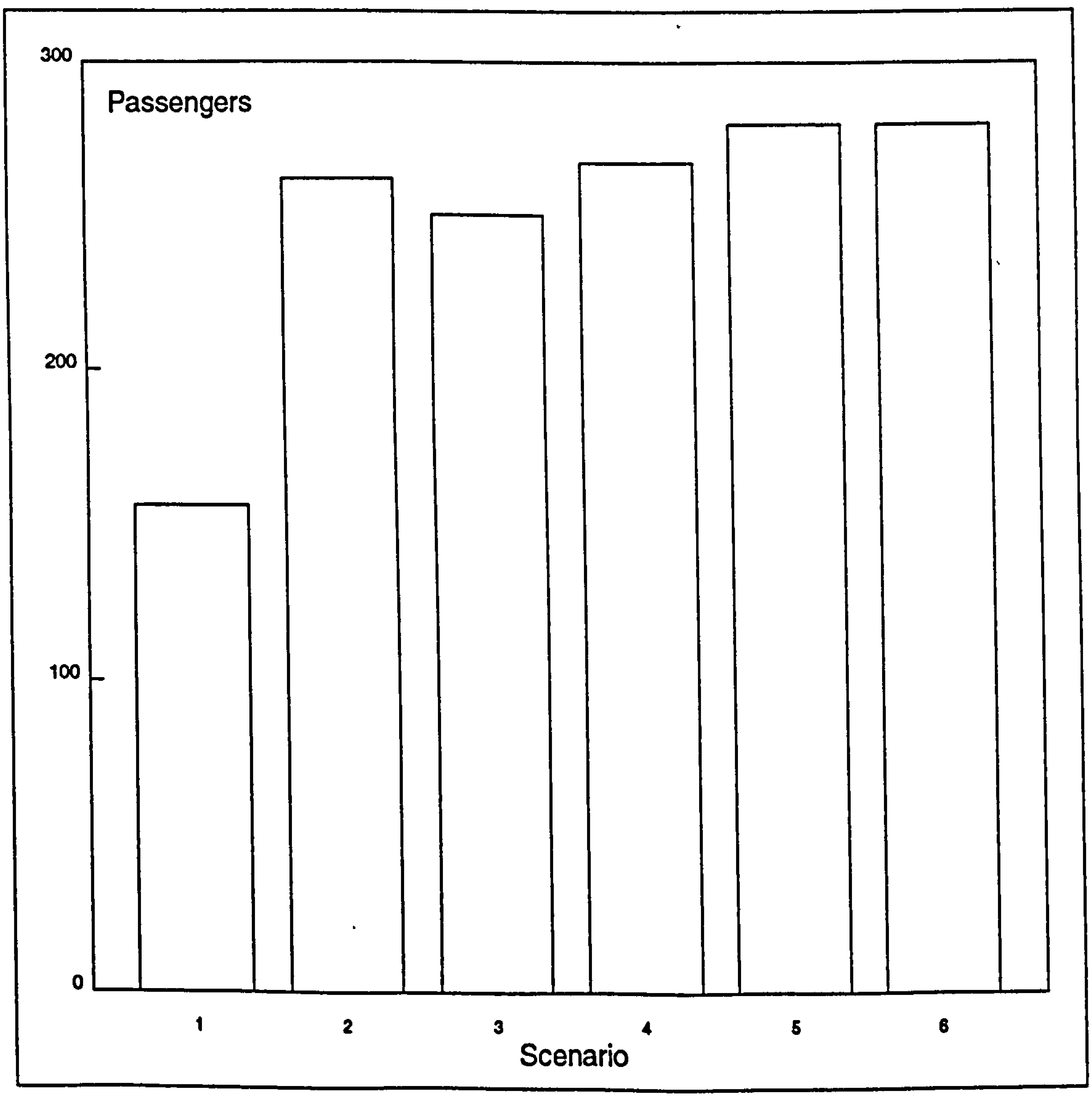
Figure 40 Peak Passenger Volume Concession Area Part 1



12.2.5 Peak Passenger Volume Concession Area Part 2

Figure 41 shows the peak passenger volume for part 2 concession area of the model. The results follow a similar trend to those in part 1. The exception is Scenario 2 which produces levels that are larger than might have been expected. As with Part 1 there may be a need for extra facilities to be provided that address the comfort and entertainment needs of passengers. Needs generated as a results of the higher passenger volumes associated with the shift in arrival patterns away from the scheduled time of departure.

Figure 41 Peak Passenger Volume Concession Area Part 2

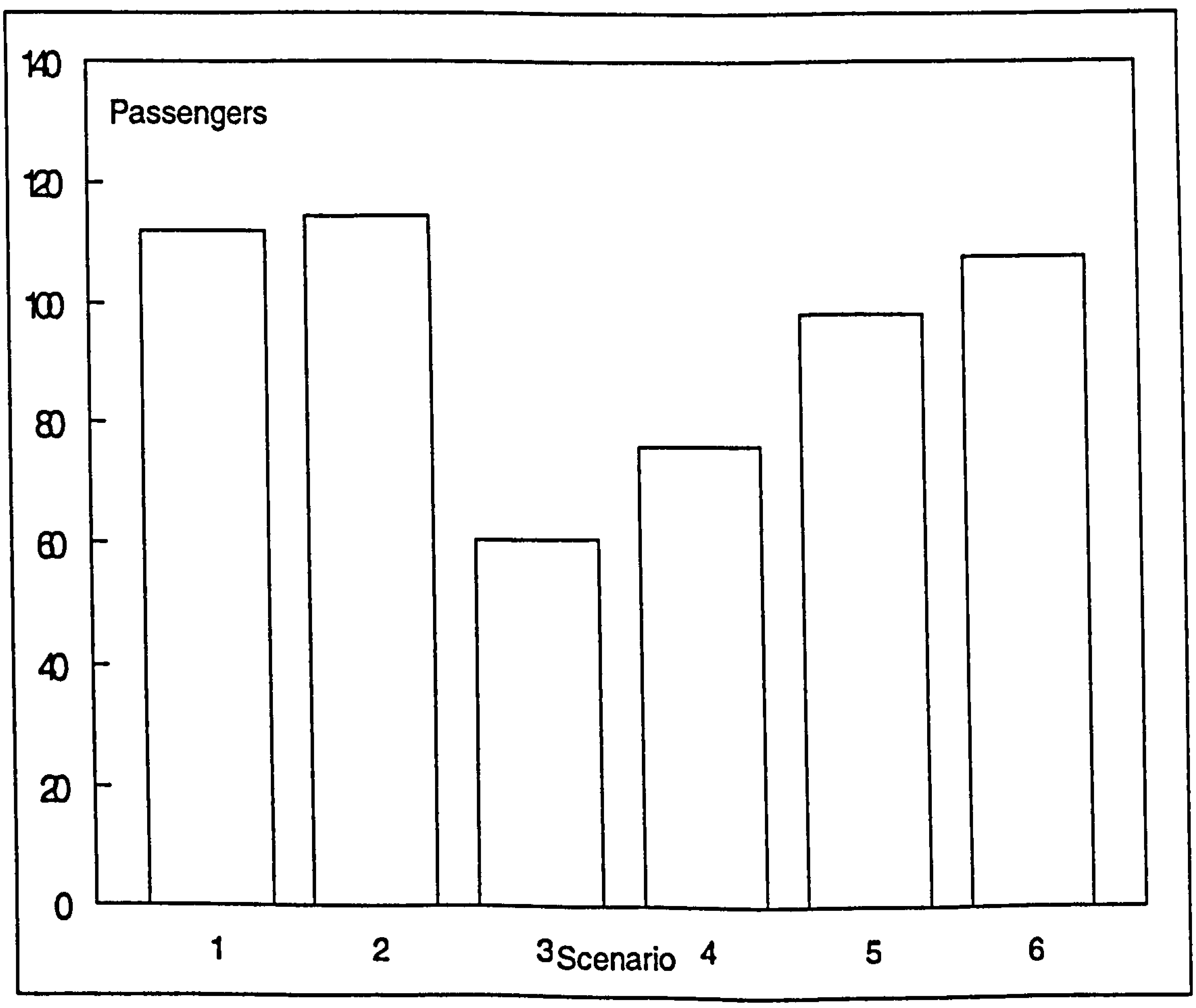


12.2.6 Peak Security Queue Length: Part 1

The results obtained for the security facility are displayed in Figure 42. The results suggest that peak levels occur when the number of passengers held in the concessions area is low, as in the cases of Scenarios 1 and 2. From Scenario 3 onwards there appears to be a steady rise in the peak queue length to a level at which Scenario 6 approaches the level of Scenarios 1 and 2.

This can be explained in that in Part 1 of the model there is a higher proportion of domestic traffic. The passengers for these flights in Scenarios 1 and 2 are arriving relatively close to the scheduled time of departure. These passengers may not be slowed down by visiting the concession area, but pass more or less straight from the check-in desks to the security queue. However, as the arrival distribution moves away from the scheduled time of departure these passengers will spend more time in the concession areas of the terminal, therefore reducing the impact on the security facility.

Figure 42 Peak Security Queue Length: Part 1

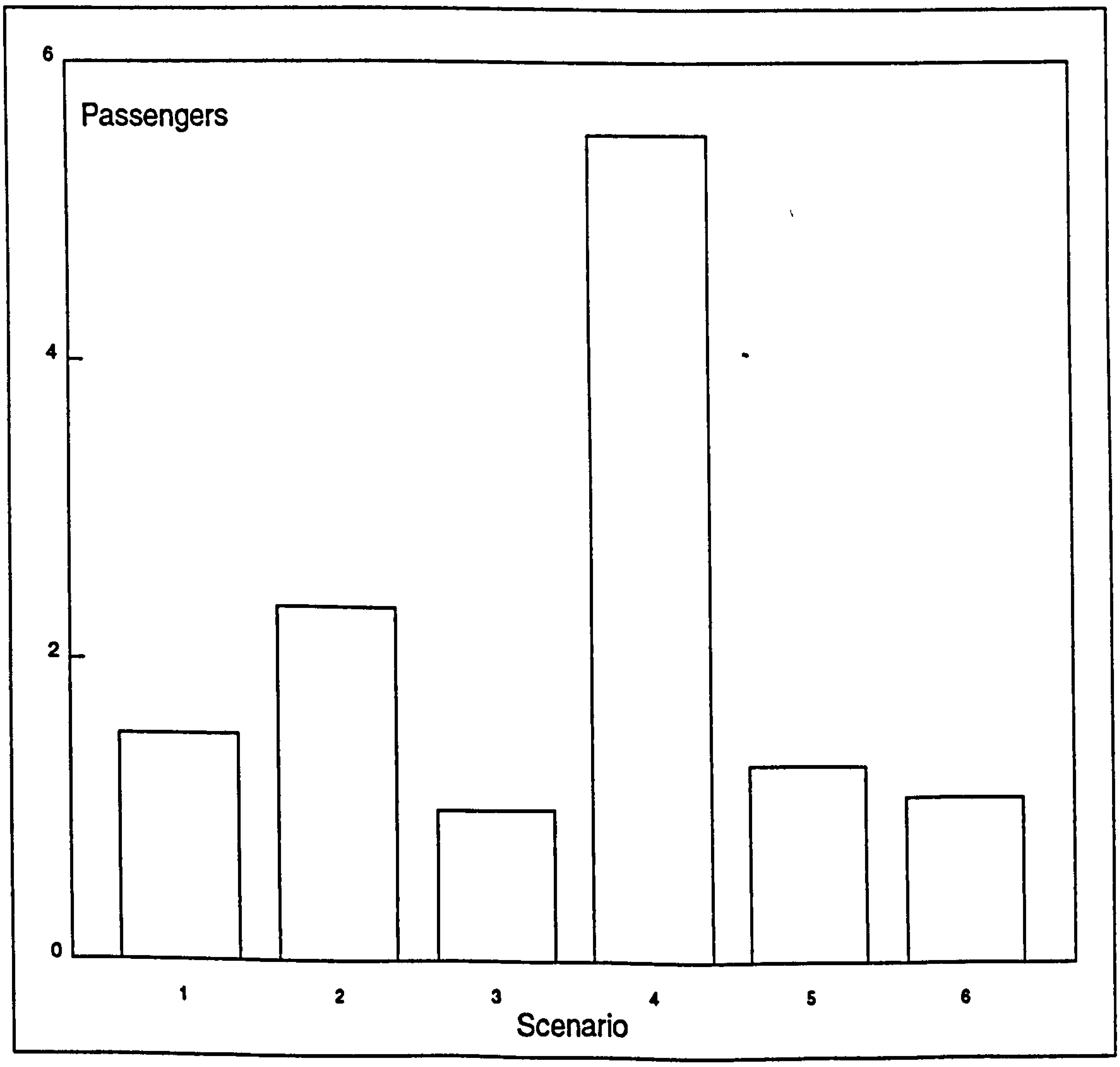


12.2.7 Peak Security Queue Length: Part 2

Figure 43 shows the results for the security facility in Part 2 of the terminal model. There seems to be a stable peak queue length for most of the scenarios, except for the result for Scenario 4. The difference between the results of Part 2 and Part 1 could be the lower number of domestic passengers in Part 2, as this is a mainly European terminal. Furthermore, the lower queue levels observed in Part 2 could reflect better handling operation and facility management in this terminal.

Considering the results from the two security queues the facility requirements for Part 1 are significantly higher than for Part 2.

Figure 43 Peak Security Queue Length: Part 2

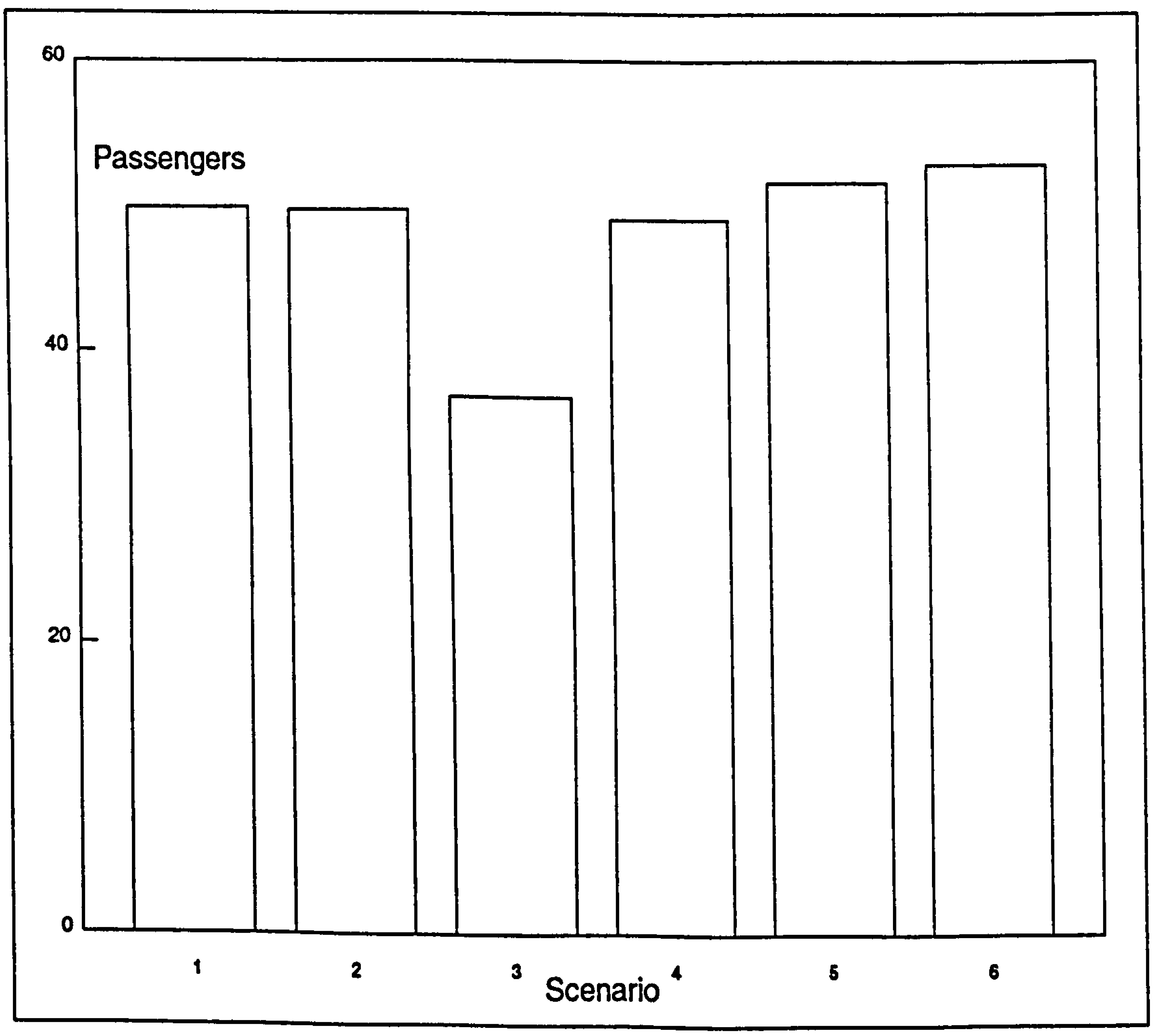


12.2.8 Peak Passport Control Queue Length: Part 1

The results for the passport control facility Part 1, as displayed in Figure 44, take a similar form to those obtained for the security facility Part 1 (Figure 42). Scenarios 1 and 2 have a high queue length, which falls for Scenario 3 and then builds again to a high level for Scenario 6.

The results would seem to suggest that this facility is not affected by a change in the arrival distribution at the airport.

Figure 44 Peak Passport Control Queue Length: Part 1

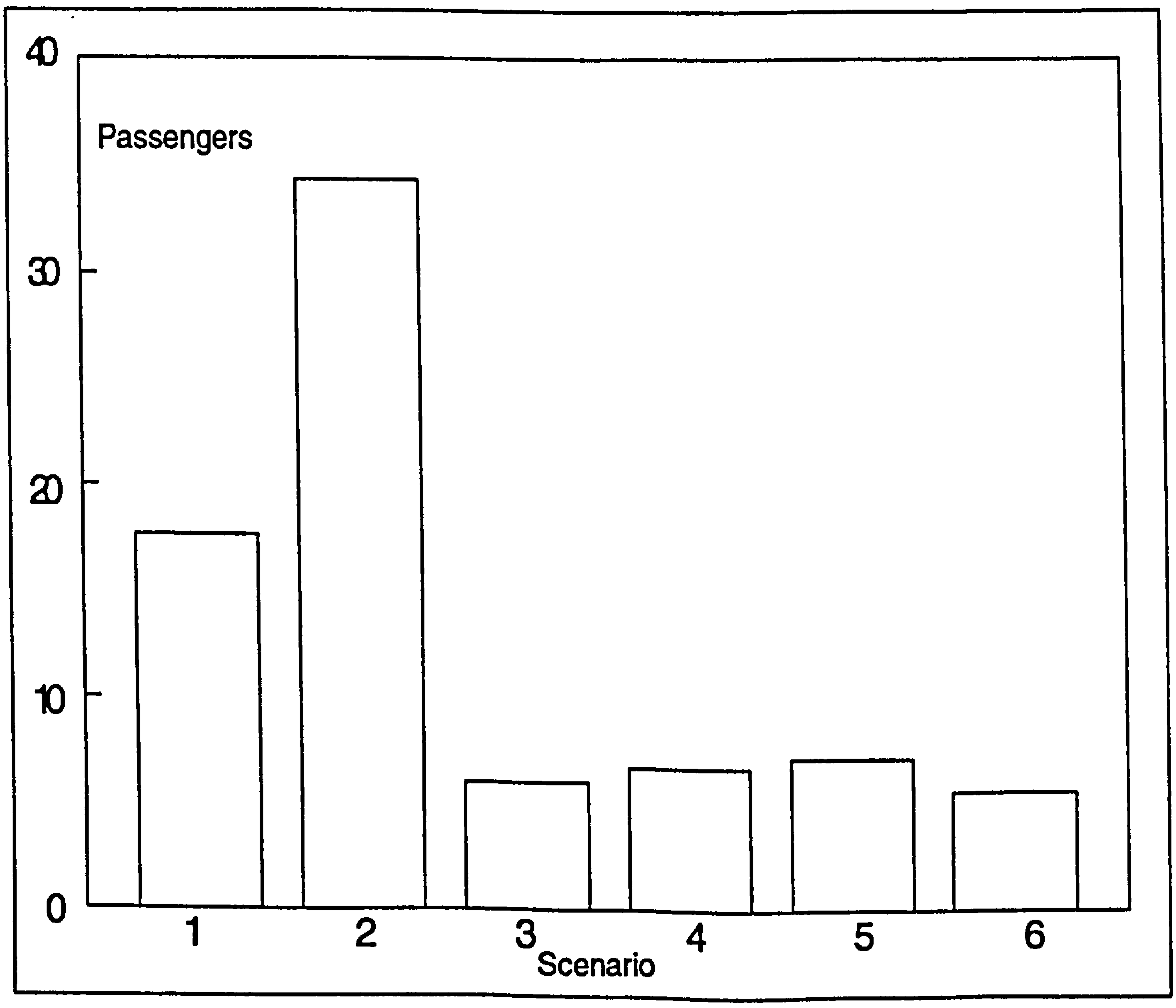


12.2.9 Peak Passport Control Queue Length: Part 2

Figure 45 displays the results for the passport control facility part 2. The results reveal high queue lengths for Scenarios 1 and 2. However, the remaining scenarios appear to experience a stable queue length at a lower level than the initial two scenarios. This could be due to steadier flows created by the spread in the arrival pattern associated with the latter scenarios.

When compared with Part 1, the passport control queues are very different in profile. Generally, the peaks are lower than those experienced in Part 1. There is no apparent reason for the increase in the queue length of Scenario 2 except a high level of passengers miss flights in Scenario 1, the cause of which is discussed later in this section. For Scenario 1, a number of passengers may not have reached this facility as they had already missed their flights and been removed from the simulation. Had the passengers not been removed from the simulation the queues experienced for this facility would be expected to be higher for Scenario 1 than Scenario 2.

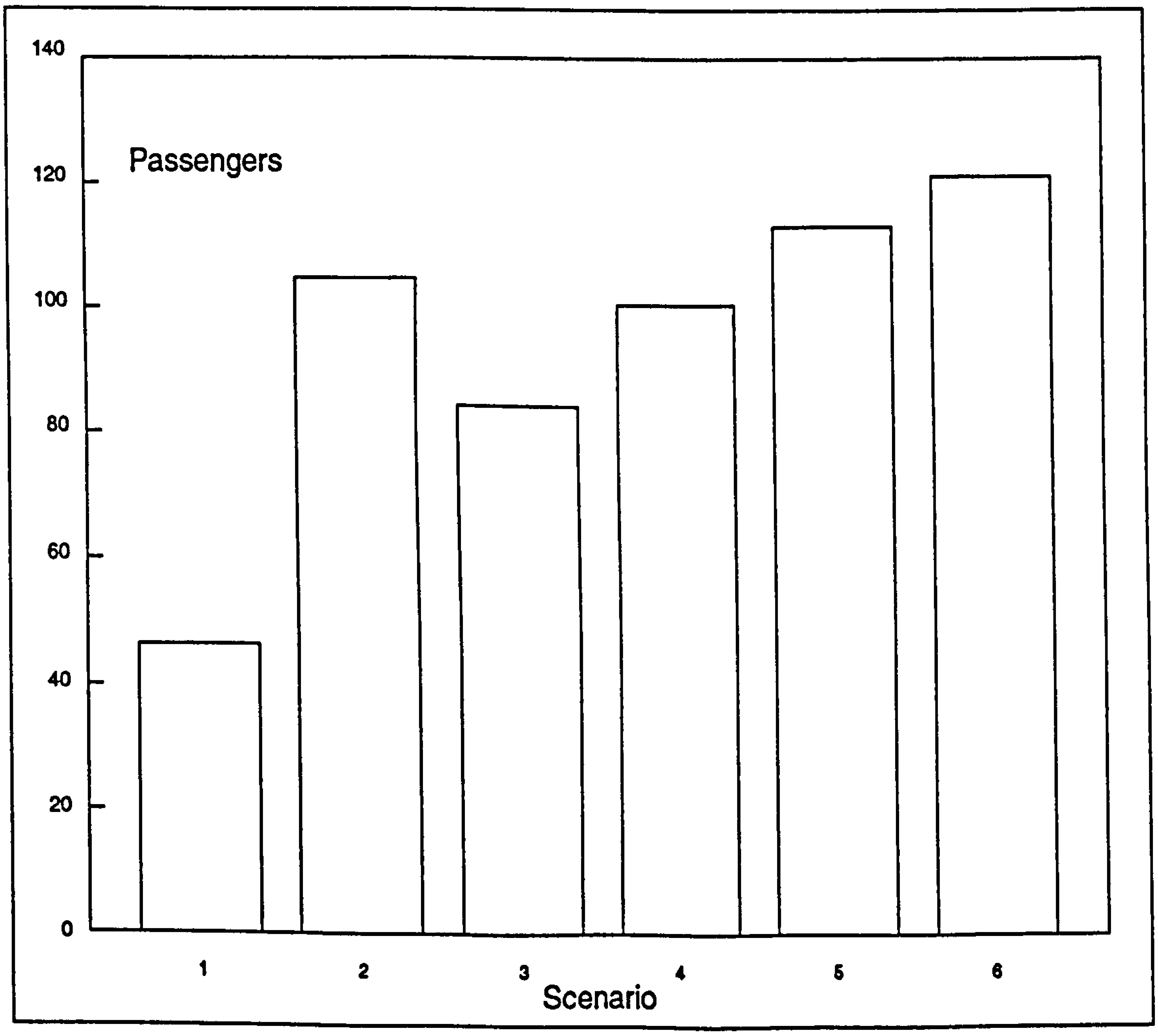
Figure 45 Peak Passport Control Queue Length: Part 2



12.2.10 Peak Passenger Volume Domestic Lounge: Part 1

The results for this facility for the domestic lounge facility part 1 are shown in Figure 46. They reveal a trend that can be related to the change in passenger arrival patterns at the airport terminal. The revealed trend is of increasing passenger volumes being recorded for this facility as passengers arrive earlier at the airport. Scenario 2 has a larger peak volume than might have been anticipated. There is a low passenger volume experienced in the domestic lounge for Scenario 1. This may be explained by a number of passengers missing flights for Scenario 1 as discussed earlier.

Figure 46 Peak Passenger Volume Domestic Lounge: Part 1

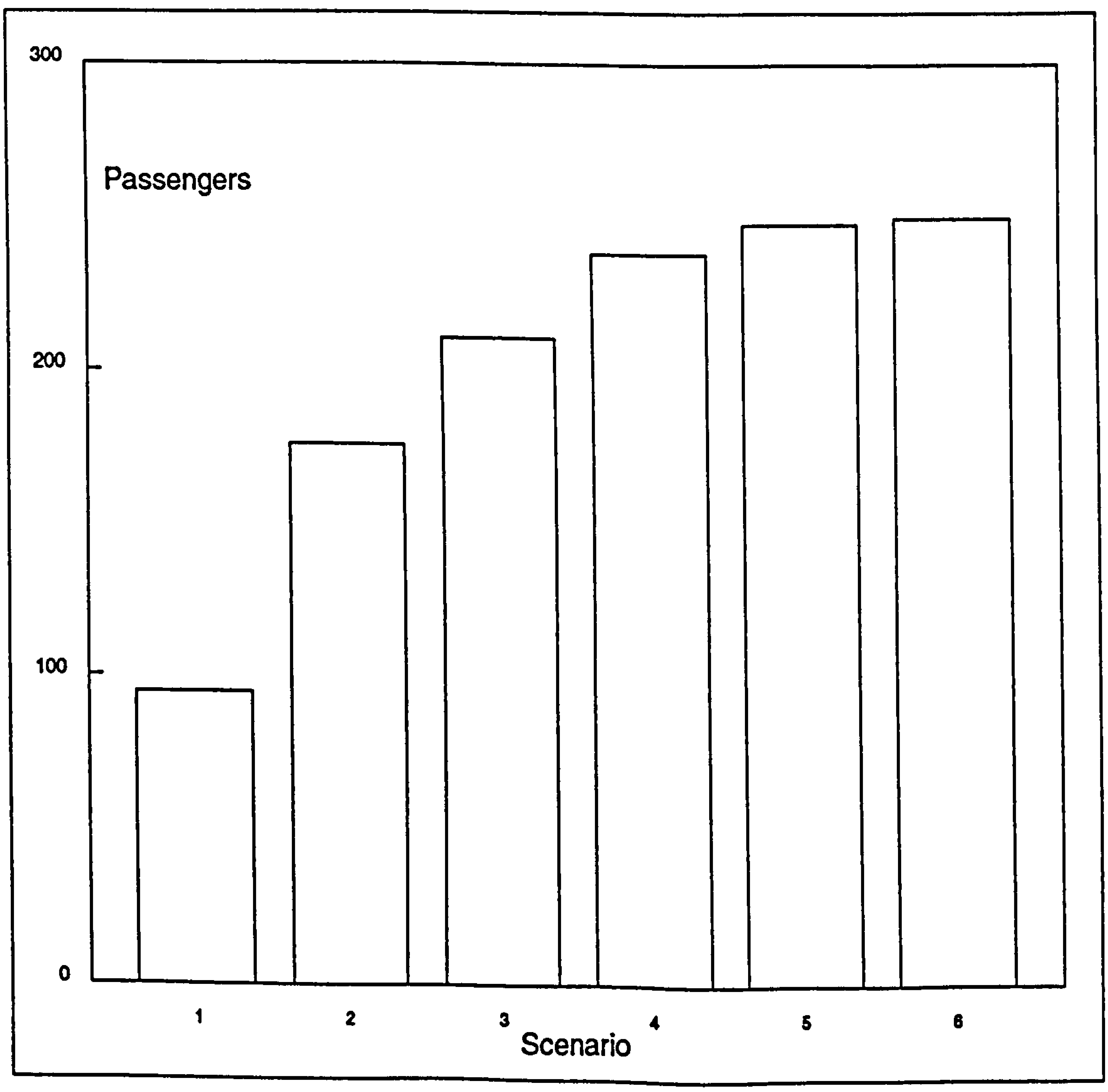


12.2.11 Peak Passenger Volume Domestic Lounge: Part 2

The results obtained for the domestic lounge part 2 are displayed in Figure 47. They show a steady increase in the passenger volumes recorded for the first three scenarios. The recorded volumes level out for the remaining scenarios. It is unclear what affect the number of passengers that missed flights in the first two scenarios has on the results.

