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A METHODOLOGY FOR PLANNING AND OPERATIONS MANAGEMENT OF AIRPORT PASSENGER TERMINALS:
A CAPACITY / LEVEL OF SERVICE APPROACH

BY
S. A. MUMAYIZ, B.Sc., M.Sc.

A Doctoral Thesis
submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of the Loughborough University of Technology

1985

Director of Research: Professor Fredrick D. Hales, B.Sc., Ph.D., C.Eng., MIMechE, FIMA, MBCS.

* Department of Transport Technology.

© S.A. MUMAYIZ, 1985
To my wife and our daughter Sarra....
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SYNOPSIS

A methodology is presented herewith to assist in the systematic evaluation of operational conditions of the vital and dynamic processing facilities of airport terminals, which could enhance planning and management practices adopted for airports. The methodology focusses on the relation between capacity of individual facilities and levels of service that passengers experience in them, whereby important operational aspects of those facilities are examined and analysed. The developed methodology consists of two main parts: Capacity procedure, and Level of Service procedure. The first establishes the relations (Performance models) between demand levels (flows) that may possibly be accommodated by individual facilities, and some service measures of particular relevance to passengers that could be used to assess the performance of facilities when subjected to various demand levels. To accomplish this, simulation techniques are utilized to synthesize required information. In the second, the way by which a framework of service standards could be established is presented. Levels of service are derived by asking passengers (through appropriate surveys) to assess service standards based upon their perception to service conditions at a particular time, and their response to different variations of service resulting at different demand levels. Through this method, Perception-Response models are derived, where they are used in the case studies conducted, to delineate the levels of service for processing facilities of the airport terminal considered.

KEY WORDS: Airport Terminals - Service Standards - Capacity - Level of Service - Airport Passenger Surveys - Airport Operation Management - Perception-Response Models - Performance Models - Facilitation and Facility Planning.
DECLARATION OF ORIGINALITY

The work described in this thesis has been carried out by the author except where acknowledged, and has not been submitted, in full or in part, to this or any other institution for a higher degree.
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CHAPTER ONE

INTRODUCTION

1.1 PREVIEW

Airports, the subject and environment of this research, are focal points of the air transport network, and constitute important parts and sensitive nodes that form vital and indispensable components of regional, national, and international transportation systems worldwide. Fully understanding their nature and characteristics would inevitably require more knowledge about their evolution and historical development. Eventually, studying airports' history and development, essentially requires a preview of the history of transport and aviation.

1.1.1 HISTORY OF TRANSPORT

Transport, in the general sense of the word, normally signifies the importance of 'place', and more particularly 'accessibility'; the ease with which one can travel from one place to another[1]. Historically, transport is deeply rooted in progress of mankind, with various civilizations that flourished and perished over the centuries, it developed in different distinct stages. Invention of the wheel was the first revolution of transport after taming the horse and using it in transport. This was followed by exploiting forces of wind and buoyancy to sail the seas. After many centuries, use of steam and introduction of internal
combustion engine mechanized transport, and triggered the start of the technical revolution, which freed man from dependence on human or animal transport power and vastly increased his movement capability over land and sea. Influence of mechanical transport on mankind and civilizations was profound. It has given people new freedoms; mobility which allows them to change their patterns of activity, to fashion them on a world scale, to think and behave in a way previously completely unknown \(^2\). It was only during the last century and a half that man has been able to move over the earth's surface at speeds faster than a ship could sail and a horse can run. Twentieth Century afforded man the potential of navigating through air from point to point over earth's surface avoiding or minimizing geographical barriers that impede other forms of transport \(^1\).

Basically, transport had always been a strong and governing factor on economic, cultural, demographic, and geopolitical aspects that influenced progress or fate of civilizations. Transport implied a means of locomotion, without which territorial specialization would be impossible, because without transport, communities must exist solely on the available local resources \(^1\). History of civilization has always shown a close relation between transport and economic development, because the importance of place in the economic sense, springs from the unequal distribution of; resources, population, and knowledge developed of how to utilize material resources. These activities require the availability or production of goods and services, regional differentials in prices, wages, and skills, and some means of transport. Modern role of transport is supplemented by the dependence on opportunities available at a particular location for business or for pleasure and their desirability relative to those existing elsewhere \(^3\).
1.1.2 HISTORY OF AVIATION

Aviation is a spatial activity concerned with supplying a transport service. Essentially, airports and their development are directly related and strongly linked to that of aviation, since airports are established in the first place, to augment the role of aeroplanes, by accommodating them and facilitating their service and operations. Aviation history is a continuous series of events and incidents, separated by time and distance during the past century or so, that formed important milestones of aviation history. Portrayal of aviation history is attempted in the remaining part of this subsection, mainly based on information extracted from Kennedy.

Sir George Cayley 'father of the aeroplane', fostered the design, production, and testing of the first manual, heavier than air glider, that took off the ground at Brompton Vale, Yorkshire in 1852. On the other side of the Atlantic, Kitty Hawk, North Carolina to be exact, history was made when Wilbur and Oliver Wright managed to fly the first mechanically-driven flying craft for a distance of 120 feet (overall, four flights totalling 852 feet, with a total airborne time of 59 seconds). In the First World War, aeroplanes flew military missions for the first time from primitive 'airports' of grassy-field landing strips. During and after the war, aeroplanes were adopted also in mail service - their first known commercial use; in 1918-1919, planes were used to deliver mail between Europe and Britain for the British forces in Germany, and U.S. Post Office established regular airmail routes between New York and Washington D.C. By 1926, contracts were let to private operators and aeroplane companies to fly U.S. Mail between California, Minnesota, Michigan, Texas, and the East Coast. A new dimension of aviation was introduced when the Atlantic was crossed in an aeroplane; in 1919 by Alcock and Brown, then in 1928, on May 20-21, when 'Slim' Charles Lindberg (a pioneer 'barnstormer' and 'mail aviator') in his
'Spirit of St. Louis', made the famous and dramatic solo cross-Atlantic, 3600 miles, journey from Long Island, New York to Paris Le Bourget (5).

The Second World War witnessed the extensive, systematic, and specialized use of the aeroplane as an effective weapon. Subsequently, after the end of the war, the substantial technological advancements, operational expertise, and hardware accumulated over the war period, were rapidly converted to civil and commercial exploitation. Post-war economic, political, and commercial climates saw the birth of a strong and ever growing air transport market, that initiated more progress in aviation; the introduction of jet engine, high-capacity long-range aircraft, and huge leaps in the supporting technologies of communications, navigation, aeronautics, meteorology, and many other fields that made aviation a safe, efficient, reliable, and a popular mode of transport. Rapid growth of international air transport that began in the 1950s, affected the contemporary economic way of life, and made substantial changes in social viewpoints, shaping the course of political history (7).

1.1.3 HISTORY AND DEVELOPMENT OF AIRPORTS

Airports, are the starting and terminal points of flights, the servicing station for aircraft, and the control center of aviation operations' safety and regulation. They were first known when the commercial use of aeroplanes, namely air transport of mail, goods, and passengers, first started. In the U.S., the first (but short-lived) rudimentary scheduled airline service, started in 1914 over a 21-mile route in Florida, while the first scheduled passenger air transport services were offered on flights under mail contracts, often in open cockpit biplanes, where the passenger shared the cockpit with mail bags! (6). But in 1927, the first permanent commercial passenger airline service started in the U.S. between Boston-Logan and Newark airports, and
by that year there were 38 airlines with regular service for 128 cities across America. In Europe, by 1920, there was scheduled service between London and Paris, Amsterdam, and other major European cities(6).

At first, airports were just farmers' fields or level beach strips, but soon they were reconditioned into packed cinder, or unpaved dirt landing strips. As the airline industry grew and speeds, payloads, and technical standards of aircrafts were increased, this situation changed; runway lengths increased, with paved surfaces, markings, and lighting; hangers for aircraft maintenance and service were constructed; and terminals in the form of hangers, sheds, or even tents where passengers gather for flight boarding, were erected either seperately for different airlines, or consolidated in an all-airline terminal building.

After Second World War, with even bigger, longer range, more reliable, and more comfortable aeroplanes, facilitated by technological advancements and operational expertise accumulated over the war period, airports were technically inferior to this new demand. Inevitably, they were have to be expanded, better planned and designed, to cope with, accommodate and facilitate efficient operations, and provide better service for the great increase in demand. This increase in demand was two-fold; increase in demand's quantity in terms of traffic flow, and in quality in terms of the technological standards of aircraft fleets.

Since then, even more technological advancements and a steady growth in air traffic, have followed. Technical advances and innovations in aviation industry promoted the air transport industry, and made air travel more attractive, reliable, and convenient for the public. Yet, as a consequence, this made airports much bigger, more complex in operation, more expensive to build or expand, and more complicated and difficult to operate, with millions and millions getting accustomed to using
air transport for business and leisure, passing through airports' terminals to catch or terminate their flights. Later on, the staged development of airports and terminals will be closely looked at.

1.2 GENERAL SCOPE

After reviewing evolution and history of air transport, and airports in particular, one can realize the great influence and vitality of the airport complex, its functions, role, and performance, on the mere existence, livelihood, and development of the whole of the air transport system. Evidently, the efficient planning and management of such a system, which would normally include a relatively high number of parties responsible for or involved (in one way or another) with its day-to-day operations, can undoubtedly prove to be increasingly difficult.

However, development of airports was strictly dictated by and directly followed technological advances in the aviation industry to fulfil the needs of growth in air traffic and the desires of the air travel market. Hence technological standards of airports were usually lagging behind those of aircraft. Planned-growth and stage-development of airports appears to have been on an ad-hoc basis reflecting de facto situation of catching-up and trying to be compatible with technical standards of aviation industry and air traffic demand. But actually, the fact that the great time lapse between first introducing specific concepts or requiring particular designs, and practically implementing them, with all the financial, planning, and administrative elements involved, contributes to this phenomenon.

Certain questions are raised concerning the following features that characterize the airport system;
1. Population of the public- air travelling public, which uses airports during any time scale considered,
2. Level of investment in the system by associated parties and organisations that necessitates a particularly high degree of economic and operational efficiency,
3. Scale of employment and local businesses dependent on the system,
4. Specificity and sensitivity of activities and transactions performed, that need utmost consideration of efficiency, planning, and good organization, and,
5. sheer numbers of travellers, visitors, and other users of the system.

These questions are:
- What are the basic principles and essential fundamentals that should be established for the planning, design, and operation of the various components of the system?
- What are the most relevant variables in this process?
- What should be the strategic objectives of every stage of the process?
- What criteria to use in the process?

Such questions, and many more others, that are raised on different aspects of this system, apart from reflecting need to obtain more information on the elements of the process, also provide fertile ground for research that could be initiated on the subject of airport terminal operations and design.

1.3 INSUFFICIENCY OF AVAILABLE KNOWLEDGE

Furthermore, when more specialized technical literature was consulted, it was realized that available knowledge was limited and insufficient. Prevailing practices of terminal facilities design were found to be dependent on three main sources that basically reflect schools of thought belonging to national governmental organisations associated with airports, and exhibit their policies, and the personal judgement or experience of their personnel. These sources are:
- The U.S. Federal Aviation Administration's publications that are based on practical experience and frequent sponsored studies conducted by consulting firms or research institutions.

- Practices developed within and implemented by British Airports Authority which are strictly for intra-organisational use and not officially published. These practices are primarily empirical developed under specific conditions with certain assumptions attached to their application.

- International organisations such as IATA(8) and ICAO(9), which have their own practices that seem to adopt some of the practices of FAA and BAA.

Insufficiency of available knowledge and lack of an appropriate methodology for planning and design of terminal facilities, can probably be partially blamed on the fact that research in airports is basically motivated and initiated by either of two sectors; joint collaboration of aviation and air transport industries, or governmental organisations associated with and responsible (as part of their institutional and statutory duties) for safety of operation, and protection of the environment. This situation left the terminal and the whole of the landside as low-priority elements of the system. The principal emphasis was placed on the airside of the airport.

However, there have been occasional demands for reconsideration of this situation; more research should be continuously initiated and studies staged to fill the gap currently existing in available knowledge.

1.4 RESEARCH NEEDS IN AIRPORT TERMINALS

Realizing the great need for research to alleviate insufficiency of knowledge and lack of appropriate practices in planning, design, and operations of airport terminals, certain efforts were
made in the early and mid seventies to focus on this subject, and
to direct researchers to emphasize issues of particular
importance.

Research Committee of Air Transport Division in the American
Society of Civil Engineers was set up to discuss needs for
research in airport terminal systems that were relevant to
society(2). Its recommendations were presented to a conference
held in 1971, which represented Federal and local government,
airlines, air transportation consultants, and universities. It
stated:" The growth in air transportation will have to be
accommodated by greatly improved utilization of existing ground
facilities. A major effort will have to be made to improve the
effectiveness of our airport terminal procedures and operations.
Unfortunately, it is far from clear how we should do this, and we
still have to implement the better approaches before the traffic
is upon us. An effective research program is therefore needed
now ". Main recommendations of this committee included:
1. Hardware technology and new machines are not going to solve
the problems of airport terminal design by themselves.
2. Problems of airport terminal planning, design, and operation
have to be extensively rethought, because major improvements in
the quality of airport terminal service are more likely to arrive
from the reconfiguration of current procedures than from marginal
improvements in current operation. So, comprehensive analyses of
the airport system, using modern techniques for optimizing and
selecting investment strategies and management procedures, appear
to be required.
3. Specific areas of concern were;
   - Potential role of different kinds of airport systems in the air
     transportation network.
   - Improving forecasting techniques of traffic and air travel
demand.
   - Peaking problems, particularly, insufficiency of capacity and
deterioration of service during peak periods.
- Spatial arrangement of terminal facilities, and different dimensions of the quality of service provided by airport terminal facilities.
- Reduction of labour intensity, and reorganizing labour-intensive activities.
- Accessibility to air services.

Another initiative was motivated by the U.S. Department of Transportation, where a conference was convened in 1975 to discuss specifically the problems of Airport Landside Capacity. Some of the conference findings were:

1. Primary emphasis should be placed on 'soft' research and development of the airport landside, because sufficient technology and hardware have been developed for use in airport landside operations. Now, needed are studies of landside systems-design, operation and management, so that optimum use can be made of the 'hardware'.
2. Capacity and level of service ratings should be developed for airports, and quantitative and qualitative measures should be determined for each landside component.
3. Data for analyzing landside functions need to be developed, where they are needed to describe capacity, level of service, and other airport landside functions. These data, combined with proper analytical tools, will increase the effectiveness of airport management.

1.5 SELECTING A RESEARCH TOPIC

Decision upon particular topic of research, came after literature available on the broad subject of airports was surveyed. List of references contain three main entries:
1. De Neufville's Airport Systems Planning(3),
2. Horonjeff's Planning and Design of Airports(7), and,
3. Ashford and Wright's Airport Engineering(11).
The first, subtitled a critical look at the methods and experiences, provide excellent reference on the subject with respect to its critical, observatory, and sometimes explanatory handling of various aspects of the system. Specifically, its general outlook on the problems of the system, and number of questions and unanswered remarks that he raised, which may open doors to investigators and researchers to pursue in a specific direction. The other two, provide a general documentation on current state of the art in airports, with compilation of research, professional experiences, organisational practices, and technical knowledge on the subject.

It was observed that collective knowledge of current planning and design practices of components of airport terminals, are obscured behind veils of empiricism and cannot scientifically support a systematic and theoretically consistent methodology. Consequently, variables that influence the physical design process are not clearly identified. At first, a provisional research topic was selected: space requirements for airport terminal facilities. However, it was realized afterwards that, although space requirement provides the main input to physical design of the terminal building, it does not have a major impact on operational conditions. What is essentially required is to investigate the critical relations between demand and supply in the operations of airport terminals, because physical design should follow and be compatible with the nature of operations, not the reverse. Instead of working with space requirements, it would be more direct and effective to investigate the different aspects of evaluating operational conditions of terminal facilities, focussing on the relation between the capacity of individual facilities and level of service that passengers experience. This work investigates this aspect, where a methodology for the systematic evaluation of operational conditions of airport terminal facilities that is based on capacity/level of service considerations is presented (described in Chapter Six).
CHAPTER TWO

REVIEW OF LITERATURE

Traditionally intended as a preliminary step to research, literature on current techniques of planning and design of airport terminals was reviewed. It included technical literature of professional nature as well as academic research previously conducted on this topic.

2.1 REVIEW OF TECHNICAL LITERATURE

Included are approaches adopted by professional organisations and practitioners responsible for planning and design of airport terminals.

Since the design of airport terminals is a process essentially similar to any other system concerned with performing various human activities in a particular enclosure or environment, it has predominantly been the task of architects. Historically, at the first stages of airport development, architects were responsible for allocating space for different activities and facilities inside an open space of fixed size and shape, e.g., aeroplane hangers. With higher technical standards, accompanying the growth of air traffic, and subsequent extensions of airports' terminals, there was a change of approach. Instead of fitting various components necessary for the required activities and facilities into an open fixed space, the terminal building would be better off if compositely and purposely designed for those components in
the most convenient way. With increased specialization and sophistication of operational procedures, coupled with great increases in traffic, it became evident that airport terminals would be so big and complicated, so expensive to build, and so costly to operate, that they should be very carefully planned and designed.

An architectural report in 1960(12) summarized the important design aspects, and provided valuable guidance to airport architects at those times.

Perrett(13) provided more specialized concepts for designing airport terminal facilities, where more specific operational and planning aspects were considered, such as service times, queuing, and crowding standards. His findings were largely based on a study conducted in 1969 in four British terminals, and basically reflects the British practice on planning and design of airports. Actually, Perrett's paper is the only published source that could be traced in literature which presents (unofficially) the British Airports Authority's approach.

The American approach is more widely publicized and readily available through Federal Aviation Administration's Advisory Circulars and other reports. Specifically, two of these circulars(14,15) provide broad outlines, recommendations, and useful advice on planning and design considerations for airport terminal facilities. Most of FAA's approach is based upon what became known as the Parsons Reports. FAA undertook efforts to set a definite approach based on the collective practices of related parties and the state of the art up to and during early seventies. This effort, sponsored by FAA, included a team consisting of: consultants (Ralph M. Parsons Company), airlines (Air Transport Association of America, with 11 major American airlines), and airport operators (represented by Airport Operators Council International). The result of this collaborative work was published in two reports: The
Apron-Terminal Complex: Analysis of Concepts for Evaluation of Terminal Buildings(16), and The Apron and Terminal Planning Manual(17). Also, ATAA published a separate report(18) that is mainly oriented to address airlines needs (which in the U.S. are often responsible for planning their own terminal facilities), which provides guidelines to approximate gate and terminal (airline-related) space requirements. Those three reports substantially supplemented knowledge on airport terminals, and enhanced existing architectural practices.

Another source of information that tackled the problem from architectural/environmental angle is by Blankenship(19), who himself had previously participated in FAA's work that produced the Parsons Reports.

There are international organisations that are also responsible for providing professional guidance and assistance to airport operators and airlines worldwide. The International Civil Aviation Organisation's publications(9,20), and the International Air Transport Association's(8,21) provide useful information and practices on the international level, but it is believed that they rely on the previously mentioned sources.

2.2 LITERATURE ON ACADEMIC RESEARCH

Apart from technical literature that reflects professional practices and approaches, previous academic research on the subject was also reviewed. Of interest was, research conducted on airport terminals and their planning considerations with respect to physical design or capacity analysis. The citings were categorized according to the respective approach adopted.
2.2.1 STATISTICAL ANALYSIS APPROACH

Through statistical analysis of information, certain facts and conclusions regarding various aspects of physical design or operations of terminals, could be reached. An example of this approach, is a study by Field(22), where he analysed information from different airports, examining the efficiency and performance aspects of each, and tried to establish a methodology to measure them. However, this approach proved unsuccessful when an attempt was made in the context of this work to gather information from European airports in the hope of categorizing airports' space requirements according to their type and size. The abandoning of this approach was largely blamed on the reluctance of airport authorities to provide required information, because of its nature, and substantial amount sought. Information was either unavailable or unaccessible to airport authorities then, or they did not feel obliged to furnish that sort of information for various reasons.

2.2.2 ECONOMICS-ORIENTED APPROACH

Gosling(23) tackled the problem of planning and design of airport terminals from a completely different angle, with a new and interesting approach. He explored and investigated the application of Production Economics to the analysis of airport terminals, by employing Production Isoquants, that may be considered as contours of the production surface and represents all those mixes of inputs that can just produce the output. Isoquants were then derived (for a particular case-study) for the terminal's processing facilities, based on the premise that the main output, or the product of the facilities is processed passengers, baggage, and/or visitors. Planning and design of terminal facilities would then be considered in light of this product in relation to input factors, capital and operating costs, and technology of operation. The main criticism is
the vast amount of information required, its nature and the diverse sources necessary for its collection, and the dehumanizing of the planning issues with respect to passengers' considerations.

Doganis and Thompson(24) studied British airports from a purely economic standpoint, but their work was not of particular use to our problem, mainly because it did not consider terminal planning issues from an operational perspective.

2.2.3 THEORETICAL-MATHEMATICAL APPROACH

This approach is mainly concerned with applying theoretical principles derived from mathematics and related sciences, to the problem of planning, design, or analysing airport terminals. Particularly, Queuing Theory was thoroughly examined to provide the theoretical background for methodologies of analysing airports operations. During the seventies, the application of this approach to transportation problems was very popular among researchers of various disciplines: Operations Research, Mathematics, Management Sciences, and Transportation Planning. Several research programmes considered adopting Queueing Theory mathematics for solving problems or developing models for airport terminals and their operations. The following work was carried out directly relating to airport:

Dunlay(25) and Park(26) derived tandem-queue algorithms for airport users' flows. They adopted deterministic queueing models to evaluate users' flows through terminals, to estimate airports' capacities, and to determine demands on individual components.

O'Leary(27) investigated the use of stochastic queueing models for the airport terminals' processing facilities, and derived relationships for branching of passenger flows at those facilities.
However, this approach proved to be unpromising, and was universally recognized that its mathematical sophistication and complication together with the theoretical assumptions involved, substantially handicapped its applicability and hampered its practicability for adoption in airport terminal design.

2.2.4 THE SYSTEMS APPROACH

This approach deals with studying the terminal as a complete system, attempting to define and examine its various components and the factors influencing them. Normally, it involves the derivation of a simulation model for the airport terminal under consideration, as in the case of ACAP and AIR-Q research programmes.

Gualda(28) describes the stages and important factors considered in developing ACAP model in the University of Texas at Austin. ACAP simulates airport terminals operations, where individual component models are derived by regression analysis from information gathered from three Texan airports. An important comment briefly raised here but discussed in detail later, is that regression analysis was used after abandoning a previous approach using tandem-queue models. ACAP was subsequently modified to alleviate certain limitations, as will be discussed in detail with more information featuring ACAP later in section 8.5.1.

AIR-Q, is a time-based simulation model very similar in basic principles to ACAP, but employs statistically deterministic control data to define the state of system at various times, according to prespecified network and loading information. Laing(29) provides comprehensive description of the model and its utilization. Originally, this model was developed by Calderbank and Kirke(30) as AIR-Q in 1972 in the University of Strathclyde,
then was further extended and improved by Laing and Gentles (31) in 1976 as AIR-Q(Mk II), which was validated by information gathered at Glasgow Airport, Scotland in 1975 (32).

2.2.5 MULTI-DISCIPLINE APPROACH

It would appear more appropriate to tackle the problems of airport terminals from more than one angle using different approaches. Department of Transport Technology undertook a multi-disciplinary research programme to investigate different aspects of the airport terminal environment, that included: "developing a more flexible approach to the design of terminals, that can successfully accommodate different demand levels and patterns, and can adapt to longer term changes in the demand for air travel" (33). The research team included experts from such disciplines as; Economics, Mathematics/Statistics, Architecture/Ergonomics, Operations Research, and Transportation Planning. The research programme did not work on developing a total airport terminal simulation model, yet it accomplished a more worthy objective, that of analysing the airport total system (34), hence providing genuine and valuable information on many aspects of that system that would back and support a systematic approach to the problem. Throughout this thesis, reports of LUT Airport Research Programme are frequently referenced, and information they contained is occasionally used in this methodology.

2.3 APPROACH IMPLEMENTED IN THIS RESEARCH

Attention is drawn at this stage to the fact that literature review mentioned so far does not represent all citations found, but only distinguished ones relevant to progress of research, and
approach it implements. Throughout this thesis many citings regarding the main subject as well as other peripheral and supporting topics are continuously referenced.

The approach implemented by this research, benefiting from lessons learned and conclusions drawn after reviewing professional and academic-related literature, emphasizes on establishing a practical and scientifically valid methodology for assessing operational efficiency of terminal components.

It was noted that most previous research programmes that adopted the systems approach, exhausted themselves on developing simulation models and allocated considerable amount of time and resources to validation studies of the models. Particularly, those studies essentially require the mounting of extensive data collection efforts to provide sufficient information on all elements of the models. Eventually, the research stopped short of developing a methodology that implements the systems approach and uses the simulation model as the major executive apparatus of the methodology. In other words, in effect, these sophisticated and effective tools were developed only to show that they work, not to actually use them in a framework to achieve the purpose for which they were initially created.

2.4 RESEARCH OBJECTIVES

Finalized objectives of this research are sought in light of the following facts:
1. The real issue of the problem: It was realized that the provisional title of space requirements does not bear any real significance in the problem, for the crux of it is really of assessing operational efficiency for various facilities, rather than considering such a 'dummy variable' as space that is static in nature compared to the dynamic operational characteristics of the system as a whole.
2. Establishing a level of service framework that could be utilized to calibrate and measure operational conditions by means of service provided to passengers, where this is considered as a major part of the work.

3. The other major part is devising a mechanism that could define capacity of facilities clearly and on realistic basis.

4. The human element of the system ought to be put into proper perspective, where greater emphasize should be placed on the contribution of passengers to setting their service standards.

5. In the absence of unified airport terminal-related terminologies, concepts, practices, and approaches, an effort should be attempted in the direction that would eventually help in developing a process of planning and management of airport terminals.

2.5 STRUCTURE OF THESIS

This thesis is arranged in a sequential order that represents the stages and components of research.

The first chapter provides an introduction to the subject from its broadest perspective, while this chapter presents a review of important literature covering the relevant parts of the subject and similar research previously conducted.

Chapter Three gives a full description of airport terminals, their function, activities performed in them, and parties involved with their operation. Also, more specific planning aspects are considered, particularly design concepts, facility design, and demand/capacity criteria adopted.

Chapters Four and Five, are concerned with background knowledge and basic principles of the important issues of levels of service and capacity, respectively, which serve as a prelude to the description of methodology.
The remaining chapters are directly related to the methodology in consideration. Chapter Six provides detailed description of all steps, features, and elements of the proposed methodology as outlined by its two procedures.

Chapter Seven elaborates on the subject of data acquisition and collection of information required in the methodology, and constituting its data base.

Chapter Eight discusses issues on simulation, which constitutes a vital element of the research, and particularly important in the capacity procedure.

In chapter Nine, case studies to test the applicability of the methodology is presented, together with results, findings, and various practical aspects of methodology implementation.

Chapters Ten and Eleven summarize the conclusions and the significance of adopting this methodology, and provide some recommendations for further research, respectively.
CHAPTER THREE

AIRPORT TERMINALS

3.1 AIRPORTS AND THEIR TERMINALS

An airport is defined by Campbell(35) as: "An area of land or water that is used or intended to be used for the landing and take-off of aircraft, and includes its buildings and facilities, if any ". However, its role could not be restricted to this technical description. Since its evolution and throughout the stages of its development, the airport had acquired multi-purpose, technically diverse, and sensitive roles. The airport environment is unique in many ways; it is not merely a functional element of a transportation system, but rather a system that contains all major ingredients of a small city—mainly excluding its domicile components—all centered around a nuclear activity; air travel. Organizational, managerial, administrative, and operational structures are quite complex, and activities within the system are initiated, motivated, or sustained by factors that are not necessarily aviation or transport-oriented; they may be commercial-financial, institutional, social, political, or environmental. From an administrative viewpoint, Wiley(6) suggested that:" Airports must be considered as part of the total social, economic, and political system in which they exist, and not be relegated narrowly to aviation issues, nor even to the wider but still incomplete system defined by transportation issues ".

De Neufville(3) tackled this subject from a wider angle incorporating more than one view, where he argued that airports are part of a complex economic and social system, and constitute important elements of the infrastructure of a nation that influence pattern and speed of regional development. They fulfil a complex role in the transport network, and perform a broad spectrum of services, through many different facilities and organisations, to a wide variety of users. Moreover, the nature and mix of activities involved is not stable but has daily, weekly, and seasonal peaks for different kinds of traffic.

The airport terminal plays a unique but decisive role within the air transport system, and Campbell(35) acknowledged this fact in his definition of the passenger terminal building: "It is the focal point in the terminal area, that portion of the airport other than landing area, and has a key function around which all the other supporting functions must be planned."

Horonjeff(36) defined the passenger terminal system as the major system for connecting ground access and aircraft, the purpose of which is to provide the interface between the aircraft and the airport access modes, to process the passenger for the origination or termination of an air transport trip, and to convey the passenger and baggage to and from the aircraft.

IATA(8) defines the passenger terminal simply as the building or facilities located between kerbside and apron within which passengers and baggage processing takes place.

Operationally, airport terminals are considered as high activity transport centres with comparatively high throughput of users(37). This, the recent large increases in air passenger volumes, and needs of different parties to provide various facilities to accommodate and serve this demand, requires that these facilities are larger in size, greater in numbers, and significantly diverse in nature, purpose, and characteristics,
than they used to be. Particularly, airports are used by people, shippers, and consignees as interchange points between ground and air movements, by carriers providing the transportation, and by a host of companies or agencies providing essential services and supplies to airports themselves as well as to carriers and patrons. Along with accommodating these intrinsic demands and offering these diverse services, airports has become important community focal points for business, recreation, and education(6). Operations associated with such a system are undoubtedly complex; accommodating significantly high air passenger flows smoothly, safely, and in short periods of time, effectively managing the needs and requirements of the users, organisations, and parties involved in this system's operations, and retaining the well-being and progress of the system as an economic and organisational entity, is inevitably complicated and is becoming increasingly difficult.

Substantial increases in demand for air travel, the introduction of wide-bodied high-capacity aircrafts, and complexity of passenger processing and servicing resulting from imposing new regulations and practices, put terminals under increasingly high pressure. Consequently, there was an urgent necessity for expanding and improving existing terminals, and building new ones. New terminals had to be much larger with different facilities for the convenience and comfort of users, more sophisticated in passenger and baggage handling operations, and provide more diverse and extended services to all users. In economic terms, terminals became much more expensive to build, both in terms of total cost, or as percentage of total airport cost. Apart from contributing to operating costs, repercussions are clearly recognized in operating airports; long lists of requirements for facilities, equipment, and other essentials of the system, and an army of specialized personnel of all the parties needed to run the system. This situation created a dilemma within the air transport system, and imposed a challenge to planners, designers, and operators of airports; To cope with
the current situation, and almost simultaneously, upgrade the services it provides and the subsequent expansion of the airport terminal that would properly accommodate future demand. According to De Neufville(3): "The challenge is how can we accommodate this expansion in the most rational and humane way? We want to be rational in anticipating the requests for service, in choosing the right combination of facilities to serve different kinds of traffic, and in using resources efficiently. We want to be humane in understanding and mediating the conflicting demands for various services in air transport in channelling growth so as to preserve the environment, and in meeting different societal objectives". 

3.2 FUNCTIONS OF AIRPORT TERMINALS

Generally, airport terminals facilitate a wide range of services and operations for many users; arriving passengers, transfers, multi-lingual travellers on international flights, commuters and business passengers with no luggage, visitors greeting or sending off their travelling relatives and friends, and holiday-makers on chartered flights.... Analytically, airport terminals perform several functions simultaneously, that are all put into a specific order and follow a particular procedure according to regulations and practices adopted, which significantly vary between different times and locations. Nonetheless, these functions could be viewed from different standpoints.

Ashford(11) viewed the passenger terminal as the system which performs three main functions;
1. Processing of passengers and their baggage.
2. Provision for the requirements of change of movement type by acting as a regulatory reservoir collecting passengers continuously then processing them into batches or vice versa.
3. Facilitating a change of mode between air and surface access trips, through the physical movement of passengers inside the terminal according to prescribed movement patterns. In other words, the main functions of passenger terminals are processing, holding (in reservoirs), and facilitating movements and circulation. In addition, other minor and miscellaneous functions are also required, but they will only contribute to comfort, convenience, and safety of passengers." To function smoothly and to ensure the premium level of service that should be associated with air travel, numerous facilities are necessary in these primary and support areas "(11).

Horonjeff(7) adopted another view very similar in principles to the previous one: "The purpose of the passenger handling system (air terminal) is to:
1. Interface with the passenger's mode of airport access,
2. Process the passenger for starting or ending an air trip, and,
3. Convey the passenger to and from the aircraft."
Hence the system is composed of three major parts: access interface, processing, and flight interface.

Campbell(35) viewed the functions of airport terminals as merely to accommodate and provide space for:
1. Airlines operations.
2. Facilities for the convenience of passengers.
3. Offices for airport management.
5. Non-aeronautical functions of government agencies.

From a purely operational standing, Ashford(37) classified terminals' functions as:
1. Direct passenger services (either commercial or noncommercial) provided primarily for the convenience of the air traveller.
2. Airline-related passenger services, e.g., Check-in, and baggage claim.
3. Governmental activities, i.e., customs, immigration, health, and agricultural controls.
4. Non-passenger related airport authority functions, e.g., management, finance, engineering, etc.
5. Airline functions.

Finally, De Neufville(3) presented the following argument on the functions of terminals as viewed within context of their planning and design: "The airport terminal provides the connection between the aircraft and the vehicles for ground transport. This function is difficult to perform well: the different size and length of stay of the air and ground vehicles imply quite dissimilar amounts of space on the airside and landside of the terminal." The aircraft stationed on stands require much longer distance than the curb needed for loading and unloading of the landside vehicles. "How to balance these conflicting requirements on the opposite sides of the same building, is the essential question of terminal design ".

3.3 PLANNING AND DESIGN ASPECTS

Although the previously mentioned functions of terminals are the principal inputs to the planning process of any terminal, the actual design will differ greatly from one case to another depending on the nature of air traffic to be handled. The design philosophy chosen for a particular terminal might depend on(11):
1. Size and nature of traffic demand.
2. Number of participating airlines using the airport.
3. Processing concepts employed and regulations imposed.
4. Traffic type and flight-sector categories.
5. Physical site and access modes.
Moreover, philosophies and concepts adopted by the different parties participating in terminal planning are also variable and dependent on views, interests, and responsibilities of the particular party. For instance, terminal planning philosophy adopted by ICAO(9) states that: "The most efficient plan for the airport as a whole is that which provides the required capacity for aircraft, passenger, cargo, and vehicle movements with maximum passenger, operator, and staff convenience and the lowest capital and operating costs. Flexibility and expansibility should be considered in conjunction and are fundamental to all aspects of planning."

However, airlines' philosophy and objectives are considerably different. Hullet(38) suggested the following major objectives the airlines should concentrate on and decisions concerning planning of terminal facilities (in U.S. the airlines are responsible for planning their own terminals):
1. Phase construction consistent with need.
2. Determination of cost acceptability and affordability.
3. Maximizing utilization and facility sharing.
4. Selecting functional economic design: differentials in the construction costs between functional economical design vs. monumental design may vary by as much as 1:5 depending upon degree of luxury in the design.
5. Evaluation concept of design with certain criteria.
6. Sound planning base, particularly how realistic and valid the forecasts are.

There are particular aspects regarding terminal planning that should be highlighted because of their prime importance in the process, they are: airport terminal design concepts, facility design aspects, and demand/capacity design criteria.
3.3.1 AIRPORT TERMINAL DESIGN CONCEPTS

The terminal design concept represents the configuration of the landside/airside (or terminal/apron) interface, which is the airside concourse of the terminal. There are no clear and distinct definitive types of design concepts that could be traced in literature, where each reference traced named and classified concepts upon personal discretion:

- Horonjeff(7) classified them as: gate arrival, pier finger, pier satellite, remote satellite, and mobile conveyance.
- Ashford(11) classified them into: open apron or linear, central/pier finger, central/pier satellite, central/remote satellite, remote apron, remote pier, and unit terminals.
- De Neufville's(3) classification is: centralized finger or satellite, linear/gate arrival, and open apron/transporter.
- Blankenship(19) classified terminal concepts as: linear, pier, satellite, transporter.
- IATA(8) classification is: pier/central, satellite/central, linear, transporter, and unit terminal.
- ICAO(9) classification is: simple, linear, finger, satellite, and others (inter alia)- mobile lounge, and unit terminal.
- Airport Landside Capacity Conference(39) provided a different version for classifying design concepts, which implicitly included a time factor: first generation, second generation (including; unit type, centralized finger, and centralized ring), and third generation (including satellite and unitized type).

An attempt was made by Braaksma(40,41) to design terminal concepts systematically. His method uses only two parameters to describe a concept: decentralization and shape, through the use of two corresponding indices: decentralization index, and compactness index. Although this work could be considered as a complete methodology for designing the terminal (in terms of concept design, facility layout, and space design), however, the two defined parameters are not enough in themselves to represent
and contain all factors influencing the terminal shape and size. Nevertheless, this work could be useful for pre-plans of new airports, planning development of existing airports, and to assist researchers and planners to have better knowledge and understanding of this problem. Its usefulness is considered by Braaksma(41): "...It introduces a computerized design method capable of synthesizing preliminary terminal concepts, to develop a fast quantitative design method to assist airport planners in developing terminal concepts."

In an effort to establish a unified definitive taxonomy and a general terminology for the terminal design concept types, which is currently seems missing, the author presents an attempt that combines the shape of the airside interface (which really defines the concept), a time scale (by including the generation), and the relative centralization characteristics of the concept. Regarding the generation evolution, it is difficult to exactly state time scale of evolution of every generation, because it depends largely on particular historic conditions (economic, political, or otherwise) at the country in question. But they are generally:
- First generation: mainly including the pre-war simple terminal up to late forties and early fifties.
- Second generation: basically the era of the fifties and up to mid sixties.
- Third generation: since mid or late sixties.

So, according to this unified terminology, terminal design concepts are classified according to generation into; unitized, satellite, pier, and apron/transporter, and as follows:
1. **First generation**: Which includes the simple terminal from which all other types evolved.
2. **Second generation**: Including:
   - Linear units.
   - Satellites.
   - Piers.
   - Open apron.
3. Third generation: Including:
   - Gate arrival units.
   - Remote satellites.
   - Remote piers.
   - Remote apron.

Figure 3.1 schematically summarizes all design concepts in one diagram, from which relative centralization characteristics could be judged by orientation; left is centralized, while right is decentralized.

The importance of the design concept in terminal planning and physical design is evident. However, it is seldom the case where a pure terminal concept is implemented for a particular airport. But rather a hybrid or mix of concepts are jointly used in such a way so as to provide operational flexibility to the airline/operator in coping with variable demand patterns and levels, and be economically cost effective. Actually, the matter of choosing the right concept that best matches a particular air travel demand and pattern, or is suitable for specific characteristics of passengers, seems indeterminant and sometimes highly debateable. Moreover, the relation between types of terminal concepts and the designing factors dictating their overall planning and design is ambiguous. Throughout technical literature, no citation could be found for a clearly stated methodology, theory, or even hypothetical approach of how to proceed with the design process from defining traffic characteristics with certain demand patterns and levels to the conclusion of choosing a terminal concept for design. There seems to be a missing link between physical design, demand characteristics, and operating conditions.
3.3.2 FACILITY DESIGN

After choosing the design concept for the terminal, planning is transferred to a higher level of detail, the physical design of the components of the building and its facilities, which is undoubtedly, the task of the architect.

One of the earliest references on this subject dates back to 1960(12), which provided valuable knowledge and put forward recommendations for architects for efficiently designing the building and its components, and listed various services and facilities thought advisable to be provided. Basically, the architectural design of the terminal was carried out as that of any other functional building, but several points were of relevance and were eventually adopted by subsequent terminal facilities design practices, they are:

1. Main purpose of building should be to ensure maximum operational efficiency, and its construction should be such that costs are kept reasonably low, commensurate with the attainment of maximum operational efficiency.

2. Physical layout of passengers buildings and aprons should always be considered in relation to their effect on the passenger, providing him with effective service and facilities. At the same time attention must be paid to the location of other necessary accommodations so as to ensure maximum efficiency.

3. Design and layout of buildings and aprons should permit flexible operations, and allow for changes in handling techniques, and seasonal and other variations in traffic loads.

4. Progressive expansion to meet increasing traffic requirements without disproportionate additional costs should be considered, and expansion should be possible without interfering with the operations of existing buildings and aprons.

5. Flow of passengers, baggage, cargo, and mail should be along a standard pattern, direct, clearly marked, and free from obstructions.
Facility design practices became more specialized and detailed with certain technical publications. FAA's Parsons manuals (16,17), discussed in section 2.1, covered amongst other things: detailed facility design for various operational and demand conditions, and charts and monographs that are derived for approximating space requirements and facilities sizes' and arrangements. Blankenship (19) supplemented the Parsons manuals, and is a valued reference for detailed architectural design and facility planning of airport terminals. IATA (8) introduced the functional adjacency matrix for recommended facilities juxtapositioning. ICAO (9) published manuals based on the previously mentioned sources and backed-up by their own practices that provided knowledge and recommendations for their members.

It might be advisable to refer directly to the previously mentioned sources, to avoid unnecessary elaboration and lengthy discussion on this issue, which is beyond our scope.

3.3.3 DEMAND/CAPACITY DESIGN CRITERIA

One of the first steps in the process of planning of airport terminals, should be to decide upon the criteria to be adopted and target goals for design. Normally, this is expressed as capacity standards of the system to handle exerted demands, the date at which capacity is expected to be reached, and the demand level, in terms of percentage of nominal capacity, expected to use the system at any future date. Usually, these criteria are defined by;

- An observable and monitorable measure adopted to represent logically a reasonable selection of factors influencing design.
- A specific magnitude of that measure chosen by the planner to represent a certain activity level.

In designing new airports, the criteria would normally incorporate forecasts of activity levels, projecting past and present demand to some predetermined future date.
In technical literature, the most common design criterion used is the peak hourly flow. Peaks are times when the system experiences the highest levels of utilization. Hence most logically, these would be chosen as the period for design. All current design criteria adopt some aspect of the peak 'hour'. Methods of describing peaking are summarized by Ashford (37) as:

1. Standard Busy Rate (SBR), previously adopted by the British Airports Authority, which is the 30th highest hour of passengers flow, or the rate of flow that is surpassed by only 29 hours of operations at higher flows annually. A modification of SBR is the Busy Hour Rate (BHR), the hourly rate above which 5% of the traffic at the airport is handled.

2. Typical Peak Hour Passenger (TPHP), adopted by the U.S. FAA (42) as the peaking measure. It is the ratio of peak hour to the annual passenger flow.

3. Peak Profile Hour (PPH), or the average daily peak in which a calculated average hourly volume for an 'average peak day' for the peak calendar month is determined.

4. Planning Peak Hour Passenger (PPHP), is the peaking measure adopted by Transport Canada (43) and used for planning and design purposes.

5. Other peaking measures that simply select other percentages of overload standards or rank of busy hour that are not mentioned above.

So, the design criterion adopted for a particular case would be the interpretation of a peak 'hour' at a future date, (the design day) (8), as the design standard, where all activity levels are measured in terms of percentage of that standard. Current practices, mainly derived from the British and American approaches, employ this concept as the design criterion, as will be seen in Section 6.2.

In addition, the development programme of any new airport must have enough flexibility to adjust to the functional and financial exigencies that will occur during its implementation (44). So, it
would seem important and sometimes necessary to develop flexible and dynamic design for air passenger handling facilities to keep pace with these exigencies. In this respect, the Air Transport Division of the American Society of Civil Engineers has undertaken interesting research(45) to study this aspect and to illustrate the influence of various impact factors on characteristics of individual facilities. It stated:" This study is hoped to be useful to those professionals dealing with the complexities of forecasting, programming, planning, designing, and operating air passenger handling facilities, as a reference in identifying which future events should be considered in the development of a particular facility. It will also provide guidelines for airport operators and air carriers to assess a specific terminal plan's ability to accommodate probable future developments and avoid constructing a facility that may become obsolete almost simultaneously with becoming operational ".

3.4 PARTIES INVOLVED IN TERMINAL OPERATIONS

The numerous parties normally involved in airport operations contribute to the complexity of the system and its sensitivity. To achieve successful planning, and efficient operations, the needs and objectives of these parties should be met satisfactorily. The three principal parties are(46): the passenger and those who accompany him (users), the airline, and airport operator. So, for the planning and operations of airports to be successful and efficient, they must take into account the interaction between those three major components or system actors, and consider their objectives. Quoting from Ashford(37): " For the system to operate well, each of the actors must reach some form of equilibrium with the other two. Failure to do so will result in suboptimal conditions ". Figure 3.2 (from Ashford(37)) is a simplified hierarchial system diagram of the primary interactions between the three main parties- airport,
PAGE MISSING IN ORIGINAL
airlines, and the user, that produce the prime parameters of operational scale, passenger demand, airport capacity, and flight capacity.

The objectives of the three principal parties do not necessarily coincide, and are likely to be dissimilar. Horonjeff(36) described the implications and reflections of the parties' objectives on planning and design of airports:

1. Users' objectives concentrate on the responsiveness of airport planning and operations to the needs of passengers relative to convenience, comfort and personal requirements, facilitation of effective passenger and access orientation through concise and comprehensive directional graphics, and the provision of maximum operational efficiency and service standards.

2. Airline's objectives, are mainly associated with: accommodating existing and future aircraft fleets with maximum operational efficiency, facilitating the direct and efficient flow of baggage and passengers, and most important of all, ensuring profitability through provision of economic, efficient and effective facilities.

3. Airport Operator's objectives basically concentrate on the provision of facilities that are functionally efficient for the expedited, safe, and convenient flow of passengers and baggage that would generate maximum revenues from concessionnaires and other sources, while minimizing maintenance and operating costs. Also, the operator acts by proxy to fulfil the community's objectives, including environmental, legal, and cultural issues, and the coordination and integration of the airport with the total transport system.

There is a certain degree of overlap that exists between airline's and airport operator's objectives, which is significantly influenced by the philosophy of management adopted in the particular airport; airport dominant, or airline dominant management philosophies.
In addition to the three main parties, or system actors involved, there are other minor parties that are also associated with daily operation, but their presence only add to convenience, service, and specialization of airport activities but are not considered essential for the system operations (e.g., concessionnaires).

3.5 ACTIVITIES PERFORMED WITHIN TERMINALS

It was established earlier that the functions performed within airport terminals are quite divers and vary in nature, operational importance, and purpose. However, they could be generally categorized into four broad operational activities:

1. **Processing**, where passengers and baggage undergo certain operational processes, the purpose of which is to facilitate their flow between air and access modes, impose safety measures, and perform certain regulatory procedures necessary to comply with laws and regulations. It will be shown throughout this work that they are the most operationally important facilities the performance and dynamic nature of which would dictate the overall efficiency of the system.

2. **Holding-storing**, where passengers, visitors, and baggage are held for varying amounts of time awaiting further activities. Its operational characteristics show a static nature defined by its capability to hold definite number of items at any time.

3. **Circulation** by means of links that provide connection between various parts and facilities of the airport terminal. Operationally, they facilitate circulation of users moving between processing, holding, and auxiliary servicing centers inside the terminal.

4. **Auxiliary activities**, that contribute only to convenience, comfort, and satisfaction of various users, but are not vital to the operational efficiency of the airport. However, certain auxiliary components (e.g., concessions) are economically crucial but not operationally vital to the airport.
More specialized information regarding the first three types of activities will be presented in the following chapters, while a special emphasize is placed on discussing the characteristics of the first type (processors) throughout this work.
CHAPTER FOUR

LEVELS OF SERVICE

Service standards are essential in calibrating the performance of operation in transportation systems, and when expressed as a framework, their 'levels' could serve as a yardstick of the system's performance. Throughout this chapter, important aspects of service standards are discussed and examined, in order to arrive at an appropriate criterion to be adopted within the methodology proposed herewith.

4.1 DEFINITIONS

The first known definition for level of service in transportation was introduced by U.S. Highway Research Board in its Highway Capacity Manual first published in 1950(47), then completely revised in 1965(48). The term was used by traffic engineers to describe and determine the capacity of highways and streets. Since then, traffic engineers and planners have used level of service in conjunction with and complementing capacity. The following quotation, is the definition of level of service by Wohl and Martin(49):" The level of service a traveller experiences represents the total difficulty of making the trip at that particular time. We may define the actual level of service experienced as the price of travel ". The definition of the Highway Capacity Manual was more comprehensive and realistic : " The level of service is a term which, broadly interpreted, denotes any one of an infinite number of differing combinations of operating conditions that may occur on a given lane or
roadway. When it is accommodating various traffic volumes, level of service is a qualitative measure of the effect of a number of factors, which include; speed and travel time, traffic interruptions, freedom to manoeuvre, safety, driving comfort and convenience, and operating costs. The structure of the Highway Capacity Manual's level of service framework is a six-level one arranged in descending order of quality of service from 'A' to 'F'. The description of each level is based on; service volumes, volume/capacity ratio, and some qualitative evaluation of driver convenience (in terms of individual freedom to choose desired vehicle operating speeds, the ability to overtake and pass other vehicles, and the freedom to change lanes). Figure 4.1 is a conceptual diagram of levels of service and their relation to operations/demand conditions as depicted by the Highway Capacity Manual. However, in the third edition of the Highway Capacity Manual scheduled to be published in mid-1985, a significant and important change has been made; criteria for level of service will be related to quality of service as defined by the highway user, rather than based on traffic volumes (as defined in the procedures of the second edition of the manual).

Nevertheless, the previously mentioned definitions of level of service and related framework, could not be readily used in the proposed methodology, simply because we are talking about two different transport systems; highways with vehicles as their basic units, and airport terminals with people. Interest should then be focussed on the behaviour of people inside airport terminals, not on highways, and to work with pedestrians levels of service, not with vehicles'.

One of the first to work on pedestrians' levels of service was Fruin, who recognized the basic differences between the two previously mentioned systems, and underlined the appropriate approach required to design pedestrian facilities. Quoting from
Fruin (51): "Design of pedestrian facilities involves the application of traffic engineering principles combined with considerations of human convenience and the design environment. Different environments logically require the application of different qualitative as well as quantitative design standards". Fruin's definition of service standards in terminals (in general) was (52): "Service standards are the quantitative design assumptions made to determine the size of the functional elements of the interface. These standards are an important environmental consideration because they also determine the efficiency, convenience, useful life, and quality of service of a facility".

Figure 4.1 Highway Capacity Manual's Concept of Levels of Service.
De Neufville(53) gave this relatively basic viewpoint for level of service in airport terminals: "As in highway design, different combinations of flow and congestion are referred to as 'level of service'. The choice of level of service for a particular facility represent a compromise between the high cost of providing extra space, and the amount of inconvenience to pedestrians."

Following shift of burden on the airport from airside to landside, and the consequent impact it had on all sectors and organisations involved in airports, a conference organized by the Transportation Research Board, was held in 1975 to discuss the airport landside capacity problems. Although no distinct conclusions of great importance were reached then, however, the conference did have the merit of directing the attention in the right course. In this conference, the definition of level of service was(54): "For passengers moving through the airport landside, level of service is a subjective impression of the quality of transfer between the access mode and the aircraft. This subjective impression is dependent on a series of factors including (but not necessarily limited to): time necessary to proceed through the landside, reliability or predictability of processing time, reaction to overall landside environment, physical comfort and convenience, reaction to treatment by airline personnel, concessionnaires, security officers, and other airport personnel, cost of air fare and airport services, type of passenger and purpose of trip, frequency of air travel, and expectation of service". This definition of level of service clearly reveals its numerous intermingled, subjective, and complex constituents, which evidently, will seriously limit its utilization, and minimize its usefulness.

Other definitions for level of service, which are not as subjective and detailed as the previous one, include:

Transport Canada(55), where level of service was defined as: "A measure or assessment of the conditions and operating characteristics of any subsystem or terminal facility at a
particular level of demand or user volume. Since the traffic demand at each airport is dynamic and varies according to such factors as schedule, flight sector, and aircraft load, the level of service measure must reflect these dynamic aspects. Level of service, therefore, can be considered as a range of values or assessment of the ability of supply to meet demand. The level of service framework of Transport Canada is a six-level one similar to the Highway Capacity Manual's, but all its factors are qualitative and subjective. This framework is shown in Table 4.1.

Table 4.1 Transport Canada's Level of Service Framework.

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>A</td>
<td>Excellent level of service; condition of free flow; no delays; direct routes; excellent level of comfort.</td>
</tr>
<tr>
<td>B</td>
<td>High level of service; condition of stable flow; provides acceptable throughput; related subsystems in balance; high level of comfort.</td>
</tr>
<tr>
<td>C</td>
<td>Good level of service; condition of stable flow; provides acceptable throughput; related subsystems in balance.</td>
</tr>
<tr>
<td>D</td>
<td>Adequate level of service; condition of unstable flow; delays for passengers; conditions acceptable for short periods of time.</td>
</tr>
<tr>
<td>E</td>
<td>Unacceptable level of service; condition of unstable flow; subsystems not in balance; represents limiting capacity of the system.</td>
</tr>
<tr>
<td>F</td>
<td>System breakdown; unacceptable congestion and delays.</td>
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</tbody>
</table>
IATA(56) defined level of service and related framework almost identically to (and seemingly derived from) that of Transport Canada. The only addition that IATA continuously emphasized was 'the combined qualitative assessment of the relative comfort and convenience'.

ACAP(57,28) research project provided the following brief definition: "Level of service is a measure of how a component, subsystem, and system performs. The specified maximum tolerable limit on the level of service measures are the level of service criteria". Assessment of service is carried out by monitoring violations to the level of service criteria through checking whether they have exceeded the specified maximum tolerable limit or not. So, in essence, ACAP's level of service framework is a two-level one.

4.2 FACTORS CONTRIBUTING TO SERVICE STANDARDS

After previous discussion on different definitions of service standards, a detailed anatomy of this expression seems necessary in order to be able to short-list its most basic and important components. The factors contributing to service standards in airport terminals are of two general types: qualitative and quantitative.

4.2.1 QUALITATIVE FACTORS

These are basically subjective, descriptive, difficult to quantify, and highly susceptible to personal influence and individualistic behaviour. They include:  
1. Environmental- such as exposure to weather, terminal internal environment, cleanliness, sense of safety... etc.
2. Psychological - including reaction to treatment by airport personnel, expectation of service, reaction to overall terminal environment, attitudes towards airport conditions, comfort, safety, privacy...etc.
3. Aesthetics - covering lighting arrangement, signing, systems facilities identification, seating provisions, catering for the disabled and infants...etc.
4. Systems-related factors - such as amenities, complexity of procedures, security measures imposed, information system (understandability, consistency, and legibility)...etc.
5. Personal: type of passengers and visitors, purpose and origin/destination of trip, convenience, personality and personal behaviour...etc.

4.2.2 QUANTITATIVE FACTORS

These are factors that can lend themselves to enumeration and statistical analysis because they are tangible and easily identifiable in the terminal environment. They are:
1. Temporal factors - they are time-related factors that include processing time, delay time in waiting for service, total time spent in a facility, reporting time prior to start of service, flight departures and arrivals delay.
2. Spatial factors - they are distance/area-related factors covering walking distance, pedestrian density (crowdedness), size and dimensions of functional areas, relative location of facilities, level changes...etc.
3. Econometric factors - such as: airline ticket cost, fare of access trip, concessions pricing structure, airline and airport pricing/charging policies...etc.
4. Statistical factors - including frequency of air travel, frequency of flights per route, number of airlines using the airport.
Table 4.2, extracted from Heathington and Jones (58), summarizes those factors for all airport users and terminal facilities. There is no reasonable and logical (or even possible) way of formulating a level of service framework that could include all those factors. The susceptibility of these factors to quantification is highly variable from one to another. Table 4.3, shows the degree of quantifiability of level of service factors of the airport landside facilities, as suggested by Brinke and Maddison (54). However, by carefully reviewing those factors, one can segregate the ones that can conform to quantification and enumeration, independent of as many qualitative factors and measures as possible, and of recognized value and significance in related capacity analysis.

4.3 SERVICE MEASURES CONSIDERED

After reviewing the factors that may contribute to service standards in airport terminals, a short-list could be finalized in order to select the most significant factors. The service measure could be any quantifiable expression of how a system (or any part thereof) performs to provide any form of service to the airport user. Service measures that may be considered within the airport environment for establishing level of service framework would include: temporal, spatial, econometric, and statistical measures.

4.3.1 TEMPORAL MEASURES

These include:
1. Processing time, which is the time that would take a passenger to be serviced (processed) at a particular processing facility at the airport terminal. It is a facility-specific variable that is relatively insensitive to demand variations, because it represents supply side of the processing activity at that facility.
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Table 4.3

Service Measures of Landside Facilities

<table>
<thead>
<tr>
<th>Landside Facility</th>
<th>Level of Service</th>
<th>Easy to Quantify</th>
<th>Difficult to Quantify</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access facilities (roads, transit)</td>
<td>Travel time</td>
<td>Adequacy of signing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delay</td>
<td>Level of congestion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transit frequency</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Cost to passenger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminal curbside</td>
<td>Availability of space</td>
<td>Level of congestion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delay</td>
<td>Curtainside check-in</td>
<td></td>
</tr>
<tr>
<td>Parking facilities (garage, remote lot)</td>
<td>Availability of space</td>
<td>Shuttle bus service to and from remote lots</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distance to check-in and baggage claim</td>
<td></td>
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</tr>
<tr>
<td>Ticket counter and check-in</td>
<td>Processing time</td>
<td>Complexity of procedure</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Courtesy of airline personnel</td>
<td>Overall environment</td>
</tr>
<tr>
<td>Security</td>
<td>Processing time</td>
<td>Actual procedure (search, X-ray)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Location in relation to concessions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Courtesy of security officers</td>
<td></td>
</tr>
<tr>
<td>International clearance (customs, immigration)</td>
<td>Processing time</td>
<td>Complexity of procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Courtesy of clearance officers</td>
<td>Overall environment</td>
</tr>
<tr>
<td>Hold rooms</td>
<td>Seat availability</td>
<td>Overall environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Location in relation to concessions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level of congestion</td>
<td></td>
</tr>
<tr>
<td>Baggage claim</td>
<td>Waiting time for bags</td>
<td>Hardware involved</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level of congestion</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Availability of skycaps</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Availability of concessions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability of seating</td>
<td></td>
</tr>
<tr>
<td>Circulation elements (corridors, moving sidewalks)</td>
<td>Walking distances</td>
<td>Overall environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Width of corridors</td>
<td>Hardware used</td>
<td></td>
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<tr>
<td></td>
<td>Height of ceiling</td>
<td>Signing</td>
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<tr>
<td></td>
<td>Travel time</td>
<td>Public address systems</td>
<td>Level of congestion</td>
</tr>
<tr>
<td></td>
<td>Frequency of service (hardware)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Cost to passenger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waiting areas</td>
<td>Availability</td>
<td>Seating arrangement</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Comfort of seating</td>
<td></td>
</tr>
<tr>
<td>Passenger services (restrooms, phones)</td>
<td>Availability</td>
<td>Service provided</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Level of congestion</td>
<td></td>
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<tr>
<td></td>
<td>Cost to passenger</td>
<td>Cleanliness</td>
<td></td>
</tr>
<tr>
<td>Concessions (newstands, restaurants)</td>
<td>Availability</td>
<td>Service provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Courtesy of operator</td>
<td>Overall environment</td>
</tr>
<tr>
<td></td>
<td>Cost to passenger</td>
<td>Level of congestion</td>
<td></td>
</tr>
<tr>
<td>Information services (signing)</td>
<td>Availability</td>
<td>Service provided</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clarity, legibility, placement</td>
<td></td>
</tr>
</tbody>
</table>
2. Delay, which could be considered as the time unwillingly spent by passengers awaiting their turn to be serviced at a processing facility, due to the incapability of the server to cope with all passengers demanding service simultaneously. It is a direct outcome of the difficiency of supply to satisfy the requirements of demand for service in that facility at that particular time. In this sense, it is a suitable measure to express quality of service at processing facilities, because of its basic theoretic properties in interpreting the operational aspects of the process, and in monitoring the performance of the facility as governed by the underlying variations in demand for service.

3. Total time spent, is a composite expression for delay and processing times at processing facilities.

4. Reporting time, is the time recommended by the operators for passengers to report for a particular process, and it indirectly defines the amount of time passengers would be expected to spend in the airport regardless of delay or processing times. This time does not have any real significance once individual activities are considered, because it represents overall time expected to be spent by passengers in waiting for a certain activity to commence.

5. Flight arrival and departure delay, is a measure of punctuality and reliability of airline service, and as such it could be used mainly to assess airlines operations performance and service.

4.3.2 SPATIAL MEASURES

They include:

1. Walking distance, which could be used as an effective measure of service for linking facilities, particularly when compared to human physical capabilities.
2. Occupation density (crowdedness), like delay, it is a direct outcome of supply-demand interaction, which could be effectively used in level of service framework for all facilities: processing (the measure used being queue length), storing (density of occupants), and links (pedestrian density).

4.3.3 ECONOMETRIC MEASURES

Including:
1. Airline ticket fare, could be used as a measure of airline service, and in airline route selection, however, it would not be suitable for use in capacity studies.
2. Fare of airport access trip, is a measure of airport access service and in the selection of access modes.
3. Pricing policies of airports, airlines, and concessionaires, is a factor passengers might take into consideration in their decision of selecting airports, when they have more than one alternative to choose from, and as such it could be considered as a measure of airport service.

4.3.4 STATISTICAL MEASURES

Including:
1. Frequency of flights, or the number of flights per route in airlines flight schedules, is considered as a measure of airline service, and is particularly included in route capacity studies.
2. Number of airlines using airport, is a measure of airport service, signifying the relative importance of that airport amongst its competitors, and defining passengers preference for the services it can provide.
4.4 DELAY: A SIGNIFICANT MEASURE OF SERVICE

The importance of delay reflects its dynamic characteristics in the processing (servicing) operation. When congestion occurs, queues and delays are the inevitable consequence, because all individuals in the queue feel and think of service (preparations necessary to consume the transport product, i.e., the flight) as an important and sometimes essential commodity worth waiting for. So, in a situation where the demand for a particular servicing facility at a certain instant is greater than the capability of that facility to serve (process) more than one item during a specified time duration (servicing or processing time), delays and queues would be a natural phenomenon. From a mathematical viewpoint, a queue would form only when the demand or arrival rate during the specified time period is greater than the supply or processing rate, and even if the arrival rate would later fall lower than the processing rate, the queue would still exist but will eventually dissipate gradually. Generally, congestion information could be obtained from the analysis of supply-demand relations, queueing problems, and capacity studies. Particularly, delay times and queue lengths could be directly observed, mathematically derived, or even synthesized using simulation techniques. From a theoretic standpoint, considering delay as a measure of congestion would delineate service conditions and monitor the balance between supply and demand of the servicing operation by appropriately interpreting the outcomes of the process as experienced by the passengers.

The importance of delay is manifested by the dynamic, interrelated, and complex nature of congestion and its attributes, reflected by the following:
1. Delay is a time-dependent variable of great mathematical complexity, influenced by the relatively high time dependency of the supply-demand relations combined with the stochastic nature of the servicing operation, as could be concluded when Queueing Theory literature is referenced.
2. Delay could be linked with the econometrics of the serving operation, knowing that the supply-demand issues have deep roots in economics. On the supply side, the provision of more service in terms of additional number of servers or higher technological standards capable of faster service, would incur certain additional expenses in terms of resources. When they are not fully utilized to provide the counterbalancing revenues (at low demand levels), financial losses will arise. On the demand side, long delays by individuals requiring service (at high demand levels), could be related to the real value of time for each individual, and to the reaction to delay- if this could ever be translated into economic terms. So, weighing server utilization and cost against delay time of passengers could show the sensitive balancing nature of the operation, and it is here where time dependency and economics of the servicing operation get exposed to each other.

3. Delay could indirectly be linked with space required for processing, in terms of area required to accommodate a certain queue length. Since they are both positively related to imposed demand, then certain relation could be established between queue lengths and delay times at respective demand levels.

4. For the problem of assessing and evaluating the effects of congestion, delay could be viewed and interpreted differently, at different conditions, by different individuals. It is the reaction and response to delay that dictates this interpretation, hence as such, it seems more psychological and personal, rather than systematic. In essence, delay has two dimensions: systematic in terms of time actually measured, and subjective in terms of how much of a nuisance and annoyance it is being considered by individual passengers.
4.5 DELAY / SPACE RELATIONS

As mentioned in point 3 above, since delay and queueing are both concurrent outcomes of congestion at operational levels where demand is relatively high, then they are mutually positively related (to each other) as well as to level of demand exerted on the facility. This will imply that for a particular demand level, congestion could be described by two values: average delay time and queue length. The significance of linking space to delay is described as follows: with fluctuating demand, the space required changes but the space provided is fixed. Theoretically, provisions for space should satisfy certain demand level that is lower (by a certain percentage) than maximum possible level. Space here, is the storing space normally in the form of a waiting line, that would be needed for passengers in the queue waiting for service to commence. It has dynamic nature because it continuously changes according to demand level and congestion. Servicing space occupied by the server (whether a person on a counter, or a machine) and one individual (or group of) passenger(s) at a time, does not have any particular significance because it is static and constant over time, and is usually calculated according to some standards derived from ergonomics.