With a shift to earlier arrival at the airport there is an increasing demand for capacity. Should the shift away from the scheduled time of departure of the arriving passengers occur there may be demand for improvements to facilities in terms of comfort and capacity.

Figure 47 Peak Passenger Volume Domestic Lounge: Part 2

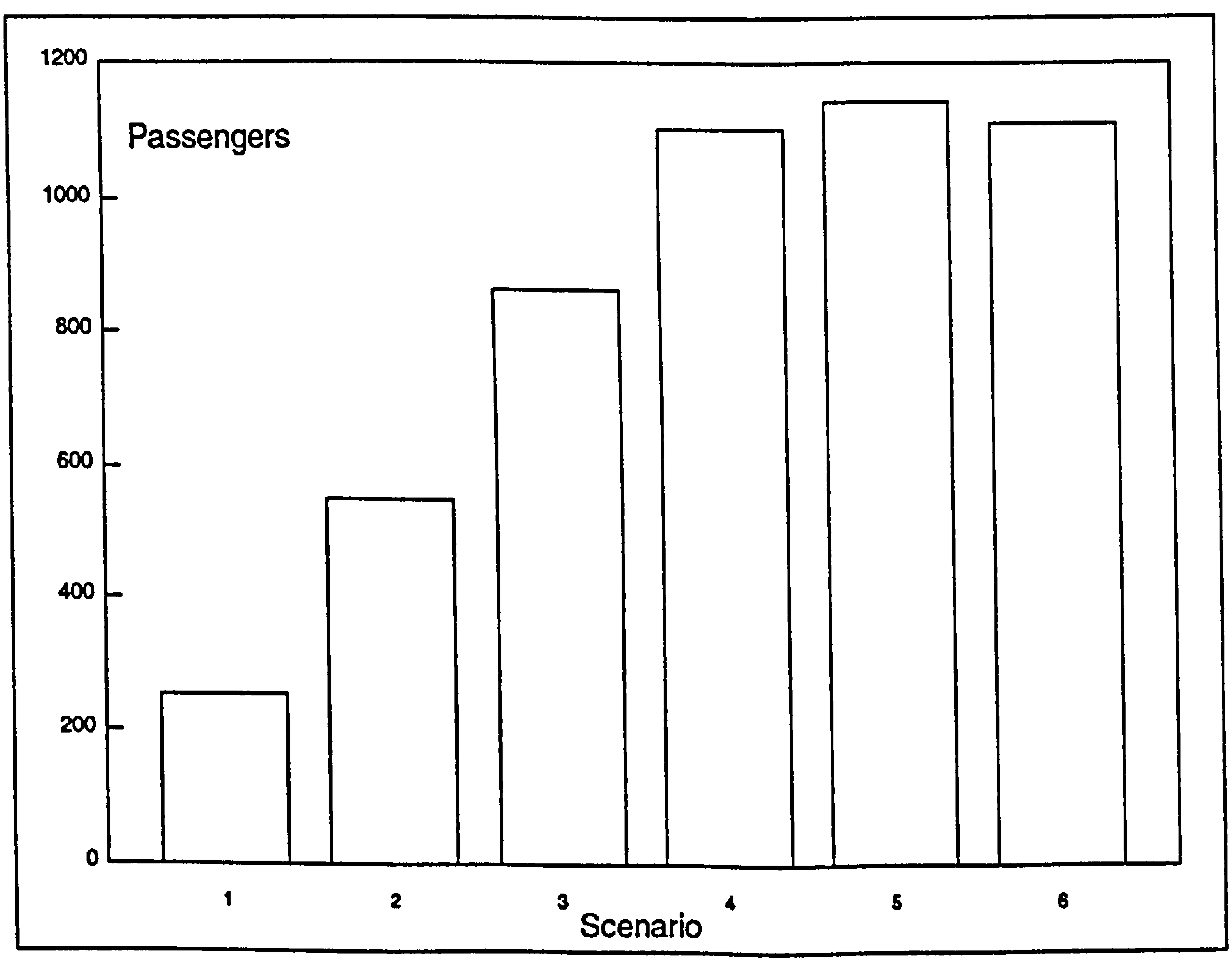


12.2.12 Peak Passenger Volume: International Lounge: Part 1

The results for the international lounge part 1 facility are shown in Figure 48. As with the domestic lounge the results reveal that there is an increase in volume with earlier passenger arrival at the airport. The reason for the peak for Scenario 4 could be due to the flight schedule, in that there may not be any more passengers to accommodate. For the subsequent scenarios the fact that the majority of the international passengers are already accommodated causes the stable results observed.

These results have implications for the operators of this airport. If passengers are spending increasingly more time in these areas there will be an associated increase in the demand for comfortable fixtures and facilities in this area of the terminal.

Figure 48 Peak Passenger Volume: International Lounge: Part 1

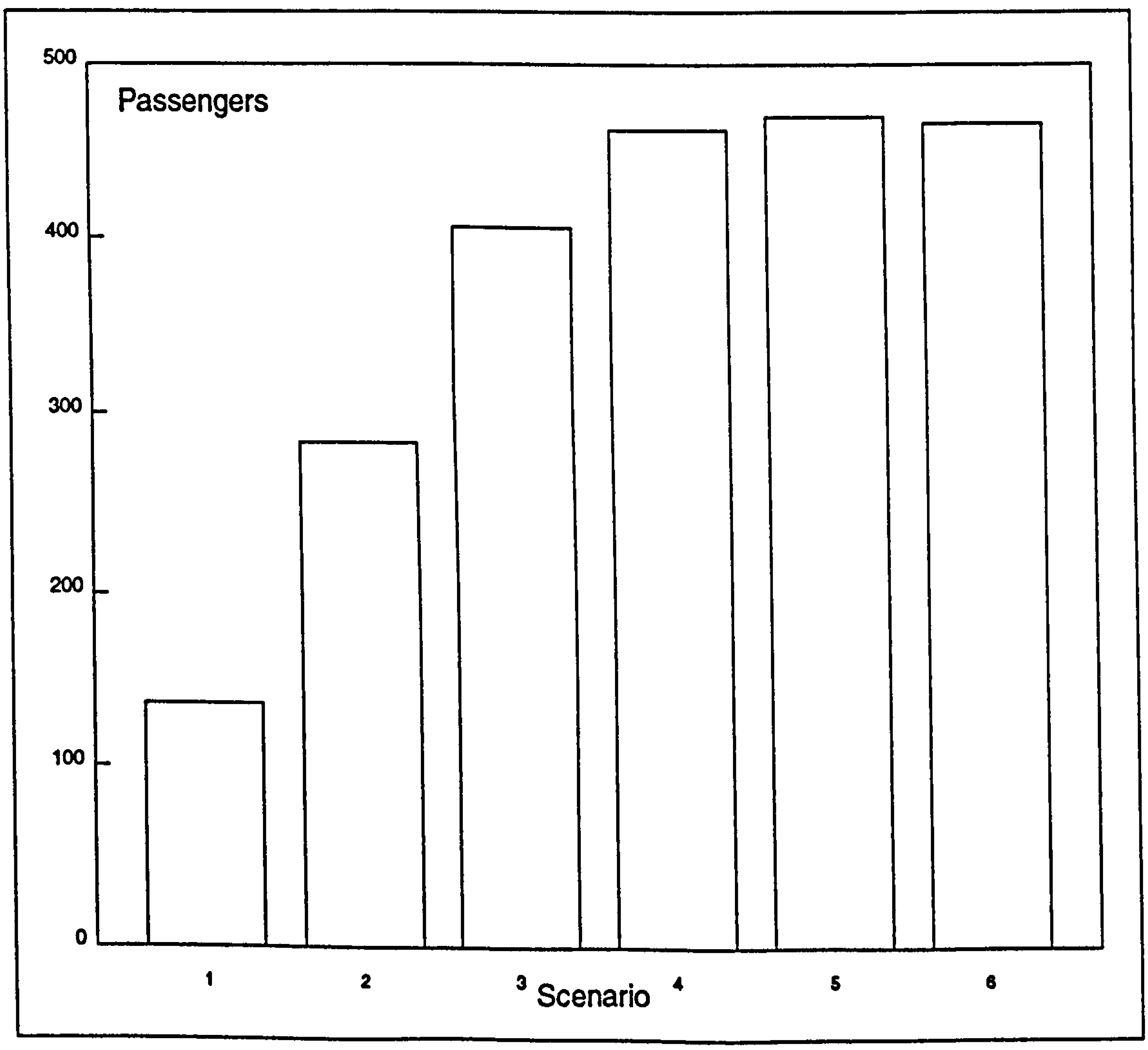


12.2.13 Peak Passenger Volume: International Lounge: Part 2

Figure 49 shows the results obtained for the international lounge facility in part 2 of the model. It is unclear what affect the number of passengers that missed flights in the first two scenarios had on the results. However, the proportion of international passengers that missed flights is likely to be lower than that observed for domestic passengers.

With a shift to earlier arrival at the airport by departing passengers there will be an increased demand for capacity. As has been identified earlier, the demand for capacity may be accompanied with demands for appropriate passenger facilities.

Figure 49 Peak Passenger Volume: International Lounge: Part 2

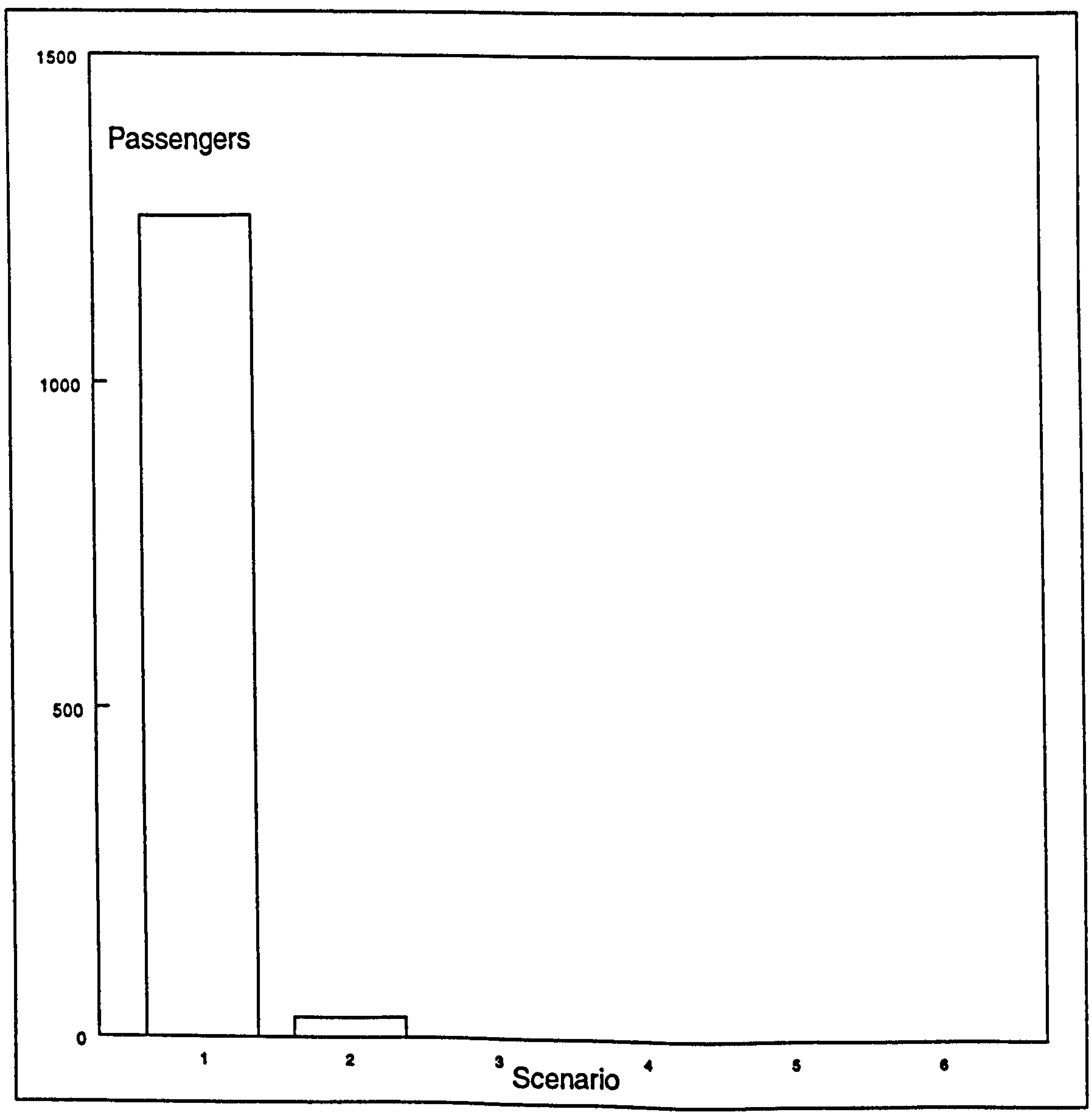


12.2.14 Simulated Missed Flights

Figure 50 reveals that the first two scenarios resulted in missed flights. It is not possible to identify which of the two parts of the Birmingham Airport model experienced most missed flights. The results for missed flights compared with the EMIA model may be different because of the proportionately higher number of domestic flights in Birmingham Airport's schedule.

More domestic flights are missed flights because of the shorter period of time passengers have to check-in and pass through the terminal. This short period of time is associated with the earlier scenarios that are characterised by late arrivals at the terminal.

Figure 50 Simulated Missed Flights



12.2.15 Summary

Generally the results for the Birmingham Airport Model are as expected. Both the public concourses and lounges experienced increases in passenger volumes. This is due to the variable used to release passengers from these facilities. This variable was set to release at a predetermined time before scheduled time of departure. The results would have been different had all the passengers been forced to spend a set period of time in the concession areas.

The characteristic 'U' shape of the observed check-in queues suggests that there could be an optimum arrival pattern to minimise check-in queue length.

The results obtained for the dynamic facilities occurring later in the model do not appear to be affected by the arrival pattern of passengers at the airport terminal. On the whole the results for the two parts of the model are very similar. The trends that occur with the change in arrival distribution are similar.

As a final point, there may be a difference in the passenger handling performance of the two parts of the model which may have a number of causes, such as different handling agent operating practices.

12.3 Manchester Airport Model 1

Manchester Airport Model 1 represents the international operation of a single terminal. A plan of this model can be seen in Figure 16.

12.3.1 Maximum Check-in Queue Length

This particular model displays peak check-in queue length by check-in desk as opposed by handling agent as in the EMIA model. Figure 51 and Figure 52 show the peak queue length of eight of the model's check-in desks that were monitored.

It is possible to observe a trend from the results. For Scenario 1 there is a peak in the observed queues at the check-in desks. As the passenger arrival pattern shifts to earlier arrivals, Scenarios 2 and 3, there is a drop in the peak queue length. This trend changes to a steady increase in peak queue length from Scenario 4 onwards.

The results for the early scenarios demonstrate that the service times for the check-in desks are insufficient to cope with the demand. As the arrival pattern spreads the check-in desks can more effectively meet demand and therefore the queues fall in length. However, the queue length increases again for the latter scenarios because of the build up of passengers in the terminal waiting for initial check-in desk opening. When then the desks open there are too many passengers waiting to check-in to keep the queue lengths minimal.

The implications of these results support the findings of the previous models. If there is a shift in either direction in passenger arrival distributions, attention should be placed on improving the processing of passengers at the check-in desks. If there is a shift to earlier arrival patterns of passengers, extra facilities will also be needed in the vicinity of the check-in areas.

Figure 51 Maximum Check-in Queue Length (Queues 1 to 4)

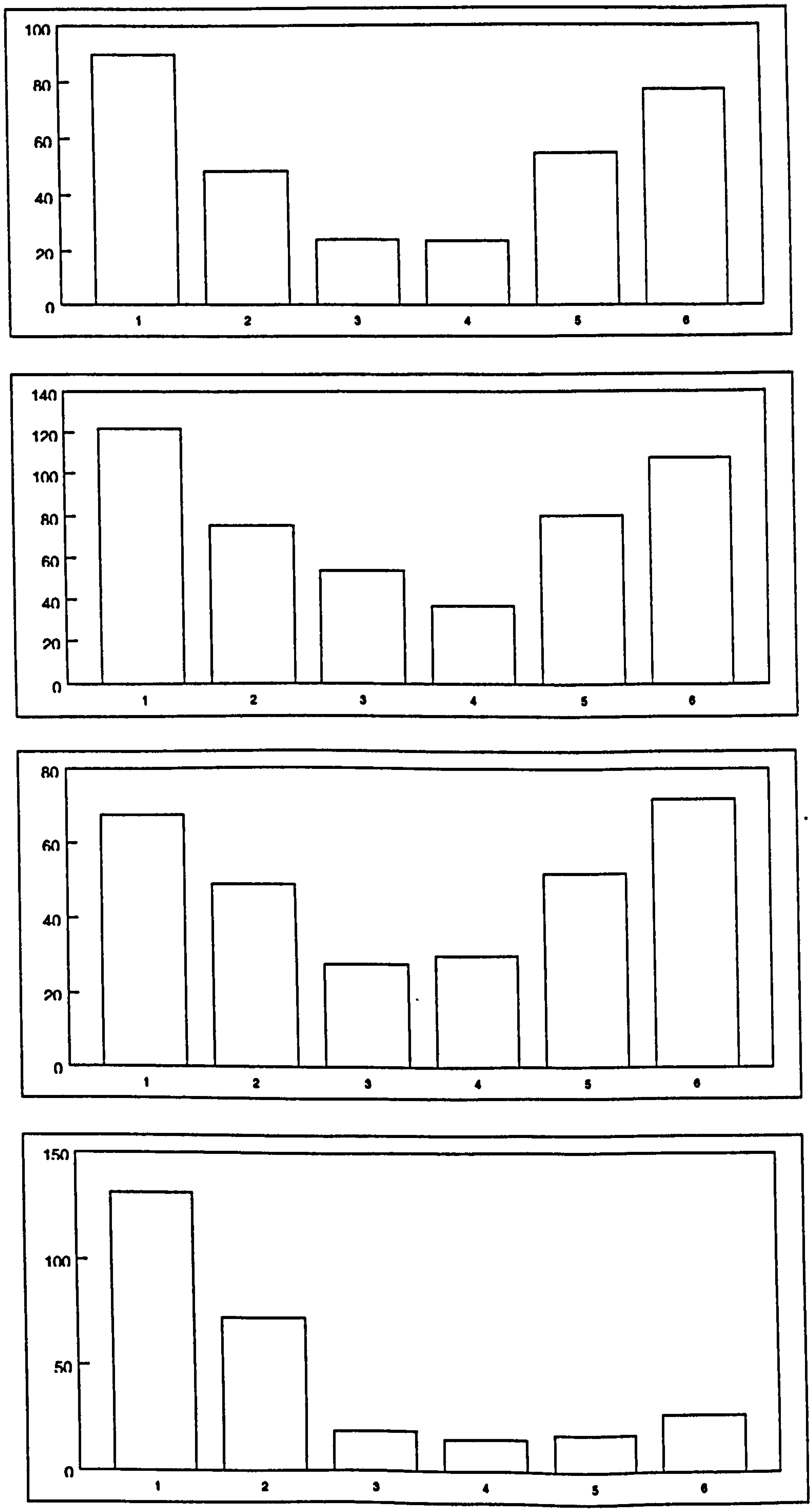
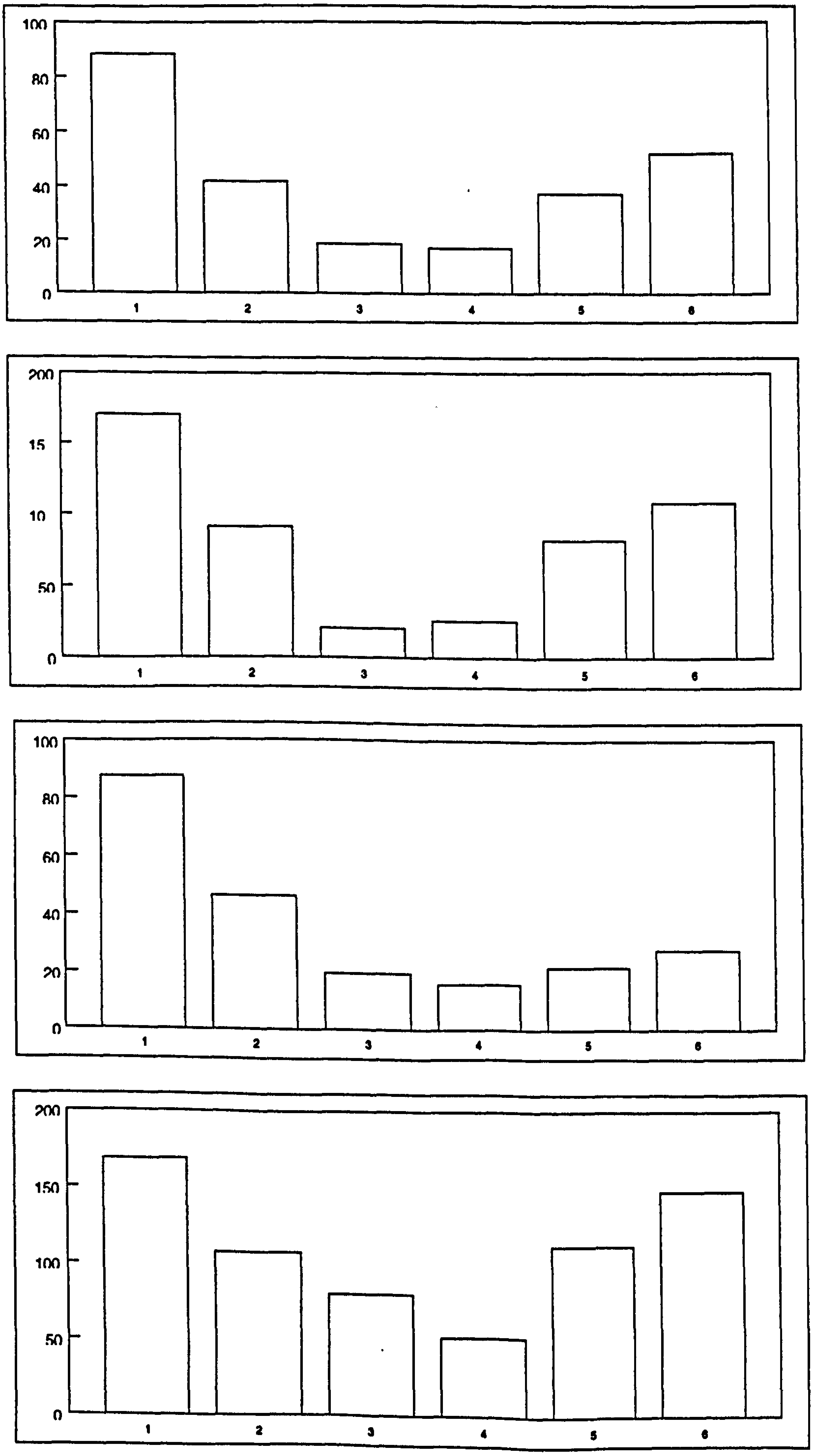


Figure 52 Maximum Check-in Queue Length (Queues 4 to 8)

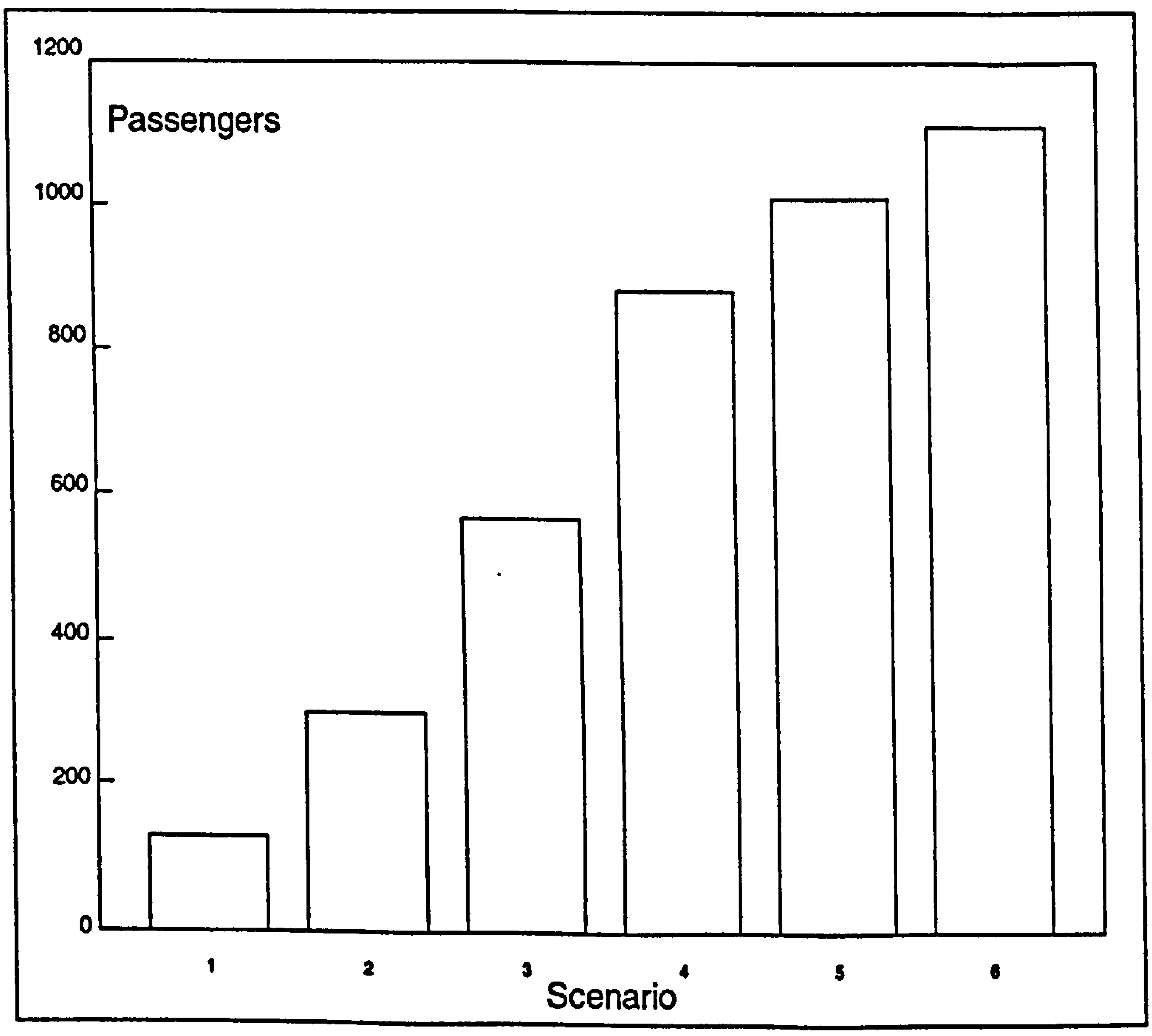


12.3.2 Peak Public Concourse Passenger Volume

The results displayed in Figure 53, show a trend that as the passenger arrival pattern shifts to earlier arrival at the terminal there is a steady increase in the peak passenger volume

The implication from these figures is that, if passengers start arriving earlier at the airport, terminals will have to be designed to accommodate more passengers for longer periods of time. This design change would need to take the form of both space and facility provision.

Figure 53 Peak Public Concourse Passenger Volume

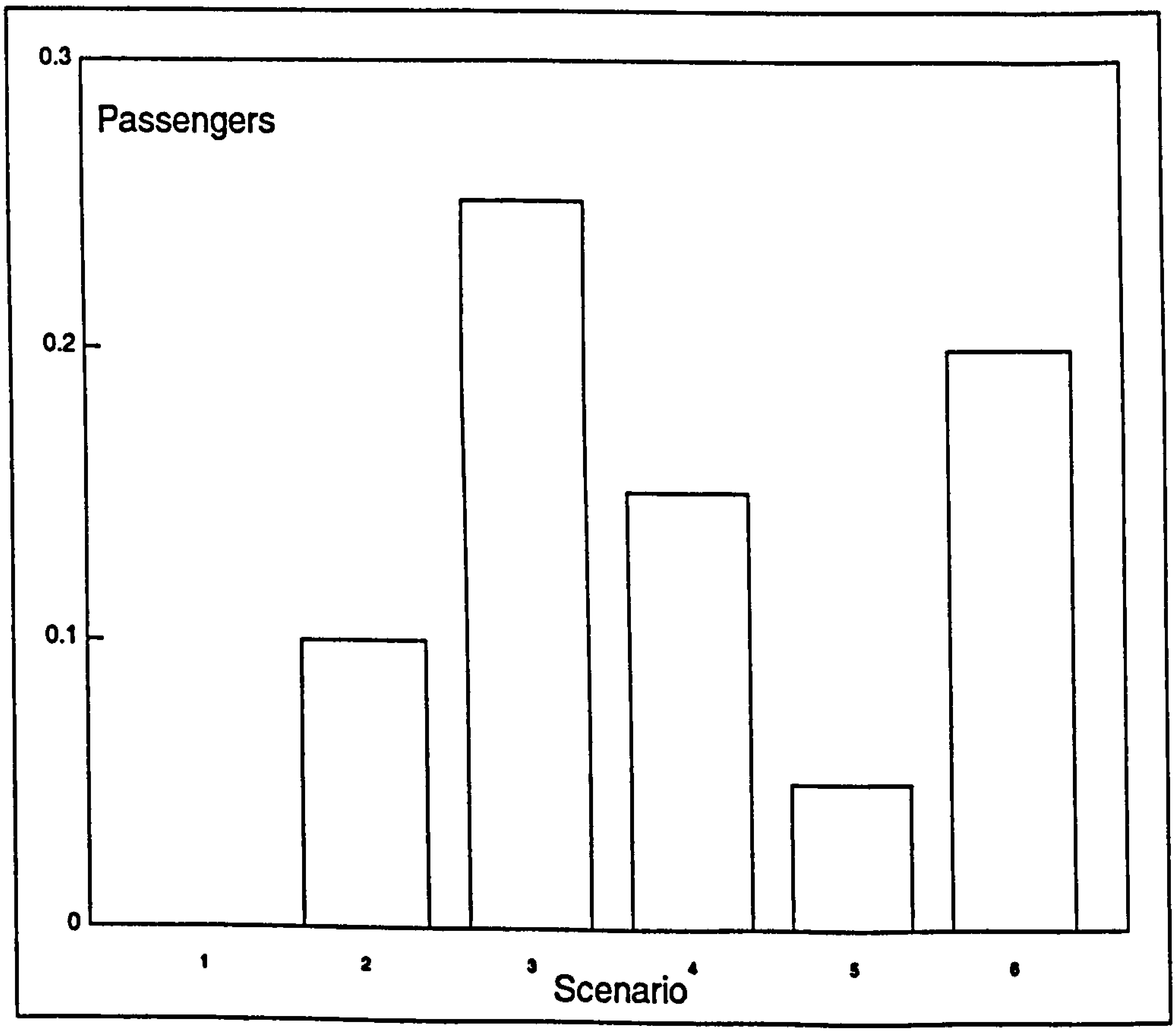


12.3.3 Maximum Security Queue Length: Common Travel Area

Although the results shown in Figure 54 are low, which is partly due to the category, it does reveal a different trend to that for check-in queue length. It appears that when the check-in queues are minimal, as in Scenarios 3 and 4, that the security queue length peaks.

The variable used to release passengers from the previous facility could be a contributory factor in the observed trend. The sensitivity of the results could also be magnified by the limited number of passengers that fall into this particular flight category.

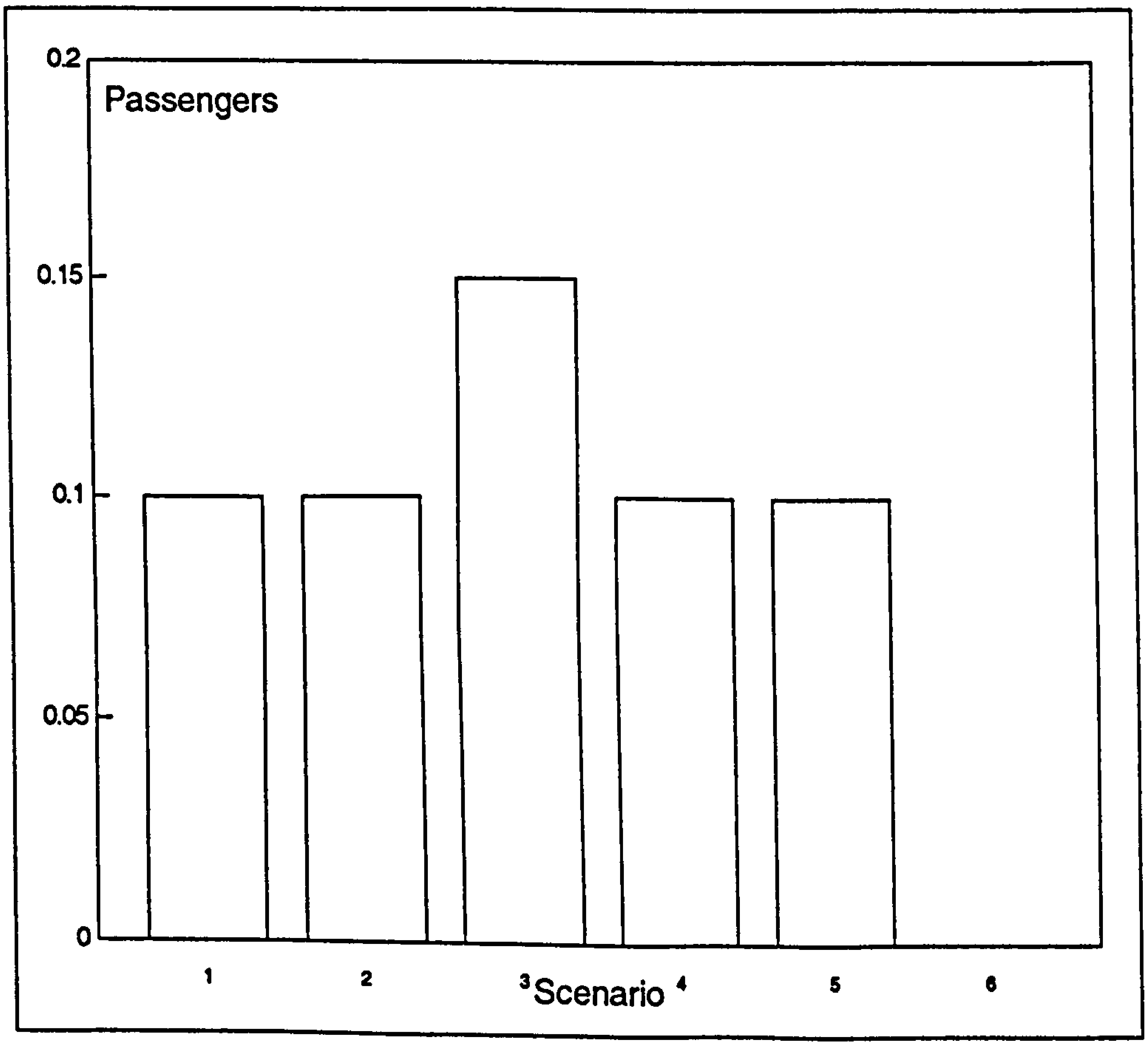
Figure 54 Maximum Security Queue Length: Common Travel Area



12.3.4 Maximum Frisk Queue Length: Common Travel Area

The limited number of passengers in the flight category of Common Travel Area causes low figures to be recorded. The results for the peak queue length for the frisk facilities are shown in Figure 55. The results recorded for this facility remain more or less constant for the first five scenarios, the last scenario failed to record a queue for the twenty iterations.

Figure 55 Maximum Frisk Queue Length: Common Travel Area

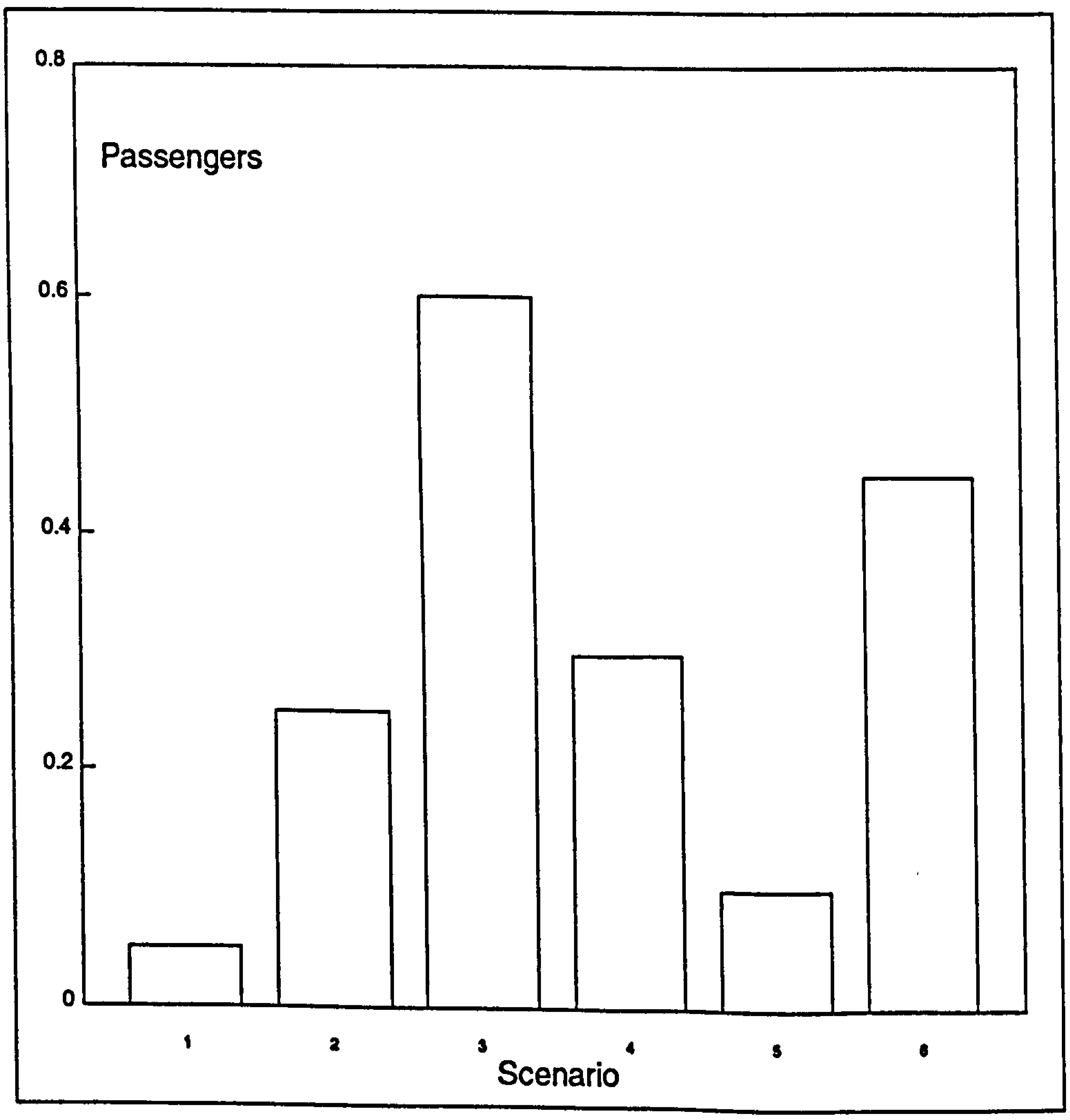


12.3.5 Peak Bag Search Queue Length: Common Travel Area

The results for the bag search queue, as displayed in Figure 56, follow the same trend as for the security queue length. It appears that when the check-in queues are minimal, as in Scenarios 3 and 4, that the queue length for the bag search facility peaks. This is similar to the results for the security queue.

The variable used to release passengers from the previous facility could be a contributory factor in the observed trend. Again these results may be influenced by the limited number of passengers that fall into the Common Travel Area flight category.

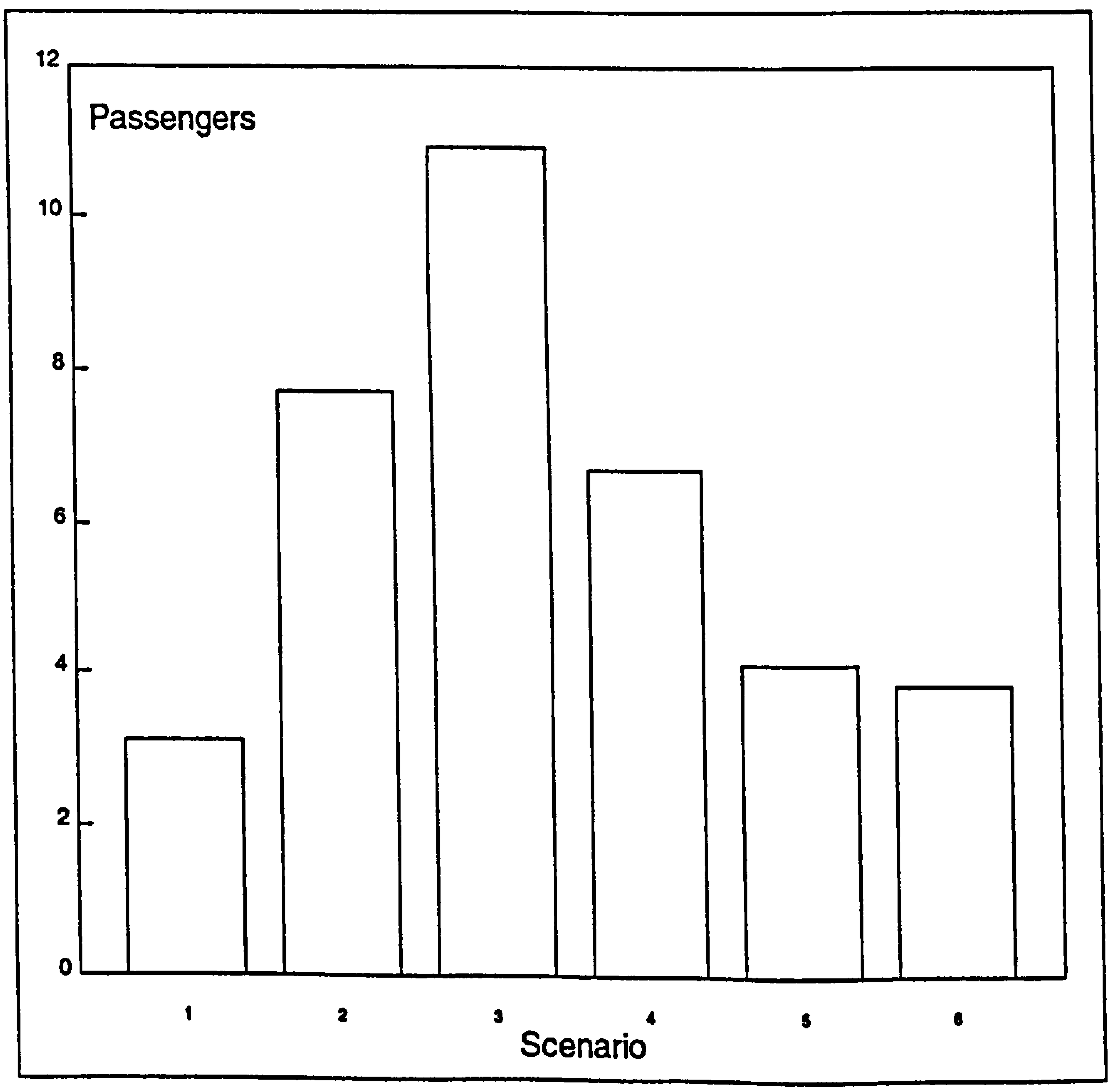
Figure 56 Peak Bag Search Queue Length: Common Travel Area



12.3.6 Peak Security Queue Length: International

The results obtained for the peak security queue length are displayed in Figure 57. The number of passengers included in this category are higher than for the Common Travel Area. With the observed trend being similar to the Common Travel Area security queue length, these results support the results obtained for the Common Travel Area. The only difference is that for Scenario 6 the peak length does not increase significantly from Scenario 5. The similarity for the trends between the international and the Common Travel Area facilities would appear to reduce the significance of the limited number of Common Travel Area passengers. Therefore, the trend must be influenced by the release of passengers from the previous facilities, and not simply the size of the sample.

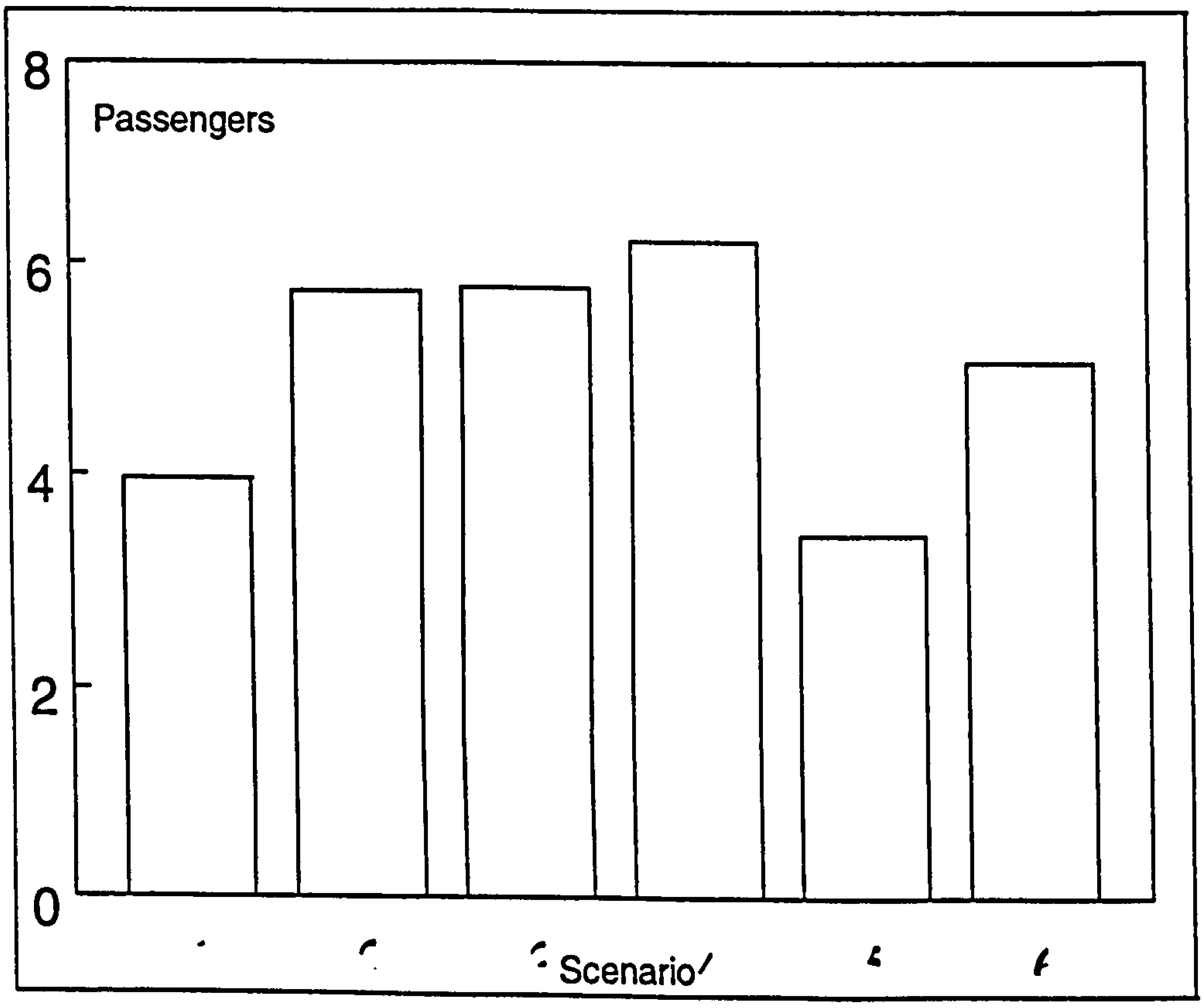
Figure 57 Peak Security Queue Length: International



12.3.7 Peak Frisk Queue Length: International

Unlike some of the other results obtained from the Manchester Model 1, the results obtained for the international frisk queue as presented in Figure 58 appear to be more stable. The fluctuation in the results would indicate that this facility is not adversely affected by a change in the arrival pattern of passengers.

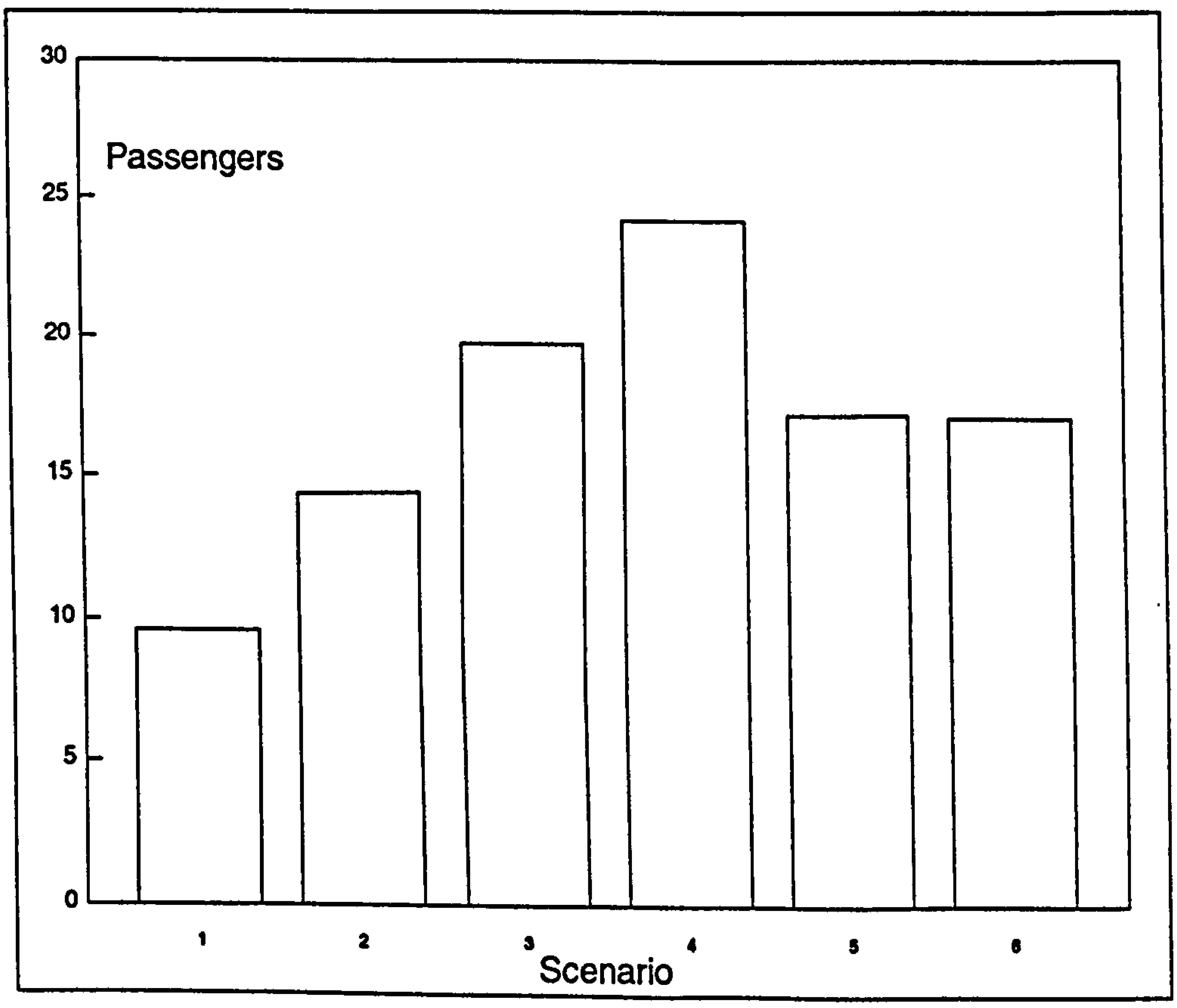
Figure 58 Peak Frisk Queue Length: International



12.3.8 Peak Bag Search Queue Length: International

The results for the bag search queue are shown in Figure 59. They reveal a trend of increasing peak queue length for the Scenarios 1 to 4, which then drops to a stable level for Scenario 5 and 6. The reason for this queue development at this facility and not the security facility is that passengers are processed slower in the bag search facility and therefore increasing the likelihood of queues developing to greater lengths.

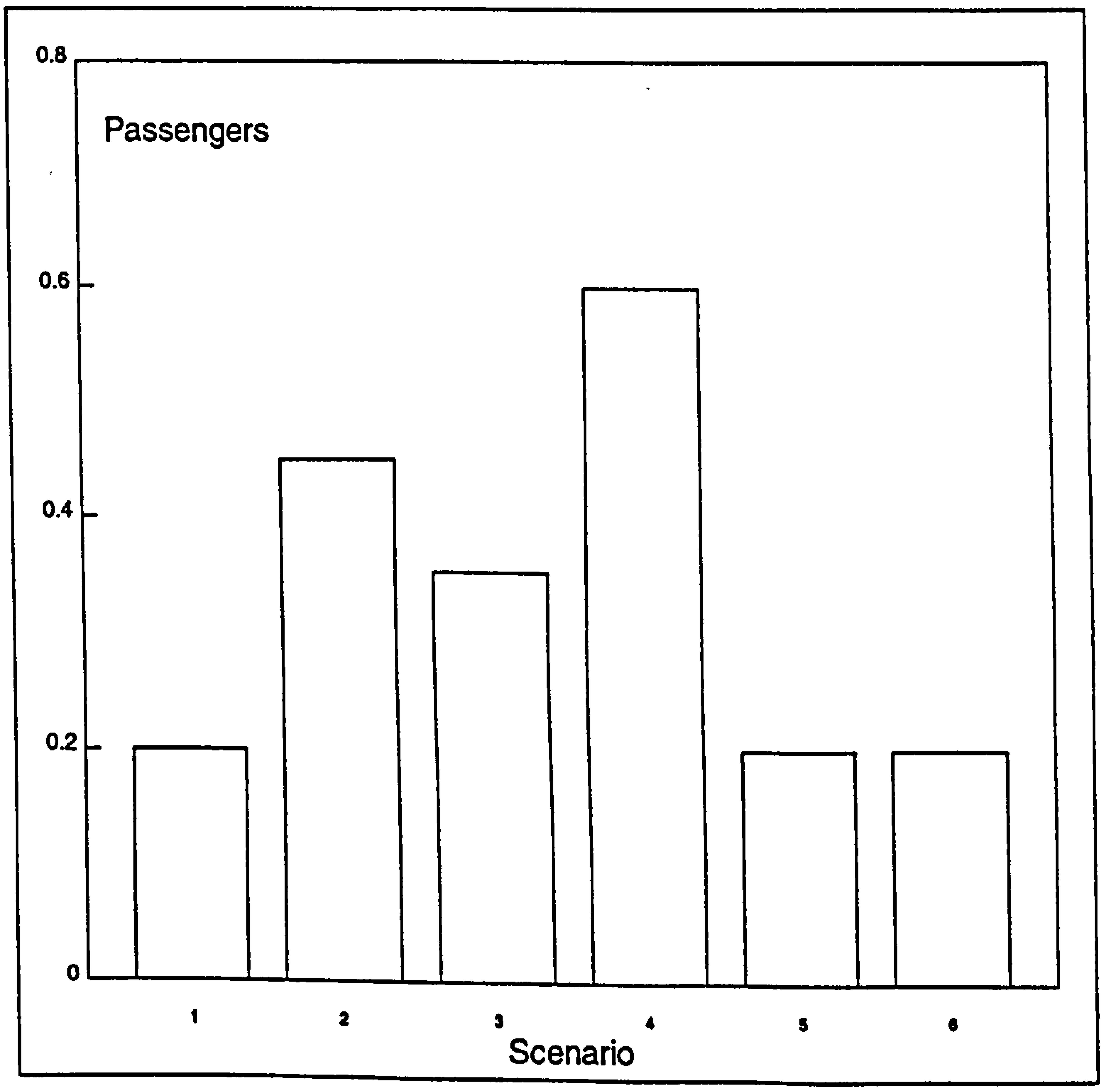
Figure 59 Peak Bag Search Queue Length: International



12.3.9 Peak Common Travel Area Passport Control Queue Length

The results for this facility are shown in Figure 60. They fluctuate for the six scenarios with no apparent trend. These results would appear to indicate that this facility is not affected by a change in arrival distribution at the airport. The results recorded are low because of the limited number of passengers in this flight category.