Deriving space from supply-demand relations could be accomplished by relating both queue length and queue time to demand level imposed. So, for all demand levels there are corresponding values for queue lengths that would result from a certain average delay to passengers. For instance, in a situation where a queue is formed awaiting service, the average queueing time is (X) and the corresponding length of the queue is (Y), then waiting for this particular service for a period of time (X) requires a space to accommodate (Y) individuals. Space is expressed either linearly as number in queue, or as occupation density (number in queue per unit area).
Needless to say that these relations are not as simple and straightforward as they might seem, because of the many complexities involved with certain operational aspects, namely, time dependency and variations of demand over time, stochastic nature of the process, and the difficulty of practical manipulation and segregation of delay. However, with proper assumptions, this argument could be utilized in formalizing service standards and implementing them thereafter.

4.6 LEVEL OF SERVICE CRITERIA FOR AIRPORT TERMINALS

Following discussion previously raised on service standards and measures, and in order to formalize the framework of service standards for airport terminals, it would be necessary to distinguish between the various types of facilities comprising the terminal, and their corresponding characteristics that would influence the service standards.

The major kinds of facilities of an airport terminal are: processing, storing-holding, and linking facilities. In this section, level of service criteria for the three categories would be reviewed. In this respect, similar service criteria for comparable situations and environments were traced in literature, which suit and could be successfully adopted for the proposed level of service framework. So, these two categories will only be briefly viewed, while most effort and attention throughout this work will be directed towards devising level of service criteria for processing facilities, as will be presented in Chapter Six.

4.6.1 STORING-HOLDING FACILITIES

Storing-holding facilities function primarily as staging areas where passengers in particular and users in general spend varying amounts of time awaiting further service. Service standards of
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these facilities are basically those used by architects to design functional space for various activities performed within the particular environment. In principle, those standards are norms derived from ergonomics (human factor engineering) to fulfil the requirements of individuals to function and perform designated activities naturally and comfortably. Basically, those functions and activities are directly attached to specific dimensions of the human body, and the space these dimensions describe in motion or in different stationary positions. Particularly, Anthropometry, which is the branch of science dealing with the application of scientific physical measurements to human subjects for the development of engineering design standards, is used for this purpose. McCormick and Sanders(59) provide excellent information on this subject (Chapter 11), specifically important body dimensions for different percentile ranges (Table 11.1).

Another concept used for this purpose is the 'human body ellipse', which was used by Fruin(15) in his work to develop levels of service based on calculating area occupancy for pedestrians. Fruin devised this concept to standardize shape and dimensions of the human body, where he considered its horizontal projection to approximate an ellipse with effective dimensions of 18 inches for the body depth (minor axis), and 24 inches for the shoulder breadth (major axis). He then calculated different occupancy levels based on different arrangements of what he called 'body buffer zones', and defined the following levels:

1. **Touch Zone**, with an occupancy level of (3) sq. ft. per person, below which frequent unavoidable contacts between individual pedestrians are likely to occur.

2. **No-Touch Zone**, with (18) inch body radius, and occupancy level of (7) sq. ft. per person, it would be increasingly more likely that individual pedestrians will be able to avoid contacts.

3. **Personal Comfort Zone**, with (21) inch body radius (full body depth separating standees), and occupancy level of (10) sq. ft. per person, personal comfort is maintained through allowing limited lateral circulation between pedestrians.
4. **Circulation Zone**, with (24) inch body radius corresponding to an area of (13) sq. ft. per person, would represent the minimum pedestrian area for circulation without disturbing others.

Some organisations involved with planning, design, and operations of airports, currently use standards derived from Anthropometry and Ergonomics that are expressed in terms of areas reasonably adequate to accommodate users of that facility. IATA and BAA(61), whose joint standards are shown in Table 4.4, use standards based on work previously conducted by BAA, and unofficially published in a paper by Perrett(13). A passenger survey was conducted at four BAA terminals in 1969, where 2500 passengers were interviewed in the departure lounges and asked to state their perception to crowding and rate the lounge environment on a five level scale ranging from 'not at all crowded' to 'exceptionally overcrowded'. The result of this survey, as shown in Figure 4.2, helped in defining service standards of storing-holding facilities in airports through the perception of passengers to various crowding levels. However, the form of 'storing' provided to passengers is different (e.g., seating or standing), and percentage of each form may also be variable. So, a departure lounge accommodating passengers that are all comfortably seated, or passengers that are standing with no seating provisions available, will have two different levels of service.

### 4.6.2 LINKING FACILITIES

These facilities provide connection between the various processing and storing centres in the terminal building. They might be areas strictly provided for movement, such as corridors, concourses, and stairways, or constitute parts of other facilities planned in such a way so as parts of them facilitate movement and circulation, like pathways in departure lounges, or walkways in the terminal main hall. By definition, those
### 1 DEPARTURE FACILITIES

<table>
<thead>
<tr>
<th>Facility</th>
<th>BAA Standards</th>
<th>IATA Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Check-in</td>
<td>(a) Occupancy time: 2 minutes per passenger</td>
<td>(a) Occupancy time: 4 minutes per passenger</td>
</tr>
<tr>
<td>Baggage Drop.</td>
<td>(b) 0.13 m² per passenger for hold luggage; 0.11 m² per passenger for table luggage</td>
<td>(b) 0.13 m² per passenger for hold luggage; 0.11 m² per passenger for table luggage</td>
</tr>
<tr>
<td>1.2 Departure</td>
<td>(a) Baggage sorting rate: maximum of 2.3 bags per minute per metre of periphery (manual handling)</td>
<td>No standards shown</td>
</tr>
<tr>
<td>Baggage System.</td>
<td>(b) Provision of seating for 10% of people present.</td>
<td>(b) Provision of seating for 10% of people present.</td>
</tr>
<tr>
<td>1.3 Departure</td>
<td>(a) Space allowance: 1.0 m² per seated person (normal density seating) 0.8 m² per seated person (high density seating) 1.0 m² per standing person</td>
<td>No standards shown</td>
</tr>
<tr>
<td>Concourse</td>
<td>(a) Curving time: 35% of passengers should queue for less than 5 minutes.</td>
<td>(a) Curving time: 35% of passengers should queue for less than 5 minutes.</td>
</tr>
<tr>
<td>1.4 Departure</td>
<td>(a) Curving time: 35% of passengers should queue for less than 5 minutes.</td>
<td>(a) Curving time: 35% of passengers should queue for less than 5 minutes.</td>
</tr>
<tr>
<td>Passport Control.</td>
<td>(b) 0.6 m² per passenger without hold luggage and 0.5 m² per passenger with hold luggage.</td>
<td>(b) 0.6 m² per passenger without hold luggage and 0.5 m² per passenger with hold luggage.</td>
</tr>
<tr>
<td>1.5 Central</td>
<td>No set standards.</td>
<td>No set standards.</td>
</tr>
<tr>
<td>Security</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2 ARRIVAL FACILITIES

<table>
<thead>
<tr>
<th>Facility</th>
<th>BAA Standards</th>
<th>IATA Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Immigration</td>
<td>(a) Curving space: 0.4 m² per passenger.</td>
<td>(a) Curving space: 0.4 m² per passenger.</td>
</tr>
<tr>
<td></td>
<td>(b) Curving time: 95% of passengers should queue for less than 3 minutes.</td>
<td>(b) Curving time: 95% of passengers should queue for less than 3 minutes.</td>
</tr>
<tr>
<td>1.2 Baggage</td>
<td>(a) Baggage delivery times (as appropriate to terminal)</td>
<td>(a) Baggage delivery times (as appropriate to terminal)</td>
</tr>
<tr>
<td>Reclaim Units</td>
<td>(b) Maximum of 35 minutes between arrival of first passenger and delivery of last bag from unit.</td>
<td>(b) Maximum of 35 minutes between arrival of first passenger and delivery of last bag from unit.</td>
</tr>
<tr>
<td></td>
<td>(c) Some baggage on reclaim unit when first passenger arrives.</td>
<td>(c) Some baggage on reclaim unit when first passenger arrives.</td>
</tr>
<tr>
<td></td>
<td>(d) 95% of passengers do not wait more than 3 minutes in baggage hall for all of their bags.</td>
<td>(d) 95% of passengers do not wait more than 3 minutes in baggage hall for all of their bags.</td>
</tr>
<tr>
<td>2.3 Baggage</td>
<td>(a) Space allowance: 1.2 m² per seated person 2.0 m² per standing passenger.</td>
<td>(a) Space allowance: 1.2 m² per seated person 2.0 m² per standing passenger.</td>
</tr>
<tr>
<td>Reclaim Hall.</td>
<td>(b) 3.1 m² per long-hand passenger (includes space occupied by reclaim unit).</td>
<td>(b) 3.1 m² per long-hand passenger (includes space occupied by reclaim unit).</td>
</tr>
<tr>
<td>2.4 Customs</td>
<td>No set passenger service standards.</td>
<td>No set passenger service standards.</td>
</tr>
<tr>
<td>2.5 Arrival</td>
<td>(a) Space allowance: 0.6 m² per seated person (normal density seating) 1.0 m² per standing passenger.</td>
<td>(a) Space allowance: 0.6 m² per seated person (normal density seating) 1.0 m² per standing passenger.</td>
</tr>
<tr>
<td>Concourse.</td>
<td>(b) Provision of seating for 10% of people present.</td>
<td>(b) Provision of seating for 10% of people present.</td>
</tr>
</tbody>
</table>

### NOTES

Additional space is required for primary throughways and circulation. In broad terms BAA adds 2 for concourses and departure lounges and 10% for gatetours.

*BAA standards are defined such that under design conditions, 95% of the passengers would receive the desired level of service.*

---

**Table 4.4 BAA / IATA Service Standards for Airport Terminals**
facilities accommodate activities associated with movements of people in the terminal building. Functionally, linking is a self-serve activity where people move (self-move or by aid of mechanical means) between different parts of the terminal building, and as such, operational standards are influenced by speed and type of movement, density of pedestrians whilst moving, and moving distance.

Previous studies have concluded that, apart from operational aspects, pedestrian traffic characteristics may also be influenced by environmental, social, and psychological factors. Fruin, Navin and Wheeler, Older, Pushkarev and Zupan, and a recent study by Polus Schofer and Ushpiz, all have tackled pedestrian traffic and their service standards to varying depths using different approaches. However, Fruin's work seems most eligible to be adopted for setting service standards in terminals, mainly because this work was originally done in passenger terminals (although not airport terminals specifically), and the fact that level of service criteria devised are more consistent and complete.

Quoting from Fruin: "A passenger terminal may be categorized as a building system that has an external or community environment, and internal or passenger interface environment. The factors that comprise the external community environment include its land-use, access system, and aesthetics. It also includes socio-economic, health, tranquility, and ecological impacts. Factors affecting the internal passenger environment include its design, service standards, traffic characteristics, visual design, patron service, comfort, convenience, and maintainability." Fruin's description can very well stand for and suit an airport terminal's. Hence, the two environments (or systems) are analogous, where the airport terminal being a specific kind (yet more complex) of passenger terminals. Factors included in Fruin's framework are: average area occupancy, design volumes, and speed conditions, where he justified considering
these factors by(60): "pedestrian service standards should be based on the freedom to select locomotion speed, the ability to bypass slow moving pedestrians, and the relative ease of cross and reverse flow movements at various pedestrian traffic concentrations. Rather than capacity, design judgement requires the evaluation of the degree of the human convenience, or levels of service, created by design assumptions within the classic restraints of economics, space, and time ". Fruin's level of service framework for pedestrians, shown in Table 4.5, is a six-level one, arranged in a fashion similar to that of the Highway Capacity Manual.

A useful addition to this subject, was described in a recent paper by Habicht and Braaksma(66), on the determination of effective widths of corridors in related environments. Widths were estimated for different service levels, based on reductions on actual widths of corridors, for different kinds of obstacles and types of walls. This approach is reminiscent of the concept adopted in the procedures of the Highway Capacity Manual for determining practical capacity of a highway based on reductions made on capacity at the most ideal operating conditions, due to various factors that would adversely influence those conditions.

4.6.3 PROCESSING (SERVICING) FACILITIES

Processing facilities form the most important and vital parts of the airport terminal, and greatly contribute to the complexity of the system. Their function is to perform certain regulatory and operational activities, that are required by the related organisations, and necessary for the passenger/baggage handling system to facilitate the smooth and safe transfer of passengers and their baggage between air and service transport modes. Each facility has its own distinct characteristics with respect to its exact function and the nature of process, arrival patterns to that facility, passengers' processing times distribution, and
### Table 4.5
Fruin's Level of Service Framework for Pedestrians

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>WALKWAYS</th>
<th>STAIRWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(1) 35 and more</td>
<td>20 and more</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>(2) 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3) Freely selected</td>
<td>Freely selected</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>(1) 25 - 35</td>
<td>15 - 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) 7 - 10</td>
<td>5 - 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3) Normally selected</td>
<td>Freely selected</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>(1) 15 - 25</td>
<td>10 - 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) 10 - 15</td>
<td>7 - 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3) Individually selected</td>
<td>Slightly restricted</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>(1) 10 - 15</td>
<td>7 - 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) 15 - 20</td>
<td>10 - 13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3) Speeds restricted and Normal speeds reduced</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>(1) 5 - 10</td>
<td>4 - 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) 20 - 25</td>
<td>13 - 17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3) Speeds restricted and Normal speeds reduced</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>forward speed only by shuffling</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>(1) 5 and less</td>
<td>4 and less</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) (( Not recommended for design ))</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3) Extremely restricted, Complete breakdown forward speed only by shuffling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1)- Average area occupancy in sq ft/person.
(2)- Design volume in pedestrian/minute/ft width.
(3)- Walking and stair speed condition.
operational procedures set by the responsible organisations. It has been difficult to set service standards for these facilities for various reasons. Basically, every facility is unique in characteristics and has a dissimilar nature of operation when compared with others, which implies that the reaction of passengers to their operational conditions is variable. These difficulties are also caused by the absence of consensus amongst organisations involved in operation, and the different (sometimes conflicting) policies, interests, and objectives of those organisations and their approach to processing. Moreover, operational procedures (or facilitation) are still undergoing a continuous (yet relatively slow) programme of standardization and simplification on the international level. This programme was initiated by IATA(67), where committees are set to try to improve and simplify procedures, regulations, and transactions, recommended by ICAO(68), or imposed by the authorities of contracting states in ICAO worldwide.

Nevertheless, there are service standards suggested by agencies and organisations concerned with airport operations. Recently, IATA and BAA(61) formed a joint group to discuss this matter, and to try to set internationally recognized service standards. Table 4.4 shows the service standards for processing facilities currently adopted by IATA and BAA. BAA uses service standards based on the two congestion measures: delay or queueing time, and queueing space. Those standards were empirically set by BAA, based on previous research conducted in their terminals. However, no information on BAA's methodology has been made available or officially published in any detail, except some basic principles described in Perrett's paper(13). Service standards for queueing time are interpreted as the recommended maximum queueing time for all passengers at a particular processing facility. IATA standards are very close to BAA's except for:

1. IATA used a second standard for queueing at peak operating times expressed as the recommended maximum queueing time for 80% of the passengers, in addition to the normal operating condition
expressed as a recommended maximum queueing time for 95% of the passengers. BAA used only the maximum queueing time for 95% of passengers.

2. For circulation, BAA adds 25% to space for concourses and departure lounges, and 20% for gates, however, their crowding standards for processing facilities are identical.

In spite of that, there is no indication that service standards were set according to some established procedure or following a systematic method. Service standards presently implemented, were set according to personal experience within organisations involved with airport operations and passenger handling. These standards were compiled over years of practice reflecting accumulated personal experience with service and operation, and were largely based on trial and error. Consequently, these procedures would be arbitrarily set and without proper consideration to viewpoints and interests of passengers.

In an attempt to explore whether or not service standards in airport terminals could be obtained directly from airlines operating in a particular airport, the author conducted a small-scale personal inquiry in the Robert Mueller Municipal Airport in Austin, Texas, which handled 2.7 million passengers in 1983 through eight airlines. A brief questionnaire was handed to station managers of those airlines, asking them to state their conception to service standards for passengers at the airport from a purely operational standpoint based on their personal experience and judgement, not on airlines policy. To avoid bias induced by the effects of market competitiveness, confidentiality was ensured and maintained by the anonymity of replies, where names of persons and airlines were not required. The outcome of this investigation showed that replies of station managers participating were so different and inconsistent, and revealed the lack of consensus between the participants in this survey. It could be concluded that it would not be appropriate to rely completely on opinions of parties involved with operations only,
to select service standards for passengers. The proper and more logical way would be to include passengers themselves in the process and ask them to state their perception to service offered, so that they would participate in defining standards of their own service.

Service standards for processing facilities, seem to be the missing link in a complete and systematically established level of service framework for airport terminals. Therefore, a procedure has to be established in order to arrive at realistic, practically achievable, and applicable service standards.

4.7 SUMMARY

In this chapter, service standards and levels of service for transportation systems in general, and airport terminals in particular, were previewed, and their terminologies defined. The factors that may possibly contribute to operational service in airport terminals and similar systems or environmentals were discussed, so as to consider those that most influence operational conditions and service standards.

Also, service standards for airport terminals' facilities were studied. It was noticed that for holding-storing and linking facilities, service standards borrowed from other similar and comparable environments could be considered as appropriate and adequate to adopt as service standards for airport terminals. Processing facilities seemed to be the only parts of the terminal that lacked suitable operational service standards, necessitating establishing a systematic method for deriving realistic service standards for processing facilities. Preferably, these should be based on passengers' perception to operational service, rather on arbitrary standards set according to the arbitrary judgement of operators and carriers.
5.1 DEFINITIONS

Defining and measuring capacity in transportation, has always been a controversy-prone subject. Capacity of highways and street intersections, the first to be tackled in transportation, was a fertile ground for research for many years and a subject of conflicting viewpoints. After the Second World War, the Highway Research Board undertook the task of compiling results of many years of research and experience involving vehicular traffic on U.S. highways and streets. In 1950, the Highway Capacity Manual(47) was published, edited by a special committee of the HRB. The first edition of the Highway Capacity Manual summarized the state of the art at those times, based on American practical experience of related agencies and research studies conducted. Highway capacity was related to the physical design features, traffic operations aspects, and other characteristics of the system. The expression for capacity itself was defined so as to indicate three separate points on the performance function:

1. Basic capacity- The maximum number of passenger cars that can pass a point on a lane or roadway during one hour under the most nearly ideal roadway and traffic conditions, which can possibly be attained.

2. Possible capacity- The maximum number of vehicles that can pass a given point on a lane or roadway during one hour, under prevailing roadway and traffic conditions.

3. Practical capacity- The volume chosen without the traffic density being so great as to cause unreasonable delay, hazard, or restrictions to the drivers' freedom to manoeuvre, under prevailing roadway and traffic conditions.
Although Highway Capacity Manual provided valuable knowledge during post-war era, it later became evident that, with the continuous extensive research and subsequent improvements in technological standards, it was actually deficient in many ways. New concepts and findings were derived to replace old and obsolete material. So, in 1965, a totally revised edition of the Highway Capacity Manual was published. The definition of capacity was changed. Possible capacity became 'the definition' of capacity: "Capacity is the maximum number of vehicles which had a reasonable expectation of passing over a given section of a lane or a roadway in one (or two) direction during a given time period, under prevailing roadway and traffic conditions". A comprehensive description was provided for all relevant aspects influencing capacity/level of service for a variety of rural and urban road systems, thereby establishing a complete methodology for determining the capacity of any part of those systems at various levels of service. This methodology incorporated procedures for determining capacity, service volumes, and level of service. Since its publication, the Highway Capacity Manual (second edition) had been considered as the main reference for road systems capacity used by traffic engineers, civil engineers, and planners worldwide. Moreover, research has continued since 1965 to improve existing techniques and explore new areas with as yet untackled problems. Consequently, a third edition is being drafted, and is scheduled for publication in mid-1985. Changes and new inclusions in the third edition are:

1. New subjects such as; public transit, pedestrians, and bicycles, which use as the capacity criterion person-capacity as well as vehicle-capacity.

2. Instead of using hourly volumes to describe average conditions within the hour, the new manual focuses primarily on the peak 15-minutes of flow.

3. Criteria for level of service are related to quality of service as defined by the highway user, rather than on criteria based on traffic volumes.

4. More emphasize has been placed on queueing and delay.
5. Procedures are more complex, but they reflect current driver behaviour and traffic characteristics.

6. More emphasis on computer implementation in the procedures.

But before proceeding on any further, it is important at this stage to cut short any confusion arising from using the terms; volume, demand, and capacity interchangeably, because their meanings are dissimilar in major respects:

- **Volume**: The measurement term referring to the quantity of movement per unit time.
- **Demand**: The term which quantitatively describes the incidence of travel under given conditions.
- **Capacity**: The volume-carrying capability that a particular facility can accommodate at the limit.

For transportation systems in general, Manheim(69) defined the capacity of any component as: "The maximum number of items per unit of time that can be processed through the component". In airport systems, however, there is no unified terminology for capacity, that could be found in technical literature, and even some inconsistencies were exposed regarding the representation of various parts of the system in capacity studies. A clear example is the inclusion of airside only in airport capacity studies. In technical literature, most references still ignore the landside capacity completely, and even use airport capacity interchangeably with its airside capacity(7,11). The conference on Airport Landside Capacity(70), organized by the Transportation Research Board in 1975, distinguished for the first time between airside and landside capacities. However, it did not furnish any promising unified definition for airport landside capacity comparable to that set by the Highway Capacity Manual for streets and roads.
In conclusion, it seems that there is no consensus amongst researchers and experts in this field on a unified terminology for landside capacities. Searching through the technical literature, a variety of definitions and terminologies that are all so descriptively different was found, as presented herewith:

1. In the conference on Airport Landside Capacity two definitions were brought up, but both of them failed to provide a useful definition for landside capacity;
   - Capacity is the physical provision required for a given demand at a given time at a specified level of service. When capacity is defined as ultimate or maximum capacity, it is generally associated with the lowest level of passenger service. Capacity and level of service are interrelated and should always be considered together. Several different levels of service can be defined for a given maximum capacity service rate.
   - Capacity is the physical capability of a facility to provide a service. This service can be flow or storage. Therefore, capacity can be measured either as flow in terms of items processed per unit time, or as storage in terms of items stored.

2. ACAP research Program: McCullough and Gualda defined airport landside capacity as: "The maximum level of demand of a given pattern that can be imposed on an airport system, subsystems, or components in a given interval of time without violating any specified level of service criterion for the airport system, subsystems, or components. It is a direct function of: level of service of the system, subsystems, and components, the period of time over which capacity is to be determined, and the pattern of demand of passengers, baggage, aircrafts, and ground vehicles for the airport".

3. Transport Canada adopts a terminology that divides the airport system into three major subsystems: groundside, terminal building, and the airside. The capacity definition for the terminal buildings includes three specific types of capacity:
- **Static capacity** is the storage potential of an area or facility usually expressed as the number of occupants which the area or facility can hold at any one moment. It is a function of the total useable space available and the level of service to be provided.
- **Dynamic capacity** is the maximum processing rate or flow of pedestrians (occupants) through a subsystem per unit time. The actual time unit selected as the measurement index depends on the nature of the operation.
- **Maximum practical throughput capacity** is the overall capacity of a subsystem to accommodate traffic demand within the space and time standards of a particular level of service, thus it is a measure of the combined dynamic and static capacities of all facilities.

4. IATA, the International Air Transport Association, adopts a terminology that is similar to that of Transport Canada but has a different breakdown of airport systems' capacities, as stated in IATA's Airport Terminal Reference Manual(8):
- **Runway system capacity** in terms of aircraft movement rate in a given period.
- **Apron system capacity** in terms of number of aircraft stands available.
- **Terminal capacity** in terms of passenger and baggage throughput per hour.

In another IATA publication(56), capacity was defined as :" A variable measure of throughput or system capability related to the level of service being provided". The definition of capacity was further subdivided into static, dynamic, sustained, maximum, and declared capacities. The first two were identically defined as those of Transport Canada:
- **Sustained capacity** is the maximum traffic flow for the chosen time unit that can be achieved over a sustained period, in accordance with safety requirements and acceptable levels of service.
- **Maximum capacity** is the maximum traffic flow which can be achieved for the chosen time unit only, but not sustained for a longer period, in accordance with safety requirements and acceptable levels of service.
- **Declared capacity** is the limiting capacity and capacities in numeric terms on individual facilities and resources, notified to the appropriate bodies to be used in preparing the flight schedules.

Other IATA publications\(^{(71,72)}\) introduced such expressions as: capacity calculation formulae, facility evaluation equations, and equivalent peak hour, however, these expressions were found to be irrelevant for this research.

5. In its Airport Planning Manual\(^{(9)}\), the International Civil Aviation Organisation- ICAO, recognized the importance of the terminal capacity as a major component of master planning: "In planning, the aim should be to ensure that capacity satisfies demand within practical economic limits and to provide capability for increased capacity as demand increases with traffic growth". Although ICAO did not provide an explicit definition for airport landside capacity, the following quotation reveals ICAO's views on the subject: "Capacity of a passenger building or its segments, is usually expressed in terms of achievable movement rates or, in some cases, of actual population for a given area. Although different criteria are in use for movements rates, the basic concept employed is one of the number of movements per unit time, where the appropriate unit of time depends upon the particular application. In some cases, it may be desirable to plan capacity so as to satisfy an estimated peak demand, but normally a figure somewhat below this will be more realistic due to costs involved and space required. What is important is to match the capacities of different segments in the processing, so that inadequate capacity in one operation does not restrict the overall flow ".

6. The British Airports Authority (73) defined capacity in general as: "The volume of traffic that can be sustained at a defined service level within a stated period."

5.2 **INTERPRETATION OF CAPACITY IN TRANSPORTATION SYSTEMS**

The capacity of a transportation system can be considered as the system's supply. The volume or number of items using the system at different times usually changes quite considerably, according to the demand imposed on the system. As the number of items per unit time (volume) varies, the level of service (in whatever expression used) provided by the system, thus experienced by the traveller, would also change. Quoting from Wohl and Martin (49): "...Volume and density turn out to be the most convenient pair of variables to use as a basis for discussing traffic flow and for formulating theoretical approaches." In this respect, it is useful to consider some of the characteristics of the physical highway system (whose basic elements are: driver, vehicle, and highway), and the manner in which the system as a whole operates, then try to set out basic operating conditions that should be satisfied as required by any explanatory theory. Using density to express level of service, defining operating conditions would require:

- Volume = 0, when density = 0.
- Volume would increase up to a maximum value (capacity), and starts declining before density reaches its maximum.
- Volume = 0, when density reaches a maximum value (jam density).

Therefore a 'fundamental diagram' could be drawn to schematically describe the behaviour of operating conditions. Figure 5.1(a), shows a typical volume-density fundamental diagram (49).

In general, for a particular supply level or specific physical layout, as the demand level or service volume changes, so does the resulting level of service. Similarly and by the same token, another 'fundamental diagram' could be established; the important
Figure 5.1 Fundamental Diagram for Highways; (a) volume-Density, and (b) Speed-Volume.
relationship between speed and volume, where speed is considered as the level of service identifying factor\(^{(48)}\), i.e., service measure. Again, operating conditions would require:
- When the volume = 0, space mean speed = 0.
- As speed increases, corresponding volume will decrease after reaching a maximum value.
- Volume approaches 0, when space mean speed is maximum.

This 'fundamental diagram', the speed-volume relationship\(^{(49)}\) is schematically presented in Figure 5.1(b).

An important attribute of operating conditions should be introduced and emphasized on here, namely, congestion; a significant phenomenon that strongly influences the performance of transport systems. Manheim\(^{(69)}\) diagnosed congestion and its roots: "Congestion arises out of the conjunction of two factors. The first is that every process has a finite capacity. The second is that every process has stochastic characteristics; there is some degree of randomness in both the demand placed on a process and the ability of the process to service those demands ". So, congestion is a phenomenon associated with processing, where supply and demand are brought together to interact (servicing activity), and when there is a situation where supply can not match heavy demands, queues and delay will consequently occur.

Since congestion necessitates queues and delays, models of congestion are provided mostly by Queueing Theory. Extensive research has been conducted implementing Queueing Theory's approach to solve problems in urban and transportation planning, and traffic engineering. To mention a few of the numerous references on this subject, text books in traffic systems\(^{(49)}\), urban planning\(^{(74)}\), operations research\(^{(75)}\), and queueing theory\(^{(76, 77, 78)}\).

However, the implementation of Queueing Theory in airport terminals capacity analysis was not very successful. Although Queueing Theory approach had been successfully utilized to solve many problems on the airside, as evident from work done for the U.S. Federal Aviation Administration by Douglas Aircraft Company.
et al(79), it was not that successful on the landside. In many occasions, it was proved that Queueing Theory could not be implemented in modelling landside operations. Lee(78) concluded this fact after analysing distributions from observations made at Heathrows' ticket counters. O'Leary(27) and Ashford et al(80,81) also confirmed this fact with observations taken at Manchester Airport. Gualda(28), in the ACAP research programme, pointed out that after observing arrivals and processing distributions in three Texan airports, the queueing theory approach to modelling airport terminal processing facilities had to be abandoned, because those distributions did not comply with basic assumptions of the queueing theory. In all those cases, because actual distributions did not follow and comply to those assumed by the queueing theory, the mathematical tractibility was lost, hence the analysis would then reach a dead-end. For a more detailed description and thorough discussion on application of queueing theory to transportation terminals, refer to Powell(82).

Now, comparing highway systems and airport systems (airport terminals in particular), the following facts are relevant:
1. Speed-volume relations are inapplicable for terminals, simply because speed (per se) of passengers in terminals is irrelevant and insignificant to the operational performance and characteristics of air terminals.
2. Volume-density relations could be implemented in air terminals, yet the limiting conditions are dissimilar. Moreover, this selection is not as significant to the system operation as in highways.
3. The most influential relation that should be adopted for analysis of operation at airport terminals is that between demand volumes and corresponding congestion, which could directly interpret the performance of processing facilities at the terminal, against some recognized service standards. A 'fundamental diagram' similar to that of the highway system, could be furnished, through considering the following conditions:
   - When demand volume = 0, congestion is non-existent.
76.

When demand volume increases, congestion builds up gradually, where its two attributes; delay, and density, increase exponentially until theoretically approaching infinite levels. Such a fundamental diagram, depicted in the methodology presented in this thesis and designated as the 'performance model', would systematically interpret the performance of terminals' processing facilities in terms of variation in congestion measures (i.e., delay and density) at different demand levels (volumes).

As in the case of highways, congestion relations, i.e., volume-delay and volume-density, could be adopted and utilized to provide a useful interpretation of capacity by describing the performance of a single facility against varying demand levels and patterns.

5.3 WHAT IS TERMINAL CAPACITY?

It has been previously mentioned in Chapter Three, that the terminal building is composed of three basic types of facilities; processors, storing-holding areas, and links, the capacities of which are fundamentally different. Processors' capacities are expressed in terms of items processed per unit time, while for storing-holding areas they are expressed in terms of items present at the facility (i.e., stored) at any time. Links' capacities are expressed in terms of the number of items that can simultaneously pass through a given section (per unit time). Terminal capacity is generally expressed in terms of passengers passing through the terminal per unit time; it is not the expression for the three types of capacities separately, nor is it the summation of all of them. It is this fact that contributes to the complexity of interpreting the capacity of the whole terminal in terms of the capacities of its components. The airport terminal is composed of facilities linked together forming a uniquely structured system. The facility that experiences the greatest congestion at any instant during operation (therefore violations to the set service standards are
encountered), would be the 'weakest link in the chain'. Provided that all facilities are essential to operation with varying degrees of importance, that particular facility that violates service standards would be the most susceptible to causing system breakdown. It is the capacity of this facility that defines system's capacity, being the closest to the overall terminal capacity.

However, systematic determination of the terminal capacity from the capacities of its components and facilities, is very difficult, mainly because:

- The effect of stochastic operations at one facility, on the operations of all other facilities.
- Fluctuations of demand, and the variability and relative instability of its characteristics on the performance of individual facilities.
- Unique structuring (kind, size, and sequence) of the terminal facilities to perform collectively the terminal's designated function of transfer of passengers and their baggage between air and surface transport modes.

All these factors would have the inevitable consequence of making the effect and influence of one facility on the others that much more unpredictable.