Figure 60 Peak Common Travel Area Queue Length

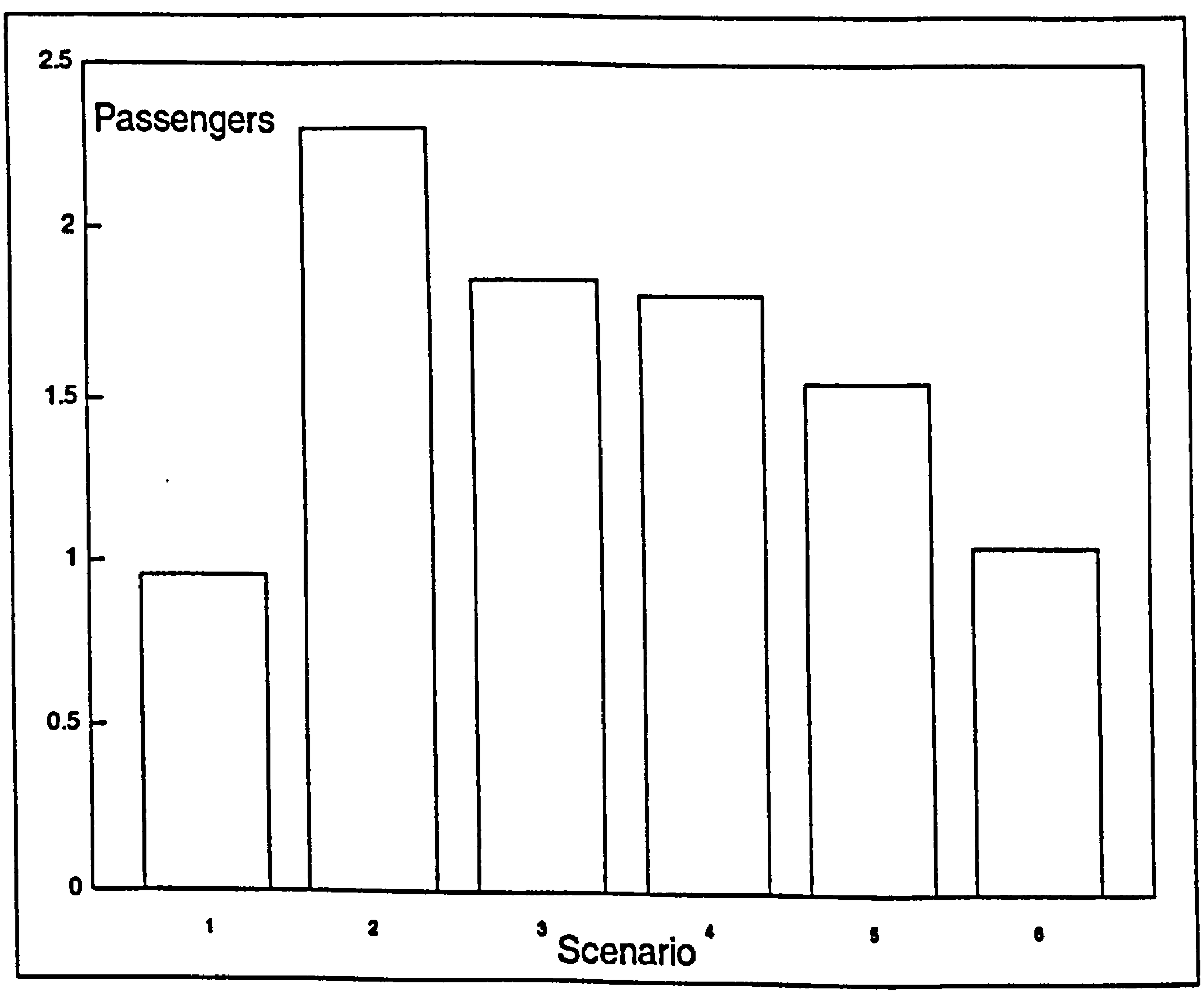


12.3.10 Peak Passport Control Queue Length

The results for the peak passport control queue length are given in Figure 61. Unlike the other queues within this model, after a rise in queue length between Scenarios 1 and 2, there is a decline for the remaining scenarios. The scale of the change in queue length is not large but yet the downward trend is consistent. The lack of a significant queue could be due to the high number of passengers that missed flights for this scenario that may not have reached this stage of the model.

The observed trend could be due to the effects of the variable controlling the flow of passengers from the public concourse and the overall impact of the change in arrival distribution being diluted. It is also useful to note that the queues forming at this point, do so as a result of previous dynamic rather than a holding facility and therefore the queue development is less predictable.

Figure 61 Peak Passport Control Queue Length

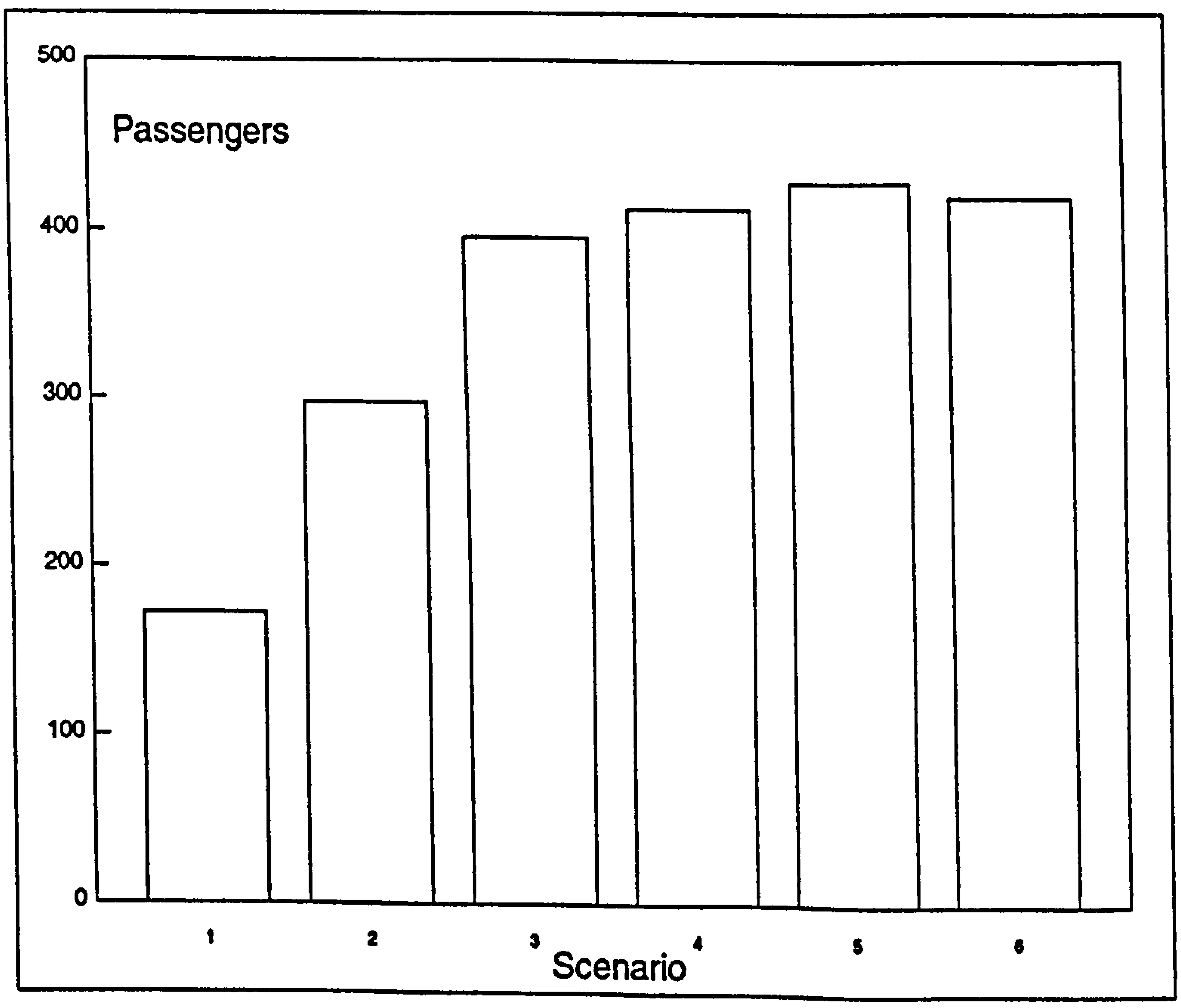


12.3.11 Peak Passenger Volume: Departure Lounge

As with previous models the results for the peak passenger volumes in the international departure lounge, shown in Figure 62, have an upward trend over the initial scenarios that peaks at Scenario 4. At this point the peak level remains more or less stable for Scenarios 5 and 6. The reason for this stability could be the schedule of flights. With no further flights, and therefore passengers to accommodate, the peak volume of passengers stabilises.

The implication of the results for the international lounge is that passengers will need more space and more comfortable facilities, if the time spent in this area of the airport increases significantly.

Figure 62 Peak Passenger Volume: Departure Lounge

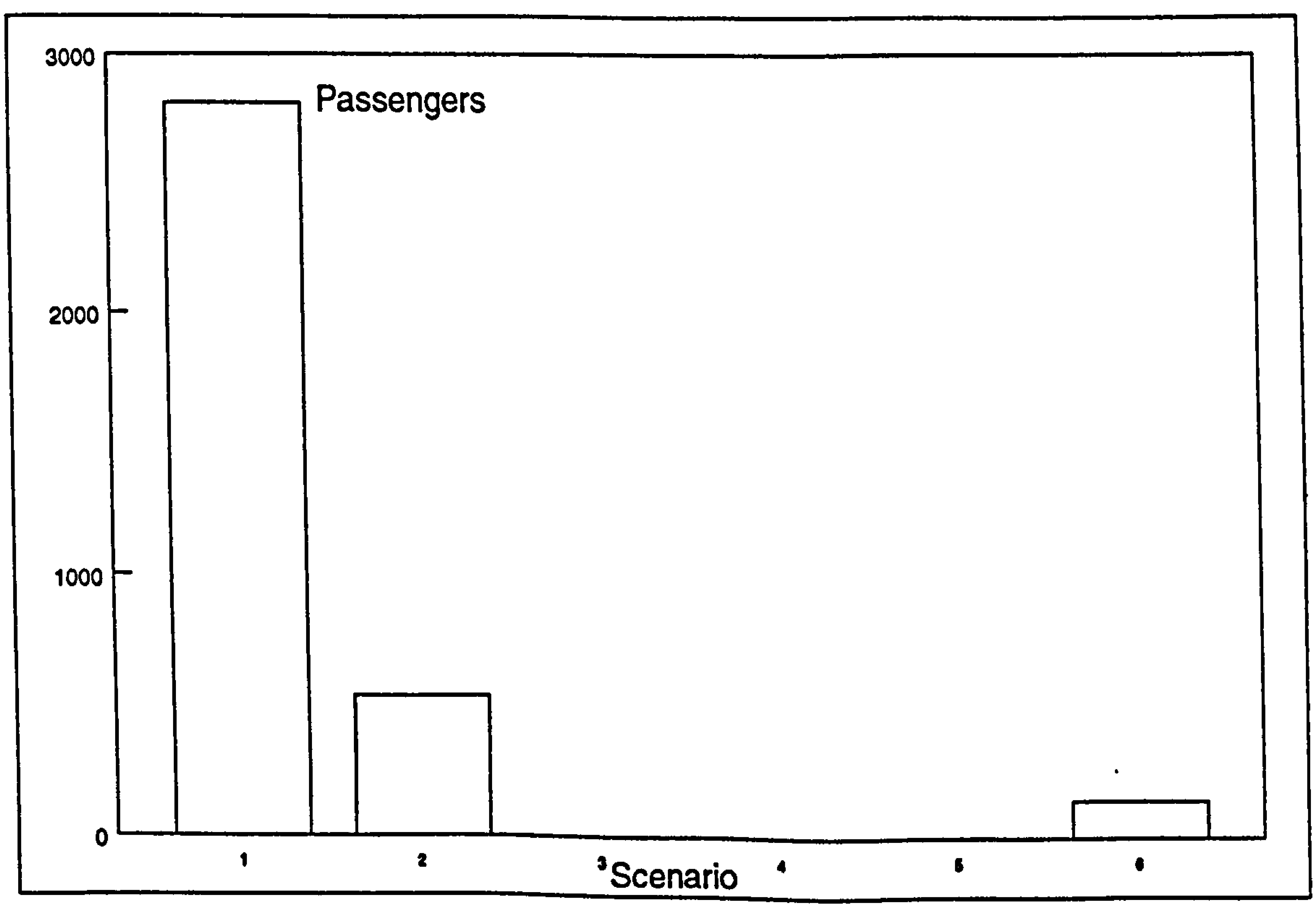


12.3.12 Missed Flights

Figure 63 reveals that three scenarios resulted in missed flights. This high level of missed flights can be explained partly by the terminals 'mix' of foreign flights, which can check-in up to 4 hours prior to schedule time of departure. In order to achieve the scenario curve requirement and maintain the balance of arrival patterns of the exceedingly long check-in periods, a steep arrival curve is formed for those flights that check-in early. The Common Travel Area flights fall into this latter category. This arrival curve, which is steepest in Scenario 1, reduces the amount time available for passengers to pass through the model. The time reduction is such that it causes a high proportion to miss their flights.

It is important to note that for this particular model there was a software problem that resulted in a 'loss' of 141 passengers for Scenario 6. These passengers were labelled as having missed their flights. This was not a failure of the airport system but a problem associated with the simulation software. It is believed that the software cannot cope with passengers arriving significantly prior to the start of simulation time.

Figure 63 Missed Flights



12.3.13 Summary

Generally the results obtained for this model show greatest impact on the public concourse. A spread in the arrival distribution causes an increased the demand for capacity. The queues recorded at the check-in desks reveal the importance of achieving the correct balance in the arrival of passengers at the airport. If this is not done queues develop which can cause terminal congestion. Congestion that may be limited to the check-in facilities.

The results for the remaining facilities, such as the peak security queue length, show a recurring trend that can be partly explained by the variable used to 'release' passengers through the model. However, the passport control queues do not show the same trend. This is partly due to the original arrival passenger distribution being disturbed by the preceding facilities within the model. The reason for this difference is that the preceding facilities in this case are dynamic and not holding facilities.

12.4 Manchester Airport Model 2

Manchester Airport Model 2 focuses on the domestic operation within a single terminal. A plan of this model can be seen in Figure 18.

12.4.1 Maximum Check-in Queue Length

This model displays check-in queue length in terms of airline carrier as opposed to handling agent. Without a pre check-in facility in the model, passengers first appear in the model at the check-in facilities.

The results for the eight check-in queues selected display a similar trend as shown by Figure 64 and Figure 65. The early scenarios reveal a fall in the peak queue length as the arrival pattern of passengers moves to an earlier arrival at the terminal. However, this trend is reversed and an increasing queue length as passengers arrive even earlier at the terminal.

This trend has already been observed and addressed in the results to earlier models. Essentially the two extreme peaks occur in Scenarios 1 and 6 because of a high passenger arrival rate at the check-in desks. In Scenario 1, this is caused by large numbers of passengers arriving over a short period of time. In Scenario 6, large numbers of passengers have arrived at the airport and are waiting for the check-in desks to open.

Figure 64 Maximum Check-in Queue Length (Queues 1 to 4)

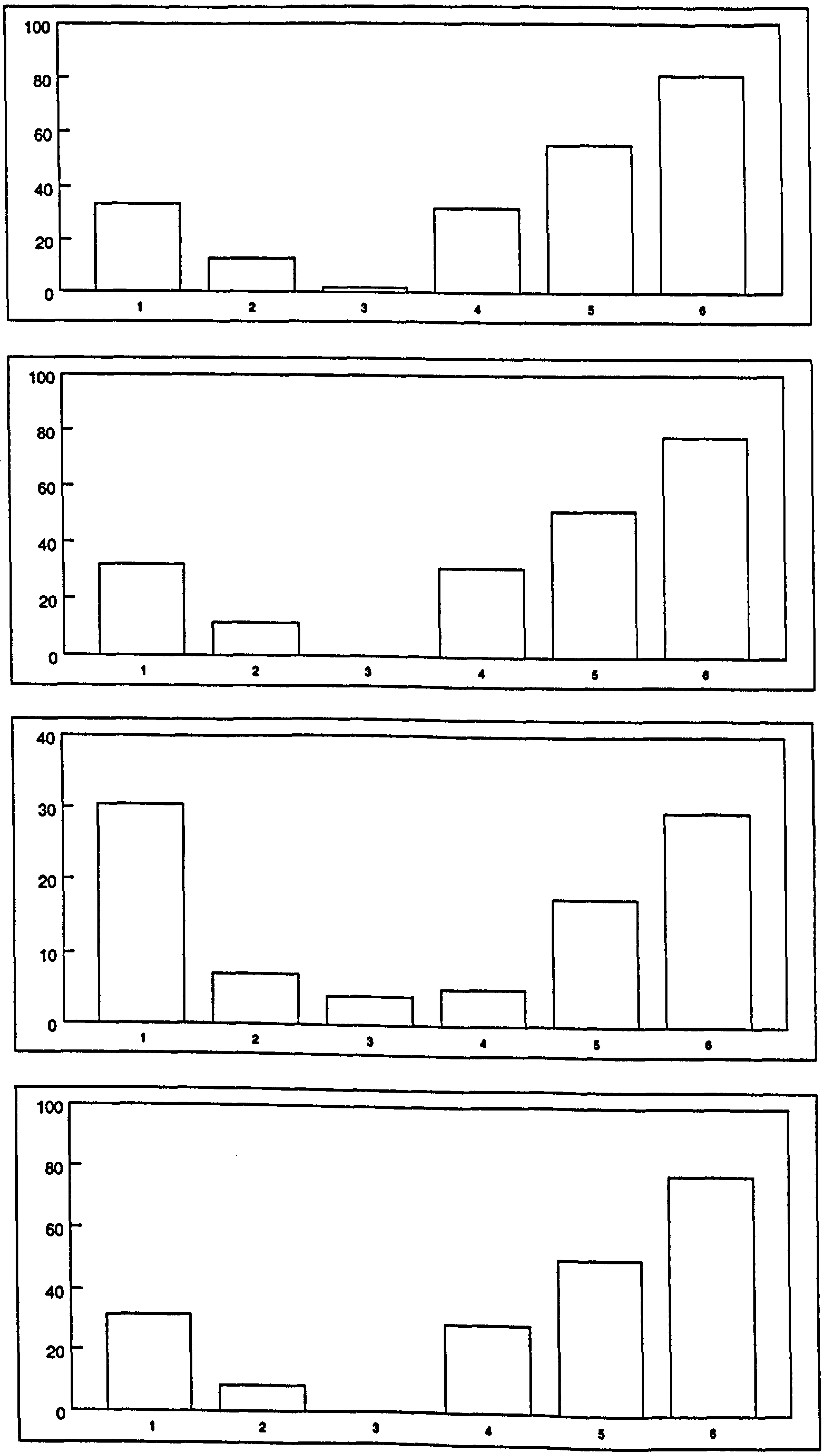
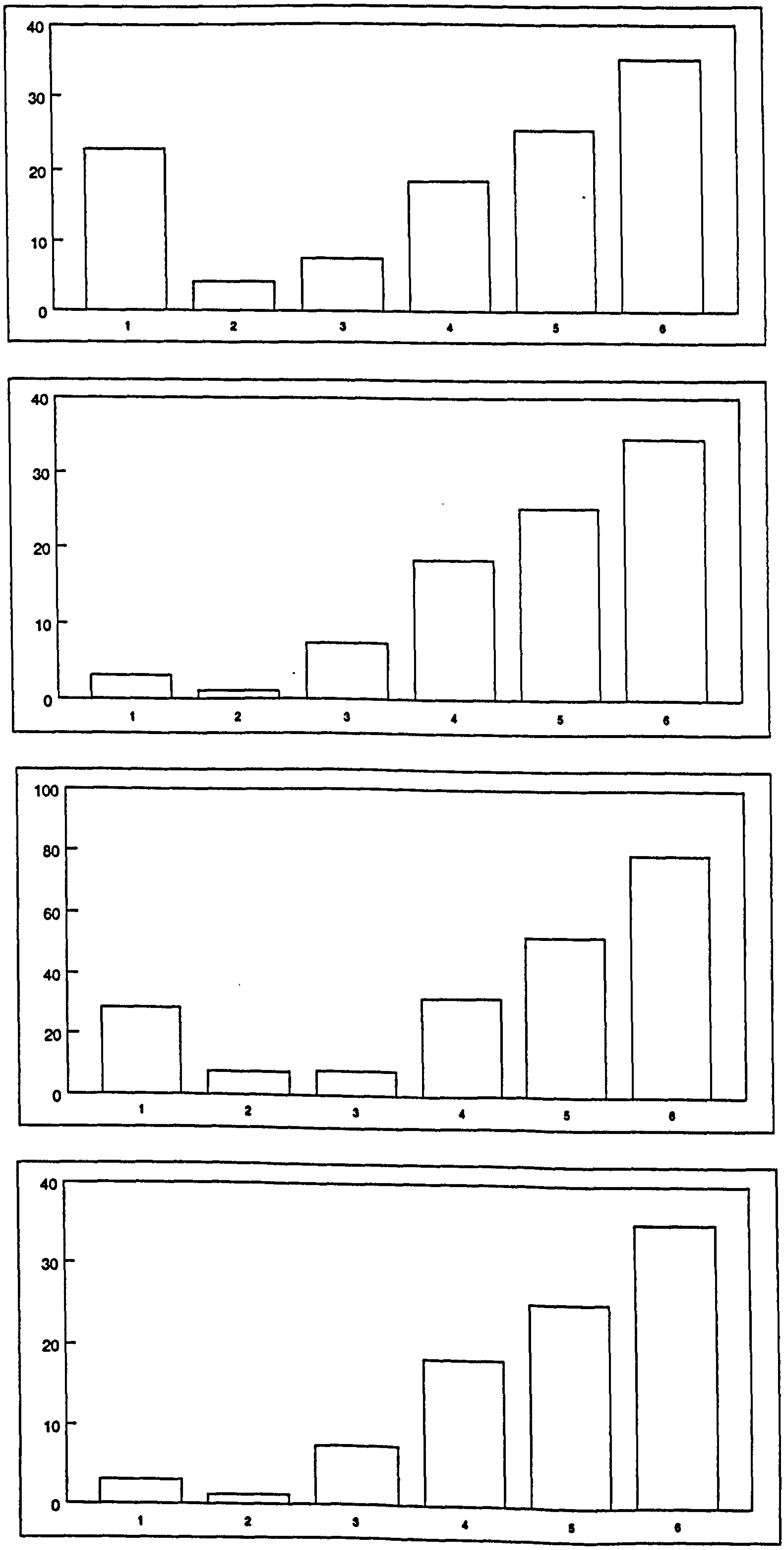


Figure 65 Maximum Check-in Queue Length (Queues 4 to 8)

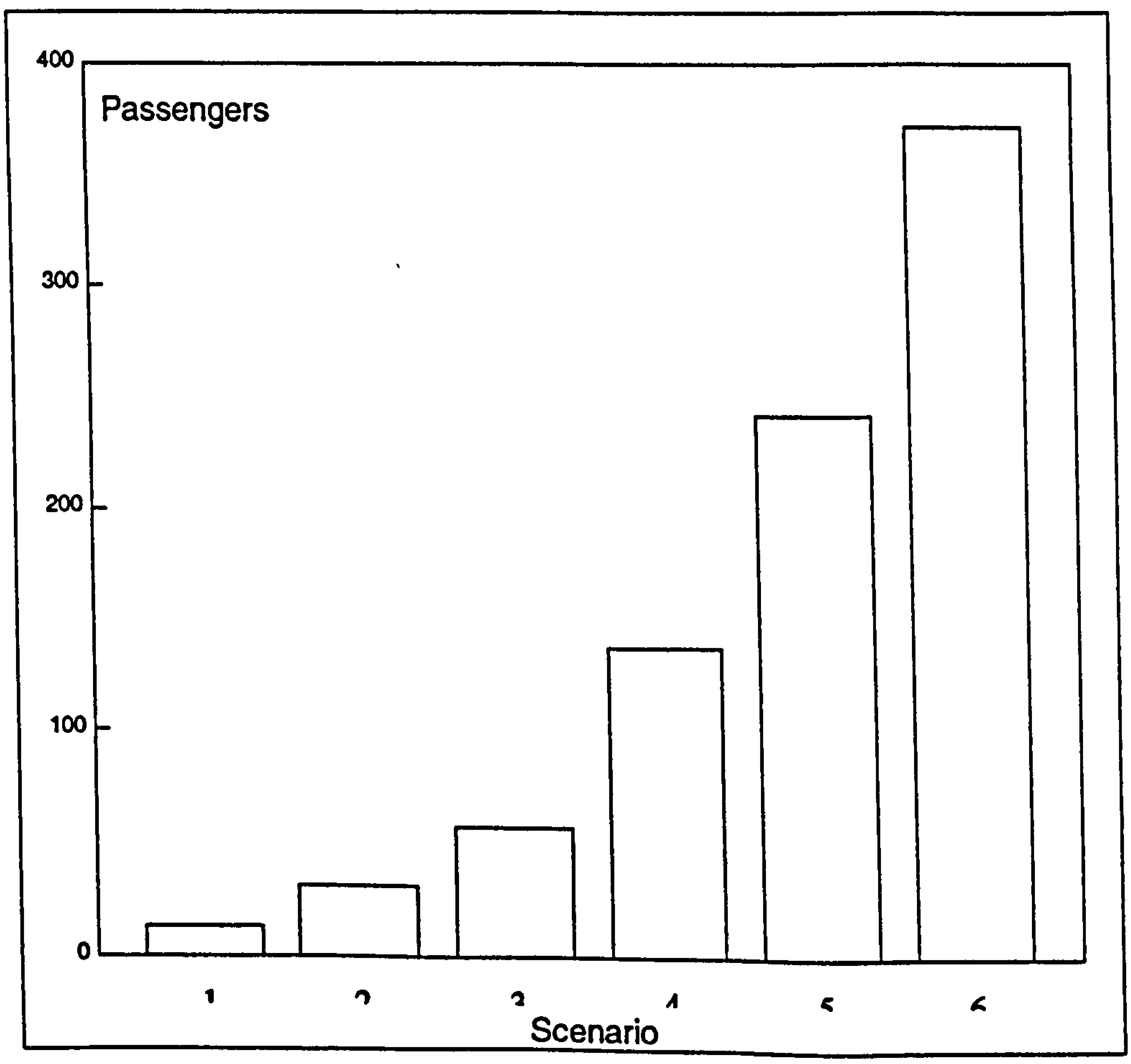


12.4.2 Peak Public Concourse Passenger Volume

The peak public concourse passenger volumes are shown in Figure 66. The results reflect the impact that passengers arriving early at an airport have on the areas open to the public. The observed trend is an increase in peak volume as the pattern shifts towards the earlier arrivals at the terminal in relation to the scheduled time of departure.

This pattern of increased volumes with the earlier arrival of passengers at the airport will cause an associated demand for facilities for passenger comfort and entertainment.

Figure 66 Peak Public Concourse Passenger Volume

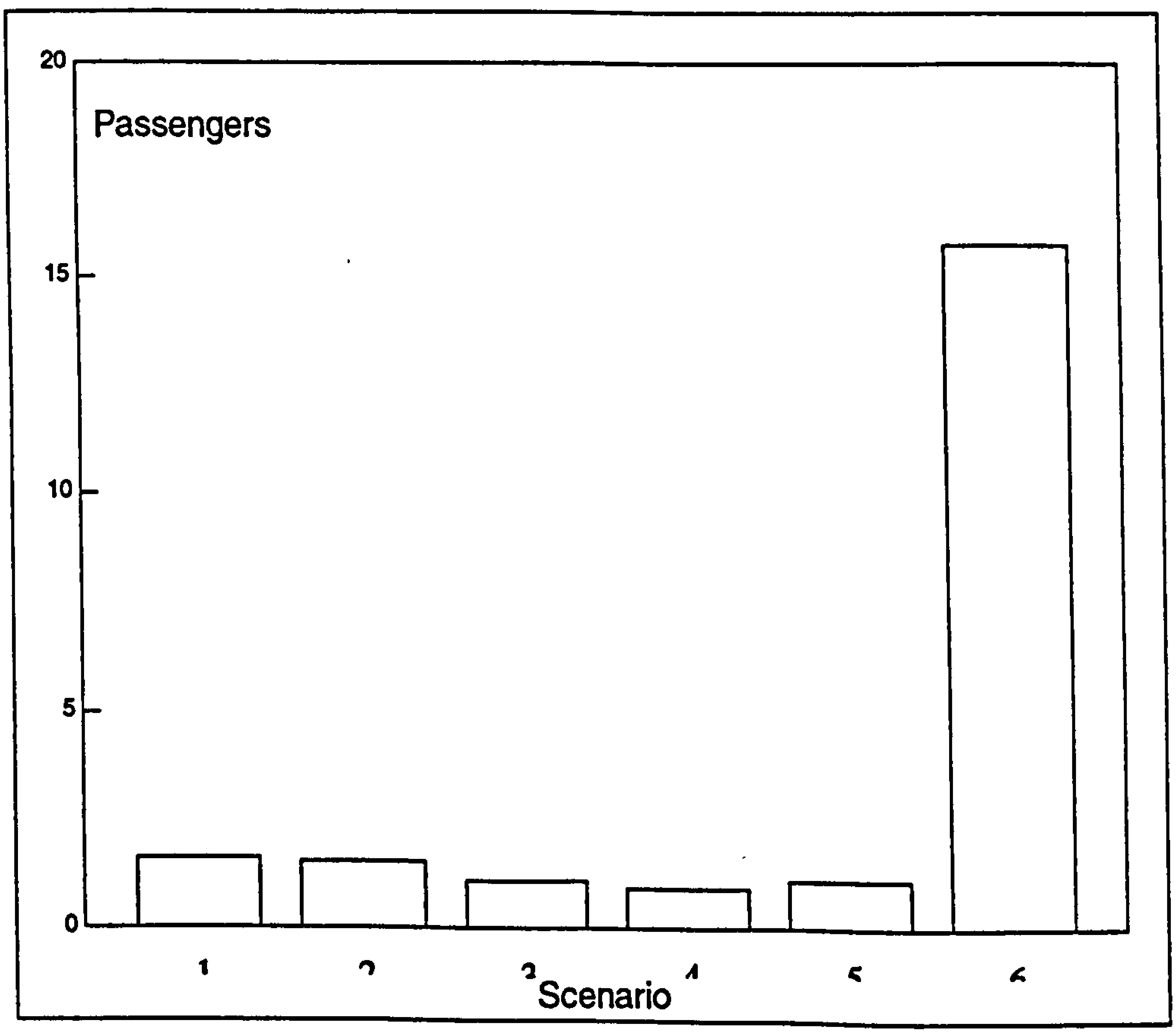


12.4.3 Maximum Security Queue Length

The peak security queue length results are presented in Figure 67. They reveal a very stable peak queue length for Scenarios 1 to 5, the exception being Scenario 6. Unfortunately, because this result occurs in the last of the six scenarios it is not possible to say whether or not this change would continue to develop with a further shift in the arrival patterns.

Further simulations would have to be conducted to evaluate whether or not there is any implication for changes in provision of security facilities given an extreme change in arrival distribution such as that reflected by Scenario 6.

Figure 67 Maximum Security Queue Length

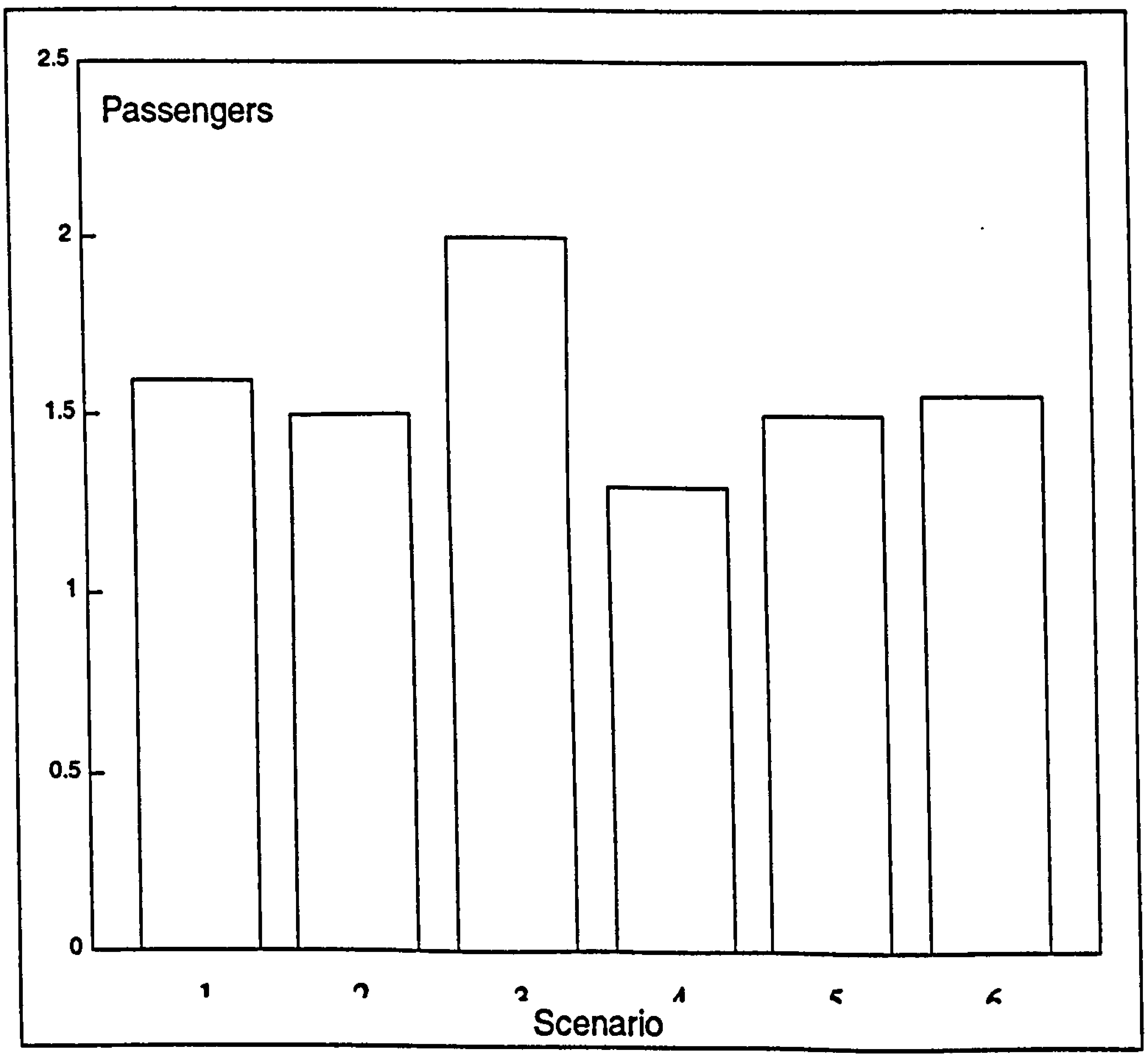


12.4.4 Maximum Frisk Queue Length

The results for the peak frisk queue length are displayed in Figure 68. They appear to be stable. The only exception to this stability is the slight fluctuation seen in Scenario 3.

The results support the earlier results that indicate that dynamic facilities in the latter stages of the airport are not affected by the change in arrival distribution of passengers.

Figure 68 Maximum Frisk Queue Length

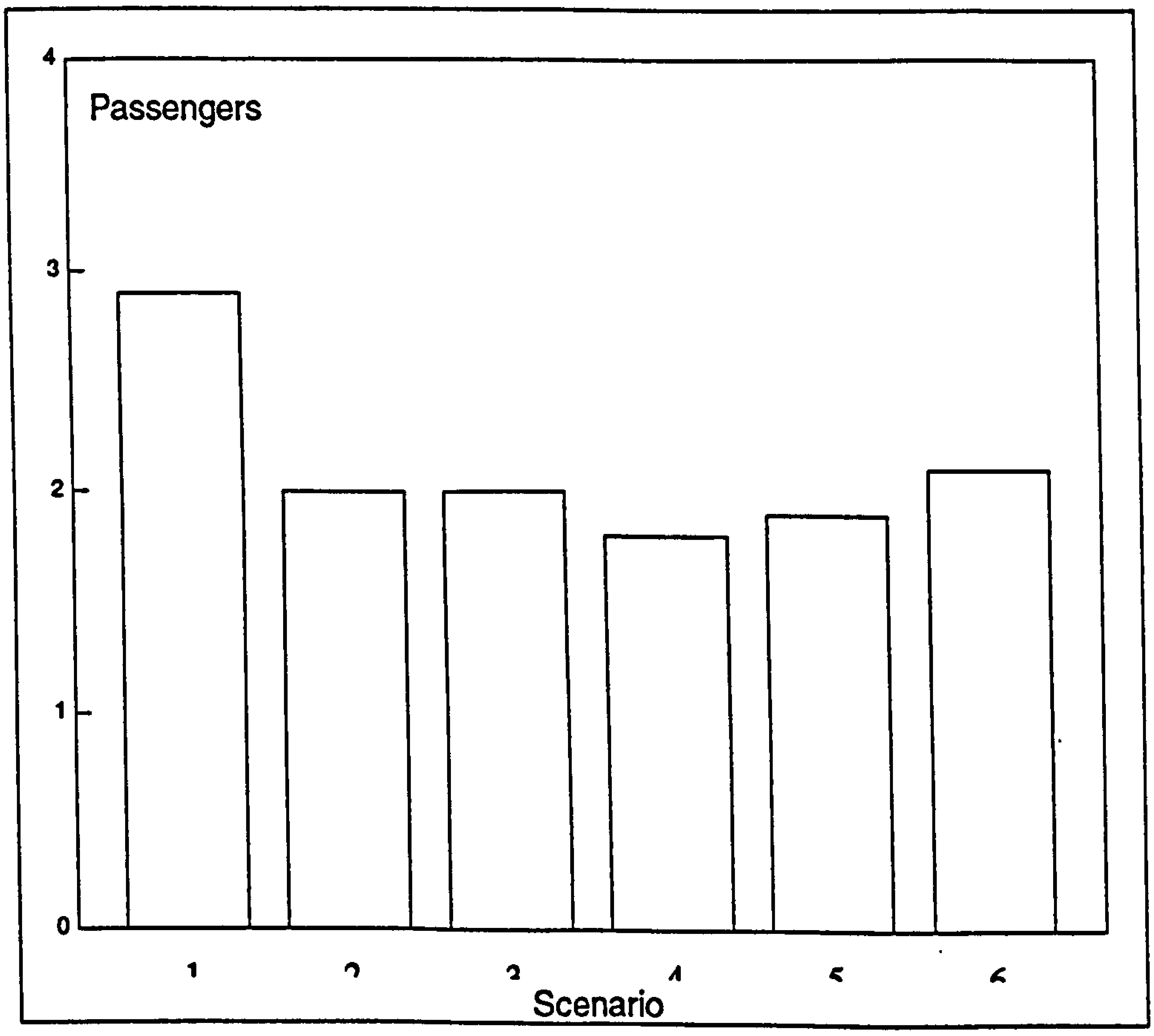


12.4.5 Peak Bag Search Queue Length

Figure 69 presents the results obtained for the peak bag search queue length. The results would suggest that the queues observed at this facility are comparable with the other facilities in this and other models. Scenario 1, has a higher value than the other scenarios, however the fluctuation level is not great.

These results again support the suggestion that dynamic facilities in the latter stages of the airport are not affected by the change in arrival distribution of passengers.

Figure 69 Peak Bag Search Queue Length

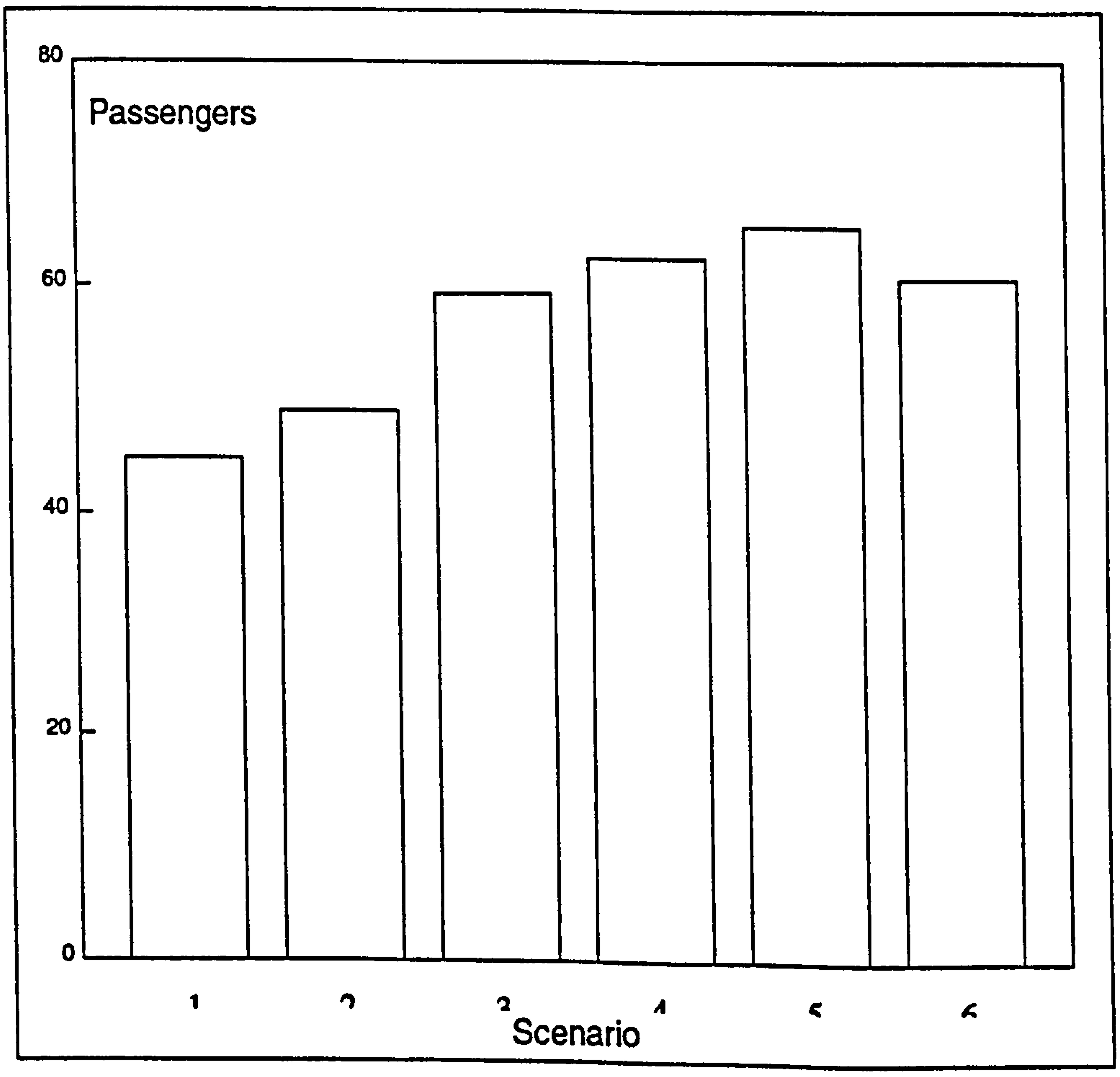


12.4.6 Peak Passenger Volume: N. Ireland Lounge

The peak passenger volumes recorded for the N. Ireland departure lounge are presented in Figure 70. The results reveal an upward trend in the peak volume as the shift in arrival distribution moves away from the scheduled time of departure.

As this is a destination specific facility, there are limited implications for the operators of this airport because, by comparison with other lounges, it is relatively under utilised facility. It is therefore unlikely to contain the comprehensive facilities found in other lounges of the airport. This facility is likely to continue to be opened at a given time before departure, to prevent it having to be staffed unnecessarily and/or upgraded in terms of comfort. Early arriving passengers will therefore have to wait in other areas of the terminal until this lounge is opened.

Figure 70 Peak Passenger Volume: N. Ireland Lounge

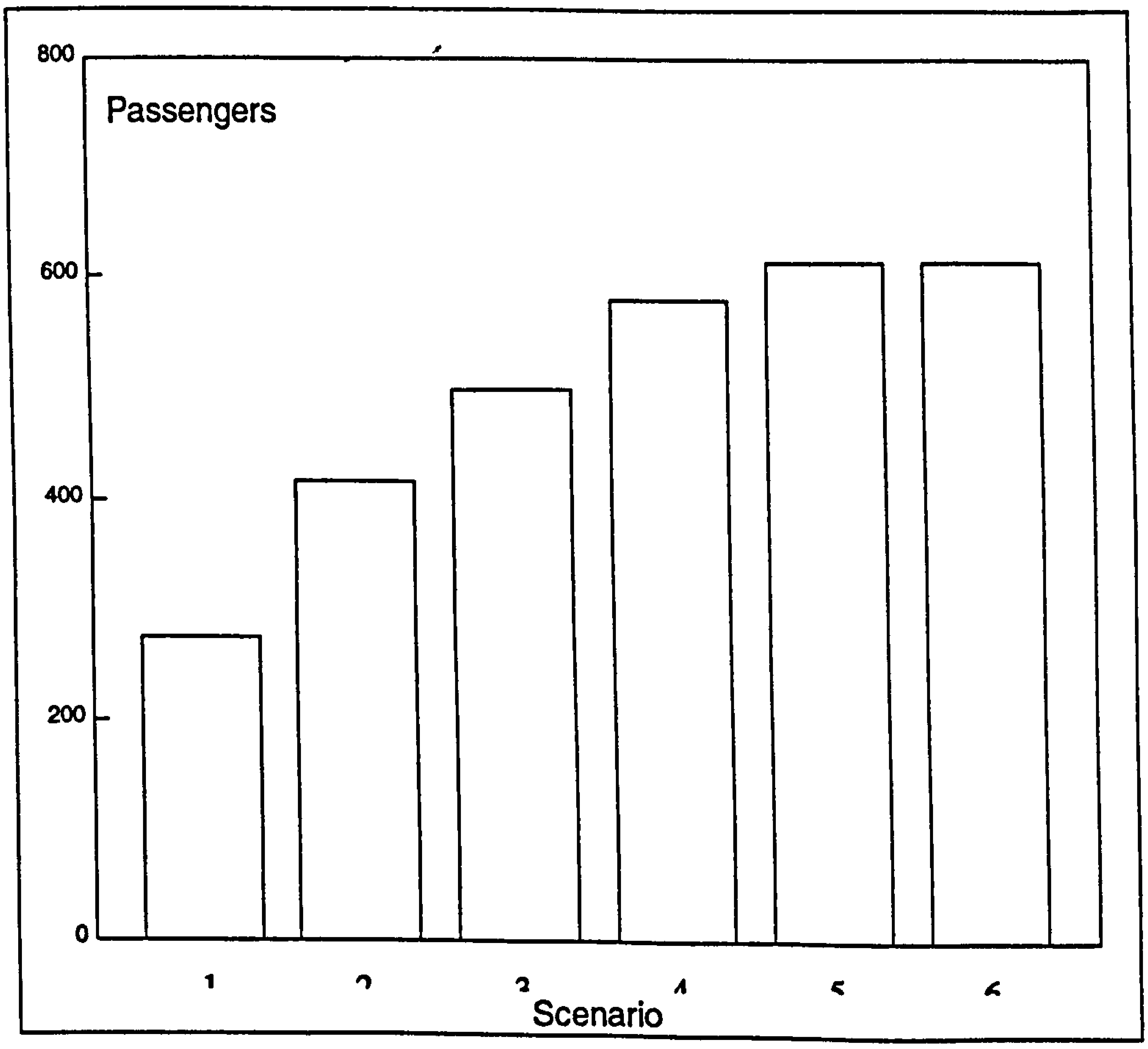


12.4.7 Peak Passenger Volume: Domestic Lounge

The results obtained for the volume of passengers held in the domestic lounge, shown in Figure 71, reveal a steady increase in volume for the first three scenarios. The peak volume continues to increase but at a lower rate for Scenarios 4 to 6.

Domestic lounge facilities are not designed for high occupancy for long periods of time. If passengers increasingly spend more time in this area, there will be a need to modify it to incorporate comfortable fixtures and facilities for passengers to reflect its use.

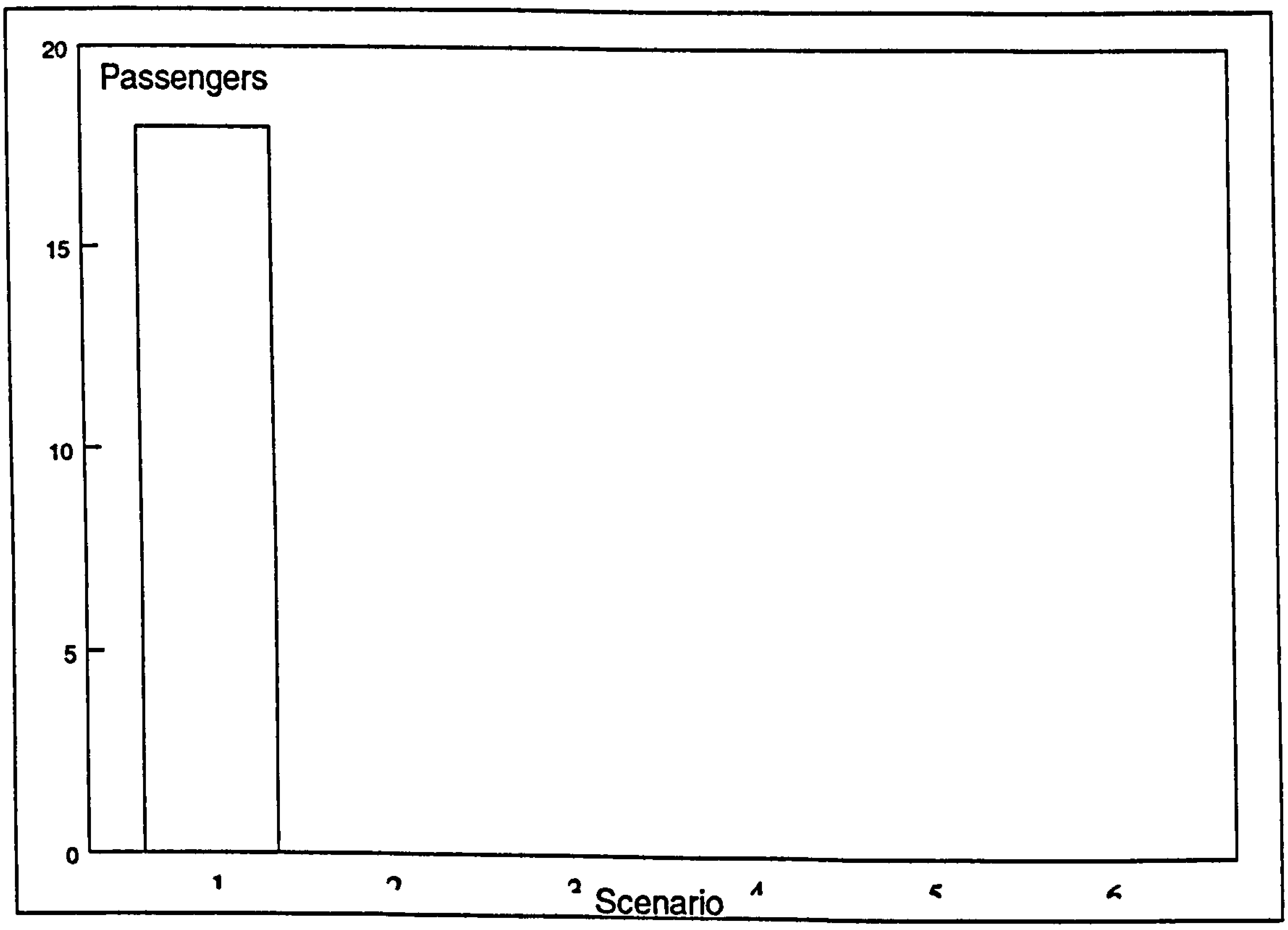
Figure 71 Peak Passenger Volume: Domestic Lounge



12.4.8 Missed Flights

The Manchester Airport Model 2 only recorded missed flights for Scenario 1, as is presented in Figure 72. The reason for missed flights for this scenario could be the exclusive operation of domestic flights in this model. The other models with domestic flights also operate other flight categories concurrently. The scenario curves in this case do not allow enough time for passengers to pass through the model, thus generating a number of passengers which missed flights.

Figure 72 Missed Flights



12.4.9 Summary

By comparison the results obtained for this model were very much as expected. The results of the 120 iterations conducted for the Manchester Airport Model 2 show an impact that tends to be focused very much on the public concourse of the terminal. This impact increases as the arrival distribution shifts further away from the scheduled time of departure.

The reason for the concentration of passengers within this area is the variable used in the model. The variable releases passengers into the security facility at a set time before flight as opposed to a set time after waiting in the public concourse.

The results show that the impact of a change in arrival distribution away from the scheduled time of departure is less noticeable as passengers progress through the model. However, there is a noticeable impact on the capacity requirement of the departure lounges. The demand for departure lounge space will increase with passengers arriving earlier at the airport in relation to the scheduled time of departure of their flight.

12.5 Manchester Airport Model 3

The Manchester Airport Model 3 focuses on the international operations within Manchester Airport's terminal 2. A plan of this model can be seen in Figure 20.

12.5.1 Maximum Check-in Queue Length

The first facility in this model is the check-in facility. As with previous models, this model displays check-in queue length in terms of airline carrier rather than handling agent. The queues displayed in Figure 73 and Figure 74 represent a consistent selection of eight queues from the model.

The simulation results reveal a trend that has been observed in earlier models. For Scenarios 1 to 3 there is a decrease in the peak check-in queue length. Generally from Scenario 4 onwards the trend is reversed and the queue lengthens to a peak for Scenario 6. This trend reflects these facilities' inability to cope with large numbers of passengers over a short period of time.

There are obviously two points at which this arrival rate for the check-in facility is at its highest, these are Scenario 1 and 6. The reason for the peak in Scenario 1 is the arrival of passengers over a short period of time. In the case of Scenario 6 the arrival rate at the check-in facility is high because there are a large number of passengers at the airport waiting for the check-in desks to open.

As has been indicated earlier, there are implications for the check-in area if there is a shift towards the scheduled time of departure. If this shift occurs then attention should be placed on the processing passengers at a faster rate to prevent queues from developing. If there is a shift away from the scheduled time of departure, consideration should be given to the provision of extra facilities, for comfort and entertainment of waiting passengers in the surrounding areas.

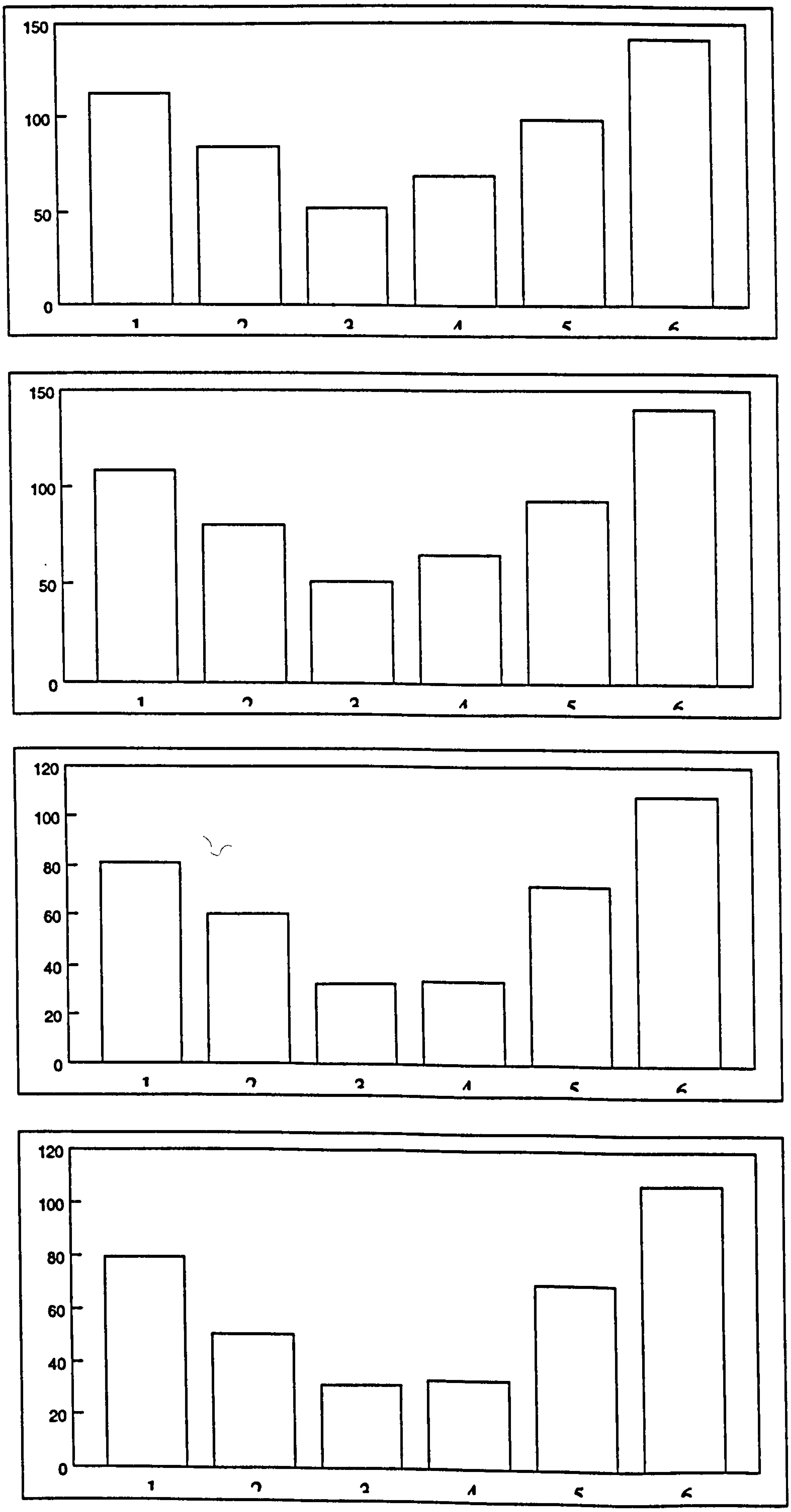


Figure 73 Maximum Check-in Queue Length (Queues 1 to 4)