5.4 BALANCED CAPACITY

It was suggested in previous research(83), that it would be more efficient operationally to have some kind of balance struck between the measures of performance (e.g., delay) of the system's control units (i.e., processing facilities). To demonstrate the relative importance of facilities, performance measures could be pro-rated accordingly. For a particular demand level imposed, each facility would perform differently according to its specific capabilities in accommodating various demand levels (i.e., capacity). Could there be a situation of 'balanced capacity', where all separate facilities constituting the airport terminal
perform in harmony?. Due to the difficulties in interpreting terminal capacity systematically in terms of its components' capacities, it is even more difficult to obtain a condition where capacities of all terminal capacities are reasonably balanced, to avoid extreme cases of congestion or underutilization of facilities at different demand levels. When the performance of every facility is checked and compared against service standards reasonably set to compromise between the desires of users and the economic considerations imposed on or dictated by the operator, there will always be instances of congestion or underutilization as governed by traffic intensity \( p \), which is the ratio of demand (arrival rate \( h \)), to the supply (processing rate \( u \)).

Balanced capacity conditions imply that traffic intensity \( p \) is continuously maintained at such a level that congestion and underutilization could be contained within allowable margins. This will undoubtedly necessitate the alteration (almost instantaneously) of facility capabilities to match the oncoming demand. However, every facility has a specified capacity (i.e., an upper bound for number of passengers that can possibly be processed by that facility at a given time interval), which could not be exceeded. The only way to process more than this volume (i.e., capacity), would be to change capacity itself through increasing number of operational channels of the facility. In doing so, there will be a redistribution of traffic intensity in all other facilities. Eventually, this iterative process will converge to an equilibrium situation, where the capacities of the processing facilities of the chain are mutually matched and reasonably balanced.

Unfortunately, the situation is not as clear as this argument implies, because balanced capacity could not be systematically achieved, due to:

1. The increase or decrease in capacity is a step-function. The overall processing rate (capacity) of a facility could not be conveniently altered, but the number of operational channels could be changed. Consequently, the overall capacity of the facility will be altered by a factor equivalent to the processing
rate of a single channel. On the other hand, Paullin(84) suggested that congestion normally follows a continuous curvilinear function. When capacity is altered for one particular facility, it will automatically incur imbalanced situations at other facilities at or near balanced conditions. In effect, this process will imply one of two facts; either the process will not converge at all, or it will converge only at situations where there are unrealistically large number of channels for different facilities.

2. The capacity of a processing facility, by definition, is the ultimate unexceedable volume that could be handled at any time. Changing the capacity of a processing facility would be possible, only when the number of operational channels is altered. In addition, facilities are contained in the physical space of the terminal building, where they occupy fixed parts of that space whether operational or idle. As a consequence, monitoring capacity to match imposed demand continuously, is infeasible from a practical viewpoint.

3. In implementing queueing theory in analyzing operations of processing facilities, the analyst is confronted by difficulties arising from the fact that major assumptions of queueing theory (attainment of steady-state conditions, and suitability of distributions) rarely hold in airport terminals, and is not the best means of operational analysis in such an environment.

4. The stochastic nature of demand prevents the pursuit of optimization for balanced capacity problems. If demand were virtually stable and deterministic in nature, the problem would be reduced to one of optimizing the components' capacities and matching them together against a given demand.

In summary, the balanced capacity condition for terminal facilities, could not be implemented conveniently or systematically, mainly because of the incompatibility between the stochastic and dynamic characteristics of demand, and the relatively deterministic and static nature of the supply.
5.5 INTERPRETATION OF TERMINAL CAPACITY

Overall terminal capacity could be considered as the net achievable capability of the terminal system in performing its basic function over a stated period of time, while conforming to specified service criteria applicable to its corresponding facilities. Throughout this research, capacity of facilities are interpreted as follows:

1. HOLDING-STORING CAPACITY: The storing capability of a facility, expressed as the number of occupants the facility can hold at any one moment, at the specified service standards. Only the effective area or useable space available in that facility should be considered when densities are calculated.

2. LINK CAPACITY: The achievable capability of the linking facility to accommodate pedestrian flows passing a given point in a unit of time, under a specified level of service criteria. It is usually expressed in terms of pedestrians per unit width per unit time.

3. PROCESSING CAPACITY: The most probable achievable capability of a particular facility in accommodating and processing demand levels and patterns imposed on it in a given interval of time, conforming to specified level of service criteria. It is expressed in terms of numbers of passengers processed per unit time at a certain level of service.

5.6 SUMMARY

Intended primarily as introduction to subsequent chapters, this chapter provides a preview of relevant aspects of capacity in broad general terms, particularly related to the airport terminal environment. It starts with basic definitions of capacity as in highways and traffic flow theory, it then presents a summary of all definitions related to airport terminals as traced and cited in technical literature, and states the interpretation of the different forms of capacity. Discussion raised and concepts
introduced in this chapter, will back up and supplement arguments on capacity/level of service considerations, which lead to the development and implementation of the proposed methodology that is presented in the next chapter.
The methodology proposed as a means of systematically evaluating and assessing the performance of airport terminal facilities, is presented and discussed in this chapter. Acknowledging the substantial restraints imposed on and difficulties associated with conducting research and gathering information related to airport operations, this methodology is intended to be simple in structure and moderately easy to implement, and is devised to minimize information collection effort. The problems normally confronted at airports in acquiring information, were clearly experienced throughout all stages of this research. These problems greatly influenced the methodology, but also had their beneficial effects by streamlining the method towards minimal information requirements. Simple measures and practical techniques were adopted, that minimally interfere with airport operations and reduce the need to approach responsible parties for information.

6.1 OBJECTIVES

The main objective of the methodology, is to establish practical, easy to implement, reasonably realistic, and systematically efficient procedures capable of providing, through quantitative measures, a clear interpretation and proper assessment of operational conditions of the processing centres at airport terminals. This approach necessitates defining some fundamental
principles that could facilitate the setting up of appropriate service standards for terminal facilities, preferably based on simple, effective, and realistic measures.

Subsequently, derived service standards could be used to evaluate the performance of the terminals' processing facilities. This may be accomplished by establishing a properly graded level of service framework, which would be practically utilized to distinguish between different levels of operational performance. In this context, this methodology could be a useful instrument to airport managers, operators, planners, and other airport-related organisations, and would provide a mechanism capable of linking components' capacities with some well-recognized service standards.

Accumulated information compiled for different airports will undoubtedly enhance planning and design of facilities, and would subsequently lead to more adequate standards of space allocation in new airports, as well as better assessment and efficient management of operation in existing ones.

6.2 CRITIQUE OF CURRENT PRACTICES

It was established earlier that there is a high degree of subjectivity in the methodologies and practices of the planning and design of airport terminals. Essentially, there are no formalized design procedures, but rather loosely knit, mostly empirical, collection of approaches, concepts, selective design criteria, and accumulated knowledge, used by airport-related organisations and consultants. The basic elements that should be considered in the design process of airport terminals, mainly: measure of design, and criteria chosen for design, are not fully justified in current practices. The design measure most commonly used is the peak hourly flow, and the criterion for design is based on this measure. In spite of the great importance of seasonal and daily variations in patterns of traffic on
operational performance of the system, it is only the peak hourly
demand that is usually included in capacity analysis and for
planning purposes, although it (peak hour) might not necessarily
represent the worst situation. Current practices of airport
terminal facilities design adopt the relation between peak hourly
flows and annual flows as the design criterion. This criterion
includes such expressions as: Typical Peak Hour Passenger (TPHP)-
used by the U.S. Federal Aviation Administration(14), Standard
Busy Rate (SBR)- formerly used by the British Airports
Authority(16), or Planning Peak Hour Passenger (PPHP)- used by
Transport Canada(17). These expressions are empirically defined
and appear to have been arbitrarily developed. They are derived
according to the statistical consideration of using a confidence
limit in planning, that reflects the decision of compromising
between efficiency in accommodating annual flows and economy by
choosing a design hour that is not the highest. This approach was
meant to be equivalent to the 30th-Hour Volume concept widely
used in highway capacity analysis practices. All current
approaches to airport design and capacity analysis implement this
criterion; selecting a design peak hour as a fixed ratio
(percentile) of the annual number of passengers to determine size
of airport(14), estimating facility requirements per equivalent
aircraft(16,17), or for planning purposes(13,43). The Highway
Research Board suggested this approach in 1950(47) for designing
rural and urban highways in the U.S., where it was used as the
design criterion that would justify necessary expenditures of
funds to provide extra capacity needed:" If hourly traffic
volumes (as a percentage of annual daily traffic) is related to
the number of hours in one year with traffic volumes exceeding
specified hourly volumes, the slope of the curve changes rapidly,
and it is at this point (knee of the curve) that ratio of
benefits to expenditures is near the maximum ". This criterion
was reinstated again in the 1965-edition of the Highway Capacity
Manual(48): "The selection of an appropriate value (design hour
volume) as the hourly volume to be served is, thus, a compromise
between annual service provided and cost". However, there are certain shortcomings associated with this approach, which include:

- The prediction of future volumes or usage of a facility, is treated as being independent of design capacity.
- It is arbitrarily assumed that the method gives the most economical cut-off point of design that would provide a beneficial level of service, without any proper economic analysis of the actual situation to justify this assumption.
- Neglect of the effect on future traffic volumes of the shift and relocation of the 'knee of the curve', due to the phenomenon known as the 'learning effect'.

Consequently, all current approaches lack structural flexibility, have averaging effects. As put by De Neufville(53), they are: "Oversimplistic, accommodating the whole on average", and are highly invariable and insensitive towards different demand levels. These expressions are void of any consideration of representing the stochastic nature of operations and the time-variant influence of demand on the performance of facilities. They exclude the effects of time-variation by destroying the chronological order of demand, especially daily-hourly demand, from the analysis of operations and the selection of design criterion. Their assessment of operational performance is virtually stripped of the important dynamic features of randomness of demand, because one of the major measures of performance, namely congestion, is the direct result of randomness in the operation of service facilities(85).

De Neufville(53) recognized the deficiencies of this approach: "...First, it is erroneous to focus on averages; it is the local extremes that will limit the performance of a facility. Second, the loads on any particular facility need to be taken over its critical period, the time over which the transient surges in traffic build up congestion. If we fail to do this, we will underestimate the degree of congestion that will occur". So, what is really needed is an alternative approach that would fill this gap. Due consideration should be directed towards influence
of stochasticity and time variation of demand on operation, incorporating the dynamics of congestion and queueing phenomena, and implementing a more realistic and effective design criterion. This important consideration is fulfilled in the capacity procedure of this methodology. The demand pattern and level selected for the design criterion represents seasonal, daily, and hourly patterns from specimens of chronologically oriented demand patterns that is extracted from actual traffic information at the airport.

The technical literature lacks any comprehensive service standards that are actually implemented, except those of IATA/BAA(61) that were presented in Chapter Four (Table 4.4), which are intended to be used by IATA based on British Airport Authority's acquired experience in passenger handling. Examining those standards would show that:

1. Their concepts are arbitrarily set; not supported by a definitive concept or based according to an established procedure, their values (levels) are empirically derived, and they do not involve passengers' perception and their viewpoints about service.

2. Contain only two levels (dichotomous structure), yet those levels are unevenly divided, and they do not represent the whole spread of service provided by facilities.

3. At varying demand levels (which is the actual real-world situation), the significance of expressing all standards in terms of 95% of passengers could not be practically justified. These standards were probably meant to be made compatible with the Busy Hour Rate, which involves the provision of service for at least 95% of annual passengers.

The proposed methodology has the merit of considering passengers' perception and their response to operational service provided, for the setting of levels of service to facilitate the grading of performance of operation. These levels are contained in a well-structured framework, based on realistic and effective measures of service that could describe operational performance, and systematically derived by a predefined procedure.
6.3 STRUCTURE AND DESCRIPTION

Structurally, this methodology is so arranged as to be composed of two main sections, presented as procedures: level of service, and capacity.

6.3.1 LEVEL OF SERVICE PROCEDURE

Service standards, by definition, should reflect the views of the public and promote their interests and desires. Keeny (86) specifies that standards should be set in light of the alternatives available and the public values. In our case, they should be set according to perception of the travelling public of the operational and environmental conditions met inside airports, in light of the operational service prevailing (or which could be made available). But do actual standards really represent passengers' interests and reflect their views? Or are their desires and preferences being considered in the process of assessing operations standards at airport terminals?

The three main parties involved with operations of airports are; users (air travelling public), air carriers, and airport operators. It is the unique interaction between all of them (and more other minor parties) that drives airport activities, and keep the airport running and moving in its designated course of providing efficient, convenient, and safe transfer of air passengers and their baggage between surface and air transport modes. The active presence of these three parties is essential for the survival of the airport system, however, their interests and objectives are not necessarily identical, in fact, they could be conflicting. For example, air passengers want to have a brief yet comfortable and enjoyable time spent in the terminal, air carriers look mainly for the economics of the operation in terms of net profit, while the operator is concerned with regulating
this transfer safely, lawfully, and efficiently (usually in terms of the best possible exploitation of capital investment of the airport).

It might be true that interests and objectives of the three major parties are equally important in the overall context of airport systems operations. However, users' considerations are not usually well-defined or necessarily included in the frame, and although it has always been claimed and declared otherwise, it seems that they form the open sided part of the triangle. If carriers are not efficient enough to operate economically, they will soon be out of the market and in the reciever's hands. Therefore, economic operation is their main objective. Airport operators (including governmental agencies) have on one hand to enforce the law and safety regulations (no matter what), and on the other must operate and run the establishment (which, most likely, involves taxpayers money either nationally or regionally) efficiently. Hence their managerial policies and decisions are usually economically motivated with some political influence. It is the user who has to yield to this complex situation, if he or she want to benefit from and enjoy services provided by the system, i.e., air travel.

Certain decisions made with respect to airport and air transport planning would inevitably characterize the system. These decisions are related to the nature, objectives, and priorities of the planning process, the criteria of evaluation, and the definition of problems. These decisions are strongly influenced by philosophically-oriented socio-political issues, which explains the significant differences existing between national practices worldwide. These issues include: concept of the role of government, concepts of public interests, what constitutes public benefits, purpose of commercial enterprise,...etc. Generally, there are two views to these issues that basically reflect the two main economic systems: socialist or capitalist. For the first, there is a unitary view, that society has collective objectives and priorities that can be quite distinct from those
of its members, and certainly should take precedence. This will lead to centralized power and authority in terms of planning, policy setting, and decision making that should fulfil declared national political purposes. For the second, there is an individualistic view, that public interest is nothing more than the sum of the desires of the individuals that constitutes a society. This quotation from De Neufville(3) would summarize this discussion: "A country's concept of the public interest- of what national goals ought to be and how they should be established- is a key to understanding who participates in the decision, what kind of evaluation will occur, and where power will lie. It generally belongs to one of two opposing notions of the public interest; the unitary, or individualistic ". In either case, the public's views and opinions should be represented, whether directly by individuals, or indirectly through the planner or decision maker (who supposedly is acting on behalf of the public and is promoting their desires and interests).

This will bring us to a discussion of how decisions concerning airport operation would effect the public (airport users). The claim that service standards for air travelling public are based upon their preferences and their views of the quality of service they expect to meet, has often been heard of but no proof of this myth has ever materialized. Keeny(86) points out that usually, the people responsible for making decisions that effect the public do not use the public values, but rather have their own set of values that are significantly different. This fact seems to hold for airport terminals, since their service standards were basically set according to carriers / operators values not users'. Obtaining service standards for the air travelling public to be used in assessing performance of operation as undertaken in this work, should not be confused with airport choice within an air transport network as derived according to some service criteria, that are actually based on certain traffic, planning, or economic considerations. It is particularly important to stress that, in the context of this work, these are two unrelated issues.
Another dimension of the problem in consideration, is the employment of available means and adequate methods to set standards that would really reflect the air travelling public's interests and desires. It is essential to adopt some device that can reasonably interpret and quantitatively delineate service standards of passengers in airport terminals. In this section, a level of service procedure is devised for the purpose of delineating distinct levels of operational service, that could be used to set service standards for terminals. In implementing this procedure, service conditions at a facility could be evaluated and assessed in terms of some measure of service, based upon desires of the passengers themselves and their perception to service at a facility subjected to a certain demand level.

It was concluded in Chapter Four that, of all potential qualitative and quantitative factors that might possibly contribute to or influence service standards of airport terminals, delay awaiting service seemed the most suitable, theoretically and practically, for implementation to interpret passengers perception and reaction to operational service. It is theoretically suitable, because it is the major attribute of congestion (with crowding) that affects operational conditions. It is practically suitable, because it is the foremost factor in the minds of passengers that influence their attitudes. Perception and reaction of passengers towards service provided could be conveniently obtained through proper surveys. In these surveys, passengers are asked to state their perception (preferably expressed in distinct levels of satisfaction with service) towards different operational conditions.

As shown in the schematic diagram of Figure 6.1, the level of service procedure follows the steps of: collection of required information, the construction of the passenger perception-response models, and finally setting the level of service framework by defining the service regions.
Figure 6.1 Schematic Diagram of Level of Service Procedure.
6.3.1.1 COLLECTION OF INFORMATION

Information required is collected by means of passenger surveys conducted separately for the two channels: departures and arrivals. The information sought include: delay information, passenger evaluation to service conditions resulting in different delay times, and certain passenger-specific information.

1. Delay Information: The amount of time passengers get delayed or spend in the processing facilities of the terminal at the time of the survey is required in order to check the replies of the passengers against the overall operating conditions that prevailed during the survey period.

2. Passenger Perception and Response: It is the prime objective of the survey, which would facilitate the construction of the perception-response models. In the case of passenger surveys, this is most sensitive part of information sought, mainly because:
   - The way in which passengers could be conveniently directed to state their perception and reaction to service conscientiously and with reasonable accuracy.
   - The ability of the individual passenger to clearly distinguish between three or more different states of satisfaction levels, and to tie each level with a boundary limit (a number).
   - Influence of the passenger's past experience with other airports when expressing the satisfaction level.
   - Probabilities of inconsistent or shifted answers resulting from a variety of causes and reasons as will be seen in the next chapter.

Each reply will constitute a set representing the passenger's perception and response to delay or time spent at a facility, expressed in terms of three distinct levels of satisfaction towards different service conditions ranging from very short to very long times at that particular facility.

3. Passenger-Specific Information: Includes factors related to demand that would identify the individual passenger and differentiate between various flight/passenger categories, such
as flight category, purpose of trip, range of flight (medium or long haul), nationality, and other minor information that the surveyor might find important.

6.3.1.2 BUILDING PERCEPTION-RESPONSE (P-R) MODELS

After all information has been gathered and processed, it would now be possible to construct the perception-response models. The Perception-Response Model is defined as the graphical presentation of the collective attitudes of a category of passengers towards the full range of operational service, expressed in terms of the perception of the passenger population to different amounts of the service measure (representing different levels of operation), and their response to the respective service conditions classified into distinct levels of satisfaction with service. In this work, the percentage of passengers replying to whether a certain amount of time spent (or delay) at a particular facility was perceived by them as: Good/acceptable, just tolerable, or bad/totally unacceptable, is related to amount of time spent (or delay). The conceptual diagram for this model is shown in Figure 6.2. But what is the significance of the P-R models in this methodology? The P-R model is a mechanism that could be practically implemented to derive and set service standards for airports' processing facilities, based on passengers' opinions and reactions towards operational service at those facilities. Mathematically, it represents a form of the role-playing model, but functionally, it serves as a scaling devise to grade operational service in terms of the service measure—time. It is unique amongst the known scaling methods presented in Section 7.7.3. It is a conglomerate of Likert and Thurstonian attitude measuring scales, where three curves demonstrate its operating characteristics: normal (tolerable) resembling the Thurstonian, and an S (bad) and inverted-S (good) resembling Likert. Implementing P-R models could achieve the following goals:
1. Assessment of service for its whole spread covering all probable conditions of service possibly attainable at a particular facility.

2. Convenient superposition and disaggregation of P-R models as related to the categories of passengers/flights, and types of facilities. Several categories of passengers/flights can be merged to form one P-R model, or a single P-R model of a facility can be split into several P-R models for these categories using that facility.

3. Manipulating the graduation (incrementing) of the service measure will help in determining the accuracy desired.

4. Easy determination of the response to service of any percentile of the passenger population.

Nevertheless, in implementing this technique, one should bear in mind the following facts:

1. Perception of passengers to service is relative as well as variable. This is particularly important when setting service standards for group of airports, or at different times during which certain aspects of operation and/or demand had changed.

2. Since it is based on responses of passengers to request by the observer (surveyor) to state their perception to service, these replies could be easily biased by: poor communication, poor wording of questionnaires, confusion and misinterpretation on part of passengers, unrealistic or inconsistent views held by passengers,...etc.

3. A certain degree of implicit hypothecism is involved in the basic principles of the P-R models, manifested by the fact that the passenger is experiencing the service of a particular demand level only, and then extending that to estimating personal perception for hypothetical demand levels, which he or she has not actually experienced.

4. Although P-R models are based on passengers personal perception and response to service, but indirectly; the influence of carriers/operators is implicitly recognized and included within the P-R model. Operational service that passengers actually experience (being the building block and
reference to their response to other demand levels) is assumed to be the kind of service those parties intend to or can provide to the travelling public. Decisions and policies of those parties, that are related to operations and service, originate from their own perception of resources available, regulations enforced by law or operational procedures dictated by the technicalities of the operation, and the various considerations imposed on or induced by the specific nature of the air travel market.

6.3.1.3 ESTABLISHING A LEVEL OF SERVICE FRAMEWORK

The level of service procedure now culminates by establishing service standards in terms of a level of service framework for processing facilities in question. Time values (T1 and T2) delineating the service levels can now be deduced. This is achieved by observing the behaviour of the three curves representing passengers perception and response to the three (or more if desired) states of service: good, tolerable, and bad. The opinion of passengers towards different durations of time spent (or delay) in particular facilities is monitored, and the dominant attitude of the passenger population (in percentage) for a state of service is examined for all increments of time. When a situation exists where there is a shift in perception of the majority of passengers from one state to another, then that point in time where the shift took place, would actually describe a change in service from one level to another as perceived by the majority of passengers. Majority of passenger population is any percentage that shows that one level of satisfaction with service is dominant over the other two. This description is demonstrated in Figure 6.2, by examining the unshaded (blank) area between the three curves. This area is bounded by the 100% line from the top and segments of the three curves (good/tolerable/bad) from the bottom. The point on the service measure scale (Time), where a shift from one curve to another is observed, represents the shift of the perception and response of the majority of passengers from one level to another.
Figure 6.2 Concept of Perception-Response Model.
Normally, when the passenger population surveyed is homogenous, and there is a high degree of consensus amongst them in formulating their opinion about the state of service, changes in levels of service usually occur around the 50 percentile, reflecting the views of the average passenger in population. However, in occasions of non-homogeniety of passenger population surveyed, lack of consensus on service amongst them, or lack of knowledge and confusion on nature of service at a particular facility, changes in the levels of service would not be close to 50 %. Non-homogeniety here implies that the P-R model is actually composed of more than one model, which could be broken down to a number of homogenous groups (e.g., flights) in the survey population. In special circumstances, there could be some large shifts in opinions between extreme states of service resulting in the absence of a middle tolerable state of service (as will be seen in the case of schedule-European traffic in Birmingham Airport study in Chapter Nine), ending with a framework having only two levels of service: good and bad.

6.3.2 CAPACITY PROCEDURE

The capacity of a facility could be determined (relative to a specified service standard) from the relationships derived from the performance function of that facility at different demand levels. To avoid confusion over terminology, and to try to understand fully the nature of these relationships, it is preferable to go back to the basics of transportation systems planning. Transportation is viewed by Manheim(69) as a process in which resources are consumed to produce transportation services in a particular environment. Thus transportation is characterized by a performance function which relates the magnitude of resources consumed \( R \), level of service offered \( S \), transportation option \( T \)- depending on the specific decision taken about design and operation of the system, and the volume of users of the system \( V \), i.e.:

\[
P.F. = \Phi_E(R,S,V,T)
\]
The performance function describes a surface in the four dimensional space \((R,S,V)\) for a given \((T)\). On the other hand, the service function \((S)\), and the resource function \((R)\), are both (separately) functions of \((V)\), \((T)\), and the environment in which the system exists \((E)\), i.e.;

\[
S = \mathcal{S}(V,T,E), \quad \text{and} \quad R = \mathcal{R}(V,T,E)
\]

The environment here includes the physical, economic, and the institutional environments. This interrelationship of \((R)\) and \((S)\) is a fundamental aspect of transportation systems performance. The actual shapes of the relationships will depend significantly on the environment \((E)\), in which a particular system is being operated, as well as on the characteristics of the system itself.

Meanwhile, the classical supply function, could be derived from the performance function to relate the capacity or the volume of users of the system \((V)\) to some function of price. In urban transportation planning and road traffic engineering, the supply function has been referred to as the user cost-volume function, to describe the capacity, level of service, and price characteristics of these transportation systems. However, Morlock(10) pointed out that, apparently, the designation of the user cost-volume function as a supply function is often inconsistent with the usual definition of a supply function in economic theory. In economic theory, the supply function describes the relationship between the price of a commodity, and the quantity of that commodity which will be produced or supplied in the market. It is probable that for this particular reason, the supply function of such transportation systems are referred to as user-cost-volume, or travel cost functions.

The capacity procedure, therefore, establishes the relationship between the service volume of a facility, and some expression that would reasonably describe the service provided by that facility for the users, at the corresponding service volume (demand). The expression for the service standards could be interpreted in terms of average time per user, maximum number of users waiting for service at any time, the density of users per
unit area, or any other suitable expression. In this methodology, the supply function of processing facilities only are derived. Processing facilities are most important to the operating conditions of the airport system, to the extent that they actually characterize the system's environment, and define the function and size of the airport, while other facilities serve mainly as staging and auxiliary components in the overall passenger and baggage transference process between surface and air transport modes. In addition, the argument raised on supply and performance functions does not apply to holding-storing facilities (which have fixed supply functions based on permissible crowding standards), or linking facilities (whose supply function could be derived from the theory of fluids as formerly accomplished by Fruin). For those two types of facilities, existing standards and relationships adopted from literature are sufficient and adequate.

Going back to supply and performance functions, the appropriate means by which these relationships could be established are, simulation techniques. It is usually very costly, and often infeasible to gather required information to construct such relations from real-world operational conditions. So, computerized techniques have been devised and developed to simulate the operation of various kinds of processes. The approach of using simulations to obtain synthesized information on real-world situations has become a common practice in operations research, and is frequently utilized for various problems in many disciplines. The following quotation justifies the use of simulation(88): "Whenever applicable, one prefers to use a simple analytic model yielding closed-form algebraic expressions relating systems inputs and outputs. However, in many cases the simplified condition assumed by solvable analytic models do not hold in the real-world, and more realistic models are too complex to solve- hence simulation. The standard use of simulation is direct; to answer a specific question or to obtain a description of the behaviour of a system as some of its
parameters are changed. Use of simulation to develop and test other mathematical models is conceptually analogous to use of experiments by physical scientists to develop new theory."

As shown in Figure 6.3, the capacity procedure follows the steps of: defining the input parameters, executing simulation runs, and establishing the relations.

6.3.2.1 DEFINITION OF INPUT PARAMETERS

Operational parameters associated with a certain process, define and characterize the behaviour of the performance function of that particular process. Those input parameters include arrival distributions, processing (servicing) time distributions, number of channels, in addition to other less significant parameters:

1. Arrival Distributions:

Arrival (rate and distribution) of passengers to a facility, is the major input to any servicing process. It describes the imposed demand for service at that particular facility. In queueing theory literature, it has been considered as the most important of the basic elements of a queueing model. It is represented by the arrival of entities from a given calling source (finite or infinite) into a servicing process in a probabilistic and time-varying fashion. Mathematically, the probabilistic arrival to and departure from a servicing system is a special case of the Markovian Birth-and-Death Process(91), in which the state of the system changes by at most one (up or down) in any infinitesimal interval. It changes up with a birth (arrival) rate ($\lambda_k$), which is the average rate of births (arrivals) when the system contains (k) entities, and changes down with a death (departure) rate ($\mu_k$), which is the average rate at which deaths (departures) occur when the number of entities in system is (k). The distribution of interarrival times (times between successive arrivals of entities) is equally
Figure 6.3 Schematic Diagram of Capacity Procedure
important in the mathematical designation of the process. One of the most widely used arrival distributions, especially in queueing systems is Poisson, which is associated with the discrete modelling of total random arrivals, and plays an important role in the development of queueing models for many real-life situations(85). Larson and Odoni(75) even go to the extent of using 'poisson' as a synonym to 'arrivals'. More detailed description of the Poisson distribution is found in Gerlough and Barnes(90). An important relationship exists between Poisson and the Exponential distributions. In effect, the Exponential distribution could be derived from Poisson(85). If the Poisson random variable (discrete) represents the number of arrivals per unit time, the Exponential random variable (continuous) will represent the time between two successive arrivals, i.e., whereas the interarrival time is Exponential with mean = 1/λ, the number of arrivals during time interval (t) is Poisson with mean = λt. The Exponential distribution has the two distinctive properties, that the probability of one and only one outcome will occur during a small time interval (Δt) is proportional to (Δt), and that the occurrence of the outcome is independent of occurrences of other outcomes - Markovian Forgetfullness Property(91). The suitability of Poisson distribution in describing the arrival incident, and the comparative ease and simplicity of mathematical manipulation and handling, coupled with the realistic phenomenon of randomness of arrivals (stochasticity and the Forgetfullness property), all warrant the implementation of this distribution in modelling arrivals to processing facilities. For the airport environs particularly, the implementation of Poisson distribution for modelling arrivals to the airport's processing facilities, has already been verified and recommended by previous research(92).

2. Service (Process) Time Distributions

Service time distribution is the other important element of a queueing model, that could define the actual departure of passengers from the servicing facility- hence its capacity in
handling passengers. The expression consists of the rate of processing or servicing (and departure from the system), and the pattern of occurrence of individual service times or frequency distribution of service times. Through determining the frequency of occurrence of various values of service times throughout operation, this major input to the servicing process could characterize capacity of the servicing unit of a processing facility. In simulation, service times are randomly selected from a particular frequency distribution with a given statistical parameter (usually the mean). Apart from this statistical parameter, the shape of frequency distributions is of special importance in simulation. Since it is derived from the population of service time values from which the frequency distribution was initially constructed, it is the means of re-establishing the particular distribution and making it known to the simulation technique. The decision of which particular type of frequency distribution should be used in the simulation process actually depends on the sample size from which the distribution was constructed:

I: If the sample size is very small, implying the lack of knowledge on the random variable (service times), then the distribution would probably be uniform (rectangular), where the probability that service time values randomly drawn would fall between maximum and minimum values is equally likely. A step further would be the triangular distribution, where there is a cluster around the mode within the range between minima and maxima, (Figure 6.4a).

II: If the sample size is large enough to represent service times observed over a certain interval of operation, then the behaviour or shape of the distribution should comply with the following logic: there would always be an ultimate lower limit (associated with natural human capabilities of servers), which bounds short service times that could possibly be attained in the real-world operations. On the other hand, extremely high values of service times are probable yet infrequent, because there is always a low probability that it would take the server a considerably longer time (for one reason or another) to handle and serve a particular
passenger than it would take with other passengers. Hence, the upper bound (maximum service time) of the distribution is a little stretched. However, if the servers are reasonably efficient, the passengers are predominantly well-experienced with airport operations and procedures, and the processing operation is more or less regular, then the distribution will show a tendency towards normality. The most commonly adopted distributions in similar systems are the Gamma family; Exponential, Erlangian, and Chi-squared, because they are used to describe random variables bounded at one end, specifically in queueing theory applications(93). The Negative Exponential distribution is a Gamma distribution with a shape factor = 1, and it is the model for the time of a single outcome to take place if events occur independently at a constant average rate(93). The use of this distribution assumes large variability; with a mean of $\mu$ and variance of $\mu^2$, it has one of the largest variances associated with it of all distribution types(91). Since prevailing operating conditions, characteristically, have considerably irregular and variable service patterns, this distribution is particularly suitable for airport terminals' processing facilities. Generally, the Exponential distribution is widely used in queueing theory applications for its mathematical simplicity and tractibility. Erlangian, is a special case of Gamma distribution (the shape factor is an integer). It is the sum of independent and identically distributed Exponential random variables(94). An interesting property of Gamma distributions, is that as the shape factor increases, the distribution approaches normality(93). In practice, previous research(95) showed that service times observed at airport terminals fitted both Exponential and Erlangian distributions (as shown in Figure 6.4b). This is expected and confirms the above discussion. So, it could be concluded that the shifted Negative Exponential distribution should be adopted for conditions where servicing conditions are somewhat varying, and Erlangian distribution should be used for more regular servicing conditions.
Figure 6.4. Processing Times Distributions.

(a) Rectangular and Triangular.

(b) Observed and Exponential / Erlangian.

(c) Normal.
III: Using normal distribution, (Figure 6.4c) would result in generating service times that are unrealistic and would not represent real-world situations.

3. Number of Channels

If service time reflects the supply of a processing unit, then the number of operational channels arranged in parallel would indicate the overall supply of the facility, and it is this parameter that defines the capacity and characterizes the size of a facility.

6.3.2.2 SIMULATION RUNS

A proper simulation technique is adopted to execute a number of simulation runs sufficient to establish the performance model. Those runs should cover all service volumes that may possibly be processed by that particular facility. Depending on the specific features of the technique and the information required, output of these runs would typically include statistics on the following:

1. Time (delay or total time spent) per passenger at the particular facility, expressed in terms of the mean, maximum, minimum, standard deviation, and frequency distribution of occurrence.
2. Queue length, expressed in the same statistical parameters as in (1) above.
3. Percentage utilization of servers, expressed as the mean, maximum, minimum, and standard deviation.
4. Number of observations (sample size) from which statistics are calculated.
5. Other more specific information of interest, produced upon the modeler's request, depending on available facilities and capabilities of the simulation package.
Aspects related to methods of modelling processing facilities and conducting simulation runs are described in detail in Chapter Seven, while Chapter Eight presents and discusses properties and capabilities of different simulation techniques.

6.3.2.3 PERFORMANCE MODELS

From the synthesized data generated by means of simulation, it would now be possible to construct the performance models, which describe the following relationships:
1. Average time (in terms of delay or total time spent) per passenger in the particular facility at different demand levels.
2. Maximum queue length or maximum number of passengers waiting for service at that facility at different demand levels.
3. If required, the average percentage of server utilization at the facility, related to different demand levels.

Samples showing performance model for processing facilities could be found in Chapter Nine.

6.4 OPERATIONS ASSESSMENT: CAPACITY / LEVEL OF SERVICE RELATIONS

After the two procedures of this methodology have been presented, it would now be possible to establish a relation between capacity and service standards of facilities in consideration. This is achieved by marking the boundary values of the level of service framework previously obtained from the P-R models, onto the performance model derived by the capacity procedure. Effectively, operating conditions at different demand levels in that facility are assessed and evaluated in light of the operational service prevailing as perceived and graded by the passengers themselves. By dividing the performance model into segments or regions where resulting operational service is considered as good, tolerable, or bad, boundary values (in terms of demand levels) could also be marked on the performance model to designate the capacity of that for the corresponding levels of service. By so doing, a
systematic method of operational assessment is obtained, where capacities of processing facilities could be directly linked and related to service standards.

The presentation, description, and application of the methodology, with discussions on various aspects and features associated with it, incorporate topics in different subjects. So, after the reader will find that the remaining chapters are so arranged as to cover capacity and level of service procedures for each aspect at a time.
CHAPTER SEVEN

COLLECTION OF REQUIRED INFORMATION

7.1 NATURE OF INFORMATION

Collection of information required for implementing the methodology fall into two main classes, corresponding to methodology's two procedures: capacity and level of service. Pieces of information sought are diverse in nature, and vary in method of collection. Their characteristics depend to a large extent on their relative importance and their influence on the performance of the terminal as a system. This diversity arises from the uniqueness and sensitivity of the airport terminal environment, where many parties involved are responsible, in different ways, for performing various activities of the system's operation. All those activities should be synchronized and performed in mutual harmony, each one fulfilling certain objectives or goals (albeit dissimilar or even contradicting) in a predetermined time and space, to successfully achieve the objectives of processing, supervising, serving, ensuring safety and comfort, regulating, accommodating, catering, and controlling thousands of people going through this system round the clock.

Generally, information sought in airports are primarily related to:
- Pedestrian traffic flow characteristics of passengers moving inside various facilities of the terminal.
Aspects that specify the characteristics of demand at a particular airport, such as: passengers' characteristics and composition of demand, arrival patterns, temporal patterns of demand (seasonal, monthly, weekly, daily, hourly).

Operational characteristics of facilities under consideration, such as: physical layout, size (in terms of number of units comprising a facility), relative arrangement and sequence of facilities in the system, detailed regulatory procedures and other measures imposed in each one, working practices adopted, and other supporting operational data.

Information that could help in categorizing service offered, and aid in establishing service standards for particular terminal facilities.

There are different means and methods to collect the aforementioned information, and certain factors that dictate the selection of the proper method should be considered. These factors include: the purpose for which the survey is needed, the required level of detail, extent of aggregation or disaggregation, time-dependency, particular situation and operational conditions at the airport, parties associated with the information collection effort, and the resources available.

7.2 COLLECTING INFORMATION IN AIRPORTS

7.2.1 INFORMATION COLLECTION METHODS IN AIRPORTS

Information collected inside airports is often carried out by means of airport passenger surveys; surveying techniques that vary according to their objectives, content, techniques adopted, and scale. The purpose of airport surveys, as Braaksma(96) points out, could be as diverse as their techniques, but in general, airport surveys are of the following types:
1. Direct observation, incorporating head counts and time readings either manually or with help of a device. It also includes tape-recorded data-logging(95), where a continuous record is kept by recording into a tape recorder, or specially designed field portable and programmable calculator.

2. Photographic techniques are sometimes used to observe operation at certain locations unsuitable for direct observations, where complete sets of information are continuously recorded, and subsequently, data could be readily extracted from films at will with no potential waste of information. Techniques include recording by cinecamera, video camera, or time-lapse photography.

3. Tagging, involves the tracing of passengers movements throughout the terminal by means of an identifiable tag which the passenger carries. Time is entered on it at every stage of the intra-terminal journey. In this sense, the passenger is actually acting as an 'agent' in timing his or her own movement, but with minimal active participation. Many surveys were successfully conducted using this technique. In Manchester Airport Survey(81) where it was called 'the Card System', and in Germany(97), and in Canada(96) where the method was named 'time-stamping'.

4. Tailing, where the surveyor follows the movements of a passenger through the airport terminal during the period of observation. Detailed information can be gathered, however, it could prove to be quiet expensive and obtrusive. This technique was adopted in the Heathrow Passenger and Baggage Survey(98).

5. Interviews; the surveyor would undertake a personal interview with passengers, ask the questions, then record the answers on the specially prepared questionnaire. This technique is adopted to determine the specific characteristics of demand and terminal population, or when the type of information sought could not be collected by any of the preceding techniques. Being a fully controlled survey, its relative cost is rather high(99). Consequently, the number of interviewing stations should be minimal, and the survey conducted when activity levels are low and the desired sample size is small(100).
6. Collected questionnaires, which are self-administered, are distributed by the surveyor to passengers, and when completed returned. This technique is most suitable when the respondents have little time to spare in answering questions of the interviewer. Collection of completed questionnaires would be either, at some point inside the terminal just prior to leaving, or with the mail-back technique, the respondent would later mail the completed questionnaire to the surveyor. Since the control of the surveyor on the respondent in this technique is lower than in interviewing, and returns of completed questionnaires depend largely on the good-will of the respondent, it would be expected that the response rate would be noticeably low. In general, success of such surveys is highly dependent on the use of a simple, concise, and readily understandable questionnaire(100).

7. Statistical records and documented data: In many occasions, certain valuable information already exists in files of documents, worksheets, and statistical records of organisations and agencies associated with airport operations collecting data mainly for their own administrative purposes. If they are unpublished, then permission to access this source of information would be required to extract whatever information found useful. For instance, all information related to air transport movements could be extracted from ATC tower logs. Similarly, much useful information could be obtained from records and files of airlines and airport handling agencies, airport and civil aviation authorities, government agencies, and even concessionnaires. Undoubtedly, airport records could prove to be a valuable source of information. With coordinated organization, efficient statistical handling, accompanied (if practicable) by computerized compilation, storage, and handling systems, a substantial airport operations data base can be made available, directly extracted from files that are usually shelved and forgotten. This could be managed and maintained cost-effectively. However, in spite of its usefulness, De Neufville(3) warns that: "...Peculiarities acceptable to airport organisations that are unappropriate for planning and design purposes, require most
careful interpretation of data related to airport traffic ". Many national organisations have already realized the importance of such information. The Federal Aviation Administration(101), Civil Aeronautics Board(102), and Air Transport Association of America(103), annually publish information compiled for the top 100 U.S. airports. In the U.K., Civil Aviation Authority(104), furnish similar annual publications. Internationally, the International Air Transport Association- IATA(8) encourages airport authorities world wide, to upgrade their data acquisition techniques, by recommending the use of special statistical forms for that purpose, and to enhance practices and techniques of forecasting future demand. Another international organisation, International Civil Aviation Organisation- ICAO(106), also publishes annual statistics for its contracting members.

Usually, airport surveys use a combination of the aforementioned methods. The appropriate combination, is decided after careful study and discussions with all associated and involved parties. A conclusion is arrived at after conducting several trial tests and pilot surveys to explore the appropriateness and feasibility of each. Certain factors should be considered when implementing the proper method of information collection in the survey. They include:

1. Scope and objectives of the survey and goal of collecting the particular type of information.
2. Approval and cooperation of all parties responsible for those parts of the airport under their jurisdiction, for which the survey is to be conducted.
3. Cost range estimated, and resources available or allocated for the survey.
4. Considerations regarding the interference with normal operating conditions, obtrusiveness, or other inconveniences caused to passengers by the survey.
5. Local and operational conditions at the particular airport (or any of its parts), which either favour or prohibit the use of one survey method or another.
6. Level of detail of survey, the study as a whole, and degree of accuracy desired (which, in turn, is linked to sample size, hence cost).

In Heathrow Passenger and Baggage Survey (98), the methods of information collection chosen were: direct 'static' observations, tailing technique, interviews, and data extraction from files and unpublished reports.

LUT's Manchester Airport Survey conducted in 1974 (95) implemented the following techniques in the main survey: random tagging technique (Card System), direct observations, interviewing, and time-lapse cinecamera photography.

In the survey commissioned by the U.S. Federal Aviation Administration to collect calibration and validation data for the ALSIM model (99), the techniques used included: self-administered questionnaires to the airlines, interviews with passengers, and direct observation of operations at various facilities in the terminal proper.

7.2.2 PROBLEMS ASSOCIATED WITH AIRPORT SURVEYS

Numerous problems and difficulties associated with airport surveys exist, which could adversely affect the information collection process. The sources and causes of these problems could be organisational, operational, or of survey-administrative nature.

1. Organisational: Due to the large number of parties and organisations involved in the operations of the airport, negotiating and coordinating with all of them is a difficult but essential task. Getting the approval of airport authority to conduct the survey should be the first step, to be followed by arranging for the approval and collaboration of other parties.
However, a situation might arise where the airport authority would approve first to include all parts of the airport in the survey, but to decide later (probably in the last moment) to restrict the survey only to certain parts of the airport. This could be a serious blow to the survey, which could evidently curtail months of preparations, waste valuable resources, and jeopardize the study as a whole. This situation was experienced during this work in the Birmingham International Airport Survey, and as will be mentioned later in Chapter Nine.

In other occasions, the airport authority would seem reluctant to help in providing information, either because they think that such type of information should not be revealed for security, political, or economic reasons, they do not have such information ready, or simply they do not feel obliged to provide that information to the surveyor. Again, this case was also experienced in this work as briefly mentioned in Section 2.2.1.

Airlines might also have reservations on some aspects of the survey. As was actually encountered in Birmingham International Airport Survey, the airlines using the airport might agree to provide some information from their own work-sheets concerning daily throughputs and load factors on their flights, but only on the condition that the surveyor should refrain from publishing any material containing disaggregate airline throughput and load factor figures. The obvious reasons for this attitude, is the airlines' public image, and influence of market competitiveness between airlines.

The most 'sensitive' organisations in the airport towards surveys are the governmental agencies (i.e., immigration, and customs). Their apprehension to participate in surveys or approve to conducting observations, stems from the sensitivity of transactions performed between them and passengers, and
confidentiality of the control measures adopted by them. Hence, information associated with governmental agencies' operations is often practically unobtainable.

The role of the Unions should be accounted for at all stages of the survey. In Heathrow Passenger and Baggage survey of 1972(98), the survey timetable had to be altered, due to delays in negotiations with the airport employees unions.

2. Operational: Possible interference of the survey with the normal operating conditions in the airport to the extent of impeding the flow of passengers, is the prime reason for the hesitation of airport authority to grant approval to conduct surveys. Moreover, the passengers might object to participating in the survey because they might feel apprehensive towards its obtrusive nature, they are press of time which they can not afford to waste if they participate and answer questions, they feel that they are simply not prepared or ready to participate, or they find the questionnaire too long or too difficult to answer.

3. Survey-administrative: Some problems might arise from restrictions on the availability of finance, manpower, or equipment, which might exert unanticipated restraints during the survey period.

7.3 DATA BASE FOR METHODOLOGY

The data base essential for the implementation of this methodology, is divided between capacity, and level of service information. These information may be airport-specific, varying between different airports. Separate sets of information should therefore be collected specifically for each airport.
Alternatively, in certain occasions, generalization could be feasible, using available information from one airport for use at another.

7.4 CAPACITY PROCEDURE INFORMATION

Predominently, establishing the performance model requires information related to the description of the operational characteristics of the system or any of its components. It is either demand-related, or facility-specific information. The first kind, is mainly constituted of information associated with the portrayal of patterns that characterize the demand on servicing facilities. It is interpreted in terms of arrival distributions of the various categories of passengers using the airport at the facilities in consideration. The second, is usually presented as distributions of processing and waiting times, number of channels, and probabilistic distributions of queue lengths. Other miscellaneous information is equally desirable to better understand operational characteristics, and to enhance a realistic representation of operation. Such miscellaneous information includes relative arrangement of facilities, specific behaviour of passengers and airport personnel, and other minor regulatory measures and operational procedures.

Logically, all information necessary to construct performance models of processing facilities could be gathered by means of direct observations, but most of the time this could not be feasible. To start with, construction of performance models require the inclusion of different demand levels (yet with reasonably similar demand patterns), waiting times, and queue lengths, at predetermined equal intervals throughout operation at those demand levels. Some demand levels (especially the highest), could not have been experienced yet or met in the airport, in fact they may never be met. Moreover, due to the stochastic
nature of the systems operations, it could not be possibly known exactly when to expect and observe a particular demand level of a certain pattern. In short, it is often not possible to collect the information required to construct performance models of facilities by means of direct observations. A reasonable alternative would then seem to be to synthesize required information through simulating the systems operations. Simulation is a transfer devise that converts systems description- input parameters, into output of interest, that may differ from the real system's output by a certain degree of distortion. This is caused by oversimplification or non-representational features in the model, and quality of the random number generating function. In simulation, not only demand levels and patterns, but the whole activity could be simulated to any level of accuracy and detail. As will be discussed later in Chapter Eight, the desired accuracy of the output of simulation would determine the level of detail of input, and what one will get in the output of simulation would most certainly be dictated by the initial input.

Finally, with current computer technology, the use of simulation could prove to be very convenient and advantageous because:

1. It is much more cost-effective than any other equivalent means of data collection, including surveys.
2. Enormous amounts of various operational information with varying levels of detail and degrees of accuracy can be readily generated.
3. Information that would be impossible to obtain accurately on site (e.g., future or indeterminate happenings) could easily be gathered by simulating their operational conditions.

7.4.1 DEMAND PATTERNS AND ARRIVAL DISTRIBUTIONS

Demand patterns could act as "fingerprints" that identify and categorize airports and characterize their operations. These patterns greatly influence capacity / level of service
considerations at airports' servicing facilities, mainly because it is the time variation of demand on facilities (ultimately arrival rates and distributions) that virtually dictates attainment of capacity. Quoting from De Neufville (3): "...The performance of a service system is, indeed, sensitive to the patterns of loads imposed, especially when they approach its capacity". Consequently, the variations in patterns of demand, not its absolute magnitude measured over some prespecified time span, should be considered in assessing performance of servicing facilities, because airports with facilities having different traffic patterns may create different levels of congestion, even though they handle the same averaged demand on a busy day.

Demand pattern variations could be: seasonal—varying monthly round the years, weekly—where daily traffic patterns are noticeably different, or hourly—varying from one hour to another in any given day. Causal factors behind those variations and fluctuations in demand are extremely diverse, complex to analyse, and certainly, this is beyond the scope of this work. Demand patterns are governed to a great extent by the airlines flights schedule, which is itself affected by two underlying factors: the development of a timetable of flights to meet a certain anticipated pattern of passenger demand, and the assignement or allocation of aircraft and/or crew fulfilling a given timetable (107). Selecting the schedules is, in turn, dictated by various socioeconomic, environmental, political, operational, and technical considerations imposed on all parties involved. Methods of analysis associated with airlines scheduling used to predict air travel demand are: dynamic programming (108,109), heuristics (107), and disaggregated modelling of air travel demand and air travel choice (110).

In the context of this methodology, it is necessary to obtain the seasonal, weekly, and hourly traffic flows. From these flows, the time-varying demand for service at the facilities in consideration is defined, and a particular demand pattern is
selected for use in the analysis. The time-varying demand is interpreted as the arrival rate and distribution of passengers at the facility, which are the major input to the simulation models. Generally, demand patterns are normally obtained from statistics compiled by airport authorities and/or airlines for administrative and operational purposes. Often, especially in large busy airports, compilation of such information is systematically computerized usually on continuous basis.

Throughout this methodology, the distribution of arrival rate used for processing (servicing) facilities and in constructing performance models, is the Poisson distribution. To simplify simulation, the arrival is modelled by using interarrival times instead of arrival rate. It was established earlier that Poisson arrivals can be interpreted as Exponential interarrival times. In SLAM computer programmes of modelling operations of facilities, arrival distributions are represented as Exponential distributions with given interarrival times (Time Between Creations- TBC) as the parameter. Values of TBC are directly extracted from the demand pattern (and level) in consideration. It will be seen later in the next chapter, how SLAM (of all the simulation languages considered) provides a uniquely efficient mechanism to model realistically the arrival distribution. By referring to Appendix C, where computer programmes for the modelling of the processing facilities are listed, it is noticed that part of the model programme is a FORTRAN-written user function (FUNCTION USERF) that actually models arrivals to the facility in 20-minute time intervals. Arrival of passengers to a facility in any 20-minute interval throughout operation period considered, is directly extracted from the pattern of demand presented as flows of passengers into the facility over time. Time Between Creations would then be the time period (in this case 20 minutes) divided by the mean arrival rate during that particular interval. Arrivals could then be totally defined by its two basic parameters: interarrival time (TBC), and arrival distribution (EXPONential). Except for the fact that mean
interarrival times are assumed constant during the time interval depending on demand level and pattern, stochasticity is maintained in the process by the random generation of exponentially distributed interarrival times. Arrival of passengers (creation of entities) is accomplished by randomly selecting TBC values from an exponentially distributed generating function with mean number of arrivals in the interval $= \frac{1}{\lambda}$.

Determination of the duration of unit interval was logically chosen as a compromise between selecting higher intervals (30 minutes or an hour), that could result in grossly averaging data sought hence losing most of its value, and selecting lower time intervals (ten, five, or even one minute), which would incur excessive computer usage with an unnecessary high level of detail that is not actually required. Theoretically, the determination of this interval is important and critical in the context of assessment of operational performance, because it specifies the unit of time scale during which the fluctuation of demand is measured. It may even be unequal for different facilities depending on the characteristics and nature of operation of each. The importance of determination of this interval was recognized by De Neufville(53) where he defined it as 'the critical period over which transient surges in traffic build up congestion'. He even suggested some ranges for that period for different terminal facilities depending on the precise nature of traffic. For corridors, concourses, and piers it is 5-10 minutes, for baggage claim areas it is in the order of 30-45 minutes, while for ticket counters it could be as high as an hour. Braaksma(55) also realized the significance of that critical period, and suggested the addition of a time duration factor resembling this interval to service standards. IATA(56) adopted Braaksma's view and recommended including 'sustained period' in capacity/demand management, and created the expression 'sustained capacity', but it was never practically implemented. Use of a sustained period was also cited in a BAA paper by Turner(112), where it was implemented to express the pattern of arrival to check-in, in
terms of percentage of total passenger arrival sustained for a certain period of time. Bearing in mind both that the scope of this exercise does not necessitate a particularly high level of detail, and the similarity of operation of processing facilities, 20 minutes seems a reasonably adequate period to monitor any tangible fluctuation in demand during operation.

By definition, performance models describe the variations of a certain service measure over different demand levels covering normal as well as extreme activity levels. Thus in essence, they could portray supply/demand interactions. Due to the nature of operation and the influence of stochasticity, obtaining real-world perfectly consistent patterns of demand over different levels of activity is close to impossible; it is tantamount to virtually asking to be able to predict randomness! Those inconsistencies in simulated demand patterns are, therefore, inevitable, and should be accepted with a certain margin of tolerance. So, the element of stochasticity inherent in the process will ensure deviations in the pattern of the simulated demand levels from that of the projected demand levels. It should be emphasized here that projected demand levels are purely theoretical. They are artificial in the sense that they are synthesized data, derived by multiplying the datum level, which was initially extracted from traffic patterns of real-world conditions, by a 'Projection Factor'. This factor is selected only for the purpose of synthesizing operational conditions that would represent all demand levels that could be anticipated or could possibly be handled by the facility. Apart from that, its exact value is not of particularly great relevance in the procedure. Nevertheless, deviations in simulated demands could be monitored and rectified on trial and error basis, until they could be considered as acceptable. Since the performance model of a facility is based on the assumption that demand patterns at all levels remain more or less similar, these patterns should be continuously monitored and the assumption checked. The 'Simulation Index' is adopted for this purpose to check that
assumption and control the degree of similarity in patterns between simulated and projected patterns. In any simulation run, the Simulation Index (SI) is:

\[ \text{SI} = 1 - \frac{\sum_{i=1}^{N} \frac{X_i - x_i}{X_i}}{N} \]

Where:
- \( X_i \) = Projected arrivals in time interval,
- \( x_i \) = Simulated arrivals in time interval, and
- \( N \) = Number of time intervals.

Selection of a value for SI depends on the acceptable tolerance desired, governed by the level of accuracy required and computer usage. For practicality, to minimize computer utilization, an acceptable Simulation Index (SI) of 0.90 seems reasonable.

7.4.2 PROCESSING (SERVICING) RATE AND DISTRIBUTION

In Chapter Six, discussion on processing (service) rate and distribution concluded that:
- The most suitable distribution to be used for airport processing facilities is the shifted Negative Exponential distribution.
- For a particular processing facility, the service rate is interpreted as the mean (average) number of passengers serviced by the servers during a time interval at that facility. Alternatively, the mean service time per passenger is used.
- Due to the fact that most service data are comparatively similar in all airports considered, and because of the limitations on data collection mentioned earlier in the chapter, service times and rates used for constructing the performance models are gathered from different sources and used interchangeably between airports. Throughout this work, source of service information is referred to whenever used.
Generally, two kinds of processing exists: batch and continuous. Batch processing incorporates the time-limited use of the facility by each flight, where passengers are processed in groups or batches according to their particular flights. Examples of this kind are the check-in and baggage claim, where each facility is 'opened' and 'closed' at prespecified times relative to the specific flight timing, only for the processing of passengers on that particular flight. Service times for check-in facilities are categorized according to flight sector by the handling agencies operating in airports considered. Categorization include: charter inclusive tours, schedule-European, and schedule-long haul flights. However, due to the complexity and unsystematic performance associated with the baggage claim facility, lack and unavailability of needed information within the handling agency itself, or other organisational reasons (security, industrial relations, or commercial confidentiality), baggage claim facilities could not be included in the capacity procedure.

The other kind, continuous processing, does not differentiate between passengers according to their flights, but rather classifies them according to the specific features of the particular facility in consideration. Arrival of passengers to such facilities is, therefore, continuous, the distribution of which is dictated by the aggregated flow and collective demand of all flights. Examples of this kind includes the security check and passport control for the departure channel, and immigration control and customs clearance for the arrival channel. Within a particular facility, the split of passengers between its divisions is important to specify the estimated demand on each. Examples of this are the split between EEC and non-EEC passengers for immigration, and split between Red and Green channels in Customs. Collecting information on all these aspects is equally important, and values for each facility and each airport are presented in Chapter Nine. Direct observation and photographic techniques are the suitable methods of collecting information on service times, IF permitted.
7.4.3 NUMBER OF OPERATIONAL CHANNELS

The number of available channels during operation is important to the simulation process, because it defines the capacity of the facility as a whole.

Adopting SLAM simulation technique facilitated more realistic modelling of terminal facilities. In the case the facility is composed of more than one channel of unidentical servers to process more than one type of entity, SLAM implements the conditional probabilistic branching of entities between those different channels. In case the facility is composed of several (identical) servers, SLAM would adopt the SELECT statement, where it branches the oncoming arriving entities (passengers) into the available servers, occasionally queueing them if the servers are busy. Details on these two aspects of SLAM will be presented in the next chapter.

Information regarding the number of operational channels is obtained through the inspection of the facility in question, and by enquiring about the splits of passengers from the related agencies with the help and assistance of airport authorities.

7.4.4 OTHER MISCELLANEOUS INFORMATION

In order to obtain reasonably accurate and representative simulations, additional data may be required, they include:

1. Particular arrangement of facilities: The arrangement of facilities relative to each other varies from one airport to another, and between countries as well, with no specific standard design or layout adopted. Consequently, the facility is modelled exactly as it stands and functions in the context of terminal operations at the particular airport. For instance, in East Midlands Airport, one passport control counter preceeds a single
security check unit, while in Birmingham Airport it is the reverse. In Manchester Airport, on the other hand, there are four security check units followed by three passport control counters.

2. Specific behaviour of passengers and/or airport personnel: There are some aspects that should be carefully observed and included in modelling. A good example of this could be seen in modelling the Customs clearance activity as will be presented later.

3. Regulatory measures and operational procedures imposed at each facility are very important and could spell service times distributions at that facility. However, these measures and procedures are not standardized and may be different between airports. So, they should be observed carefully and considered separately from similar facilities in other airports. Modelling the security check is a clear example of this situation, which is going to be discussed in the next chapter.

4. Service discipline: Since the various service transactions imply some kind of interaction between the server and all passengers demanding service, the manner in which the server ranks passengers for service is important. The typical service discipline most widely used in queueing processes is the FIFO (first-in-first-out), where the order or rank of passengers in the queue is specified by their arrival time to the facility.

7.5 LEVEL OF SERVICE PROCEDURE INFORMATION

Unlike information required for the capacity procedure, level of service information is mostly associated with personal judgement and individual reaction towards quality of service offered. Service conditions are reflected to an observer through personal views and reactions of the air travelling public to service offered. So, the observer should select appropriate service measures that would be most suitable for isolation by observations, collection, and lend themselves to analysis.
The objective of the level of service procedure is to try to erect a frame for service standards that reasonably reflect passengers opinions and reaction to service within context of practicality of the authentic system. Effectively, the task is two-fold; first to decide upon a service measure that is susceptible to isolation, and secondly, to facilitate collection of information associated with it so as to enable the structuring of some practical mechanism by means of which the level of service framework could be successfully established.

As seen in Chapter Four, service standards for similar systems used service measures that could be quantified, either directly (by simple measurement or by applying a scaling technique), or indirectly through subjective grading. In highway capacity analysis, it was seen that service measures adopted were both qualitative (e.g., freedom to manoeuvre, traffic interruptions, driving comfort, and convenience to drivers), and quantitative (e.g., speed, travel time, and safety- in terms of accidents records). Similarly, in a more comparable environment, service measures used in the operational analysis of pedestrian systems were seen to include qualitative measures (conditions of flow relative to freedom of selecting individual walking speeds, relative ease of cross-and-reverse flow movements, and the ability to bypass slow moving pedestrians), and quantitative measures (flow volumes and pedestrian area occupancy).

Chapter Four concluded that the most promising service measure that could adequately be used for processing facilities in airports is congestion with its two attributes: delay and queues. These measures are quantifiable and suitable for collection.

Thus far, the first part of the task is resolved. The remaining sections are dedicated to resolving the second.
7.5.1 DISCUSSION ON PASSENGER PERCEPTION-RESPONSE MODELS

Devising the proper mechanism to be utilized to establish level of service framework, was seen in Chapter Six to involve the construction of passenger Perception-Response Models. P-R models are implemented because of their capability of providing a full description of the reaction of the passenger population towards service, by stating their views on perception and response to requests of how would they individually assess service conditions at a processing facility. Those service conditions, in terms of a service measure (e.g., time), representing different service and activity levels, range from very short times (no delay), to very long times and delays. Here assessment of service conditions is carried out according to a three level grading system, describing good, tolerable, and bad service conditions.

The aggregation and superpositioning properties of P-R models, as seen in Chapter Six, is a valuable asset to the model. By this means, a detailed level of service framework could be achieved (with disaggregated service standards) for different types of facilities as well as for various categories of passengers.

Another advantageous feature of P-R models, is the fact that service standards could be interpreted for any percentile of passenger population desired; for the 95th percentile as used in BAA/IATA standards, for the 50th percentile representing the perception of the average passenger, or any other percentile.

Also, selecting the appropriate method to collect the information required to build the P-R models could be decided upon by the planner after investigating all aspects of the particular situation. Basically, the planner has two available alternatives: to approach the passengers themselves for the information sought, or to obtain the required information from experts who are closely associated with airport operations and act by proxy for the passengers.
In collecting P-R model information, utmost care and consideration should be directed towards designing the passenger survey, particularly the questionnaires. Interpretation of passengers to service conditions, their perception to those conditions, and their response to survey questionnaires, should be thoroughly investigated and carefully studied well in advance. That seems absolutely necessary in order to try to eliminate the likelihood of possible distortions and shifts in the results, and to make sure that the passenger actually understands the question as it was meant to mean. What should be emphasized on here are the underlying effects of the factors that mainly contribute to those inconsistencies of passengers replies—especially the influence of the socio-psychological factors. In social surveys, of which passenger surveys are only one type, replies of respondents to questionnaires may be seriously affected by those factors. In order to have a good grasp of the implications of the socio-psychological influences on individuals' views and responses, the broad subject of social surveys and expected attitudes will be reviewed in the next section.

The P-R model in its basic concept, is only a form of scaling device that is utilized to distinguish between different service conditions—expressed in terms of a service measure (time), as perceived by a group of people (passengers). Effectively, the P-R model could be classified as a scale, similar in many ways to those developed by social scientists to help in describing attitudes of individuals and to distinguish between different responses towards various social phenomena or any aspect of life covered by a social survey.

7.5.2 PASSENGER CATEGORIES AND FACILITY TYPES

Passenger categories, and to a lesser extent facility types, would normally vary from one airport to another, depending on the characteristics of the air transport system in general, planning
considerations and the specific design of the airport in particular, socio-economic and demographic attributes of air traffic, and the influence of prevailing demand levels and patterns of the airport in question. In this work, data were collected from within U.K. regional airports environment, hence passenger categories and facility types considered are those typical in such environment. The international airports of Manchester and Birmingham were taken as case studies, and East Midlands Airport was selected for the pilot survey.

P-R models were constructed on the disaggregated level for passenger categories and facility types in those airports, and as follows:

A- Passenger categories (according to flight sector) included are:

1. Charter (Inclusive Tours), which constitutes a large proportion of total traffic (around 65%).
2. Scheduled service, which is further subdivided according to flight range into: Schedule-European ranging between 15% to 20% of international traffic, and Schedule-Long Haul (intercontinental) forming approximately 5% of international traffic.
3. Common Travel Area, traffic from Ireland and the Channel Islands, constituting about 15% of total traffic. It was included only in Birmingham Airport survey, because it shared the use of baggage claim and customs with the arriving international traffic.
4. Domestic traffic, which includes traffic from other UK inland airports, was not included in this study.

B- Facility types, are divided into the two channels:

1. Arrivals, which contain immigration control for EEC and non-EEC passengers, baggage claim, and H.M. Customs and Excise control with Red and Green channels.
2. **Departures**, which contain check-in (which is subdivided according to the category of passengers and their specific arrival pattern, i.e., charter I.T., schedule-European, and schedule-long haul), security check, and passport controls.

In addition to those facilities, P-R models for the combined processing facilities in a channel were also constructed, but only for descriptive reasons. These were not included in the capacity procedure.