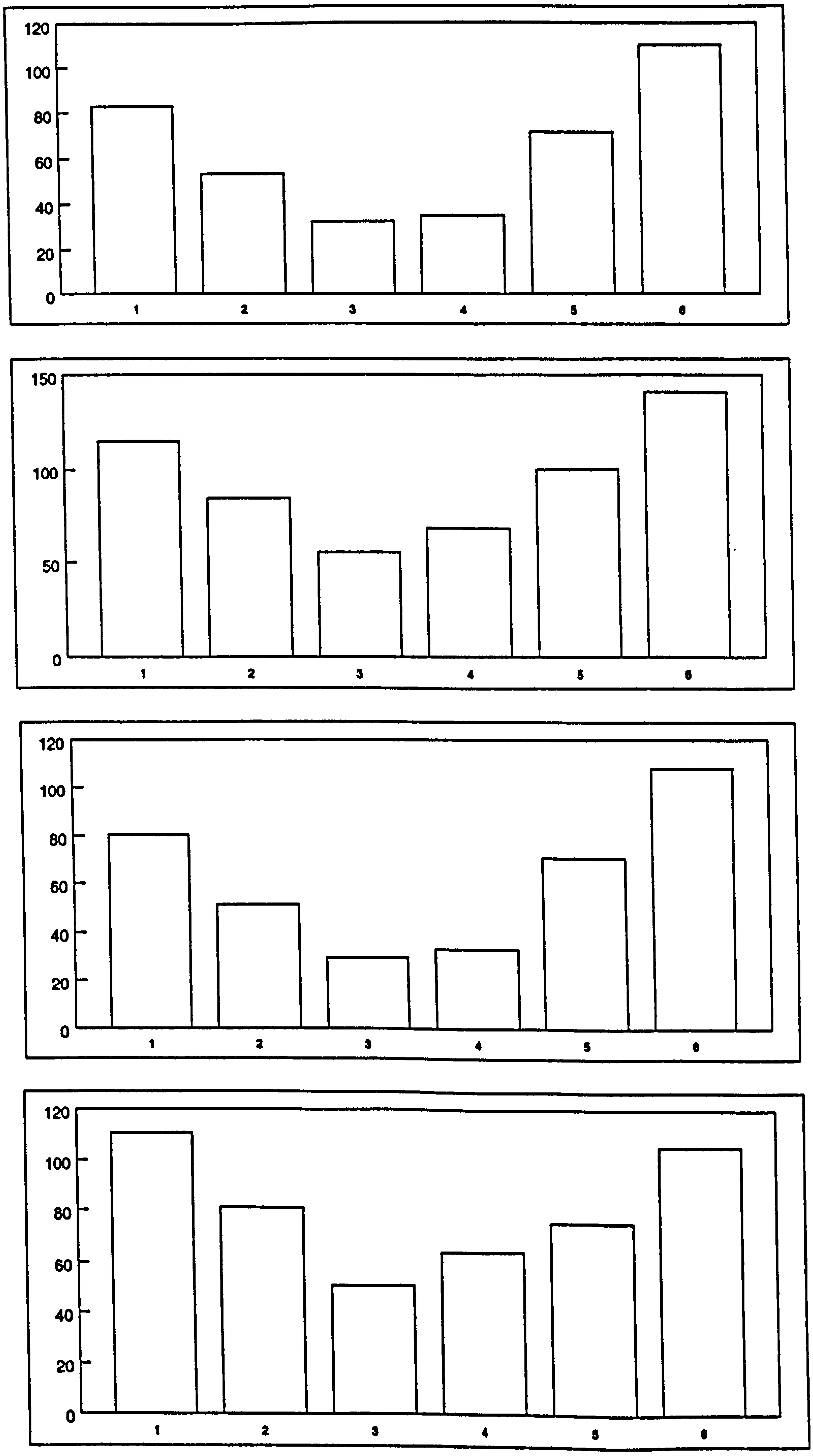


Figure 74 Maximum Check-in Queue Length (Queues 5 to 8)

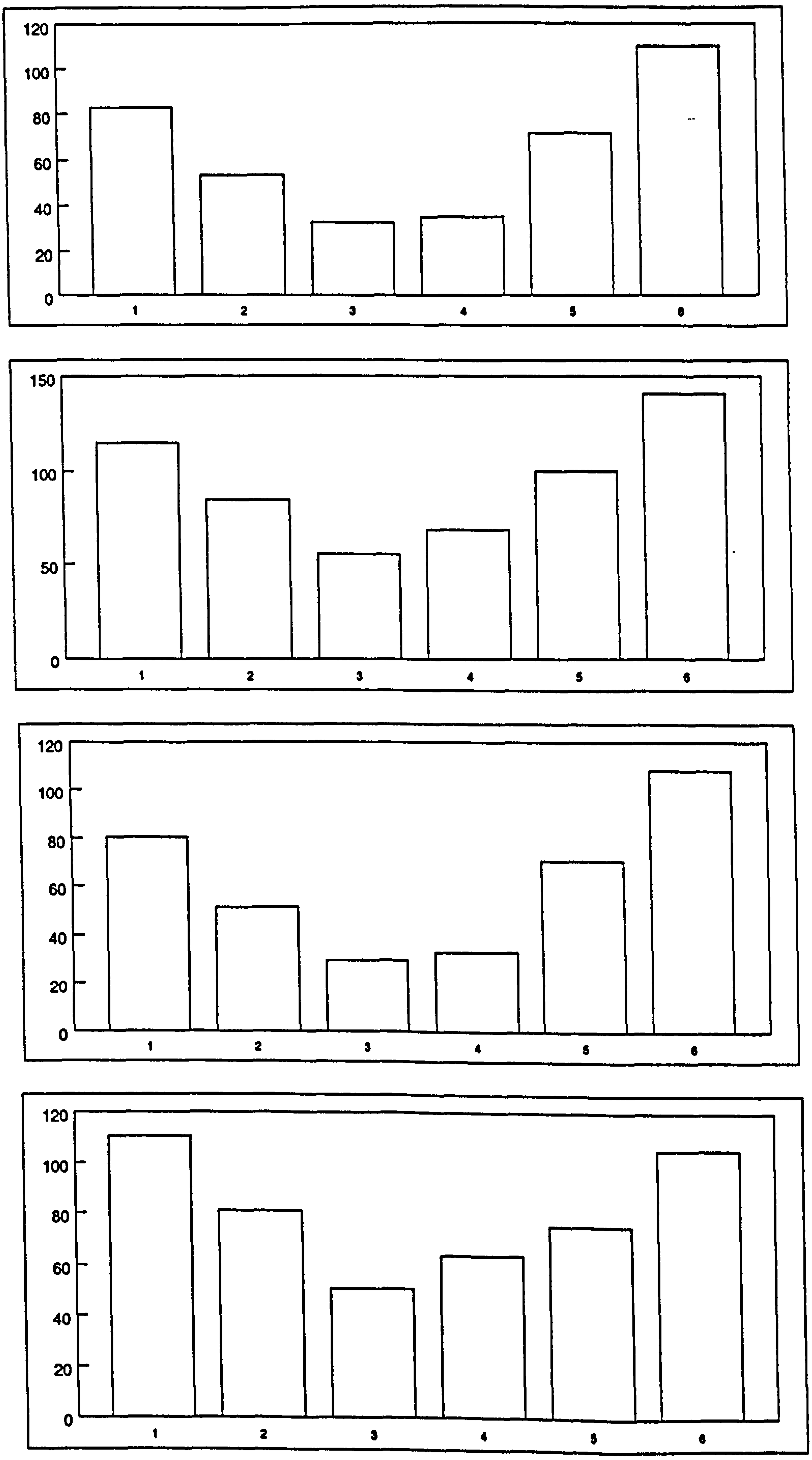


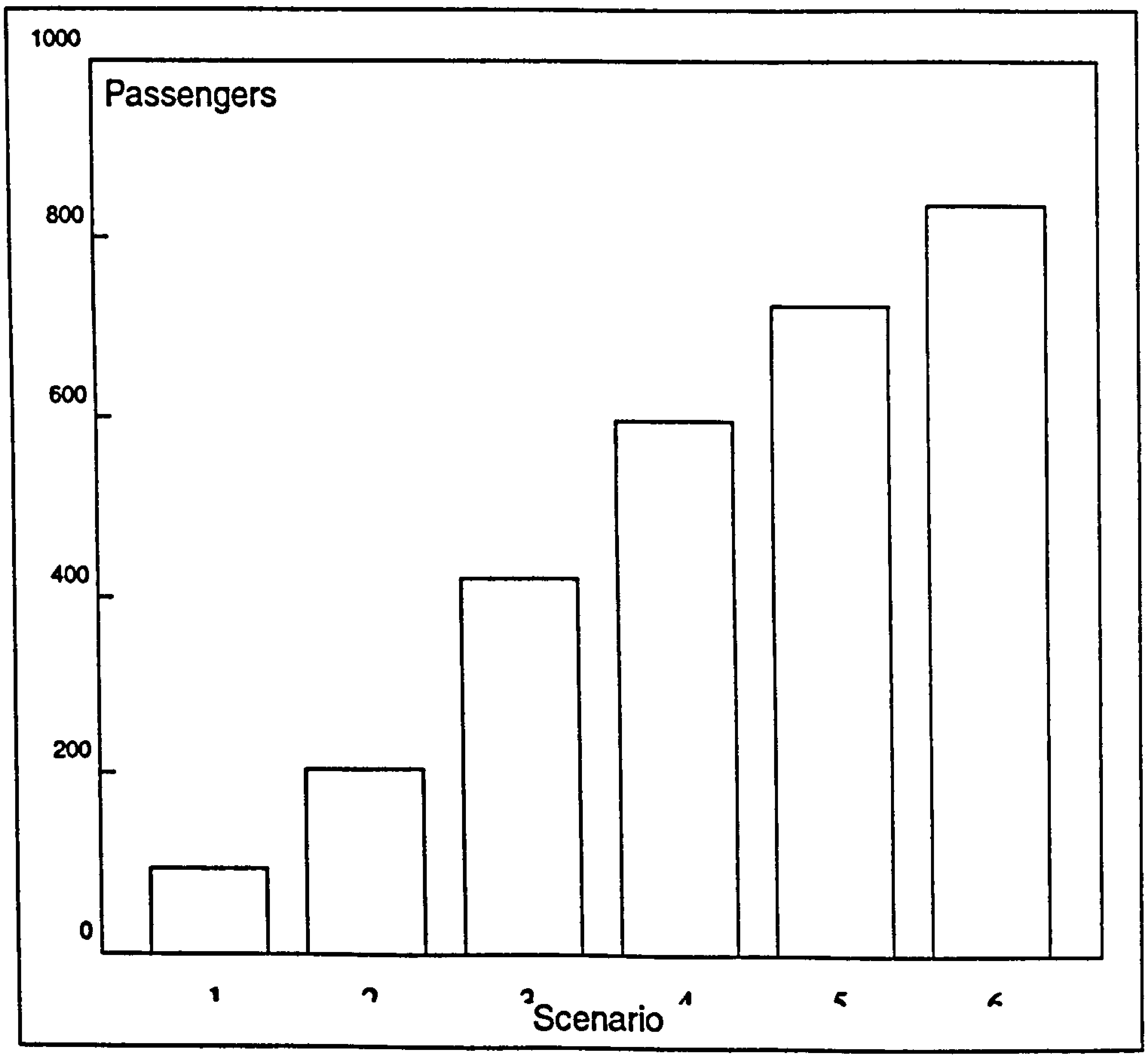
Figure 74 Maximum Check-in Queue Length (Queues 5 to 8)

12.5.2 Peak Public Concourse Passenger Volume

From the results obtained and displayed in Figure 75 reflecting peak passenger volumes in the public concourse. There is a clear upward trend in the peak passenger volume from Scenario 1 to Scenario 6. The results are as one might expect with passengers arriving earlier in relation to the scheduled time of departure. The results are similar to others obtained in other models for public concourses.

With the increase in passenger volumes there is an associated demand for this facility to provide more functions and entertainment for passengers.

Figure 75 Peak Public Concourse Passenger Volume

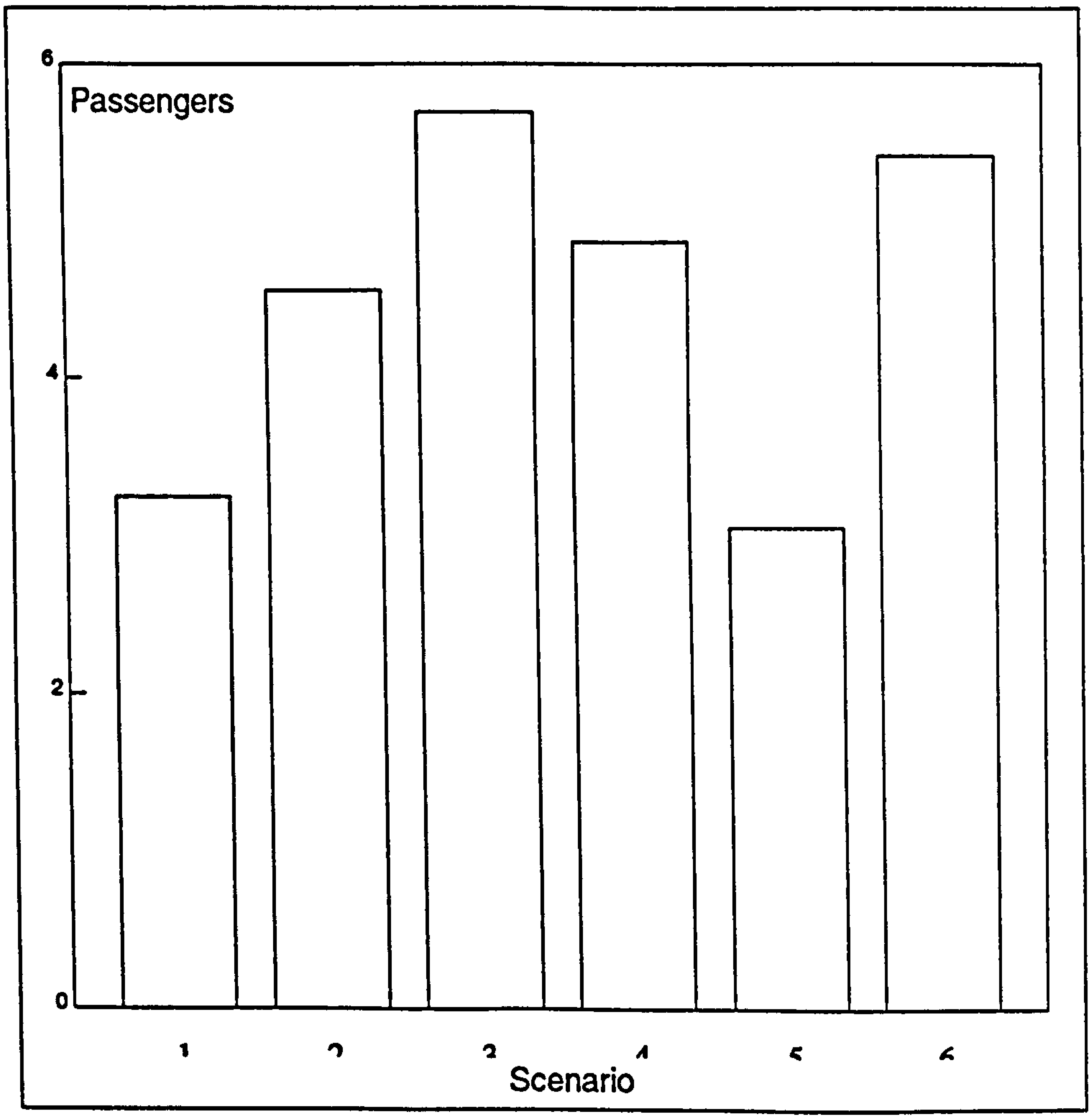


12.5.3 Maximum Security Queue Length

Figure 76 displays the results obtained for the security queue length, which take a similar form to those obtained for Manchester Airport Model 1. The peak security queue length increases for Scenario 1 and 3. The queue length then falls for Scenario 5 before rising in Scenario 6.

The results indicate that movement and subsequent processing of passengers through the security facility is not adversely affected by the change in arrival distribution of passengers.

Figure 76 Maximum Security Queue Length

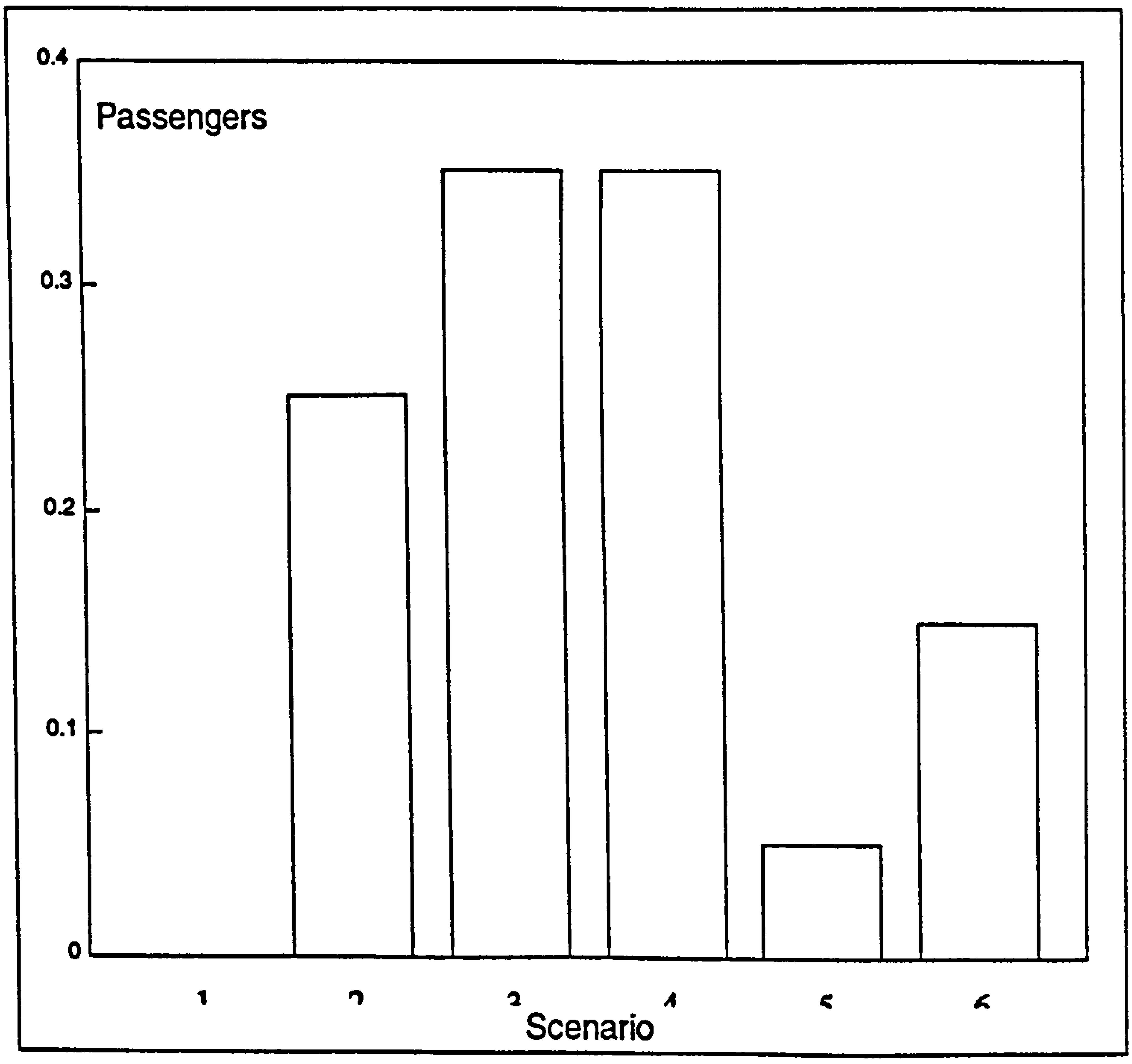


12.5.4 Maximum Frisk Queue Length

The results obtained for peak frisk queue length reveal no pattern, as is shown by Figure 77. No queue develops for Scenario 1 and the remaining scenarios experience fluctuating peak queue lengths. The significance of these results is not be affected by the low numbers recorded because the number of iterations conducted for each scenario was consistent.

These results again support the conclusion that, the movement to and the subsequent processing of passengers through this facility are not adversely affected by the change in arrival distribution of passengers.

Figure 77 Maximum Frisk Queue Length

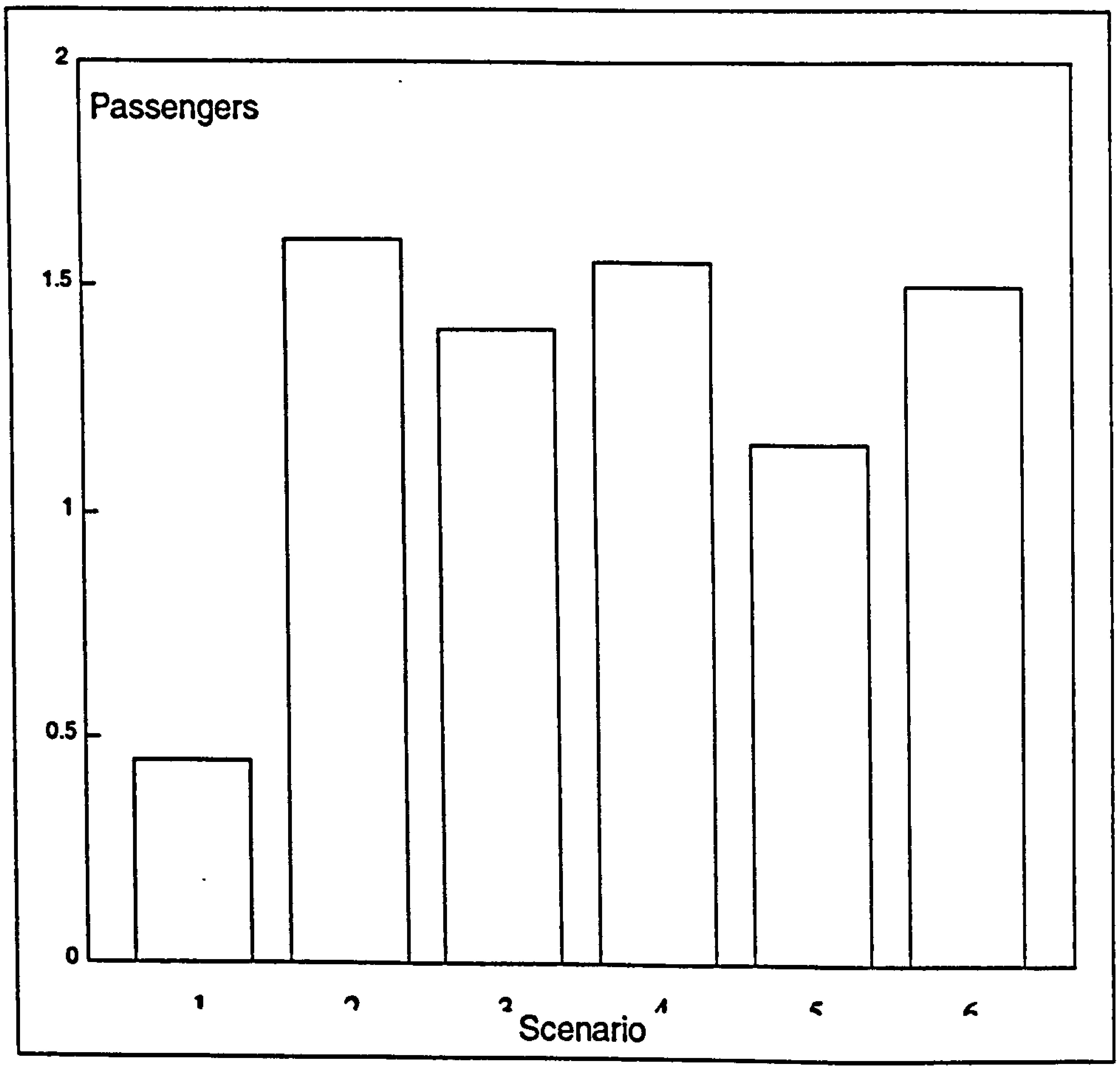


12.5.5 Peak Bag Search Queue Length

Figure 78 displays the results obtained for peak bag search queue length. The results appear to be stable, with only Scenario 1 falling below the lengths recorded for the other scenarios. This result is probably due to the high number of passengers that missed flights for this scenario. The significance of these results should not be affected by the low numbers recorded because of the number of iterations conducted for each scenario was consistent.

A change in arrival distribution of passengers at the airport does not appear to influence the processing of passengers through the bag search facility.

Figure 78 Peak Bag Search Queue Length

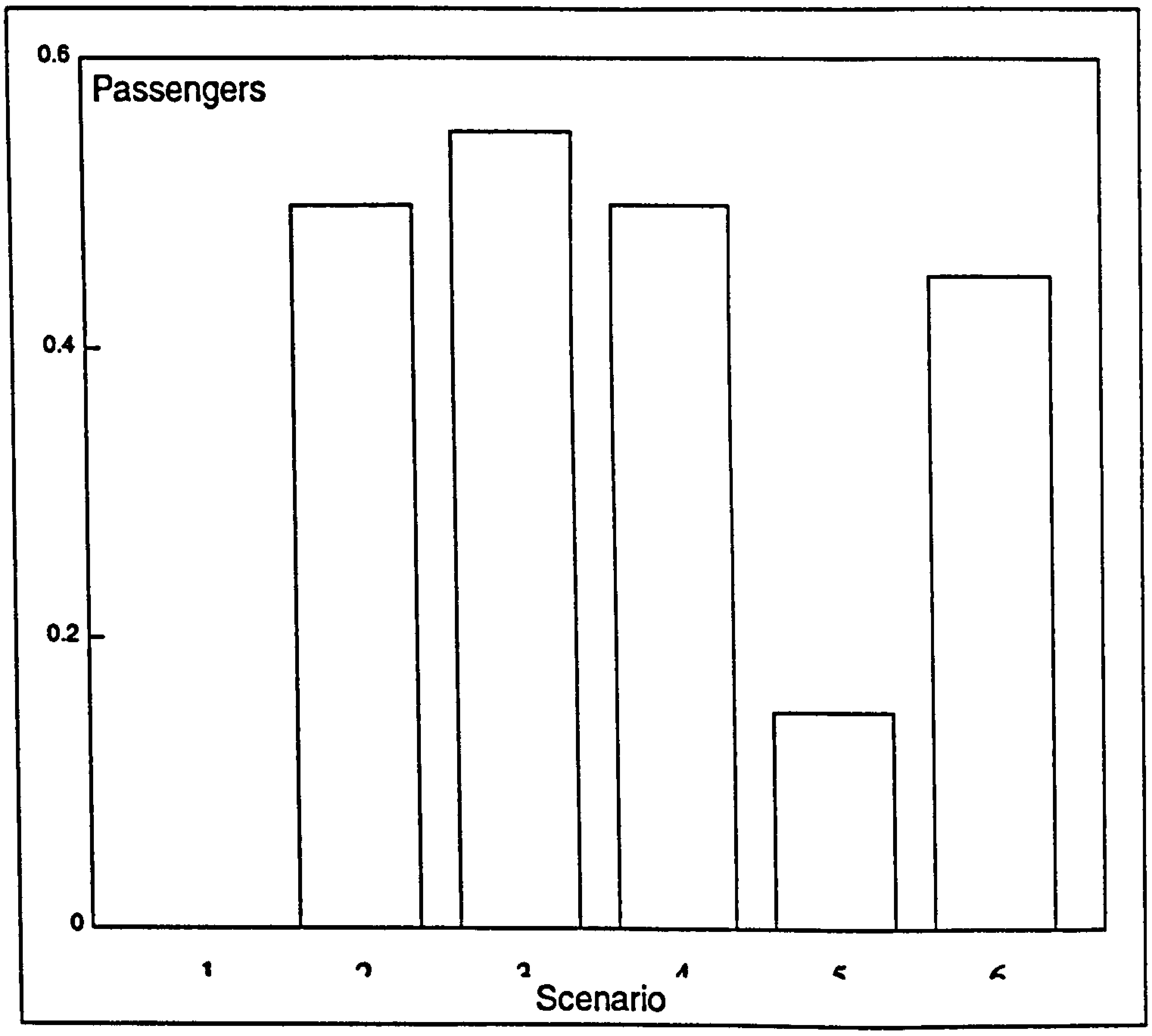


12.5.6 Peak Passport Control Queue Length

The results obtained and displayed in Figure 79 are for peak passport control queue length. The results appear to follow the same basic form as for the peak frisk queue length. The reason for this similarity could be that both facilities immediately follow the security facility.

The passport control queue comes after the frisk queue in the model. However, the number of passengers that are actually affected by the frisking procedure is only 30% of the total number passing onto the passport control. Therefore impact of the frisked passengers the on the passport control queues would be noticeable but not enough to significantly change the overall pattern of queuing at this facility.

Figure 79 Peak Passport Control Queue Length

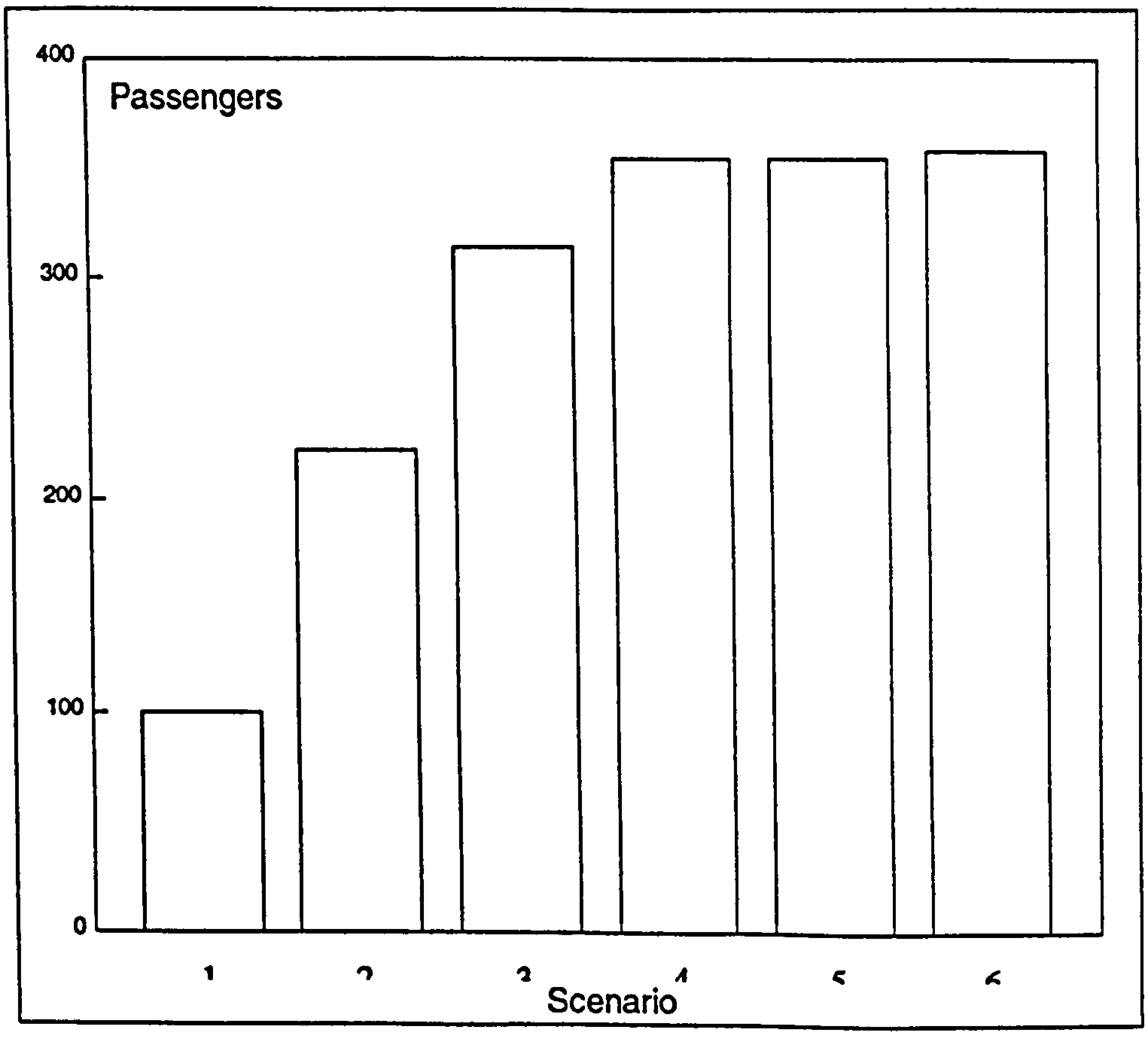


12.5.7 Peak Passenger Volume Departure Lounge

Figure 80 displays the peak departure lounge volume. As occurred in the previous models, the trend in peak passenger volume rises for Scenarios 1 to 4. Scenarios 5 and 6 produce the same peak passenger volume as Scenario 4. The probable cause of this levelling off is the peaked nature of flights within this terminal's flight schedule. With no further flights and therefore passengers to accommodate the peak volume of passengers will remain stable.