### 7.5.3 ALTERNATIVE APPROACHES TO P-R MODEL BUILDING

Generally, the alternative methods to collect information required to build the P-R models are:

1. **APPROACHING PASSENGERS**

Turning to the air travelling public or passengers population—whose interest and convenience the system is presumably operating, to collect the necessary P-R model information, implies that viewpoints of the passengers are included and directly considered in the setting of service standards. Consequently, those standards should reflect the accumulate perception and response to service of individual passengers. It is important that passengers have certain attributes or be of such quality (as individuals), that would reassure the planner that P-R models based on information extracted from them would be consistent, realistic, and reliable. The main requirements for passengers as the basic units of population, the planner should be investigating are:

- Reasonable level of personal time-estimating capabilities, where an individual can judge, with reasonable tolerance, the lapse of time without unnecessary reference to a time-measuring device. In technically developed societies, this is not
considered a major problem, because in our culture all aspects of life are strongly tied to time, and individuals become trained to improve their estimation of time-lapse.

Awareness of the passengers that service provided to them is to be compatible with the nature of air travel. Important factors they should consider include: fare of air ticket and corresponding quality of service, imposed safety, regulatory and operational procedures (presumably set for the benefit and interest of the public), and other airport-specific or air travel demand-related considerations. Passengers should not be let to interpret service from an unrealistic and personally motivated angle, and if they are not well informed and properly instructed about this particular aspect in the survey questionnaire, certain inconsistencies might arise.

The general assumption that service standards are set for normal situations of airport operations.

This approach was chosen as the appropriate means of collecting required information for building P-R models for the case studies presented in Chapter Nine.

2. APPROACHING EXPERTS

An alternative to collecting P-R model information directly from the air travelling public, is to collect that information indirectly from individuals or groups of individuals that are well experienced in passenger processing and the service conditions that passengers find suitable. Such experienced individuals are well-acquainted with airport operations, particularly passenger handling. Based on their knowledge, those individuals are capable of giving a reasonably representative view about service from the viewpoint of the average passenger. An example of this approach in setting service standards in airports, is the BAA and IATA standards, which were founded on the experts' views on service, not on the passengers'.
In circumstances where it is infeasible to obtain passengers' views and perception to service directly from them, this approach can be pursued by forming a panel representing all parties associated with air transport activities, or airport operations. This panel may include different experts from airport authority departments, airlines, airport handling agencies, tour operators, governmental agencies, and civil aviation authorities. This panel will then be asked to assess service according to prespecified service measures (e.g., time passengers spend in facilities), using a well-defined grading system. Replies of those experts could be considered equivalent to those of passengers. In the case that replies would appear to be relatively inconsistent or that they did not properly reflect the real situation, then discussion between the panel's experts might be encouraged to iron out any inconsistencies through feedback from those discussions. This would be very similar to the Delphi technique. However, this would prove to be very lengthy and time consuming practice, especially if number of participants is large. The ideal number of participants is difficult to specify, but 20-25 participants seems reasonable, being large enough to reduce probabilities of dominance over the panel.

A similar procedure for a completely different environment and context, was used when Kleine(113) conducted a survey of experts' views of discrete simulation languages. The purpose of this survey was to assess the popularity and use of different simulation languages, and try to scale this assessment according to four measures: familiarity and experience, preference, evaluation of ease-of-use, and evaluation of capability. Nine simulation languages were included, and 103 responses were solicited by direct request from expert users of simulation languages. Replies were statistically analysed. Popularity and utilization scaling systems for each measure were established. This study demonstrated the approach to practically achieve the
ranking of the nine simulation languages considered for the four measures included as perceived and evaluated by their expert users.

This approach is particularly suitable for environments where certain aspects of air travel are not well-defined. In such environments, social, economic, and demographic variables would not be similar to those of the environment of the case studies in this work. This approach would be particularly suitable for establishing service standards for the airports of the Third World, where replies of individual passengers are not likely to be useful to the planner.

To demonstrate the implementation of this approach, a small-scale panel of experts survey was conducted in LUT, where 25 experts representing 14 European airports and one Middle Eastern airport were requested to reply, first, on how would they assess service conditions in the processing facilities at their airports, then try to estimate service conditions for a hypothetical airport of a given annual throughput whose processing facilities are similar to those of their airports. Detailed discussion on this survey together with the resulting P -R models, is in Chapter Nine.

7.6 SOCIAL SURVEYS

The objective of this section is to provide a broad review of the basic principles of social surveys and to state some of the relevant aspects that would enable the efficient design of the passenger survey on a sound basis. It is not intended to explore all corners of this subject, consult all references, or provide a literature review for research in this particular topic, but only to provide some advisory guidelines and explanatory comments that would help in launching a successful passenger survey. The two main references consulted are, Moser and Kalton(114) and the Handbook of Survey Research(115), but the following references
were also helpful: Gardner(116), Oppenheim(117), Simon(118), Nachmias(119), Young(120), Babbie(121), Hyman(122), and Smith(123) in the planning of social surveys, and Belson(124), Berelson and Steiner(125), as well as Oppenheim(117) on the topic of questionnaire design and attitudes.

7.6.1 DEFINITION AND USE OF SOCIAL SURVEYS

Social surveys were defined by Moser as: "surveys concerned with the demographic characteristics, social environment, activities, or the opinions and attitudes of some group of people". Surveys in general, are essential to the two important stages of modern research: formulation of a hypothesis, and testing that hypothesis. However, they are not substitutes for ingenuity and thought. The purpose of surveys was seen(114) to involve 'the provision of descriptive and explanatory information'. Gardner(116) later added 'predictive and evaluative information' to these purposes. Such surveys could be used in a variety of ways covering various fields and topics, including regional and transportation planning, population census, social research, market research, and public opinion polls.

7.6.2 PLANNING AND DESIGN OF SURVEYS

Important issues relevant to the passenger surveys should be examined well in advance to ensure efficient planning that will lead to the success of these surveys. Survey design is decided upon in the light of what is practically feasible and theoretically desirable. Since allocated resources would, most likely, be the major influential individual variable on the design of the survey, due consideration should be given to the following factors, so as to achieve maximum advantageous utilization of funds:
1. Purpose of survey.
2. Accuracy required in results.
3. Cost per sample.
4. Time considerations.
5. Mode of questionnaire administration.
6. Labour involvement and requirements for personnel training.
7. Population from whom information is sought.

Implementation of passenger surveys would normally necessitates the following phases:
1. Preliminary.
2. Exploratory.
3. Selection of objectives and survey methods.
4. Final overall plan.
5. Pre-tests and pilot surveys.
6. Main survey.
7. Data processing and analysis.

This sequence was observed in the methodology implementation, but emphasis was focussed on the last three points. In the remaining sections of this chapter discussion on pilot and main surveys will be raised.

7.6.3 PRE-TESTS AND PILOTS

Pilot tests and pre-tests, are an important step in developing survey instruments. Their primary function is to uncover potential problems and errors in questionnaires, because it is extremely difficult, even for experienced social scientists to write a questionnaire with no confusing or ambiguous questions. Moser indicated that: "It is exceedingly difficult to plan a survey without a good deal of knowledge of its subject matter, the population it is to cover, the way people will react to questions, and, paradoxically though it sounds, even the answers they are likely to be given ". So, pre-tests and pilots, are used to obtain the necessary knowledge to design the questionnaires, and have a 'feel' of what is to be anticipated in
the main survey. They should always be treated as indispensible parts and important stages of any survey. However, one should not be carried away with excessive piloting of surveys, because as pointed out by Oppenheim(117): "Almost every aspect of a survey inquiry can be made the subject of pilot work, so obviously, a line has to be drawn somewhere", and that is where experience and common sense would have their influence in organizing pilot work. Usually, pre-tests are carried out as exploratory step in early stages of piloting, where they could involve: lengthy unstructured interviews, 'silent' observations, talks with key informants, or the accumulation of essays written around the subject of the inquiry(117). Pilots can provide guidance to the surveyor on:

1. Adequacy of sample frame from which it is proposed to select the sample.
2. Variability within population to be surveyed.
3. Non-response rate to be expected, so as effective measures could be taken to increase response, or alternatively increase the sample size.
4. Suitability of method of data collection and mode of administration, its relative cost, accuracy, and likely response rate.
5. The most valuable function of pilots is to test the adequacy of questionnaires, ease of handling them in field, efficiency of their layout, clarity of definitions, and adequacy of the questions themselves (type of questions, their simplicity in wording, clarity and absence of any terms that may be uncomprehensible to the respondent).
6. Indicating probable costs and duration of main survey, and any chance of possible economies that could be made.
7. Testing organizational efficiency, and monitoring practical aspects of field work.

Regarding required number of samples, in general, a pilot test of about (20-50) cases is usually sufficient to discover major flaws in a questionnaire before they damage the main survey(115).
Therefore, after carrying some of the 'exploratory steps' mentioned above, it was decided that a pilot should be conducted in the East Midlands airport to explore the different aspects of obtaining this kind of information from passengers, and to test the suitability of questionnaires. Another pilot, Panel of Experts Survey, was conducted to examine the alternative of approaching experts to obtain the required information.

Finally, this subsection is concluded by these remarks on pilots quoted from Moser(114): "Pilot surveys nearly always result in important improvements to the questionnaires and a general increase in the efficiency of the inquiry. Moreover, the pilot survey is the researcher's last safeguard against the possibility that the main survey may be inefficient."

7.6.4 DESIGN OF QUESTIONNAIRES

Design of questionnaires is more of an art than science(114). Logical steps for designing questionnaires begin with defining the type of question that should be asked, i.e., factual questions or opinion (more widely called attitude) questions, and outlining the principles of question wording. Attitude questions are more sensitive and fundamental, and generally, more troublesome and complicated than factual questions, mainly because:
- Uncertainty whether the respondent, in any meaningful sense, is aware of what is asked about and 'knows' the answer.
- A person's opinion on virtually any issue is many-sided, and probably there is no one correct answer to the survey question, but the answer the respondent gives, will largely depend on the aspect of the issue that is uppermost in his or her mind.
- The problem of assessing the intensity of opinions and personal attitudes must inevitably be faced, because on any given subject, some people feel strongly, others just moderately, while some are indifferent.
Answers to opinion questions are most sensitive to changes in wording, emphasize, sequence, and many other factors, than those to factual questions.

Nevertheless, Moser (114) gave some advisory rules and general guidelines of particular relevance to successful wording and overall structuring of questionnaires, which are summarized in:

1. Avoid asking general and insufficiently specific questions, where an answer on a specific issue is actually required.

2. Use simple language and avoid technical terms and jargons in surveys of the general public, and in choosing the language for a question, the population being studied and problems investigated should always be kept in mind.

3. Ensure clarity and always remember that a simple question is more readily understood than a long complex one, and is more sensitive to wording problems. Ambiguous questions, particularly double-barrelled ones, are to be avoided at all costs, because vague questions encourage vague answers.

4. Clearly explain and make it crystal clear to the respondent what is actually required of him or her to answer, because replies are totally based upon respondents' understanding and comprehension of question asked, not on what was actually meant by the question.

5. Ordering of questions needs to be carefully planned when putting individual questions together to form the questionnaire, because their order may influence response rates, especially when one is primarily concerned in opinions that are basically unstable or marginal. In this regard, the questionnaire should preferably begin with straightforward and interesting questions which the respondents will have no difficulty in answering, not on complicated or sensitive topics.

6. Avoid leading questions, which by its content, structure, or wording, lead the respondent in the direction of a certain answer.
7. Personalized questions should always be carefully considered, and void embarrassing questions on subjects which people do not like to reveal publically.

8. Since most factual questions involve the respondent in recalling information, questions associated with memory should always be carefully studied, because the degree of accuracy with which information is recalled is a basic determinent of quality of his or her response.

Belson(124) conducted an exploratory study designed to investigate respondents misunderstanding to 29 types of survey questions tested, and to provide insight into the process and principles involved in such misunderstandings. The following are his recommendations regarding the design of survey questions, put as warning statements to the surveyor:

**AVOID:**
- Loading up the questionnaire with a lot of differing or defining terms.
- Offering long alternatives as possible answers to a question.
- Use of words that mean something different if partly misheard (in interviews) or misunderstood (in self-administered questionnaires).
- Giving the respondent a different task to perform.
- Giving respondents a task that calls for a major memory effort.
- Offering alternative answers to a question that could both be true.

**BEWARE OF:**
- The strong tendency of respondents to answer questions about their behaviour in terms of what they usually do- as distinct from what they in fact do.
- Use of a qualifying clause, especially at the end of a question.
- The tendency of respondents to start answering as soon as they have heard or read enough to start formulating a reply.
- The very strong tendency of respondents to narrow down broad concepts, especially vague ones, in some selective and personally appropriate way, and a tendency in others to broaden a narrow concept.
- The tendency of respondents to apply their own special qualifications to a question.
- The often strong influence of the question's content upon the interpretation of specific terms in that question.
- The distortion of the meaning of a wide range of terms of the sort frequently used in survey questions (e.g., you, regularly, proportion, usually,...).

The abovementioned guidelines and recommendations were taken into consideration in preparing the questionnaires of the two pilots (East Midlands Airport, and Panel of Experts surveys), and the main passenger survey of Birmingham International Airport.

The next important decision to make would be, which mode of survey administration to implement: interviews, or mail-back questionnaires. The self-administered questionnaires have the following advantages:
1. Generally cheaper than interviewing, provided there is a reasonable response rate.
2. Wider spread in applicability, especially to rare and scattered population.
3. Avoid personal contacts of interviewing, with its relative cost, manpower required, administrative problems, and errors.
4. Allow more inter-personal consultations, and provide more time for considering the answers, hence more accurate results expected.
5. Require less time for preparations and undertaking.

On the other hand, self-administered questionnaires do have certain limitations, they include:
1. Greatly depend on characteristics and quality of population surveyed, and should be considered only when questions are sufficiently simple and straight-forward to understand with the help of printed instructions and definitions.

2. Comparatively inflexible, because answers have to be accepted as final, with no opportunity for probing beyond a given answer, or clarify ambiguities encountered.

3. Inappropriate when spontaneous answers are required.

4. Independency of questions are destroyed by the fact that respondents can read all questions before filling the questionnaire.

5. No guarantee that the questionnaire is filled by the right person.

6. Supplementing questionnaire information with observational information is usually not feasible.

7. The significance of response rate, and its great influence on the outcome of the survey.

In this work, it was realized that it would be very difficult to interview passengers inside the terminal. In the East Midlands Airport pilot it was first planned to interview passengers in the departure lounge, but soon after the survey commenced it became evident that it would be more convenient to the passenger and practical to the surveyor to switch to the self-administered mode. In the main passenger survey conducted in Birmingham International Airport, self-administered questionnaires were used, because apart from lessons learned from the East Midlands Airport pilot, interviewing was not allowed inside Birmingham Airport, due to its potential obstruction to normal operation, and also for security reasons.

To ensure efficiency and success of the main passenger survey, the response rate should be particularly investigated, and factors contributing to it should be carefully studied. Although it seemed a specifically difficult task to predict what the response rate would be for particular conditions and in different
situations. Nevertheless, previous social surveys suggested that
the surveyor may have some control (although comparatively
limited) on some of the factors contributing to and influencing
response rates:
1. Sponsorship: It is of great relevance to outcomes of the
survey, to attempt to secure the sponsorship of the survey under
the auspices of a body connected in some favourable way with the
population under study.
2. Population suitability: Actually, there is little one can do
about the particular properties and nature of survey population,
except to consider how suitable a self-administered questionnaire
is for it. It has been found that the less educated, those in
lower occupational categories, and those uninterested or feel
bothered about the subject of the survey, have higher than
average rates of non-response.
3. Subject matter and length of survey: Unfamiliar subjects,
inclusion of awkward questions, and considerable length and
unnecessary details in questionnaires, could result in low
response rates.
4. A covering letter accompanying the questionnaire (or
preferably integrally printed with it) to take the place of
interview opening or introduction, is favourable and could prove
to be substantially helpful in increasing the response rate.
Aimed at establishing rapport with respondents, it attempts to
overcome any prejudice respondents may have against the survey.
It should make quite clear why and by whom the survey is being
undertaken. The surveyor must also decide what tone to adopt in
the covering letter – should one plead or persuade, be
authoritarian, or excessively polite. A decision should be made
in the light of particular circumstances of the situation, but
perhaps the best approach is to explain in simple terms why the
survey is being undertaken, and why and by whom it is considered
important.
5. Enclosing a stamped-addressed or business-reply envelopes with
the questionnaires, would be a natural courtesy and a common
sense step to increase response rates. The first way might
probably lead to higher response than the second, due to the 'real value' of stamps that add to the 'importance' of the questionnaire, yet the second is more convenient for the surveyor.

6. Assurance of anonymity and confidentiality would definitely lead to increased response.

7. Prize concept: Payments or gifts as an incentive for completed questionnaire could also be adopted to increase response.

8. Quality of questionnaire production, including general appearance, printing quality and graphic design, type-face, even quality and colour of stationary (using different colours gives an impression of 'prestige and importance' to the survey), could contribute to increased response.

Most of these recommendations were seriously considered, and whenever feasible, they were implemented in the main passenger survey of Birmingham Airport. As will be seen in Chapter Nine, the resulting response rates were better than anticipated. Statistical considerations concerning response rates are discussed in more detail at the end of this chapter.

7.7 ATTITUDES AND SCALING METHODS

Behavioural aspects are paramount in the study of response patterns in social surveys, however, investigating them would lead us to avenues that are not particularly close to the scope of this work- behavioural sciences, sociometry, and social psychology. To try to avoid unnecessary indulgence in researching in these areas, only elementary and basic principles of these topics, specifically those related to attitudes and their scaling methods, would be dealt with and reviewed. Definitions and the broad revision of the subject were extracted from: Oppenheim(117), Belson(124), and Berelson and Steiner(125), and
Sills (128). For the discussion on attitude scaling methods, Moser and Kalton (114), Handbook of Survey Research (115), and Dunn-Rankin (127), were consulted.

The behavioural considerations of passenger surveys are very important in establishing the concept of P-R models. Expressions frequently used in this discussion that require defining are: perception, response, and attitudes.

**Perception** is a complex process by which people select, organize, and interpret sensory stimulation into a meaningful and coherent picture of the world (128).

**Response** is the output that defines a unit of behaviour (125).

**An attitude** is a relatively enduring organization of interrelated beliefs around a common focus, that describe, evaluate, and advance action with respect to an object or situation (128). Or, it is a state of readiness, and a tendency to act and react in a certain manner when confronted with certain stimuli (117).

### 7.7.1 CHARACTERISTICS OF ATTITUDES

The response of people to certain stimuli define their behavioural 'output', where their attitudes would describe their reactions towards those stimuli (132). In passenger surveys, the response of people to questions asked and their attitudes towards the subject matter dictate their replies. In our situation, P-R models require surveys whose questions are mostly opinion (attitude) questions. These type of questions are particularly sensitive, due to:

- Uncertainty whether the respondent, in any meaningful sense, is aware of what is asked about and 'knows' the answer.
- A person's opinion on virtually any issue is many-sided, and probably there is no one correct answer to the survey question, but the answer the respondent gives, will largely depend on the aspect of the issue that is uppermost in the mind.
- Difficulty of assessing the intensity of opinions, and giving a reasonable estimation of the measure used.
- Influence of different aspects of questionnaire design on opinions.

Basically, an attitude organization, and beliefs within which, are conceived to have three components; cognitive, affective, and behavioural(114). The cognitive component represents a person's knowledge, held with varying degrees of certitude, about what is true or false, good or bad, desirable or undesirable. The affective (or emotional) component, where under suitable conditions, the belief is capable of arousing affect of varying intensity, centering around the object of belief, the other objects taking a positive or negative position with respect to the object, or the belief itself when its validity is seriously questioned (as in an argument). The behavioural (action tendency) component, where the belief, being a response predisposition of varying threshold, must lead to some action when it is suitably activated, and the kind of action it leads to is dictated by the content of the belief.

Other characteristics of attitudes that are relevant to this discussion are:
1. Attitudes are always present but dormant most of the time, and they become expressed in speech or other behaviour only when the object of the attitude is perceived. In social surveys, attitudes as perceived by people could be observed and recorded when individuals are confronted with survey questionnaires.
2. They are abstractions, but real enough to individuals who hold them.
3. They are variable, where the degree of differentiation at one end of an attitude continuum may be very different from that at the other end.
4. They are acquired and modified by absorbing, or reacting to, the attitudes of other people.
5. They are highly emotional, both in the sense of irrational or illogical. Interrelations such as these follow no logic except Psycho-logic; the logic of feelings and emotions.

6. Same attitudes may express themselves in different ways by different people, while some may have no such attitudes at all.

Some of the important aspects that are related to the topic of perception and response are:

1. Development of behaviour in humans is manifested by the following findings by Berelson and Steiner (125):
   - Human behaviour is variable and relatively unpredictable.
   - Human behaviour is dependent upon learning and less regulated by instinct or other innate behavioural disposition.
   - Since human behaviour is adaptive, and is accumulated by learning, it is therefore communicated.

2. Regarding perception, probability of perceiving (or which stimulus get selected) depends on:
   - Nature of stimuli involved.
   - Previous experience, or learning, as it affects the observer's expectations, because, other things being equal, people are more likely to attend to aspects of the environment they anticipate than those they do not, and they are more likely to anticipate things they are familiar with.
   - Motives in play at the time (i.e., needs, desires, wishes, interests,...), because not only do people look for things they need or want, but stronger the needs, the greater the tendency to ignore irrelevant elements.

3. Response is not under conscious control or awareness.

4. The greater ambiguity of the stimulus, the more room and need for interpretation. In interpreting ambiguous stimuli, the observer typically assumes the involvement of the most likely object(s), because familiar objects retain their perceived size, colour, shape,... etc., though their sensory projections fluctuate tremendously. Also, familiarity with various possible alternatives is not the only determinant of 'likelihood', but expectations regarding what is likely in the specific situation
are also involved. As the ambiguity of stimulus increases and/or as the strength of motivation or subjective importance increases, people's interpretation will move in the 'relevant' direction—they will tend to see things as they want or need to see them.

5. Interpretation of quantities are affected by expectations and motives.

6. Judgement of magnitude are made within a frame of reference established by the total range of relevant stimuli.

7. People develop an 'adaptation level' with respect to given stimulus magnitudes, based on range of values that has been present in the relevant series.

8. People hold opinions, attitudes, and beliefs in harmony with their group memberships and identifications, and when they (opinions, attitudes, and beliefs) are developed, the evaluation of people of an objective situation, would then depend on whom they compare themselves with—different groups different evaluation.

9. The more interested people are in an issue, the more likely they are to hold consistent position on that issue, and the more a person is emotionally involved in his beliefs, the harder it is to change that by argument or propaganda (through an appeal to intelligence) to the point of virtual impossibility.

7.7.2 ATTITUDE MEASUREMENT AND SCALING PRINCIPLES

Since the passenger survey is one kind of attitude surveys, by means of which P-R models are built, previous discussion should be augmented with an overview of attitude measurements and scaling.

Measurement, is the assignment of numbers to observed phenomena according to certain rules(115), or the correlation with numbers of entities which are not numbers(126). Scaling, is the procedure for the assignment of numbers or words (or other symbols) to a property of objects in order to impart some of the
characteristics of numbers of the property in question. Attitude measurement is normally carried out through judgement. Sills stated that: "Customarily, attitudes are measured by eliciting acts of judgement—agreement or disagreement with standard statements of opinion. Much of the behaviour to which attitudes give rise, is mediated by further acts of judgement that involve the placement of the issue or object in an evaluative framework and its assignment to a category." In this work, this is accomplished by asking the passengers to give their judgement on the issue of service standards (in terms of time as the service measure) in terminal processing facilities, and assigning this judgement to one of three categories: good, tolerable, or bad service.

7.7.3 TYPES OF ATTITUDE SCALES

Attitude scales are techniques the major function of which is to divide people roughly into a number of broad groups with regard to a particular attitude, placing them on a continuum in relation to one another, in relative and not in absolute terms. Known types of attitude scales are:

1. **RATING SCALES**: Sometimes called the social-distance scales, where they try to get a measure of the respondent's actual position on the attitude continuum. It is an old method seldom used in modern social surveys.

2. **THURSTONIAN SCALE**: Referred to also as differential scale, it was developed by L.L. Thurstone in three stages—paired comparisons, successive intervals, and equal appearing intervals which is the most widely used. Judgement of individuals 'judges' are 'scaled' with respect to various physical properties, and the judges are asked to make objective evaluation of the positioning of items considered on the attitude continuum. Thurstonian scaling generally assumes approximately normalized
pattern of operating characteristics, when attitudes are placed along an underlying continuum running from extremely unfavourable to extremely favourable (115).

3. **LIKERT SCALE**: Or the scale of summated ratings, was developed by Rensis Likert. Respondents are asked to choose between several response categories, indicating various strengths of agreement or disagreement. The categories are assigned scores and the respondent attitude is measured by his or her total score, which is the sum of scores of categories he or she endorsed for each item. Likert scale assumes a continuous underlying attitude dimension that is monotonically related to the continuum, where the operating characteristic has an S-shaped or inverted-S-shaped curve depending on favourability or unfavourability of the attitudes (115). This type of scale is more oriented towards attitude measurement than other methods (126).

4. **GUTTMAN SCALE**: A cumulative scale developed by Louis Guttman, sometimes referred to as scalogram analysis, where the attainment of a high degree of unidimensionality is a major concern. It is constructed by first defining the total attitude (universe of content) being scaled, and a 'sample' of items representing this universe is selected to be included in this scale. 'Scalogram analysis' is then carried on, where two operations are needed to deal with errors and complications arising from the fact that ordering of items is unknown in practical situations:

- Analysis of items responses to reorder those items according to response patterns constituting the scale types.
- Measure extent to which the scale approximates to a perfect scale (where errors are minimized), by means of coefficient of reproducibility. 'Errors' mentioned here, are the false predictions of an individual's item response on the basis of the scale scores.

In spite of the sophistication of this method, it has the following disadvantages (114): analytical complexity, no guarantee of items scaling, less realistically treated as being
unidimensional if the items set range is wide, its underlying model is strictly deterministic, and its laborious nature where computerization becomes a necessity.

5. **SEMANTIC DIFFERENTIAL SCALE**: Sometimes called bi-polar scale, is a summated rating scale, where series of graphical rating scales are completed on a particular subject with graduated scales, the two ends of which are described by adjectives that are polar opposites.

6. **FACTORIAL SCALES**: Statistical-mathematical analysis techniques based on intercorrelating all the items with one another, which would enable the identification of one or more 'factors' that items have in common.

7. **UNFOLDING THEORY**: A recent scaling method developed in University of Michigan by Coombs (130).

Where does the P-R model fit amongst these categories of scales? It seems difficult to classify P-R models as distinctly related to an individual scaling method. But from description of properties and operating characteristics of known scaling methods stated above, it would be thought that P-R model technique is a conglomerate of the Likert and Thurstonian scaling methods, because: respondents are asked to state their judgement and evaluation of different items (in this case service conditions), and they are also asked to choose between several response categories (in this case only three; good, tolerable, and bad). Moreover, this conclusion would become more evident when the shape of the P-R model is closely studied. In terms of scaling operating characteristic, it is composed of a Thurstonian and two opposite (favourable and unfavourable, resembling the S and inverted-S shaped curves) Likert scales. No comparable method was cited in literature that used any similar scale representation (% population and time) as in P-R model technique.
7.8 PASSENGER SURVEYS CONDUCTED

In this work, P-R models were built based upon information collected in four surveys (two pilots, and two case studies), they are:

1. East Midlands Airport pilot survey.
3. Manchester International Airport survey.
4. Birmingham International Airport (main) survey.

These surveys (except Manchester Airport's) were planned and conducted by the author as methodology applications. Discussion raised in this chapter on surveys and attitude scales, was taken into consideration and included in the planning of these surveys and in the design of questionnaires. More details on particular considerations for each survey are found in respective sections of Chapter Nine.

Finally, certain statistical aspects of passenger surveys that needed investigation are discussed. Typically, statistical analyses form a major and vital part of any survey, depending on the objective of survey, analysis approach, and nature of required outcomes. Statistical analysis of surveys considerably vary in detail and degree of mathematical sophistication. In this work, little emphasize was put on the mathematical-statistical aspects, mainly because the urgent task, initially was, to establish an appropriate procedure for this kind of surveys, interpret, and manipulate the results to achieve the objective of facilitating setting of service standards, in the overall context of a practicable methodology.

The most important statistical factor investigated was sample size. One of the first questions that confronts the designer of a new survey is how big the sample should be. Although it appears to be a simple straight-forward question, it is one of the most difficult to answer accurately. An accurate answer would be
possible when substantial information related to the survey and its population is provided. Adequacy of the sample size would then depend on details of the analysis. Not only total sample size, but breakdown of the categories it contains are also required. A general rule is that the sample should be large enough so that there are 100 or more units in each category of the major breakdowns, and 20-50 in the minor breakdowns (115).

From a theoretic standpoint, Moser (114) stated that: "If the cost and other practical limitations do not enter into the picture, there is no basic difficulty in determining the desired sample size. The concept of the standard error of the mean could be used to estimate sample size." However, in our case this would not be very helpful because, first, 'cost and other practical limitations' do enter into the picture, and second, the concept of standard error of the mean is not particularly applicable to P-R model information. Other possible and more practical approaches for sample size determination are:

1. Empirical approach, by seeking what sample size was used by others with similar problems.

2. Formal approach, by emphasizing the balance value of increased information with costs of gathering data.

Current practices of sample size determination contained in the Handbook of Survey Research (115), were reviewed. Due to the restraints imposed on airport surveying, and the uniqueness of the sets of information sought, a target sample size of 200 units in the major categories (channels) was aimed at, with an absolute minimum of 20 in minor categories.

For self-administered questionnaires, sample size is strongly governed and dictated by the response rate of passengers to the questionnaires, which happens to be extremely difficult to predict, and no reference was cited in the literature of social surveys that suggested any range of values for airport passenger surveys. So, after lengthy discussions with experts associated with social surveys and airport operations, response rates
between 10% and 25% were suggested. In the light of this range a decision was made to aim at distributing around 1400 questionnaires for each channel, so that if the actual response rate was in the lower third region of the suggested range, the target sample size would still be achieved. Actual response rates experienced in the main survey of Birmingham Airport, were in the upper third region and sometimes beyond, thus the actual sample size was well within the target and fully attained.
In this chapter, those aspects related to simulation techniques utilized to synthesize the data required to derive the performance model of the airport terminal facilities, are reviewed and discussed. Prior to that, an overview of terminologies involved, is appropriate.

8.1 OVERVIEW

Simulation referred to in the context of this work, as a technical instrument, is a relatively recent introduction to scientific research, and is increasingly becoming a popular tool in operational research. However, modelling in general is not recent at all. In fact, it has been associated with scientific research since its evolution, especially in physical science, where models were usually developed based on theoretical laws and principles. In operations research, models are considered as idealized representation of reality, of some subject of inquiry which may be already in existence, or of a conceived idea awaiting execution. Models are utilized instead of the real-system, due to the impossibility of manipulating the real world, or high costs associated with such actions. In this sense, a model is usually an abstraction of the assumed real system, identifying the pertinent relationships of the system in the form of an objective and a set of constraints. A model is constructed so as to be much simpler than the real-system. Complex models would be difficult to implement and control. One
must still be able to use the model to explain or predict phenomena associated with the real-system with a high degree of accuracy. Finding the right variables and the correct relationships between them is the essence of good modelling, because although a very large number of variables may be required to predict a phenomenon of the real system with perfect accuracy, only a small number of variables usually account for most of it. Nevertheless, the reliability of information obtained from a model, would eventually depend on the validity of the model in representing the assumed real-system.

The importance of models to scientific research, is manifested by this quotation from Churchman, Ackoff, and Arnoff (131): "Since scientific theorizing itself becomes identical with model construction in some aspects, it follows that science would be as impossible in the absence of models as it would be in the absence of theory."

8.2 TYPES OF MODELS

Generally, models are classified as: iconic (physical), analogue, symbolic (abstract), heuristic, and simulation models. Of these models, simulation is of particular importance to this work. Simulations are models that utilize mathematical-logical representations of the real-system, to convert systems description, or input parameters, into output of interest that would describe some features of the system. Taha (85) regards simulation as imitations of the behaviour of the real-system under investigation over a period of time. They seek to duplicate this behaviour by studying the interactions among its components. Shannon (133) envisaged simulation as the process of designing a model of a real-system and conducting experiments with this model for the purpose of either understanding the behaviour of the system, or evaluating various strategies. (within the limits imposed by a criterion or set of criteria) for the operation of
the system. Pritsker(91) considered simulation models as the laboratory version of systems, on which when developed, experiments can be performed. With these experiments, simulation models can be used for the design, procedural analysis, and assessment of performance of the real-system. Inferences could be drawn about real-systems without the need to:
- actually build them (if they are only proposed systems),
- disturb them (if they are operating systems that are costly or unsafe to experiment with), or,
- destroy them (if the object of an experiment is to determine limit of capability-capacity).