The implication of the results for the lounge is that passengers will spend more time in this area of the airport. The a change in passenger arrival distribution will require more space and comfort for waiting passengers.

Figure 80 Peak Passenger Volume Departure Lounge

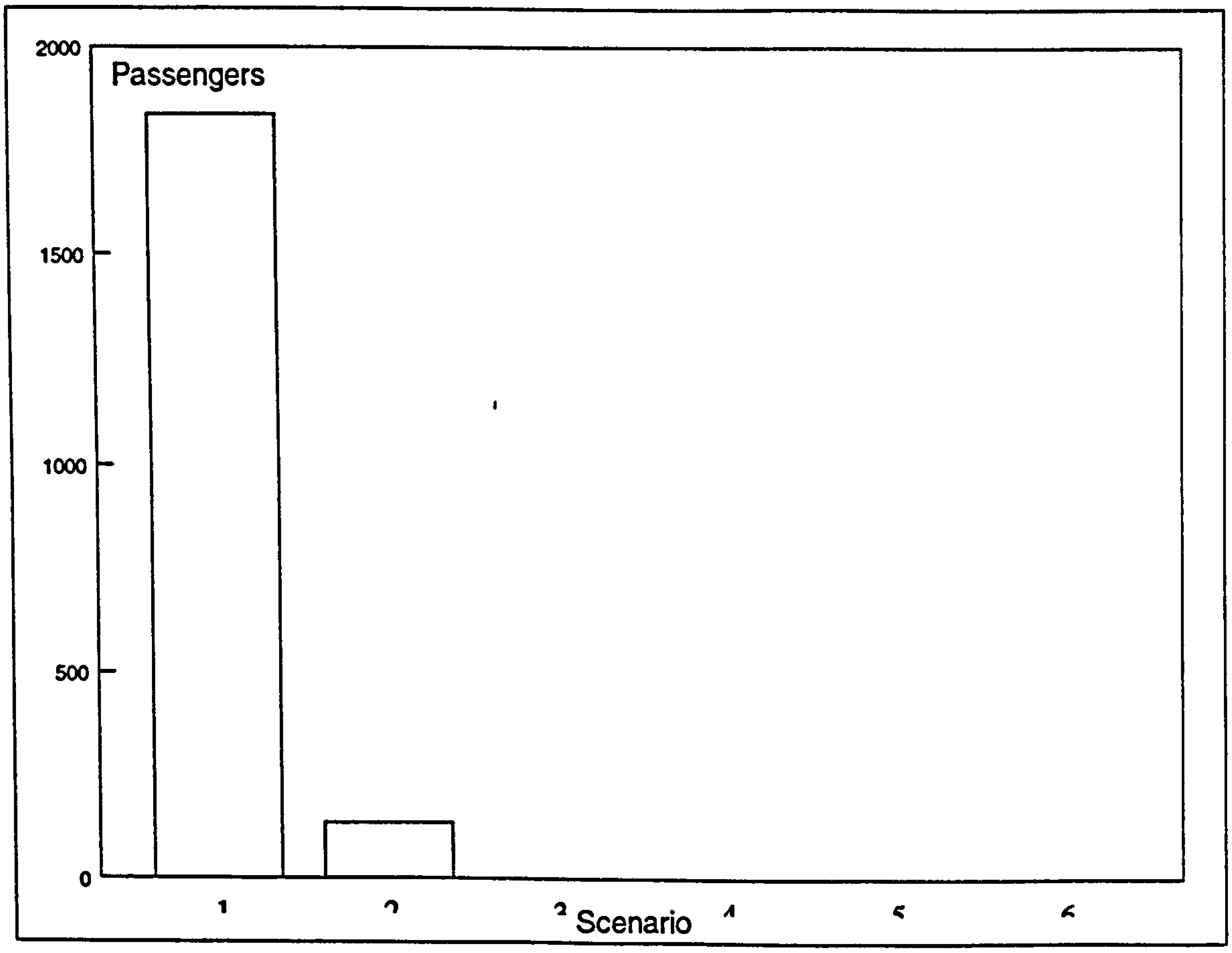


12.5.8 Missed Flights

Figure 81 shows that Manchester Airport Model 3 experienced missed flights for Scenarios 1 and 2. There are large numbers of passengers that miss flights because of the limited time that passengers have to pass through the system. This system cannot support the high arrival rate of passengers at the terminal.

This therefore has implications for the design of facilities should passenger arrival patterns shift closer to the scheduled time of departure of flights.

Figure 81 Missed Flights



12.5.9 Summary

Generally the results for this model are very similar to those obtained for the other models. The notable results are again the impact of a change in arrival distribution on the check-in facilities. The greatest impact occurs in conjunction with a high proportion of late arrivals or a high proportion of early arrivals.

Other important results include the queue lengths observed at the dynamic facilities, such as passport control. These results indicate that dynamic facilities are not impacted noticeably by a change in arrival distribution. The other area that is affected is the peak passenger volume is the departure lounge. In this case, the peak volume levels out at Scenario 4 but, as was pointed out, this was probably due to the nature of the flight schedule for the terminal. The results might have been different with an alternative flight schedule.

12.6 Simulation Summary

12.6.1 Dynamic Facilities

It is clear from the work with the five models that a change in arrival pattern has a significant impact on a passenger terminal. Considering first the dynamic facilities, the models only appear to experience bottlenecks at the check-in facilities. The reason for this lack of other bottlenecks at other dynamic facilities could be the functions used to control the flows. However, the functions used in the models were based on data provided by the airports. It is important to note that the more holding and dynamic facilities that passengers pass through, the less a change in arrival pattern has on the remaining dynamic facilities in the terminal.

The dynamic facilities that are most responsive to a change in arrival patterns are the check-in desks. The characteristic 'U' shape of the graphs produced from the results of the modelling suggest that there is an optimum arrival pattern for passengers. The high queues for the 'late' biased arrival pattern, such as Scenario 1, would indicate a change in the operating practices of the ground handling agents might be required, changes specifically designed to improve the processing time of checking-in passengers. The high queue levels for the scenarios building up to Scenario 6, would not affect the practical process and likelihood of catching a flight, but might cause a 'feeling' of overcrowding within the terminal. This feeling may well make an airport unattractive to passengers. Planners should address the issue of increasing the rate of passenger processing at check-in in preparation for potential arrival pattern shifts. In the latter example, another option might be to open check-in desks earlier. Opening the check-in desks earlier requires the support of the airlines and handling agents. This may be hard to gain as it will require airlines to increase their staffing levels and therefore its operating costs. Adopting such a policy may also increase the number of check-in desks required. This action will place demands on terminal space, both in the check-in areas and other areas of the terminal.

These negative points might be counterbalanced by the introduction of automated check-in, which will reduce the need for staff and floor space. However, customer conscious airlines, such as British Airways (BA), would not automatically welcome such developments as it reduces the level of contact the airline has with its customers. BA is trying to provide a consistent quality of service reinforced through the use of brand image. This service should be consistent from the first point of contact with its customers to the last. This approach includes travel agents or telephone salespersons, through to passenger disembarking an aircraft. This range of contact could be extended further by providing new services for passengers in the future.

It may appear to be something that airport planners have little control over, however they should strive to achieve an optimum arrival pattern. Such a pattern would typically involve passengers arriving evenly between the time just prior to check-in desks opening and desks closing. This will help maintain queuing at a minimal level. How this might be achieved will be addressed in the next chapter.

12.6.2 Holding Facilities

Clearly a change in arrival pattern also has a significant impact on the holding facilities within a passenger terminal. This impact will demand changes in the spatial requirements and facility provisions. Considering a situation where there is a spread in the arrival pattern, for example, Scenario 6 of the EMIA model, the public concourse experiences very high passenger volumes. This is due to the combined number of passengers waiting for the check-in desks to open, those waiting to check-in and those that have checked-in. There will be a need for the airport authority to provide greater space for passengers, or reduce the number of flights originating at the airport. The latter option is probably not financially desirable and therefore the former option becomes a necessity. Opening the check-in desks earlier could reduce the pressure on the public concourse but at the expense of creating pressures elsewhere in the terminal. Associated with the extra spatial requirements there might be an increased demand for alternative services to be provided within the terminal environment. These services may affect future passenger choice in favour of using a particular airport. If this view is shared by others this may increase the number of people trying to access the airport. This will obviously perpetuate the cycle of facility development at the airport.

Conversely, considering the implications of the earlier scenarios, where passengers arrive over a short period of time, there is a need for a change in operating practice. This may be to improve the performance of the facilities provided, or the enforced earlier check-in of passengers. To prevent flights being missed by passengers another possible option is to enhance the processing of passengers. BAA's 'Fast track' scheme for business travellers is an example of a scheme that allows for rapid checking-in and swift passenger progress through the terminal. An alternative is to delay the aircraft departure, which will allow more time for the passengers to pass through the airport system, but this is not a practical solution for everyday operation of an airport.

The other area which is greatly affected by a change in arrival pattern shown by the models, is the departure lounge. The models showing this impact are those designed with a variable that releases passengers from public concourses or concession areas either, after a set period of time, or at a set rate. This effect can only be confirmed with further study of passenger flows within the terminal environment. The models suggest an impact might occur if passenger flows are not controlled by the airport authority, for example preventing entry into lounges until a flight is called. This will cause higher volumes in holding facilities at earlier stages of the terminal system. However, there is generally more flexibility for modification and freedom of movement in the publicly accessible areas.

12.6.3 General

As was described in the previous chapter, to develop these models requires specific pertinent airport related information. The request for some types of data revealed a surprising lack of knowledge by some airports about the passenger flows which occur in their airports. This lack of knowledge also affects the level of detail that could be entered into a specific model. The greater the level of synthesised data input into a model, the less the results that are obtained can be fully associated with the terminal that the model is supposed to represent.

This lack of knowledge extends to the behaviour of different groups of passengers within the terminal. Questions remain as to the what differences, if any, exist between the terminal activities of different types of passengers, such as charter and schedule passengers. The airport planner's knowledge of their passengers should be thorough, if for no other reason than because passengers are becoming more quality conscious, and passenger continued patronage is the difference between an airport's commercial success or failure.

12.7 Other Observations

12.7.1 Napa Software

With regard to the software used and models created for this research, a number of more specific observations should be made. The first relates to the NAPA software used to build the models. On the whole it performed well, it was fairly straight forward to use and produced useful results. During the course of the research a number of weaknesses were discovered in the software's capabilities that limits the recommendation of this software for future work.

The number of facilities that can be modelled at any one time is too restrictive. A passenger terminal can be broken down into many areas of activity; to limit the number facilities that can be modelled, reduces the level of detail that a user can produce within a model. Another limitation is that the flows of traffic between the facilities is unidirectional. The restriction of unidirectional flow would not allow for passengers to visit areas on more than one occasion. This limits the development of detailed model of passenger activity within specific areas of a terminal, such as a public concourse. In such a facility passengers may use a number of facilities more than once, such as information desk, toilet facilities and retail outlets, which would not be conveniently be modelled using this software. If a software package limits the modeller in this way, its suitability for more detailed modelling of passenger flows must be questioned. Another aspect that the software did not appear to cater for was delayed flights. The nature of air travel will often result in a number of delays to departing and arriving aircraft. The inability to model such factors will again limit the usefulness of the software for realistic simulation.

Fortunately for the purposes of this research the level of detail required could be achieved with the selected software. However, its use in more detailed projects would have to be evaluated in the light of the revealed restrictions. Another criticism to be made of the software relates to the results facility. The report facility was not suited to the running of a large number of iterations. It was quicker to record manually iteration results than using the automated report facility.

12.7.2 Limited Information

Because of the limited availability of information, the models that were produced for the research were not as detailed as they could have been. The reasons for this lack of information include the general naiveté of airport operators about the behaviour of passengers in their terminals and a reluctance to change this position. As was indicated earlier, it may be easier in the future to use new techniques to gather suitable data for modelling activities. This could allow airport operators to plan more effectively the type and location of facilities provided within the terminal environment.

13. Research Conclusions

Ground access problems have affected the overall impact of air transport developments and its benefits. An ever increasing number of ground access vehicles, increasing distances required to reach airports, and the inevitable growth in peak time travel both in the air and on the ground are detrimental. Air and ground transport modes are increasingly experiencing congestion which causes delays.

Knowing delays are likely, travellers can prepare for their journeys by leaving their origins earlier. This allowance for perceived journey problems will cause a change in the passenger's arrival time at the airport. The change in the arrival pattern will depend on how accurately travellers can predict the delays.

The accuracy of this prediction will depend on a combination of factors, including prior knowledge of the journey to be undertaken. The nature of air travel means that a large proportion of travellers will fly no more than twice a year, and not necessarily from the same airport. This implies that their journey knowledge will be very limited and as a result there will be uncertainty of the optimum departure time in order to reach the airport for a given time. A level of uncertainty helps to ensure a spread in the arrival of passengers at an airport. However, results in this thesis suggest that passenger's confidence in their ability to predict journey time may cause extreme arrival times. The resulting extreme arrival patterns have been shown to have a detrimental effect on airport efficiency.

Modal choice depends on mode availability, journey cost and journey time reliability. It will also depend on the traveller's willingness to pay to increase the probability of arriving on time. Passengers with a higher perceived value of time can exploit faster and more expensive modes of transport.

Surveys conducted at Manchester Airport and Birmingham Airport produced results that were very much as expected. Some key aspects were observed, such as the high proportion of passengers starting their journeys from home as opposed to work and other locations. Results show that travellers generally allow a margin of safety in their journey time. Margins of safety allocated to journeys take the form of time bands, typically 15, 30 or 60 minutes. The size of the margin of safety is dependent on the volumes of traffic expected and the level of experience they have of their journey. Therefore, the effect of the increase in vehicle flows on roads will be to produce a more diverse range of arrival patterns at airport terminals. There will still be times where traffic volume will be minimal such as at night, but there will be an increasing proportion of the day where demand will exceed capacity and delays will occur.

From the surveys it was possible to calculate expected and actual journey times for each traveller, and from these an associated accuracy of prediction of journey time values could be obtained. These were then compared with specific characteristics of the flight such as destination and frequency of travel to evaluate if there were any significant relationships. Some significant results were obtained. These results show that specific factors affect the ability to predict journey time.

The evidence of the surveys suggests that there is no single factor that can be identified and used consistently to explain airport access journey decisions. This emphasised by the difference in the calculated arrival patterns for Manchester and Birmingham airports.

Simulation of passenger flows in airport terminals show that a change in arrival pattern has an impact on a passenger terminal. This impact will demand change in the spatial requirements and facility provision. If there is a shift in arrival patterns to earlier arrival at airports there will be a need for the airport authority to react. This reaction could be to provide greater space for passengers, or to reduce the number of flights originating at the airport. There might be an increased demand for alternative services to be provided within the terminal environment because inevitably passengers will be spending more time in the terminal area. If a shift occurs to more late arrivals, there will be a need for a change in the performance of the facilities. The change required should to allow for rapid processing of passengers and swift passenger progress through the terminal system.

The other area that is greatly affected by a change in arrival pattern shown by the models is the departure lounge. This effect can only be confirmed with further study of passenger flows within the terminal environment. The models suggest an impact might occur if passenger flows are not regulated in some way.

The dynamic facilities within the models, except for the check-in facilities, do not experience excessive delays. The reason for this could be due to a combination of the functions used to control the models' flows and the holding facilities. These have the effect of diluting the impact of the change in arrival pattern on following facilities. The results indicate check-in desks within the terminal are the most susceptible dynamic facility to a change in arrival patterns.

The modelling results indicate that there is an optimum arrival pattern. This pattern is characterised by passengers arriving evenly between the time just prior to check-in desks opening and desks closing. However, as this thesis has shown, airport planners cannot be expected to identify with any consistency, factors that influence the arrival of passengers at all airports. Therefore the solutions adopted to achieve this objective must take into account the behaviour characteristics of the passengers using the airport in question.

Strategies that could be adopted include issuing a variety of requested check-in times based on a number of criteria. These criteria may include: the number of recent trips from the airport, the journey distance to the airport, the mode of transport to be used, the amount of luggage passenger will be carrying and the time of the day.

Another option is to encourage transport operators to provide services that offer both reliable and frequent arrivals at airports, for example, a high frequency shuttle train service. This style of service will reduce the amount of time that passengers would have to allow to ensure their arrival at the airport in time to catch their flight. This also makes the mode transport more attractive to existing and potential users.

While trying to encourage optimal arrival patterns by whatever methods chosen, airport planners will be dependent on other organisations such as airlines and other transport operators to be successful. However, by definition the optimum arrival distribution depends on a level of uncertainty, and so it is in the interests of planners to maintain a level of uncertainty. If the journey was entirely predictable most passengers would arrive in a short space of time just prior to departure. This type of arrival pattern has also been shown by this research to be unsuitable for existing terminal design and operations. Therefore the elimination of uncertainty entirely would be counterproductive.

13.1 The Hypothesis

To summarise, this thesis has shown by a systematic and logical process of surveying and simulation based on a robust methodology that airport passenger terminal operational efficiency is affected by travel time uncertainty. With the forecast growth in congestion levels experienced by all modes of transport, in the future, not only will travel time uncertainty increase, but so will its associated impacts on the airport terminals. Considering the original general hypothesis, this research can conclude that:

With an increase in ground access journey time uncertainty, there is an impact on traveller behaviour. The resulting behavioural change will alter arrival patterns and affect passenger flows experienced within airport terminals.

The general hypothesis is therefore corroborated by the supporting evidence.

Apart from confirming the hypothesis, this research has also identified that passenger decision making can only be explained by various combinations of different factors. This thesis is the first substantive piece of research to examine the issue of airport access travel time uncertainty. It is also the first to use this particular methodology to achieve this understanding.

14. Discussion

Through the contact with the three airports involved in this research, it is clear that there is little understanding of the issues associated with travel time uncertainty. This lack of understanding extends to access journey decision making as a whole. Most airports conduct passenger surveying as part of their marketing activities to identify aspects such as passenger profiles and catchment areas. If a greater understanding of travel time uncertainty is to be achieved, airports need to address this issue when sampling their passengers. Alternatively, airports should allow those that are interested in this subject greater access, albeit supervised, to the travelling public in restricted areas such as departure lounges.

Although the surveys conducted for this research were limited in terms of their composition and scope, the findings generally support existing knowledge and opinion. Some interesting aspects regarding passenger travel arrangements and the planning of journeys to airports were identified. For example, a larger than anticipated proportion of passengers start their journeys to airports from home as opposed to work. Also the margins of safety allocated for journeys tend to be allocated in blocks of minutes to the nearest 10 minutes or so.

Comparisons of expected and actual journey times and journey time prediction with specific passenger profile characteristics revealed some significant results. These results indicate that specific factors affect passengers' access planning decisions and their ability to accurately predict their arrival time.

However, the results were not the same for both airports, which suggests that the passengers travelling to the two airports behave differently. This is emphasised by the difference in the calculated arrival patterns for Manchester and Birmingham airports. This also provides evidence to support the argument that there is no single factor that can be identified and used consistently to explain access journey decisions made by air travellers.

If this research was to be repeated at some time in the future, the survey samples should be larger in size and represent as completely as possible the spectrum of travelling public. The significance testing conducted for this research was occasionally limited by sample size in that some variables appeared to be related and yet could not be demonstrated statistically. These relationships could only be confirmed through additional surveys.

The method of passenger surveying could be enhanced by the introduction of computer based surveying equipment within the airport or onboard aircraft. Perhaps the ideal location for such surveying would be onboard aircraft where access to passengers is complete, or in the airport departure lounges after all the processing formalities have been concluded. With the advent of seat based in-flight entertainment systems, it would not take much to extend the capabilities of these computer based systems to allow passenger surveying in-flight. The drawback for airport planners is that this would require full co-operation with the airlines, a phrase that does not characterise their existing relationship. A modified surveying system could be developed and introduced for the airport environment. It may be harder to achieve the same percentage of completed surveys compared with in-flight systems. However, there should be a significant increase in the volume of passengers surveyed and the processing time of the completed surveys.

With regard to simulation, it is a tool that could become increasingly utilised within the air transport industry if a number of restrictions on its use are minimised. Limits include the level of information known about passenger behaviour both inside and outside the airport environment. This knowledge needs to be increased dramatically, and also the simulation tools for modelling passenger behaviour need to become more sophisticated.

A possible solution to this problem could again lie in the use of modern technology. Developing a system that can track passengers' movements within a passenger terminal would allow for both real-time tracking of passengers and historical analysis of passenger movements. The initial setting up of such a system is likely to incur significant development costs.

The information gathered through this process could be used in both operational and business planning. The resulting better quality information would be beneficial for airport planners in helping them to design and locate their facilities more effectively. It could also be used to improve the level of detail used in simulation projects for future developments, and thereby increasing the accuracy of the models developed. Business planners could also benefit from being able to identify with supporting evidence the key locations within the terminals where passengers congregate.

Obviously, to utilise this increased level of detail would require a vast improvement in the quality of the simulation tools available to airport planners. Existing tools are not as sophisticated as they might be because airport planners have not expressed a need for more advanced systems. However, as the costs of airport developments continue to rise and the forecast growth in the number of passengers is set to continue, the ability to conduct accurate simulation modelling will become more crucial. This will help particularly in the design and planning of new effective facilities.

This thesis has shown, with an increase in passenger uncertainty comes a change in behaviour. This behavioural change would probably be to increase the margin of safety for the journey. This precautionary action increases the likelihood of early arrival time of passengers at the airport terminal. Early arrival at an airport terminal has been shown to affect its operational efficiency. If the travel time uncertainty is reduced the opposite trend would be expected, however, its impact on the terminals would not be as significant. This is because travellers are motivated by the need to catch a flight, and so will continue to arrive at airports with more than enough time to successfully catch the flight.

In attempting to maintain or improve operational efficiency, airport authorities can tackle the problem from two directions. The first focuses on the cause of the change in passenger behaviour, the second addresses the ways of dealing with the unwanted effects of the change in passenger behaviour.

There are a number of ways of reducing the levels of uncertainty for travellers. The first of these is to improve the standard of the ground transport infrastructure. Particular attention should be focused on providing better road and rail links especially in the vicinity of airports. This option is probably the most costly and has the major drawback that the extent of improvements implemented is beyond the control of the airport authorities. The decisions and to a large extent the funding for such developments remains the responsibility of central and local governments. These bodies are unlikely to change their reactive approach to infrastructure development, when perhaps a more pro-active policy might better solve existing problems.

The next available option to reduce travel time uncertainty is to provide passengers with other modes of transport into the airport. The development of frequent rail, bus and coach services, will allow travellers greater choice of access mode. Therefore, airport authorities should encourage both public and private companies to provide services into airports, perhaps working in co-operation with each other. Coach or rail companies could negotiate with airlines to offer combined travel options at special rates to tempt travellers away from cars. The services that are provided should be well publicised, as well as being reliable, of high frequency and possibly flight connected.

Airport directors, such as Gatwick Airport's Eric Lomas [1995], appreciate that airports cannot continue to provide parking facilities ad infinitum, even though significant income is generated by providing this service. Therefore his company is actively investigating other modes of transport for Gatwick Airport. For example, BAA are looking into the possibility of buying British Rail's Gatwick Airport Station.

Airports could develop and operate their own, or partly owned, transport links. The Heathrow Express is an example of such a venture that BAA and British Rail are jointly funding. Improvement in the transport services into airports will benefit the airports. However, operating 'passenger friendly' high frequency, low yield services may affect the profit levels that the operators might achieve. Therefore it might be necessary to find ways of encouraging potential operators by reducing the costs involved with providing frequent services.

An option that can be used independently or in conjunction with other improvements is the enhancement of the knowledge of people travelling to the airport. This can be achieved by providing travellers with relevant details about the possible transport modes available into the airport. Information regarding the frequency, journey time duration and cost information of the transport services available would be beneficial. Knowledge of the factors will help passengers to make informed decisions. Surveys have shown that a high proportion of travellers are flying for the first or second time from an airport in a year. By increasing the knowledge and confidence levels of travellers, there is likely to be a reduction in the size of margin of safety they allow. This policy might also prove beneficial in encouraging passengers to adopt other modes of transport to the airport.

With the objective of providing better information to passenger, an innovative method for achieving this would be to develop an electronically integrated transport network. The network would involve the linking of all modes of transport using a specific communications protocol. With this link, information could be given to travellers relating to available modes, or combination of modes, and their associated arrival time and costs to complete a specific journey. Such a system would allow travellers to make informed decisions about journeys of which they have little experience. Perhaps the lead in such a development should come from the airlines as they already have years of experience in similar systems. Existing airline reservation systems already perform the function of providing a complete information and booking facility for the travelling public for flights, rail tickets, hotels and hire cars. Airline reservation systems are often shared between airlines - for example, British Airways staff can book passengers onto other airlines. This can be done by simply calling up availability displays for given routes on their computer terminals and requesting seats.

However, not all modes of transport are technologically advanced as the airlines. Such a system would probably require a level of Government incentives to produce. It would also require realisation on the part of all modes of transport that they should be able to perform better if such a system existed.

This idea could be developed further and combined with traffic monitoring systems to provide up to the minute information for travellers. This system could warn passengers of traffic delays, cancellations to transport services and other factors that could influence journey times.

It is probable that whatever policies are adopted to reduce travel time uncertainty, that it will never disappear altogether. It is possible to approach the problem from a second direction by changing the design and operation of airports.

Assuming there is no modification to existing operating practices the first noticeable change in the airport caused by journey time uncertainty will be that queues develop. Queues can be reduced by increasing the ability to process passengers more effectively, or by starting processing activities earlier which has implications for staff requirements.

This raises the issue of the difference in the objectives of the airlines and the airport authorities. Airlines would like their passengers to pass through the airport with the least amount of delay and the highest level of quality service. Airport authorities on the other hand would like passengers to spend a great deal of their time in the terminal areas parting with their disposable income in their concessionaire's outlets. Revenue generated through the concessionaires allows the airports to charge the airlines lower landing fees. Airlines attempt to eliminate the 'dwell time' for its premium passengers by offering them dedicated lounges. This also allows the airlines to provide a seamless branded service to their customers. There are drawbacks to the airlines of opening check-in desks earlier. Firstly there is increased operating costs, and secondly an increase in the amount of time that customers will be out of contact with the airline. By keeping this separation time to a minimum, airlines can attempt to maintain some continuity of service with their customers. Similarly with the IT revolution tending towards computerised self-ticketing and check-in, some airlines fear that their prized customer service will become even more impersonal. The possibility of passing through an airport without making personal contact with airport or airline personnel is not far off.

From an airport perspective increased terminal dwell time will result in passengers demanding facilities that provide them with comfort (seating and space to move around), and occupy their time (shops, information and entertainment). The outcome therefore is an increase in demand for capacity for passengers and the facilities that they require. Increased floor space is what is required and this can only be achieved by extending or building bigger terminals. This requires not only funding but also local authority approval. In these times of environmental awareness, approval is not easily achieved. Even with planning approval funding is the next hurdle. Privately owned airports find it easier to raise the capital required, compared with the publicly owned airports, which face similar problems that confront most transport infrastructure developments.

Other options do exist which are not so costly to introduce. One option is to attempt to alter the arrival times of the passengers at the airport by changing the time that passengers are asked to check-in for their flights. For example, to request those passengers that live within a specific radius of the airport to check-in later than normal. This will hopefully reduce the volumes of passengers within the terminal.

This policy would be enhanced if all airlines allocated seats to passengers at the time of booking rather than on arrival at the airport. This would reduce the number of passengers arriving early at the airport to claim the 'best' seats. Scheduled airlines actively overbook flights to allow for cancellations and no-shows and so there would be a number of stand-by passengers who would not have seats. However, their impact on terminal efficiency would not be significant. Operating an allocated seat policy would not affect the day to day running of airline operations but could change passenger behaviour.

Other options exist such as the growth in remote check-in facilities, which the Heathrow Express will offer, which will reduce the amount of time that passengers need to be in the airport terminal still further.

Compared with the cost of infrastructure developments, options such as alternative check-in time, offering remote check-in and airlines allocating seating on booking are all relatively cheap. These options would also be quicker to implement, as roads for example take years to progress from the planning office to reality. These operational changes could be put into effect relatively quickly, subject to funding, because these options do not require local authority approval.

This work has highlighted the airport industry's lack of knowledge about travel time uncertainty. It is recommended that airport management should become more politically active, lobbying those with the power to make improvements to the ground transport infrastructure. Such involvement can only be of benefit to the air industry, and might well enhance ground transport performance simultaneously. Airport management should make conscious effort to be aware of changes to local ground infrastructure. Improvements in the transport infrastructure will not necessarily always be of benefit; it may make competitor airports more accessible.

The functions of airports have changed. No longer are they simply a node for inter-modal change. Airports perform secondary roles, supplying goods and services. These secondary roles are dependent on people spending time and their money in the airport. Airports might start trying to attract non-passengers to the airport as well.

Airport authorities and passengers probably have different perceptions of the undesirability of travel time uncertainty. Airport authorities are least likely to be concerned about travel time uncertainty because of the likely benefits of an increase in passenger dwell times within the terminal areas. Airport authorities need passengers to have excess time in order for them to spend money in the commercial outlets housed in the airport terminals. Because commercial income forms a major source of revenue for an airport, if travel time uncertainty was significantly reduced a large proportion of opportunist shopping income would be lost, such as the sale of refreshments.

However, the effects of extreme uncertainty will affect terminal efficiency and may require changes to the terminal, such as expansion. At airports where the ability to expand is physically restricted, the effects of travel time uncertainty might generate more concern for airport operators than at airports where expansion is not such a problem. If in the future journey time uncertainty is reduced to a level where passengers are arriving with little time for shopping and similar activities, airport authorities would have to promote shopping opportunities. This promotion would have to be at a level to make early arrival for shopping at the airport an attractive proposition for travellers.

Airline passenger handling depends on a degree of travel time uncertainty. If all passengers arrived simultaneously, it would be impossible to process them in the time available without excessive levels of staff and check-in facilities. The travellers inability to accurately predict the journey time to the airport produces a random effect. This random effect creates a distribution of the arrival of passengers at the check-in facilities. This distributed arrival pattern allows the airline to process the passengers with a limited number of check-in desks and staff. Furthermore, the airlines may benefit from lower landing charges at popular airports as a result of passenger spending in the airport terminals. On the other hand, if the uncertainty rises to extreme levels as this thesis has shown, airlines will have to alter their check-in practices. As was discussed previously, this might reduce the airlines' continuity of contact with their customers, unless they can find other ways of maintaining contact. Any solution is likely involve demands for terminal space that will have implications for terminal design and operation and therefore airport planners.

To summarise, extreme levels of travel time uncertainty create a number of problems for airports and their customers. The future of the air industry looks destined to be one of increased competition. Because of the complex interrelationship that exists between the airlines and airports, to be successful, airports will have to find the correct balance between their primary and secondary functions. This might require the airport operators to curb their desire to exploit an existing captive market, the passengers, in favour of addressing the needs of the airlines. Passengers are generated by airlines operating specific routes. By securing the support of the airlines, airports should be ensured of continued presence of and growth in passengers with increased probability of long term profitability.

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Appendix 1 The Air Traveller Survey Questionnaire

ID No. ☐☐☐ Time ☐☐☐☐

Sex -Male=1 Female=2 ☐ Airport Code ☐☐☐

Mon	1	Fri	5
Tue	2	Sat	6
Wed	3	Sun	7
Thur	4		

Q1 To which destination airport are you flying?

______________________ ☐☐☐

(Domestic=1, European=2, USA=3, Other International=4) ☐

Q2 (i) By what means of transport did you arrive? (In order from origin)

Private Car	1	Charter Bus/coach	5
Chauffeur Driven	2	Public Bus/coach	6
Rental Car	3	Hotel courtesy coach	7
Taxi/minicab	4	Underground/rail	8
other	9		

☐☐☐☐

(ii) Is this your preferred method?

Yes 0
No 1-9 ☐

Q3. Where in the UK did you start your journey today?

Town: ______________________

Country: ______________________

Place of work 1
Home 2
Other 3
(Specify): ______________________ ☐

Q4. What is your flight number?

A A A N N N N A
☐☐☐ ☐☐☐☐ ☐

LOUGHBOROUGH UNIVERSITY ACCESS QUESTIONNAIRE

Q5 What is the purpose of your journey? (Circle Number)

Business	1
Conference/trade fair/exhibition	2
Package tour holiday	3
Package tour	4
Visiting friends or relatives	5
Other non-business	6

Q6 How many people in your group? ☐

Q7 How often do you fly from this airport ?(Trips per year) ☐☐

Q8 What time did you leave home? (24hrs) ☐☐☐☐

Q9 What time were you asked to check-in? (24hrs) ☐☐☐☐

Q10 What time did you arrive at the airport? (24hrs) ☐☐☐☐

Q11 What time did you expect to arrive at the airport? (24hrs) ☐☐☐☐

Q12 What caused the difference between Q10 and Q11? (e.g. Less traffic than expected)

Q13 How much time did you allow in your journey time for delays? ☐☐☐

Appendix 2 The NAPA Suite of Models

The NAPA models were selected after deliberation over the possible options, based on the criteria of software functionality, cost, and availability. To assist the understanding of how the NAPA suite of planning models fits together, and in particular its relevance to this work, an overview is provided below.

The NAPA package consists of three independent models which are:

a) Schedule Impact Model (SCIM)

b) Gate Assignment Model

c) Terminal Flow Model (Graphic and Animated outputs)

These models each have a different function which is valuable to the terminal planner.

The Schedule Impact Model

The Schedule Impact Model (SCIM), as its name suggests, assesses the impacts of specific schedules on an airport terminal. This is achieved by providing at fifteen minute intervals, hourly totals for enplaning and deplaning passengers. Displaying the results in a graphic form, the model allows the planner to identify the 'peak' periods in the schedule. In addition to a total passenger figure, the SCIM model can be used to identify daily passenger volumes by categories (airline, ground agent and origin/destination sector). Furthermore, the time scale can be modified to allow planners to concentrate on particular 'peaks and troughs' in the daily schedule.

The SCIM model, in addition to its function as an analyser of current and future schedules, can be used to formulate a desired passenger flow profile for a terminal. A planner faced with achieving a near constant flow of passengers through a terminal without surpassing capacity, could devise a suitable schedule using the SCIM model. A technique of continual modification of a 'trial' schedule could be used to reach an optimum result. This solution could be used as a template to devise a strategy, which would encourage airlines to utilise the desired slots. Pricing incentives, for example, could encourage airlines to move less time restricted flights from peak to slack periods.

The Gate Assignment Model

This model allows for the evaluation of either an existing or a proposed terminal. Specifying within this model aircraft types, airlines, sectors and gate procedures, a planner can either optimise an existing schedule in terms of gate allocation or evaluate alternative schedules.

The planner can control a number of operating criteria such as towing operations, buffer times between aircraft, aircraft size restrictions at gates and adjacent gates. The planner can also weight aircraft and gate selection factors.

The model adopts a three stage process:

1. Assign aircraft to pre-assigned gates;
2. Assigns aircraft to preferred gates where possible;
3. Assigns aircraft to gates where they are allowed;

Any aircraft not accommodated are identified to the planner for manual placement.

Optimisation of gate allocation is achieved by allocating the most restrictive aircraft first and the most flexible last. There is also an 'overrule' facility; which utilises a interactive gating facility within the model. This allows the planner to place a particular aircraft on a specific gate, increasing the manual control of the placement of individual aircraft.

The Terminal Flow Model

After the gate requirements of a schedule have been evaluated by the Gate Assignment Model, the Terminal Flow Model can be utilised to estimate queues and volumes within existing facilities or the size requirements for a new facility.

This model requires a great deal of information such as arrival distributions, service rates at check-in desks, and average dwell times in public spaces. Using the post-gate assigned schedule the terminal flow model generates queues at dynamic facilities within the terminal (e.g. check-in desks and security check points) and running totals in static facilities (e.g. lounges and public concourse). The importance of using the post gate assignment schedule is that the simulation models individual passengers and will account for walking times and boarding procedures which may differ between gates.

The output from the Terminal Flow Model takes two forms:

1. Graphic Output
2. Animated Output

The graphic output produced takes a similar form to the SCIM model. The Animated Terminal Flow Model gives a dynamic representation which is extremely valuable to planners as it reveals clearly the time and locations where congestion builds up. With the ability of simultaneously displaying the schedule used to produce the output planners can identify the aircraft which cause the problems.

The basis for all the NAPA models is the schedule database. Schedules can be either simply for a single day or a current schedule of a set time scale. Information stored in this database relates to the airline, the aircraft used, type of flight etc. This combined with two further databases, the aircraft database and the airline database form the inputs into the analytical models. Aspects such as aircraft load factors and gate stipulation can also be included in the schedule database. As will be illustrated later in this chapter, the ability to modify the simulated arrival distributions for passengers allows the modeller to make the models 'sensitive' to passenger access, and therefore suitable to this research.

Essentially the models provide a low cost, effective method for minimising development risks, while maximising the opportunity for optimising a facility's design and operation.

For the purposes of this research the latter of these three models provides the greatest value. By using the terminal flow model it is possible to obtain an indication of how flows within the terminal environment might be effected by changes in passenger arrival distributions.

Appendix 3 NAPA Model Data Tables

The following represent some of the data tables used in the NAPA models created for this research. This data is included to show firstly, how the tables are compiled and secondly the level of detailed information required to build such NAPA models.

Part of the agreement with the airports featured in this research requires that only a few of the tables produced for this research are contained within this appendix.

(A) East Midlands International Airport

Arrival Table

STATUS	PROB 1	MIN PRIOR 1	PROB 2	MIN PRIOR 2	PROB 3	MIN PRIOR 3	PROB . 4	MIN PRIOR 4	LAST PAX ARV	SECT	AIRL	AGT	S TIME	E TIME
	20.00	90	40.00	60	37.00	30	3.00	20	15	UK				
	20.00	130	40.00	125	37.00	45	3.00	35	30	EUR				

Check-in Table

STATUS	FAC_NAME	MIN_PAX	MAX_PAX	COUNTER	OPEN_AT
	CKINSAR1	0	50	1	90
	CKINSAR1	51	80	2	0
	CKINSAR1	81	9999	3	0
	CKINSAR2	0	80	2	120
	CKINSAR2	81	120	3	0
	CKINSAR2	121	170	4	0
	CKINSAR2	171	210	5	0
	CKINSAR2	211	240	6	0
	CKINSAR2	241	9999	7	0
	CKINBMA1	0	50	1	90
	CKINBMA1	51	80	2	0
	CKINBMA1	81	120	3	0
	CKINBMA2	0	80	2	120
	CKINBMA2	81	120	3	0
	CKINBMA2	121	170	4	0
	CKINBMA2	171	210	5	0
	CKINBMA2	211	240	6	0
	CKINBMA2	241	9999	7	0

Precedence Table

STATUS	VISITOR	CFAC_ NAME	PFAC_ NAME	FFAC_ NAME	SECT	AIRL	AGT	S TIME	E TIME	PER CENT	SERVERS
	Y	PUBCON	NONE	CKINSAR1	UK					100.00	
	Y	PUBCON	NONE	CKINSAR2	CHT					100.00	
	Y	PUBCON	NONE	CKINSAR2	EUR					100.00	
	Y	PUBCON	NONE	CKINBMA1	UK					100.00	
	Y	PUBCON	NONE	CKINBMA1	NI					100.00	
	Y	PUBCON	NONE	CKINBMA2	EUR					100.00	
	Y	PUBCON	NONE	CKINBMA2	CHT					100.00	
	N	CKINSAR1	PUBCON	PUBCON1	UK		SER			100.00	
	N	CKINSAR2	PUBCON	PUBCON2	EUR		SER			100.00	
	N	CKINSAR2	PUBCON	PUBCON2	CHT		SER			100.00	
	N	CKINBMA1	PUBCON	PUBCON1	UK		BMA			100.00	
	N	CKINBMA1	PUBCON	PUBCON1	NI		BMA			100.00	
	N	CKINBMA2	PUBCON	PUBCON2	EUR		BMA			100.00	
	N	CKINBMA2	PUBCON	PUBCON2	CHT		BMA			100.00	
	Y	PUBCON1	CKINSAR1	DOSEC	UK					100.00	
	Y	PUBCON2	CKINSAR2	INSEC						100.00	
	Y	PUBCON1	CKINBMA1	DOSEC	NI					100.00	
	Y	PUBCON1	CKINBMA1	DOSEC	UK					100.00	
	Y	PUBCON2	CKINBMA2	INSEC						100.00	
	Y	PUBCON2	CKINBMA2	INSEC						100.00	
	N	DOSEC	PUBCON1	FRISK1						100.00	1
	N	INSEC	PUBCON2	FRISK2						100.00	3
	N	DOSEC	PUBCON1	BAGSER1						100.00	1
	N	INSEC	PUBCON2	BAGSER2						100.00	3
	N	DOSEC	PUBCON1	DOLG	UK					100.00	1
	N	INSEC	PUBCON2	PASSQ						100.00	3
	N	FRISK1	DOSEC	DOLG	UK					2.00	1
	N	FRISK1	DOSEC	NILG	NI					4.00	1
	N	FRISK1	DOSEC	BAGSER1	UK					5.00	1
	N	FRISK1	DOSEC	BAGSER1	NI					10.00	1
	N	FRISK2	INSEC	PASSQ						2.00	3
	N	BAGSER1	DOSEC	DOLG	UK					10.00	1
	N	BAGSER1	DOSEC	NILG	NI					20.00	1
	N	BAGSER1	FRISK1	DOLG	UK					10.00	1
	N	BAGSER1	FRISK1	NILG	NI					20.00	1
	N	BAGSER2	INSEC	PASSQ						10.00	3
	N	BAGSER2	FRISK2	PASSQ						10.00	3
	N	PASSQ	INSEC	INLG						100.00	3
	N	PASSQ	FRISK2	INLG						100.00	3
	N	PASSQ	BAGSER2	INLG						100.00	3
	N	DOLG	BAGSER1	TERM	UK					100.00	
	N	DOLG	FRISK1	TERM	UK					100.00	
	N	DOLG	DOSEC	TERM	UK					100.00	
	N	INLG	PASSQ	TERM						100.00	
	N	NILG	BAGSER1	TERM	NI					100.00	
	N	NILG	FRISK1	TERM	NI					100.00	
	N	NILG	DOSEC	TERM	NI					100.00	

Facility Table

STATUS	FAC_NAME	FAC_TYPE	ADV_TYPE	ADV_NAME	DISP_GRP
	PUBCON	STA	VAR	PBCN	1
	CKINSAR1	CHK	FUN	CHKS1	2
	CKINSAR2	CHK	FUN	CHKS2	2
	CKINBMA1	CHK	FUN	CHKB1	2
	CKINBMA2	CHK	FUN	CHKB2	2
	PUBCON1	STA	VAR	PBCN1	3
	PUBCON2	STA	VAR	PBCN2	3
	DOSEC	DYN	FUN	DSEC	4
	INSEC	DYN	FUN	ISEC	4
	FRISK1	DYN	FUN	FSK1	5
	FRISK2	DYN	FUN	FSK2	5
	BAGSER1	DYN	FUN	BAGS1	5
	BAGSER2	DYN	FUN	BAGS2	5
	PASSQ	DYN	FUN	PASS	6
	DOLG	STA	VAR	DOMLOUNG	7
	INLG	STA	VAR	INTLOUNG	7
	NILG	STA	VAR	NILOUNG	7

Function Table

STATUS	ADV_NAME	FUN_TYPE	MIN	MAX	MEAN	STEP	ERLANGK	C_D	POINTS	FUN_BLOCK
	CHKS1	ERLANG	0.42	2.00	0.86	0.05	2		0	
	CHKS2	ERLANG	0.33	1.61	0.65	0.05	2		0	
	CHKB1	ERLANG	0.33	2.86	1.28	0.05	2		0	
	CHKB2	ERLANG	0.26	2.16	0.75	0.05	2		0	
	DSEC	ERLANG	0.06	0.25	0.10	0.01	3		0	
	ISEC	ERLANG	0.06	0.25	0.10	0.01	3		0	
	FSK1	ERLANG	0.10	1.00	0.33	0.05	3		0	
	FSK2	ERLANG	0.10	1.00	0.33	0.05	3		0	
	BAGS1	ERLANG	0.16	1.50	0.50	0.05	3		0	
	BAGS2	ERLANG	0.16	1.50	0.50	0.05	3		0	
	PASS	ERLANG	0.05	0.30	0.08	0.01	2		0	
	WW51	USER	0.00	4.00	0.50	0.00	0	D	5	
	WW50	USER	0.00	4.00	0.50	0.00	0	D	5	
	WW100	USER	0.00	8.00	1.00	0.00	0	D	9	
	EVEN	USER		1.00	0.60			C	5	

Variable Table

STATUS	ADV_NAME	VAR_TYPE	DEFINITION
	UK	VAR	P$2=1
	EUR	VAR	P$2=2
	NI	VAR	P$2=3
	PBCN	FVAR	V$DESKS*(P$8-C$1)
	DESKS	VAR	P$8>C$1
	PBCN1	FVAR	V$TIME60*((P$1-C$1-60)*FN$EVEN)
	PBCN2	FVAR	V$TIME30*((P$1-C$1-30)*FN$EVEN)
	INT	VAR	(P$1-150)>C$1
	DOM	VAR	(P$1-100)>C$1
	NILOUNG	FVAR	(P$1-10-C$1)*V$NI1
	DOMLOUNG	FVAR	(P$1-10-C$1)*V$DL1
	INTLOUNG	FVAR	(P$1-15-C$1)*V$IL1
	IL1	VAR	P$1-15>C$1
	NI1	VAR	P$1-10>C$1
	DL1	VAR	P$1-10>C$1
	TIME60	VAR	P$1-60>C$1
	TIME30	VAR	P$1-30>C$1

(B) Manchester Airport

Arrival Table

STATUS	PROB 1	MIN PRIOR 1	PROB 2	MIN PRIOR 2	PROB 3	MIN PRIOR 3	PROB 4	MIN PRIOR 4	LAST PAX ARV	SECT	AIRL	AGT	S TIME	E TIME
	10.00	200	40.00	115	40.00	60	10.00	35	30	CHT				
	10.00	175	40.00	75	40.00	60	10.00	30	25	EUR				
	10.00	150	40.00	50	40.00	30	10.00	25	20	CTA				
	10.00	200	40.00	120	40.00	70	10.00	30	25	INT				

Check-in Table

STATUS	FAC_NAME	MIN_PAX	MAX_PAX	COUNTER	OPEN_AT
	CHKINBA3	1	57	1	120
	CHKINBA3	58	80	2	120
	CHKINBA3	81	114	3	120
	CHKINBA3	115	171	4	120
	CHKINBA3	172	228	5	120
	CHKINBA3	229	9999	6	120
	CHKINBA4	1	76	1	150
	CHKINBA4	77	152	3	150
	CHKINBA4	153	228	4	150
	CHKINBA4	229	304	5	150
	CHKINBA4	305	9999	6	150
	CHKINBA5	1	144	1	150
	CHKINBA5	145	288	2	150
	CHKINBA5	289	432	3	150
	CHKINBA5	433	9999	4	150
	CHKINBA6	1	80	1	240
	CHKINBA6	81	119	2	240
	CHKINBA6	120	238	3	240
	CHKINBA6	239	357	4	240
	CHKINBA6	358	475	5	240
	CHKINBA6	476	9999	6	240
	CHKINMN3	1	57	1	120
	CHKINMN3	58	80	2	120
	CHKINMN3	81	114	3	120
	CHKINMN3	115	171	4	120
	CHKINMN3	172	228	5	120
	CHKINMN3	229	9999	6	120
	CHKINMN4	1	76	1	150
	CHKINMN4	77	152	3	150
	CHKINMN4	153	228	4	150
	CHKINMN4	229	304	5	150
	CHKINMN4	305	9999	6	150
	CHKINMN5	1	144	1	150
	CHKINMN5	145	288	2	150

	CHKINMN5	289	432	3	150
	CHKINMN5	433	9999	4	150
	CHKINMN6	1	80	1	240
	CHKINMN6	81	119	2	240
	CHKINMN6	120	238	3	240
	CHKINMN6	239	357	4	240
	CHKINMN6	358	475	5	240
	CHKINMN6	476	9999	6	240
	CHKINSR3	1	57	1	120
	CHKINSR3	58	80	2	120
	CHKINSR3	81	114	3	120
	CHKINSR3	115	171	4	120
	CHKINSR3	172	228	5	120
	CHKINSR3	229	9999	6	120
	CHKINSR4	1	76	1	150
	CHKINSR4	77	152	3	150
	CHKINSR4	153	228	4	150
	CHKINSR4	229	304	5	150
	CHKINSR4	305	9999	6	150
	CHKINSR5	1	144	1	150
	CHKINSR5	145	288	2	150
	CHKINSR5	289	432	3	150
	CHKINSR5	433	9999	4	150
	CHKINSR6	1	80	1	240
	CHKINSR6	81	119	2	240
	CHKINSR6	120	238	3	240
	CHKINSR6	239	357	4	240
	CHKINSR6	358	475	5	240
	CHKINSR6	476	9999	6	240
	CHKBA	1	38	1	120
	CHKBA	39	78	2	120
	CHKBA	79	118	3	120
	CHKBA	119	9999	4	120
	CHKBAN	1	38	1	120
	CHKBAN	39	9999	2	120
	CHKMN	1	38	1	120
	CHKMN	39	78	2	120
	CHKMN	79	9999	3	120
	CHKMNN	1	38	1	120
	CHKMNN	39	9999	2	120
	CHKSR	1	38	1	120
	CHKSR	39	78	2	120
	CHKSR	79	9999	3	120
	CHKSRN	1	38	1	120
	CHKSRN	39	9999	2	120

Precedence Table

STATUS	VISITOR	CFAC_ NAME	PFAC_ NAME	FFAC_ NAME	SECT	AIRL	AGT	S TIME	E TIME	PER CENT	SERVERS
	N	CHKINBA4	NONE	PUBCON	ES		BA			100.00	
	N	CHKINBA5	NONE	PUBCON	IT		BA			100.00	
	N	CHKINBA6	NONE	PUBCON	INT		BA			100.00	
	N	CHKINMN4	NONE	PUBCON	ES		MAN			100.00	
	N	CHKINMN5	NONE	PUBCON	IT		MAN			100.00	
	N	CHKINMN6	NONE	PUBCON	INT		MAN			100.00	
	N	CHKINSR4	NONE	PUBCON	ES		SER			100.00	
	N	CHKINSR5	NONE	PUBCON	IT		SER			100.00	
	N	CHKINSR6	NONE	PUBCON	INT		SER			100.00	
	Y	PUBCON	CHKINBA4	SECUR						100.00	
	Y	PUBCON	CHKINBA5	SECUR						100.00	
	Y	PUBCON	CHKINBA6	SECUR						100.00	
	Y	PUBCON	CHKINMN4	SECUR						100.00	
	Y	PUBCON	CHKINMN5	SECUR						100.00	
	Y	PUBCON	CHKINMN6	SECUR						100.00	
	Y	PUBCON	CHKINSR4	SECUR						100.00	
	Y	PUBCON	CHKINSR5	SECUR						100.00	
	Y	PUBCON	CHKINSR6	SECUR						100.00	
	N	SECUR	PUBCON	FRISKINT						100.00	3
	N	FRISKINT	SECUR	XFER						30.00	6
	N	XFER	SECUR	BAG						100.00	4
	N	XFER	FRISKINT	BAG						100.00	4
	N	BAG	XFER	PASSQ						30.00	6
	N	PASSQ	XFER	DEP						100.00	4
	N	PASSQ	BAG	DEP						100.00	4
	N	DEP	PASSQ	TERM						100.00	

Facility Table

STATUS	FAC_NAME	FAC_TYPE	ADV_TYPE	ADV_NAME	DISP_GRP
	CHKINBA4	CHK	FUN	CHK34	2
	CHKINBA5	CHK	FUN	CHK5	2
	CHKINBA6	CHK	FUN	CHK6	2
	CHKINMN4	CHK	FUN	CHK34	2
	CHKINMN5	CHK	FUN	CHK5	2
	CHKINMN6	CHK	FUN	CHK6	2
	CHKINSR4	CHK	FUN	CHK34	2
	CHKINSR5	CHK	FUN	CHK5	2
	CHKINSR6	CHK	FUN	CHK6	2
	PUBCON	STA	VAR	PCONT2	3
	SECUR	DYN	FUN	SEC	4
	XFER	DYN	NUM	0	5
	FRISKINT	DYN	FUN	FRISK	5
	BAG	DYN	FUN	BAGS	5
	PASSQ	DYN	FUN	INT2	6
	DEP	STA	VAR	BRDINGT2	7

Function Table

STATUS	ADV_NAME	FUN_TYPE	MIN	MAX	MEAN	STEP	ERLANGK	C_D	POINTS	FUN_BLOCK
	CHKS1	ERLANG	0.42	2.00	0.86	0.05	2		0	
	CHKS2	ERLANG	0.33	1.61	0.65	0.05	2		0	
	CHKB1	ERLANG	0.33	2.86	1.28	0.05	2		0	
	CHKB2	ERLANG	0.26	2.16	0.75	0.05	2		0	
	DSEC	ERLANG	0.06	0.25	0.10	0.01	3		0	
	ISEC	ERLANG	0.06	0.25	0.10	0.01	3		0	
	FSK1	ERLANG	0.10	1.00	0.33	0.05	3		0	
	FSK2	ERLANG	0.10	1.00	0.33	0.05	3		0	
	BAGS1	ERLANG	0.16	1.50	0.50	0.05	3		0	
	BAGS2	ERLANG	0.16	1.50	0.50	0.05	3		0	
	PASS	ERLANG	0.05	0.30	0.08	0.01	2		0	
	WW51	USER	0.00	4.00	0.50	0.00	0	D	5	
	WW50	USER	0.00	4.00	0.50	0.00	0	D	5	
	WW100	USER	0.00	8.00	1.00	0.00	0	D	9	
	EVEN	USER		1.00	0.60			C	5	

Variable Table

STATUS	ADV_NAME	VAR_TYPE	DEFINITION
	CTA	VAR	P$2=1
	ES	VAR	P$2=2
	INT	VAR	P$2=3
	IT	VAR	P$2=4
	DOM	VAR	P$2=5
	SHT	VAR	P$2=6
	NIT	VAR	P$2=7
	PCONT2	FVAR	V$PCT21*V$TIMEL60+V$PCT22
	PCT21	FVAR	V$TIM45*(P$1-C$1-45)*FN$EVEN
	PCT22	FVAR	V$TIME60*((P$1-C$1-60)*FN$PCDWEL)
	TIMEL60	VAR	P$1-60<C$1
	TIME60	VAR	P$1-60>C$1
	TIME210	VAR	P$1-210>C$1
	BRDING	FVAR	V$B1*V$TIMEL45+V$B2
	B1	FVAR	V$TIME30*(P$1-C$1-30)*FN$EVEN
	TIME30	VAR	P$1-30>C$1
	B2	FVAR	V$TIM45*15
	TIM45	VAR	P$1-45>C$1
	TIMEL45	VAR	P$1-45<C$1
	BRDINGT2	FVAR	V$BT21*V$TIMEL50+V$BT22
	BT21	FVAR	V$TIME30*(P$1-C$1-30)*FN$EVEN
	BT22	FVAR	V$TIME50*20
	TIMEL50	VAR	P$1-50<C$1
	TIME50	VAR	P$1-50>C$1
	OTIM	FVAR	V$ES*FN$IMMES+V$INT*FN$IMMINT
	BGS	FVAR	(V$BAGS1+V$BAGS2)/2
	BAGS1	FVAR	(V$BL100*P$11*V$CHKBAGS)/13
	BAGS2	FVAR	(V$BM100*P$11*V$CHKBAGS)/10
	BL100	VAR	P$11<100
	BM100	VAR	P$11>99
	CHKBAGS	FVAR	V$INT+V$IT+(V$ES*.82)+(V$CTA*.75)
	PCONWAIT	VAR	5+V$GR*5
	GR	VAR	P$5>0
	HOLDDOM	FVAR	V$TIME15*(P$1-C$1-15)
	TIME15	VAR	P$1-15>C$1
	PUB	FVAR	V$DESKS*(P$8-C$1)
	DESKS	VAR	P$8>C$1

Appendix 4 Scheffé S Test

The Scheffé S Test is particularly applicable to groups of unequal sizes. Basically it is used to compute the limits of confidence interval (I) for each difference between means.

Where:

$$I = S\sqrt{(\text{Variance within Group})(Wg)}$$

$$S = \sqrt{(k-1)(F_{.05})} \text{ or } \sqrt{(k-1)(F_{.01})}$$

and

$$Wg = 1/n + 1/n$$

k is the number of columns and $F_{.01}$ and $F_{.05}$ are the F ratios for significance at the 1% and 5% levels that are obtained from the Scheffé S Test Tables of Significance.

n is the number of values within the group.

By calculating the Scheffé S Test formula for the 5% and 1% levels and comparing them with the difference between the means it is possible to determine if the difference is significant.

Where I for a given level (1% or 5%) is smaller than the difference between the means then the means are significantly different at that level.