In airport planning, Low(134) treats simulation as a technique for developing artificial historic data for a situation described by the model builder. Characteristics of simulations can be quite variable depending on their features and specific approach in modelling the particular situation. Their basic properties could be:
- Static vs. dynamic,
- Analytic vs. numeric,
- Deterministic vs. stochastic,
- Discrete vs. continuous, or,
- Interactive vs. closed.

Functionally, simulation models could be of four broad types:
1. Analytic queueing models; that use mathematical-probabilistic expressions derived from Queueing Theory, relating standard statistical measures to input and service parameters.
2. Accounting (time-based) models: Being macroscopic and deterministic in nature, they operate according to predetermined and invariable rules analogous to book-keeping practices, to describe the state of the system at any time. When computerized, these models usually use general-purpose computer languages (e.g., FORTRAN).
3. **Time-oriented (event-based) models:** They are microscopic, time-dependent, and stochastic in nature. States of the real-world system are reproduced at a fast-time either by continuous solutions of dynamic equations which use mathematical-logical representations to describe the simulated real-world situation, expressing relations between its components, or by adopting Monte Carlo-based techniques to generate simulated data that have similar distributions to those of the real-world system.

4. **Role-playing models:** They are real-time models, where human participants are permitted to react as they would in the real-world (life) situation being simulated. P-R models devised in this methodology, could be considered as one of these models.

### 8.3 SIMULATION LANGUAGES

The recent giant leaps taken by computer technologies, with impressive advances in machine capabilities both with respect to hardware and compatible software, opened new doors for scientific research which made it feasible as well as affordable for researchers to employ computerized simulations efficiently and conveniently for the analysis of systems.

Early computerized simulation models were coded in general-purpose programming languages (e.g., FORTRAN, BASIC, PL/I, and ALGOL). However, due to the widespread use of simulation as a more efficient research tool, the need for simplifying the routine task of programming soon lead to the development of specialized computer simulation languages, especially during the late 1950s(135).

In developing a simulation model, the modeller has to select a conceptual framework to describe the system to be modelled. Essentially, this would contain a 'world view' within which the system functional relationships are perceived and described(91).
If the modeller is employing a general-purpose computer language, then the perspective for organizing the systems description is the modeller's responsibility. Alternatively, if the modeller chooses to employ a simulation language, then the 'world view' will normally be implicit within the simulation language.

Since high-order simulation languages are extensively used to construct simulation models, it would then seem necessary to examine and discuss properties of presently known simulation languages, with description of the technical features and characteristics of each. In this section, simulation languages are explored to decide on selecting an appropriate one to be used in the methodology.

Basically, simulation languages are founded upon two different 'world views': discrete, and continuous. In the context of this methodology, the discrete-event orientation is considered, because the continuous world view is inapplicable to the system under consideration (the airport terminal). In the airport terminal environment, the system can be modelled by describing the changes of state that occur discretely in time. These changes occur at isolated points in time (event times), and between those times the state of the system remains constant. On the other hand, continuous modelling involves the characterization of the behaviour of a system by a set of equations. The state of the system is represented by dependent variables which change continuously over time. The state is defined by the equations for a set of state variables whose dynamic behaviour simulates the real system. Since no set of equations could be derived to define the characteristics of the airport terminal and describe the nature of the systems operation, the behaviour of the system is better understood by adopting the discrete-event simulation.

Objects within the boundaries of a discrete system are called entities. There could be many types of entities each having various characteristics called attributes, that are common to
groups of entities although they engage in different types of activities. Groupings of entities are called files, because inserting an entity into a file implies that it has some relation with other entities in the file. The aim of a discrete simulation model is to reproduce the activities in which entities engage, hence learning about and understanding the behaviour and performance potential of the system. This is accomplished by defining the state of the system (in terms of numeric values assigned to the attributes of the entities), and constructing activities that move the system from one state to another. The state of a discrete system can change only at event times. In between those times, the state remains constant. In this way, a complete dynamic portrayal of the state of the system can be achieved by advancing simulated time from one event to the next, using a 'next event' timing mechanism.

Discrete simulation could be of three general types: event-oriented, activity-oriented, and process-oriented. An event and an activity were described earlier, while a process is defined as a time-ordered sequence of events that may encompass several activities. Figure 8.1 graphically describes the relation between an event, an activity, and a process.

Hence, depending on their specific features, simulation languages could be categorized as: event-oriented, activity-oriented, and process-oriented. In this subsection, simulation languages related to the three categories will be described. The most widely known are ECSL, GASP, GPSS, Q-GERT, SIMPL/I, SIMSCRIPT, SIMULA, and SLAM.

Generally a simulation language should possess certain minimum requirements of built-in capabilities and facilities. McCredie(136) listed them as:
1. Flexible methods of describing state changes during an event.
2. Techniques for scheduling events to occur relative to the independent variable time, or upon satisfaction of a set of logical relations of state variables.
3. Extended data structures such as lists and trees, and capabilities for easily manipulating these structures.
4. Since many discrete models are stochastic processes, the language must have built-in capabilities for generating random variables and random functions.
5. Methods for gathering statistics, and controlling experiments in the system.
6. General arithmetic capabilities.
7. Interfacing capabilities with other segments of the computer system, such as FORTRAN library and standard statistical packages.
8. Extensive debugging features.
8.3.1 EVENT-ORIENTED SIMULATION

Here, a system is modelled by defining the changes that occur at event times, by determining the events that can change the state of the system, then developing the logic associated with each event type. Therefore, the system is simulated by executing the logic associated with each event in a time-ordered sequence. Simulation languages included in this category are SIMSCRIPT, and GASP.

SIMSCRIPT was developed by Markowitz(137,138) at RAND Corporation in 1962(139). It is a FORTRAN-based simulation language, but it also exists in different dialects or versions;
- SIMSCRIPT II, a completely new non-FORTRAN version, which was released by RAND in 1968(140).
- SIMSCRIPT II.5, is a SIMSCRIPT II with process-oriented capabilities(141).

One of the appealing features of SIMSCRIPT is its English-Language-like statements, where attributes are named not numbered and are interpreted as clauses. This syntax-free-form of SIMSCRIPT enhances model description, thus programmes written in this simulation language are comparatively easier to read and comprehend, and tend to be self-documenting. Structurally, SIMSCRIPT programmes normally consist of a main programme (PREAMBLE), and event subprogrammes. The main programme is mainly used for initializing variables, scheduling initial occurrence of events, and starting the simulation. Event subprogrammes are used for defining the logic associated with processing each event in the model.

The General Activity Simulation Program- GASP, was first introduced by Kiviat(142) in 1963. In 1968, GASP II was developed by Kiviat and Pritsker(143). GASP IV, the current version of GASP, was extended and enhanced by Pritsker(144). Other versions or dialects of GASP include;
- GASP-PL/I, a PL/I-based version of GASP IV, where PL/I replaces FORTRAN as the programming language.
- GASP IV/E, an interactive version of GASP IV, where simulation data are displayed on graphics terminal (screen) during simulation. At the user's request, simulation variables can be reinterpreted or changed.
- GASP V, is an extension of GASP IV, where continuous simulation capabilities are further expanded to include integration, partial differential equations, and other features.

Structurally, in GASP IV, a conceptual framework and supporting routines are provided for writing the programmes, where the modeller codes in FORTRAN the following:
1. A short Main Program.
2. Subroutine EVENT(I), to define the mathematical-logical relationships for processing changes in state corresponding to each event type.
3. User-coded subroutine INTLC, to initialize the system.
4. User-coded subroutine OUTPUT, for the documentation of output results.
5. Other subprogrammes which include procedures and supporting routines for file manipulation, event scheduling, and statistical collection.

8.3.2 ACTIVITY-ORIENTED SIMULATION

In this approach, the system is modelled by describing the activities in which the entities in the system engage, and prescribing conditions that cause each activity (but not events which are automatically initiated from conditions specified for the activity itself) to start or end. As simulated time is advanced, conditions for either ending or starting an activity are scanned, and if the prescribed conditions are satisfied, then the appropriate action for the activity is taken. To ensure that each activity is accounted for, it is necessary to scan the entire set of activities at each time advance. For this
particular reason, activity-oriented simulation may prove to be relatively inefficient when compared to other discrete simulations.

Falling in this category is the ECSL simulation language. Originally, the Control and Simulation Language- CSL, was developed by John Buxton of IBM(UK) for Esso Petroleum Company in 1960(148). Later, a basic FORTRAN version of CSL was developed for Honeywell as the Extended CSL- ECSL. Clementson(149) enhanced ECSL and introduced CAPS- Computer Aided Programming Service, where the modeller can easily use ECSL to construct the model without necessarily being familiar with FORTRAN programming.

8.3.3 PROCESS-ORIENTED SIMULATION

In this case, the system is modelled by including sequence of events occurring in a defined pattern. The logic associated with these events can be generalized and used as single statements. These statements can then be employed to model the flow of entities through the system by defining the sequence of events (which are automatically executed as entities move through each process). In this sense, features from both event and activity-oriented approaches are here combined, and the fact that event logic is implicit and is automatically contained within the corresponding statements greatly contributes to its relative simplicity. This category of simulation languages includes: GPSS, Q-GERT, SIMPL/I, and SIMULA.

GPSS, the most widely used simulation language, was developed by Geoffrey Gordon of IBM in 1961-2, as the General Purpose Systems Simulator(150,151), where it was implemented on IBM 704-709 computers. Other improved versions of this language followed later; GPSS II(152,153) was introduced in 1964, followed shortly by GPSS III(154). in 1967, GPSS/360 was later introduced(155,156) and the package was renamed as General Purpose Simulation System.
The latest version is GPSS V(157,158). Another version is the GPSS F(159), a FORTRAN-based package. Basically, a model in GPSS is constructed by combining a set of standard blocks into a block diagram, which maps the flowchart defining the logical structure of the system. The modeller would then translate the block diagram into equivalent block statements for interpretation and execution by the GPSS processor, by writing a programme in GPSS coding consisting of blocks logically interconnected to form a network. Each block, which is actually a small subroutine or macro-instruction in GPSS, performs a given function on entities. There are more than forty blocks, each is pictorially represented by a stylized figure, which is intended to be suggestive of the block's operation. The creation of temporary entities, or transactions, is accomplished by the use of a special block (GENERATE), and the movement of those transactions through the network of blocks is controlled by the operation of various blocks, before being destroyed by a (TERMINATE) block. The features and characteristics of GPSS, make it a simple and easy language to use. However, it also has certain shortcomings: comparatively limited computer power and longer computer execution times, lack of floating point capabilities and real arithmetic, and difficult procedures for sampling from non-uniform distributions. Many textbooks, including Schriber(160), and Bobillier, Kahan, and Probst(135), demonstrate and discuss all aspects of GPSS; its structure, syntax, programming techniques, and elaborate on its various applications.

SIMULA, a simulation language based on ALGOL 60, was developed in the Norwegian Computing Center by Dahl and Nygaard(161,162). It was first released in 1965, and gained popularity in Europe. SIMULA 67, is a newer generalized version(163). For detailed information on SIMULA, and its applications, refer to Hill(164).
SIMPL/I was introduced by IBM in 1972(165). It is based on the general-purpose Programming Language- PL/I, where the components of a system and the characteristics of their behaviour are represented by SIMPL/I processes, entities, and lists, and by PL/I variables, structures, and procedures.

Queue Graphical Evaluation and Review Technique, Q-GERT, was developed by Pritsker(166). It employs an activity-on-branch network philosophy in which a branch represents an activity that models a processing time or delay. A network is a pictorial representation of the system to be modeled, where entities flow through the network model defined by its nodes and branches. The pictorial representation of the system would then be transcribed by the modeler into an equivalent statement model for interpretation and processing by Q-GERT Analysis Program. Recent development on Q-GERT involved the capability of displaying Q-GERT network models on graphics terminals. For more details on the use and applications of Q-GERT, refer to Pritsker(166).

8.3.4 SLAM

Simulation Language for Alternative Modelling- SLAM, is a FORTRAN-based simulation package recently developed by Pritsker(91). SLAM is unique in certain characteristics and features, that makes it distinct from other languages mentioned so far. It is a hybrid package containing advantageous characteristics of more than one language. The simulation languages mentioned previously were categorized according to the approach adopted for modelling in the particular language (i.e., continuous, discrete-event, discrete-activity, or discrete-process). In SLAM, the alternate modelling approaches are combined to provide a unified modelling framework. SLAM can operate in three different modes: event, network, and continuous modes. For the network mode, SLAM provides network symbols (blocks) for building graphical models that are easily translated...
into input statements for direct computer processing. In this respect, SLAM is similar to GPSS's block-statement approach, and Q-GERT's philosophy of graphical representation of networks. For the other two modes, event and continuous, SLAM contains numerous subprogrammes that support both discrete-event and continuous model development, and specifies organizational structure for building such models. For the discrete-event mode, this approach is very similar to GASP IV language.

Not only can SLAM operate in three different modes, but the three modes can also be combined simultaneously within the same simulation model. In all, there could be six specific interaction situations which can take place between the network, discrete, and continuous modes in SLAM(91):

1. Entities in the network model can initiate the occurrence of discrete events.
2. Events can alter the flow of entities in the network model.
3. Entities in the network model can cause instantaneous changes to values of the state variables (in continuous simulation).
4. State variables reaching prescribed threshold values can initiate entities in the network model.
5. Events can cause instantaneous changes to the values of state variables.
6. State variables reaching prescribed threshold values can initiate events.

Considering the ability to construct combined network-event-continuous models with interaction between each orientation, SLAM can provide for the modeller a more than adequate conceptual mechanism for articulating the system description, which undoubtedly will greatly enhance the modelling power and flexibility available to the modeller. More specific technical features and practical aspects of SLAM are discussed in detail later. For more information on SLAM structure, syntax, programming techniques, and a wide and varying range of applications, refer to Pritsker and Pegden(91).
8.4 AIRPORT LANDSIDE SIMULATIONS

Airport landside-related research programmes boomed in the early seventies. They were triggered by unprecedented congestion and passenger delays encountered in airport terminals, which accompanied the substantial growth in air traffic then. Their prime objective centered on investigating this phenomenon scientifically, then benefiting from their eventual outcomes and conclusions in extending knowledge on airport terminals, and enhancing their planning, design, and operations management.

Typical methods used in those research programmes were experimentation, analytic modelling, and simulations. Researchers of the airport landside\(^{(167)}\) encouraged the use of simulation for its convenience, because it is potentially able to describe detailed activities in a manageable fashion. Organizations related to airports\(^{(168)}\) credited simulation as the most promising method of analysis, because it could efficiently cope with the time-varying nature of demand and the stochasticity inherent in the system.

Apart from the simulation categories mentioned in Section 8.2, simulation could be of different functional classes according to the purpose of simulation, the characteristics of models, the degree of simulation sophistication, and the level of precision anticipated. In an attempt to classify simulations for airport terminals, Gentry and Doyle\(^{(169)}\) identified four levels of simulations:

**LEVEL I:**
- Simplest and most basic level.
- Time-variation and stochasticity are not taken into account.
- Only fixed peak demand patterns at each part of airport landside are considered.

**LEVEL II:**
- Time-variation in the average demand rate are explicitly considered, but not stochasticity.
- Only when the average demand rate at a particular component in a given time exceeds its maximum service rate, will queueing and delays be incurred. Hence, it would not predict any delays if the average demand rate is just below the maximum service rate, unlike Queueing Theory applications.

LEVEL III:
- Probabilistic aspects of demand (time-variation), and service rate (stochasticity) are explicitly considered.
- It is based on steady-state queueing analysis, with its two basic assumptions:
  1. For given time periods, the average demand and service rates remain constant, but with random fluctuations, which are probabilistically described.
  2. Each time period is long enough so that statistical equilibrium (steady-state) can be attained.

LEVEL IV:
- Highest level of theoretical sophistication.
- Demand arrivals and service rates are both probabilistic and time-varying or can be explicit functions of time.
- May prove to be impractical to use in current landside modelling because of its high degree of mathematical complexity.

Basically, airport landside (terminal) simulation models were developed by academic institutions as a vehicle to extend existing knowledge in this field, or by the air transport industry and governmental agencies responsible for administering and operating airports. For the latter, simulation models were actually utilized in the process of planning and design of airport terminals.
8.4.1 ACADEMICALLY-DEVELOPED SIMULATIONS

Academic institutions pioneered in conducting airport-related research. In the US, extensive airport and air transport-related programmes were conducted in Massachusetts Institute of Technology, The University of California at Berkeley, and The University of Texas at Austin.

MIT drew attention to air transportation-related problems, when a transportation workshop was convened in 1967(170). Since then, elaborate research has been conducted there, a major part of which was directed towards the theoretical aspects of airport systems, namely, the applicability of analytical queueing models for the processing facilities in airports. One of the outcomes of this research was an analytic simulation model of the terminal developed by Pararas(171), employing analytic queueing models, written in GPSS simulation language.

In the University of California at Berkeley, earlier research by Horonjeff(172) produced models for individual terminal facilities using deterministic queueing models. Under Horonjeff's supervision, the following facilities were analysed for the purpose of analytical modelling: departure lounges(173), baggage claim facilities(174,175), movement in piers(176), and security facilities(177). Although no complete airport landside (terminal) simulation model was developed at Berkeley, but the abovementioned work on individual facilities was useful to subsequent research that produced airport landside simulation models.

Research on this subject was conducted in The University of Texas at Austin, and airport terminal simulation was developed in 1978(28,57) as a part of this research programme. This simulation, Airport CAPacity (ACAP), is a useful and convenient tool when used in simulating terminal operations, and in particular capacity analysis.
In the UK, research was conducted in University of Strathclyde, Scotland, where a complete airport terminal simulation model AIR-Q was developed by Calderbank and Kirke (30) in 1972, and extended later by Laing (31). AIR-Q is similar in many aspects to ACAP.

Loughborough University of Technology conducted a multi-disciplinary research programme in airport terminals, which included a survey of passenger behaviour in Manchester Airport (95). Reports of this research programme were quite useful in many aspects for this methodology, especially in describing behaviour of passenger processing and service times distributions (178). However, no complete terminal simulation was developed in LUT.

Similar research in airport terminal simulations was also conducted in universities in Australia (179), Canada (180), and in Denmark (181).

8.4.2 INDUSTRY-DEVELOPED SIMULATIONS

In order to place planning and design of new terminals on sound and realistic assumptions, organisations responsible for this task had to devise some systematic tools which could aid in achieving their goals. Many of the known airport simulations were purposely developed to enhance the planning process of new terminals, or to improve management of operations of existing ones.

The consulting firm Tippetts-Abbetts-McCarthy-Stratton (TAMS), developed a simulation model for the planning and design of Maiqueta Airport in Venezuela (182). It is a LEVEL III, GPSS-based airport landside model using time-oriented queueing models.
One of these FAA-sponsored research programmes is the FAA Airport Landside Model, which was developed by H.H. Aerospace Design Co. (169) in 1978. It is a LEVEL III simulation, which uses computerized analytic queueing models to represent activities performed within individual components of the landside. To have a workable model of this kind, three major assumptions have to be enforced:

1. Flows, demands, and services are in steady-state condition.
2. The demand distribution at each service can be represented as Poisson.
3. The arrival rate at each service is independent of the dynamics of any preceding service.

As part of this research programme, a data base for all airport landside elements has been compiled for large US hub airports. Six of these airports (Boston-Logan, Denver, Detroit, Miami, LaGuardia, and San Francisco) were modelled at the level of detail availed by on-site data. While for 19 other hubs, basic airport data were compiled at a lesser level of detail, based on FAA(187) and CAB(102) statistics.

Recently, FAA released what seems to be the 'final' FAA landside simulation, the Airport Landside Simulation Model- ALSIM. Its original version was obtained by The US Department of Transportation from Bechtel Corporation, and was subsequently enhanced and modified in FAA's Transportation Systems Center, Cambridge, Mass. The FAA plans to disseminate ALSIM, encourage airport authorities and operators to use it, and promote its wide-scale implementation. Description of ALSIM's characteristics and use will be presented later.

In Canada, the Canadian Air Transport Administration developed the Calgary Model(188), which is a GPSS-based simulation that uses time-oriented queueing models.
In the UK, the British Airport Authority has recently developed its own airport landside simulation. However, no publication has been released for the BAA model.

8.5 SIMULATION TECHNIQUE ADOPTED IN METHODOLOGY

The task of synthesizing necessary data required for establishing and constructing the performance model of processing facilities as outlined in the capacity procedure, warrants the close examination and inspection of the data synthesizer, or simulation technique, employed. Scrutiny of the proposed technique is important to ensure that:

1. It would be theoretically suitable to conceptualize the simulated situation, with little possibility of logical conflict with the real-world system.
2. It would be relatively convenient to use.
3. It consumes a reasonable amount of real-world information, while its output remains uncompromised.
4. It can provide necessary flexibility in simulating the time-variant demand pattern, and other important features of the system.

Four techniques, covering macroscopic and microscopic approaches to simulation were examined and considered for implementation in this research. Trial sample runs of each of the following simulation techniques were actually attempted: two airport terminal simulations (ACAP and ALSIM), and two simulation languages (ECSL, and SLAM). Considerable time and effort was dedicated to selecting the appropriate data synthesizing technique. Close inspection with comparisons between the techniques were conducted for this selection procedure in the light of; specific features of each technique, extent of realistic interpretation of the real system, and probability of ready availability of input information.
8.5.1 MACROSCOPIC APPROACH

Logically, terminal simulations were the first to be considered for implementation, because they seemed more attractive and suitable for this job. Since they are all particularly oriented to the simulation of airport terminals, they are more system-specific, because they include all variables and parameters that characterize the airport. Originally, terminal simulations were specifically and purposely developed for modelling activities (and thereby the interaction between facilities) which are performed within the system. In this sense, they deal with simulating the system on both levels; macroscopic, defining the system as a whole and describing interactions between all its components, and microscopic, where the logic governing every process within the system is specified with its contributors defined.

8.5.1.1 ACAP

ACAP was considered seriously for implementation, because of its attractive characteristics, particularly, its relative structural and operational simplicity was appealing.

Structurally, ACAP constitutes of:
- The MAIN Program, which defines and initializes the variables and parameters included, and controls and accounts for all movements.
- FLOWIN Subprogram; The mechanism that provides the essential logic for interaction between components, and organizing flow from one component to another.
- Modular component subroutines that provide logic for activities performed at each component.
- Other supporting ancillary subroutines.
Operationally, a middle-sized computer with a FORTRAN compiler would be sufficient to run ACAP, with no requisite substantial programming skills, provided that operational and airport-specific information are entered in the right order and format as the input deck (189). In addition to simplicity, ACAP provides excellent book-keeping (accounting) capabilities, well organized and thorough output documentation, and special emphasis on the user defined level of service, hence recognizing the important capacity/level of service considerations.

However, ACAP had certain disadvantages:
1. **Deterministic nature**: Modular component subroutines, basic function of which is to provide logic to simulate activities performed at each facility in order to estimate waiting times and queues, employ deterministic models that were derived by regression analysis of service times and arrival distributions taken from data base accumulated from surveys conducted in three Texan airports (28).
2. **Limited applicability**: As a consequence, ACAP could only be used in situations very similar to those where and when surveys were conducted. Operational conditions of those surveys, upon which the regression-derived models were based, could not be replicated even in those airports where they previously prevailed.
3. **Comparatively small size**: ACAP was first developed to simulate Austin Municipal Airport's terminal in 1976 (190), when it was a small airport handling around one million passengers annually through (3) airlines. Thus it could only be used to simulate airport terminals of that size.
4. **Input data required**: Because it is a complete airport terminal simulation, the required input data would include: airport geometry, flight schedule information (including flight timings, number of passengers on flights, their passenger/visitor ratio, and passenger/bag ratios), and all possible paths of movement in the terminal, which undoubtedly requires considerable on-site effort.
Due to the abovementioned shortcomings, an attempt made by the author to use ACAP to simulate Austin Airport in May 1983 was unsuccessful. Austin Airport in 1983 was bigger in size and different in demand and service characteristics from that of 1976; (2.3) million annual passengers, (10) gates segregately used by (8) airlines serving the airport, and different (extented) terminal plan. It was necessary to extended and improve ACAP. So, it was modified as follows:

- Number of gates was increased from a maximum of (4) to (10), while retaining their segregated utilization, and with compatible increase in maximum numbers of nodes and paths of movement.

- The most important modification, which drastically changed the nature of ACAP, was the deletion of all regression-derived models from the modular component subroutines. They were replaced by Monte Carlo-based stochastic models that provide logic for simulating activities performed at each facility, and predict queueing times and lengths accordingly. This particular improvement, changed ACAP's simulation classification from LEVEL II to LEVEL III.

This modification achieved two important goals: First, attaining stochasticity of operation, and secondly, promoting general utilization. The modified ACAP could be used to simulate any terminal of size comparable to that of Austin Airport in 1983, regardless of other characteristics. Nevertheless, ACAP was not used in this methodology, because in the circumstances of this research, the input data required was still substantial and unmanageable to collect.

8.5.1.2 ALSIM

Compared to ACAP, ALSIM is of a gigantic dimension, with the capability of simulating very large airports. The following is a description of the nature and general features of ALSIM extracted
from its published literature\(^{168,191}\). ALSIM is a computerized simulation which quantifies parameters describing flow due to the movement of people and vehicles through the airport landside. The landside, region between the aircraft and airport boundaries, can be viewed as a combination of service or processing facilities. In this sense, ALSIM represents essential landside processing facilities and simulates the arrival, queueing, and service processes simultaneously occurring at each location. This is accomplished by representing enplaning and deplaning passenger groups, airport visitors, and vehicles by transactions that are routed through programme modules resembling landside processing facilities.

ALSIM is written in GPSS V with an extensive FORTRAN supporting subprogramme, thus utilizing the advantages of both languages. GPSS V programmes creates transactions to represent passengers and accompanying visitors, which are directed through the programme blocks to describe the simulated landside processors in a manner closely resembling the routing of passengers through actual processors. The FORTRAN subprogramme is used to provide efficiency in matrix searches during programme execution, to assign facility numbers to GPSS transactions, and for flexibility in input and output operations with large data files used such as airport configuration, and flight schedules. IBM Assembly Language subroutines are used to provide programme linkages between the GPSS Main Program and the FORTRAN Subprogramme, perform in-core reading and writing, set logic switches, and to obtain and assign parameter values for transactions in the FORTRAN Subprogramme.

Structurally, the components of ALSIM are:
1. Programme definition containing matrix size specifications, service time distributions, routing functions, and GPSS variables definitions.
2. Deplaning passenger logic, which creates and assigns routing functions to deplaning passengers and visitors transactions.
3. Enplaning passenger logic, which creates transactions representing originating passengers and accompanying visitors.
4. Facility modules representing essential landside processors.
5. Control section for dispatching transactions to facility modules.
6. Timer section to start and stop the simulation process.

Input data required to run ALSIM include:

1. **Facility characteristics**: Including the location of each processor, number of servers available or size of facility, and applicable service times distribution.
2. **Passenger characteristics**: Each transaction is assigned its designated attributes (parameters), which will determine the passenger characteristics. Those passenger characteristics include group size, ground transport modal choice, visitors per group, number of bags distribution, route selection through landside, arrival distribution prior to flight for enplaning passengers, and selection of check-in counter type.
3. **Flight schedules**: It represents the demand and provides a mechanism for generating the model transactions by specifying number of arriving, departing, or transfer passengers on each flight, arrival / departure time, the type of flight (domestic/international/commuter), and baggage claim facility identification number.
4. **Airport geometry**: Including point number, coordination of point, facility type at point, and facility number within type.

Evidently, such input requirements necessitate substantial data gathering efforts, which usually are the most time consuming and costly part of implementation. Size and cost of such an effort will eventually depend on how much of the necessary information is already on-hand through earlier airport surveys, and on degree of detail and accuracy desired. Overall, a typical large-scale data collection exercise at a major airport, aimed at gathering all data necessary to operate ALSIM, may cost as much as 50,000 US Dollars in 1978 prices[191].
Model output includes flow, queueing information, and occupancy for all facilities accumulated every five minutes. Output statistics are maintained individually by the program for each facility. A summary of numbers of passengers served, queue length and waiting time averages or distributions, average usage of facilities, and time series of facility outflow aggregated over a specified time period, are also made available.

Computer storage and time requirements are dependent upon the number of facilities simulated, the total number of passengers and visitors simulated, and an input scale factor which specifies how many passenger groups are simulated by one GPSS transaction. For example, a single simulation run for a 100-gate airport during a busy period extending over three hours, involving 20,000 passengers on 165 flights, require approximately (7) minutes of central processor unit (CPU) time and 556 K bytes of storage on an IBM 370/158. That is for an input scale factor of (1), but for an input scale factor of (2), storage requirements would increase to 800 K, and CPU time to (15) minutes.

Calibration and validation of ALSIM required a separate study by itself conducted by Wilbur Smith & Associates(99), where comprehensive surveys were conducted in 1978 at three large hub airports in the US: Miami International, Denver-Stapleton, and LaGuardia airports. These surveys were so extensive— and obviously expensive, that they had around 400 field staff employed to collect data for two days at each airport using 32 different kinds of survey forms and sampling techniques.

However, ALSIM was not selected for use in this methodology. ALSIM's input requirements are substantial with a level of detail that necessitates the collection of data compatible with that level. This would imply conducting surveys of the size mentioned above. The cost and manpower needed for such surveys in the circumstances of this research work was unthinkable. Moreover, congestion information (waiting times and queue lengths) for the
different runs that are required to construct the performance model for various demand levels anticipated, could not justify the use of a tool of that size, cost, and sophistication. It would be like cracking a nut with a sledge hammer!

8.5.2 MICROSCOPIC APPROACH

For the microscopic level, the characteristics of an individual component are examined and its performance analysed, to identify basics of the process, and to clearly delineate the logic that governs the performance of activities. It would be of prime importance to examine the detailed aspects of operational characteristics of facilities in consideration, and to define its distinguished features.

Typically, airport terminal processing facilities are cases of queueing processes, where waiting and congestion are intrinsic. For the analysis of queueing systems, Fishman(192) diagnosed their features, which include:

1. Demand:
   - Arrival pattern.
   - Required service for demand.
   - Willingness to wait.
   - Resource requirements.
   - Server preference.
   - Priority, as a special attribute of demand.

2. Resources:
   - Number of servers.
   - Service time characteristics.
   - Selection rule for service (queue discipline).
   - Skill level.
   - Service interruptions, caused by preemption of new demand, or server failure.
   - Waiting space available.
3. Performance:
- Percentage of demand waiting.
- Waiting time characteristics of demand.
- Resource (server) utilization.

In adopting the microscopic approach, the task would then be reduced to simulating individual components, subsequently, reducing the information collection effort from costly and inconvenient airport surveys necessary for input, to that of much more manageable information, in terms of data gathering effort and cost. Consequently, information is restricted to arrival demand patterns, number of servers, service time distributions, and queue discipline. Now, would this approach be adequate for synthesizing required information to establish the performance model? Would it be realistic or justifiable?

Congestion and delay information from individually simulated components should have no reason to be inconsistent with or notably different from equivalent information for that particular component simulated as a part of the overall context of the complete system, provided that arrival demand patterns to that component (with exactly the same service characteristics for the two cases), are identical. On the condition that the arrival demand pattern for a particular component (which actually dictates congestion and delay if service characteristics are kept constant) could be closely approximated to the actual demand anticipated, then such approach would be reasonably suitable for predicting congestion and delay information for individually simulated components.

This approach is reasonably realistic, because, conceptually, it attempts to detach an individual component from the system, but still retaining all factors that influence its operation whilst the component remains within the system. One can imagine pointing an observation device (camera) on that individual component alone and recording all movements and other aspects related to its
operational performance. This is analogous to the concept of free-body-diagram used by structural and mechanical engineers to interpret forces acting on a particular structural element or component, in the attempt to analyse the whole system. Justification of this approach stems from the need to comprehend the behaviour and operational performance of the components of the system without the inevitable necessity of conducting costly and obtrusive information collection exercises.

To choose an appropriate technique to simulate components individually, Shannon(133) recommended the following considerations to the process of choosing between several simulation techniques:

1. Training required in terms of:
   - Ease of learning the language.
   - Ease of conceptualizing simulation problems.

2. Coding considerations, such as:
   - Ease of coding random sampling and numerical integration.
   - Degree to which coding is self-documenting.

3. Portability and availability of the language on other and new computers.

4. Degree of flexibility to which the language supports different modelling concepts.

5. Processing considerations, including:
   - Built-in statistical gathering capabilities.
   - List processing capabilities.
   - Ability of core allocation.
   - Ease of producing standard report.
   - Ease of producing user-tailored reports.

6. Debugging capabilities and technical reliability.

7. Run-times consideration covering compilation and execution times.
For availability reasons, only two packages (simulation languages) were considered, and were thoroughly inspected for adequacy of implementation in this research, they were ECSL, and SLAM.

8.5.2.1 ECSL

ECSL package available in LUT Computer Center, was inspected with trial runs to test its suitability to simulate terminal processing facilities, however, after closely examining its properties from output of the runs, it was discarded. It proved to be inadequate for implementation, largely because of its inflexibility in interpreting input parameters, and incapability of representing arrival demand in a time-varying pattern.

8.5.2.2 SLAM

SLAM is a recently developed simulation package, that offers higher modelling power and flexibility, and promotes the articulation of systems description. Specifically, the combined-mode features of SLAM, are extremely useful in simulating the airport terminal facilities, where combined network-discrete event simulation capabilities of SLAM were efficiently utilized to model all terminal processing facilities. Adopting SLAM as the simulation technique facilitated more realistic modelling of the terminal facilities. Important features of SLAM that proved to be of particular significance for the methodology were:

1. Unlike ECSL, SLAM was flexible in representing the demand arrival to facilities in a time-variant pattern throughout operation. This is accomplished by including the fluctuations in demand pattern (for 20-minute time intervals) in subroutine (ARVL), which conveniently simulates the time-varying arrival of demand to the facility.
2. Stochasticity in simulating the processing activity is accomplished by exploiting SLAM's capabilities in this respect. For instance, calling subroutine \texttt{SCHDL(1,EXPON(0.20,3))} in discrete event mode, or statement \texttt{ACTIVITY/1,EXPON(0.20,3)} in network mode, both would simulate activity number 1: processing an entity (passenger) with a service time whose value is randomly generated from a Negative Exponential distribution with mean service time \((1/\mu)\) is 0.20 minutes, using the random number generating function (string) number 3.

3. Conditional probabilistic branching of oncoming entities between unidentical servers according to predefined percentages, by using the function (\texttt{ACT}).

4. Conditional probabilistic branching of oncoming entities between identical servers according to some priority rules, by using the function (\texttt{SELECT}).

5. Monitoring capabilities, which include:
   - Clearing statistics during the 'warm-up' (transient state) period, by using the function (\texttt{MONTR,CLEAR}).
   - Tracing all events attributes or other SLAM parameters throughout simulation, by using the function (\texttt{MONTR,TRACE}).
   - Producing summary reports at selected intervals throughout simulation, by using the function (\texttt{MONTR,SUMRY}).

6. SLAM output report is provided, with the statistics and operational information the modeller desires, by using the functions (\texttt{STAT}), (\texttt{COLCT}), and (\texttt{TIMST}).

7. Description of various aspects of the system through the use of such SLAM variables as: \texttt{ATRIB(.), SS(.), and XX(.)}.

8. SLAM time-keeping provisions, such as (\texttt{TNOW}), and (\texttt{TNEXT}).

In the coming section, SLAM utilization to simulate terminal processing facilities under consideration is thoroughly described.
8.6 SIMULATION OF TERMINAL FACILITIES USING SLAM

The first step in constructing a facility's simulation model, would be to express the real system in terms of its key events. In a simple servicing situation, the system's operation could be simulated by considering two events:
1. **Passenger arrival**—either starting service immediately, or alternatively, join a queue and wait.
2. **Passenger departure**—when service ends and the passenger leaves, then, either service starts for another passenger waiting in queue, or the facility becomes idle.

This is the basic outline of logic associated with servicing or processing in general, and for individual passenger processing facilities, only complementary details that change. Typically, simulation execution starts from an initial condition, then proceeds in chronological order according to the scheduling times and durations of either type of event. Continuously, records are updated and statistics amended at each event.

SLAM 'next-event' logic is the structural framework within which discrete-event models are simulated. The logic, as depicted in Figure 8.2, begins by entering the MAIN Program, where all variables are defined and dimensioned. In programme MAIN, there is a call to SLAM processor, where SLAM input statements are read to define the simulation parameters. Next, the system is initialized by calling subroutine INTLC (if INTLC is not included by the user, SLAM processor will automatically initialize the system as empty and idle). Execution of simulation begins by removing the first event from the event calendar, where they are sequentially ordered based on low values of event times. SLAM processor will then call the user-written subroutine EVENT(I)—where I is set to the event code, which in turn calls the appropriate event subroutine. TNOW (current time) is then advanced to the event time for the next event. A test is made after the user-written event subroutine is executed, to check if simulation run is complete. If the run is not complete, then the
Figure 8.2 SLAM Processing Logic for Discrete-Event Simulation
new first event is removed from the event calendar and processing continues, otherwise, execution is terminated and the output documentation is printed.

Observations gathering and statistics collection, are done by the following SLAM input statements:
1. STAT statement, which collects statistics on variables based on discrete observations upon user request through instructions from within the user-coded FORTRAN programmes by calling subprogramme COLCT, or within the network model by the COLCT statement.
2. TIMST statement, which collects statistics on time-persistent variables, corresponding to statistics for the dimensioned XX(.) variables over a period of time.
3. In addition to STAT and TIMST statements, statistics on files (queues), and regular or service activities are automatically generated in the SLAM Summary Report, which contains all generated information on observations and their statistics.

SLAM also provides good monitoring capabilities through the following:
1. MONTR, SUMRY statement, which causes SLAM Summary Report to be produced. Its parameters are starting and ending times of documentation of results as desired by the user.
2. MONTR, TRACE statement, which provides a trace report on all times of events that entities (with their attributes) perform activities. Its parameters are starting and ending times of trace as desired by the user, and attributes of entities to be included in the trace report.
3. MONTR, CLEAR statement, which causes the clearance of all statistics during the initial 'warm-up' period until steady-state (statistical equilibrium) is attained. Its parameters are starting and ending times of clearing statistics.
Terminal facilities considered for simulation in the methodology are: ticket check-in facilities (for all types of flights), departures outbound official controls (security check and passport control which for convenience were included in one model because of their close proximity to one another in the juxtapositioning of facilities), inward immigration control, and arrivals customs control. Excluded is the baggage claim facility, because of the widely varying operational conditions associated with baggage handling, largely due to unstandardized working procedures. Thus, it is difficult to obtain representative operational information to use as input parameters in the simulation process, particularly when this information could vary between different airports, airlines, and even between flights at the same airport. This information largely depends on the baggage handling agency's efficiency, policy, work procedures, and many other factors. In such circumstances, it would be irrelevant to assess the performance of the facility within the structure of this methodology. It would probably require a separate study itself.

8.6.1 TICKET CHECK-IN FACILITY

This is an airline-operated facility, either directly, or subcontracted to a handling agency. It is usually manned with one server on a counter, where passengers' tickets are checked, seats assigned, and baggage accepted, weighed, and labelled before it is conveyed to the baggage staging and sorting area, or is directly transported to the aircraft.

Operationally, the facility processes passengers in batches (flights), where each counter is opened and closed at prespecified times that are directly related to flight departure times, and only passengers on that particular flight are serviced. However, common check-in facilities, where passenger processing is continuous and is not performed according to
flights, are sometimes used. Arrival distributions, usually expressed in terms of time prior to scheduled departure time, characterize the type of flight (i.e., charter, long/medium haul schedule, or commuter). Service is offered on a first-come-first-served basis, and service times distributions are assumed to be shifted negative exponential, with mean value depending on kind of service and activities encountered.

Processing logic for ticket check-in facilities is:
1. Passengers arrive to the facility in a demand pattern typical of that particular flight. Interarrival times are Poisson, the value of which vary according to the actual arrival pattern, but the distribution is kept constant within 20-minute time periods (subintervals).
2. If a server is free, then service for the first passenger commences immediately, otherwise, the passenger will wait in the queue.
3. As for the server, if there are no passengers waiting in queue, then the server is made idle, otherwise, service starts for the first passenger in queue for a duration (service time) that is randomly chosen from an exponential distribution with a mean value of the average service times.
4. After completion of service, the passenger leaves the facility, and the cycle starts again.
Events associated with this process are depicted in Figure 8.3a.

Discrete-event simulation is adopted, using SLAM's event mode, and is carried out by coding the following FORTRAN subroutines and SLAM input statements:
1. Program MAIN.
2. Subroutine INTLC, to initialize the system.
3. Subroutine EVENT(I), to provoke appropriate event when called during simulation.
4. Subroutine ARVL, to simulate the arrival event.
5. Subroutine ENDSV, to simulate end-of-service event.
6. SLAM input statements to specify;
- Number of files (queues) present in the system.
- Maximum number of attributes per entity.
- Maximum number of entities concurrently present in system at any one time.
- Gathering observational information and collection of statistics.
- Start and end times of simulation.
- Monitoring requirements.

Listing of a sample of check-in simulation model is shown in Appendix C-1.

8.6.2 OUTBOUND OFFICIAL CONTROLS

These facilities constitute of security check units(s), and passport check counter(s), the function of which is to perform certain regulatory controls on departing passengers, that provide flight security and safety, control against passengers possession or transport of illegal items, and passport checking/stamping for outward enplaning passengers. Passport check counters are manned and operated by the related governmental agency, while manning and operating the security check units are the airport authority's responsibility, either directly, or through specialized security agencies. The main reasons for including both facilities in one model are that they are usually situated in direct succession to one another, and they have relatively similar operational characteristics. Simplicity and convenience favour using one model to simulate operations in both facilities.

Operationally, passengers are processed after checking-in, handing-in their baggage, getting their boarding passes, and when they feel ready to proceed to the departure lounge. Frequently, the security check unit comprises of a magnometer frame through which passengers have to pass, and conveyorized X-ray bag scanning where hand luggage is inspected for prohibited items.
Figure 8.3 Facility Processing Events For Departures.
Manual search compartments may also be used but only for special cases and in certain occasions. A passport check is made on all departing passengers to check status of their passports where required processing on the passport is carried out. Service is offered in both facilities on a first-come-first-served basis, and service times are also assumed to have exponential distribution. Unlike check-in, this facility is a continuous-processing type, where the arrival of passengers is continuous, and not flight-specific. The arrival demand pattern should be deduced by various means from the departure channel throughputs, preferably during peak periods. Beyond this facility, passengers enter the 'sterile area' of the airport, and are considered as departed.

Processing logic for these two facilities is:
1. Passengers arrive in a predetermined demand pattern, deduced from that of the total departure channel, with Poisson interarrival times, the values of which vary throughout operation according to the actual arrival pattern, but are kept constant within 20-minute subintervals.
2. If a security unit is empty, then security search is commenced for first coming passenger immediately, otherwise, the passenger has to join the queue and wait.
3. If there are no passengers waiting in the queue for security search, then the unit is laid idle, otherwise, the first passenger in queue is searched. Security search in normal conditions is performed as follows (which is the order implemented in the two airports considered in this study): Passengers are asked by a security officer at the entrance of the facility to show their boarding passes. After being cleared the passengers would then have to walk through the Mangnometer frame for self-checking. Before that their cabin luggage is put on the conveyorized X-Ray scanning device for baggage-check. After the passenger and his luggage are cleared, he leaves the facility. Being that complicated, security search is considered as one composite activity from the moment the passenger steps inside to
the point of leaving the facility. Accordingly, service times are considered as one time in terms of how long it took individual passengers to clear the security check from entry to departure, regardless of what was actually done in between. Security search times are randomly selected from a Negative Exponential distribution with a mean value of the average service time.

4. After the security search has been completed, the passenger proceeds to the passport controls. If a server is free, then the passport check commences immediately, otherwise, the passenger will have to join the queue containing least number of passengers (in the case of more than one passport check counters), and wait.

5. If there are no passengers waiting in the queue for the passport check, then the server is laid idle. Otherwise, the server would start checking the passport of the first passenger in the queue for a duration (service time) that is randomly selected from an Exponential distribution with a mean value of the average service time.

6. After completion of service, the passenger would leave the facility heading to the departure lounge, and the cycle starts again.

Events associated with outbound official controls are depicted in Figure 8.3b.

SLAM's combined network-discrete event mode, is conveniently adopted in simulating this facility. This is accomplished by coding an event-mode FORTRAN user-function (FUNCTION USERF) that would simulate the arrival of passengers to the first facility on 20-minute subinterval basis. This is done by assigning Poisson interarrival times (Times Between Creation- TBC) specified according to a predetermined arrival distribution reflecting demand patterns and levels. Conditional IF statements are used to control assigning the right interarrival time specified by the demand pattern with respect to current simulated time (TNOW). A sample listing is shown in Appendix C-2. SLAM's network mode segment of the model contains statements for:
1. Creating entities (according to TBC values of FUNCTION USERF).
2. Assigning attributes to entities.
3. Branching entities to channels and servers.
4. Assigning service times to activities.
5. Queueing passengers into files.
6. Collecting required statistics on all entities, files, and servers.
7. Graphical representation of statistics (distributions).
8. Monitoring of results.
9. Controlling simulation execution.

Listings of combined network-event simulation of outbound official controls are shown in Appendix C-3.

8.6.3 **INWARD IMMIGRATION CONTROL**

This facility is concerned with checking the status of passengers entering the country and controls the admission of foreign citizens to the country, as well as marking passports of nationals returning from foreign countries. Normally, passengers are processed in separate channels according to type of passport they hold. Generally, they are conveniently separated into different channels; national passport holders, and foreign passport holders (which, in turn, could be further subdivided). For the first category, service is usually restricted to examining the passport. While for the second, in addition to passport stamping and checking status and validity of passports, it may include issuance of visas, and granting appropriate visiting permits. Governmental agencies (immigration authorities) are responsible for the manning and operation of this facility.

Operationally, passengers arrive at this facility after deboarding the aircraft, where they split into channels according to type of passport. Beyond this facility, passengers are officially considered as having entered the country. Service is continuously offered for both channels on a
first-come-first-served basis. Service times are drawn from an Exponential distribution. Interarrival times are Poisson, the values of which vary according to the fluctuation of demand, but the arrival rates are kept constant within 20-minute subintervals. Arrival demand pattern could be extracted from actual arrival channel throughputs during desired periods of operation.

Processing logic for the facility is:
1. Passengers arrive to the facility in the designated pattern, and are categorized immediately by assigning an attribute value to the arriving passengers that would identify them according to type of passport. This is done as follows; a random selection from a uniform distribution between 0 and 1 would define the attribute value according to the percentage of each of the total passengers (e.g., if the split in actual demand is 75% national and 25% foreign passports, then selected random values that are less than 0.25 would be assigned an attribute value of (2) (foreign passports), while all other random values greater than 0.25 would be assigned a value of (1), national passports). In other words, attribute values are assigned to passengers by Monte-Carlo method according to a prespecified proportion. Consequently, each arriving passenger would be directed to the designated channel.
2. For each channel, if the server is free, then service immediately starts for the first arriving passenger, otherwise, the passenger would have to wait in the queue. If there are many servers in a channel, the passenger would choose the server with least number of passengers queueing.
3. If there are no passengers waiting in a queue, then the server is laid idle, otherwise, first passenger in the queue is serviced for a duration (service time) that is randomly chosen from an Exponential distribution with a mean value corresponding to the particular average service time.
4. After completion of service, the passenger leaves the facility, and the cycle starts again for the next arriving passenger. Events associated with this process are depicted in Figure 8.4a.

Simulation is carried out using SLAM's combined network-event modes capabilities, similar in principles to that of the outbound official controls, except that attributes that identify the category of passengers (ATRIB) are assigned to all passengers, to distinguish between their passports types, and direct them to corresponding channels. Listing of a sample of the inward immigration control simulation model is shown in Appendix C-4.

8.6.4 ARRIVALS CUSTOMS CONTROL

The function of this facility is to control importation of items subject to customs and excise taxation or prohibition by law. In some occasions, it also includes currency control. Manning and operation of this facility is the responsibility of customs and excise authorities.

Operationally, passengers are processed after leaving the baggage claim hall, after they are reunited with their baggage. To organize operation, many countries (including the U.K.) implement the Dual-Channel system, where the facility is divided into two parts; Red Channel, for passengers who have something to declare and report to the customs authorities for taxation or inspection, and the Green Channel, for passengers who have nothing to declare (theoretically, they are not of interest to the customs authority, however, they are actually subject to occasional inspection and spot-checking).
Figure 8.4 Facility processing Events for Arrivals.

(a) Inward Immigration Processing Events.

(b) Customs Control Processing Events.
Servicing logic for customs is as follows:

1. Passengers arrive to the facility in a predetermined demand pattern as implied by FUNCTION USERF, with Poisson interarrival times, the values of which vary according to fluctuations of demand but arrival rates are kept constant within 20-minute subintervals.

2. Immediately after arrival, a decision is made of whether the passenger would go through the Red or Green channels. This decision is based on the percentage of passengers in actual demand that were observed to have used either channel. As described previously, this is carried out through assigning attribute values to passengers using Monte-Carlo method according the specified proportion. Green Channel passengers are considered in the simulation as having left the system, and no statistics are collected for them (unless the time it takes to go through the Channel (walking time) is included in the simulation). For Red Channel passengers, if a customs official is free, then service commences immediately, otherwise, the passenger has to wait in queue.

3. If there are no passengers waiting in queue in the Red Channel, then the server (customs official) is laid idle. Otherwise, the server will start service for the first passenger in the queue for a duration (service time) that is randomly selected from an Exponential distribution with a mean value of the average service time observed for customs clearance.

4. After completion of service, the passenger would leave the facility, and the cycle starts once again.

Events associated with this process are depicted in Figure 8.4b.

Simulation is carried out using the combined network-event mode capabilities of SLAM in a way almost identical to that of immigration control, except for the fact that Green Channel is considered either as, a linking facility where the only activity performed and time consumed is that of walking through the facility, or that walking time is considered as negligible hence Green Channel passengers are virtually out of the system.
Passengers going through the Green Channel hesitate in their walk in anticipation of being stopped by customs officials. Although this is a complex situation to model, one can make a simplifying assumption that would not effect the operational aspects of the situation, where a certain time period is assigned to the passengers' slow-down walk. Since target percentage of Green Channel passengers stopped by customs officials is unobtainable, it can be assumed for simplicity that those passengers initially went through the Red Channel. The percentage of passengers going through the Red Channel (whether voluntarily or after being stopped) is made available from the airport passenger survey. Listing of simulation model of customs control is shown in Appendix C-5.

It should be noted that the walking times within facility boundaries are included only in modelling customs control, while in modelling all other facilities it is considered for all practical purposes as negligible.

Amount of information generated in a standard SLAM output report is quite substantial, depending on the particular simulation and the requisites and desires of the user; a typical run would be at least 20-40 pages. However, only a small fraction of that generated information would be normally required in constructing performance models. So simulation outputs are summarized and all required information are collapsed into one summary sheet.

8.7 STATISTICAL CONSIDERATIONS IN SIMULATION

Simulation is basically an experiment, where observations are gathered, usually when the system is tested under different conditions. In this sense, observations from simulations are not different from observations collected from an experiment in a laboratory, and it should always be treated as such. Moreover, since the user can self-design his experiment to obtain specific
output data thought to be necessary to describe the system and answer pertinent questions related to it, he would then be able to experience more control on the running of the experiment. In addition, statistical analysis of simulation output is similar to statistical analysis of data obtained directly from the actual system. Therefore, observations gathered from simulations must be statistically independent and identically distributed, so as to have appropriate statistical inference made about the operational performance of the system(85).

So, statistically, analysis of the simulation output should be examined in relation to the following aspects:

1. Inherent variability associated with simulation, understanding the activities and processes the model simulates, and verifying that it performs what it is designed to perform. Issues of interest here are: the sensitivity of simulation output to changes in input and model parameters, and the accuracy and precision of the output with respect to the inherent probabilistic nature of the system.

2. Inferences about the performance of the real system from the use of simulation, especially the validity of simulation and its usefulness. This involves describing and performing related statistical computations of the system performance variables. Thus, in simulation, all generated information, including statistical tables and distribution plots are viewed as if they were possible outputs from the real system, and computations and statistical analysis made are similar to those performed on data obtained from the real system.

Nevertheless, variability and stochasticity is treated in simulation in exactly the same manner as in collecting information directly from the real system. The fact that a single simulation run represents one sample or time series of a stochastic process, is no more bothersome than the fact that an historic record represents only a single time series(91). As for stochasticity, efficiency of generation of randomness is an
important issue in simulation, where random number generation devices (i.e., streams or sequences) are used as the basic building block to reflect the stochastic features of simulation. Basically, random numbers are better known as pseudo-random numbers, because they actually are completely deterministic although they pass different tests of randomness. Literature on this subject is quite substantial and it can not be included here, but generally there are two basic methods of random number generation; Midsquare method, and the Congruential methods (multiplicative, mixed, and additive). Before their use, random number sequences should be thoroughly tested and verified that the resulting sequence is statistically independent, is actually random, and can pass randomness tests. Literature on testing randomness is extensive, and one can refer to Shannon(133), Fishman(192), and a more detailed source, Hull and Dobell(193). Analytical and empirical tests have been used to inspect and investigate randomness, where there could be almost unlimited number of tests(133). The most common tests are: Frequency, Serial, Gap, Sums-of-digits, Runs, Spectral, Poker, Autocorrelation, Distance, Order Statistics, and Latticed tests. In SLAM, there are ten different random number sequences, which have undergone different tests to ensure its efficient performance(91), and in running simulations on SLAM, it was found that using any one of the ten will yield similar results.

In experimentation, it is the main objective of statisticians to minimize sampling errors when gathering observations associated with an experiment. In discrete simulation, sampling errors are reduced when observations are gathered in the condition of statistical equilibrium (steady-state). Reaching steady-state depends on the initial condition of the system which affects length of simulation run needed to reach steady-state, and the input parameters, where relative values of arrival and service rates directly affect the amount of simulation time needed to reach steady-state. However, bypassing transient-state before reaching steady-state may be costly and impractical. Although
sampling error could be reduced by gathering observations under steady-state conditions, Taha(85) indicated that it can also be reduced even further by taking the average of these observations, since the standard deviation of the average of \( n \) observations is \( \frac{1}{\sqrt{n}} \) of the standard deviation of the individual observations. Preferably, the objective of minimizing sampling error should consider the following courses of action:

- Controlling the cost of simulation by reducing the length of simulation runs to a reasonable limit, or utilizing improved sampling techniques specially designed to reduce statistical errors (variance reduction methods). Variance reduction techniques are:
  - Antithetic, by using a random number and its complement (which itself is a random number), in two identical runs.
  - Common random number streams for repeated runs.
  - Prior information employing analytically-deduced results.

Pritsker and Pegden(91) describe various procedures for estimating the variance of the sample mean, which could play an important role in the reliability of simulation output. These methods are too statistically complicated and mathematically advanced to be included in this study, they are:

1. Replication, employing separate runs using different random number streams.
2. Subintervals, where a single run is divided into equal subintervals (batches), hence effects of transient conditions would be eliminated with running time.
3. Regenerative cycles, where a run is divided into cycles that starts when a specific state of the system is reached, and when a return is made to that state, the cycle ends.
4. Parametric modelling, where a model to describe the output from a simulation is built by fitting equation(s) to the observed (simulated) data values.
5. Covariance/spectral estimation, where estimates of the autocovariance is deduced from the sample output using spectral analysis techniques.
From this discussion, it appears certain that analysis of simulation output could involve sophisticated statistical and mathematical analysis techniques, especially with respect to variance and covariance estimation. However, for this particular study, the following facts justify not going into such elaborate analysis:

1. Since averages of statistics of observations are of interest from all simulation output, sampling errors are reduced.
2. The fact that some of the observations were probably made in transient-state conditions is countered by the fact that non-attainment of steady-state will not greatly bias those averages, because the number of observations at transient-state is normally low compared to total number of observations.
3. Indirectly, the subinterval method causing the elimination of effects of transient state, is actually used in the simulation of facilities considered in Section 8.6. This is done to simulate the fluctuation of demand, where the arrival demand is interpreted as variable interarrival times during 20-minute subintervals.

A remaining issue that is specifically important and needs some consideration, is the validity of simulation, a very sensitive issue that could be a subject of endless debate and raging argument. Validation is the process of establishing that a desired accuracy or correspondence exists between the simulation model and the real system(133). In simulation, the approach to model validation is more philosophical than statistical. " We believe that the process by which a model is constructed, validated, and implemented, are inseparable of one's theory of scientific inquiry ". This and the following quotations are Shannon's(133) views on this issue. " A model should only be created for a specific purpose, and its adequacy or validity evaluated only in terms of that purpose. To evaluate a model means to develop an acceptable level of confidence that inferences drawn from the performance of the model are correct and applicable to the real world system; concept of validation
should be considered one of degree and not one of either-or notions". However, as the degree of confidence (i.e., validity) increases, development costs (and value) will also increase to a level that it would become inconvenient and unattractive to use. This dilemma, will consequently include a measure of cost-benefit into the process. "What is the value of true correspondence between the model and the real life system? How isomorphic need the model be to be considered valid? If the model consistently predicts results or reproduces problems that are bourne out in practice, how important is it that the model be a true and isomorphic reflection of the real system? Can a model be grossly homomorphic and still valid?". The answers to these questions raised by Shannon might define a validation approach, but he admittedly argues that: "Despite extensive literature dealing with validation procedures, the problem of validating simulation models remains as difficult and elusive as ever, but it is an issue we cannot avoid or push lightly aside”. So, what approach to adopt and what technique to implement in simulation validation? Realizing its philosophical nature, it might seem appropriate to deal with the problem in the same manner researchers deal with scientific inquiry in its broad general sense; subjective or objective, rational or empiric, pragmatic, or a viewpoint that incorporates them all. Usually, a multistage verification process arises that adopts a utilitarian approach. The stages are:

- Validation of the internal structure of the model based upon a priori knowledge, past research, and existing theory, which entails looking at each of the simple processes modeled to ensure that their building blocks are the best possible.
- Empirical testing of the hypothesis used in the internal structure of the model.
- Verify the model's ability to predict the behaviour of the real world system, and its usefulness in doing so. It entails comparing input-output transformations generated by the model with those generated by the real world system, and is highly critical to gaining user acceptance.
The three stages occur in an interactive manner throughout model derivation, development, and implementation, where usually, there exists a continuing interplay among rationalist, empiricist, and pragmatic philosophies throughout the process.

Throughout this research, simulation validation followed this approach. The internal structure is first investigated (the process of servicing is a very simple and basic one, therefore, not so difficult to understand), and then tested. Comparisons were continuously made between input-output transformations generated, and those of the real world (which are either observed in surveys, or evaluated by experience and common sense). These comparisons served as a means of the verification of the model's ability to predict the behaviour of the real world system, and give an assurance that simulation is realistic and could be used to predict required information.
This chapter involves the practical applications of this methodology, including presentation of practical aspects, necessary supporting information, discussions on related relevant issues, and findings. Contained in this chapter are the following applications: East Midlands pilot survey, Panel of Experts survey, Manchester Airport study, and Birmingham Airport case study.

9.1 EAST MIDLANDS AIRPORT PILOT SURVEY

This survey was conducted in East Midlands Airport, which is situated about ten miles north of Loughborough, during September 1983. The East Midlands is a small regional airport that experienced substantial increase in traffic in recent years; 75% increase for the years 1978-83, and 32% between 1981-83 alone. It was specifically chosen for the pilot mainly for its proximity to LUT. The objective of this pilot survey was to test the suitability of the questionnaire, the reaction of passengers to it, and to check the appropriateness of the service measures used, the layout of questions (especially graduation of intervals of the service measure), and other supporting information that needed to be examined beforehand.
After initial negotiations with the airport management, permission was granted to enter airside and interview passengers. The plan was to approach passengers in the departure lounge for departures and after leaving customs for arrivals, and conduct personal interviews with randomly selected samples. However, only departures was actually considered. It was found that it would be very difficult and inconvenient for the surveyor to conduct personal interviews with passengers after they had left customs. The only thing they were anxious to do then was to meet friends and relatives and get with their luggage out of the airport terminal.

The passenger traffic of the East Midlands Airport is about 65% charter-tourist. It was decided therefore to include only this category in the pilot. A weekend day (Saturday, September 17th) was chosen for the survey, because peaks at the airport occur during weekends. Passengers were selected at random from different flights and were interviewed while waiting in the departure lounge. The target sample size was set as 20 to 25 samples.

The questionnaire used (shown in Appendix B-1) included three segments: a covering letter (introductory explanatory note), PART I- sample information, and PART II- service measure information. The introductory explanatory note contained a general description of the nature, objectives, and importance of survey, the grading system to be used, and an example of how to go about answering PART II. PART I included specific information on passengers interviewed: age, sex, nationality, preference and frequency of air travel, and flight information, the purpose of which was mainly to facilitate categorization of population according to some selective attribute. PART II basically deals with P-R model information, namely, the personal judgement of passengers to service conditions for different facilities, and their assessment of these conditions.
The service measure chosen was delay awaiting service, because theoretically, delay is the major attribute of congestion. Hence this could be used as the yardstick because it is directly related to the level of usage of a processing facility. However, it seemed that passengers had difficulty in comprehending (and thus could not easily judge) delay, probably because delay is an emotive expression and it is not very clear in the minds of most passengers to what it actually refers. It was quickly decided then, to ask passengers to state their perception to, not delay, but the total time they spent in each facility. Fortunately, this swift change in altering a major part of the survey took place at the beginning of interviewing, after its necessity was realized.

Average interviewing time for the 25 samples was 5.1 minutes. This was relatively high taking into account the characteristics of operation, the circumstances associated with airport surveys, and the required number of interviews to conduct the main survey with the target sample size desired and within the definitive time frame allowed. The parts of the questionnaire found to be contributing most to the interviewing time were the introductory explanatory note and PART I. For the first part, most passengers could not follow the introductory explanatory note. Much more time than expected was taken to answer all sorts of questions the passengers asked on the (presumably) explanatory note itself. This was evidently awkward and indicated the counter-productivity of this part. As for the second part, many questions seemed irrelevant to the purpose and objectives of the survey, and were therefore redundant to the analysis.

The facilities covered in this pilot were: check-in, passport control, and security check. Passengers were interviewed to state their perception to service in those facilities. From information of PART II of the questionnaire, P-R models were built for each of these three facilities, as well as for the overall departure processing, and Figures A.1, A.2, A.3, and A.4 show these models, respectively. From the models, service standards as perceived by
the passengers could be derived. Employing the concept explained in Section 6.2.1.3, a level of service framework could be set as in Table 9.1. The levels of this framework are expressed in terms of the time values separating the good/tolerable service levels (T1), and the tolerable/bad service levels (T2).

<table>
<thead>
<tr>
<th>FACILITY TYPE</th>
<th>P-R Model</th>
<th>T 1 Good/Tolerable</th>
<th>T 2 Tolerable/Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check-In</td>
<td>Figure A.1</td>
<td>10.5</td>
<td>16.5</td>
</tr>
<tr>
<td>Passports</td>
<td>Figure A.2</td>
<td>7.0</td>
<td>11.5</td>
</tr>
<tr>
<td>Security</td>
<td>Figure A.3</td>
<td>6.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Overall</td>
<td>Figure A.4</td>
<td>25.0</td>
<td>42.0</td>
</tr>
<tr>
<td>Departure</td>
<td>Processing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Finally, some of the outcomes of this pilot were:
1. Delay was not suitable for use as the service measure, mainly because it is an emotive expression that would be difficult for most passengers to interpret and transform into figures.
2. The introductory and explanatory note was too long and detailed for its purpose, and it would be much more appropriate to have it as concise as possible.

3. Many questions of PART I were actually unnecessary. They were redundant and time wasting, and did not contain any information useful to the surveyor.

4. Interviewing as the mode of administering the survey seemed difficult to implement, especially for arrivals. For departures, active involvement of the surveyor with passengers on the airside is not always welcomed by airport authorities. This implied that interviewing should be replaced by self-administered questionnaires, particularly when the type of information sought does not necessitates personal contacts.

9.2 PANEL OF EXPERTS SURVEY

This survey was administered primarily for exploring and testing the appropriateness of an alternative approach to passenger surveys. It was conducted during October-December 1983, by distributing the questionnaire shown in Appendix B-2 to airport experts closely associated with airport operations and passenger handling, who participated in a LUT departmental short course in October. Also, additional replies were sought from European airports, by distributing questionnaires seperately to other 'experts', so as the total number would reach at least 20 participants. Participants were either airport-related or airline-related personnel. Experts from governmental agencies, tour operators, and other parties were not represented in the panel. In all, the panel included 25 participants from 14 European airports and one Middle Eastern airport, 80% representing airport authorities, and 20% representing airlines, as shown in Table 9.2.
Table 9.2
Participation in Panel of Experts Survey

<table>
<thead>
<tr>
<th>AIRPORT</th>
<th>Airport Expert</th>
<th>Airline Expert</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birmingham</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Dublin</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>East Midlands</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Fiumicino- Rome</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Gatwick- London</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Heathrow- London</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>King Khalid- Riyadh</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Linate- Milan</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Lisbon</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Munich</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Schiphol- Amsterdam</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Vantaa- Helsinki</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Zagreb</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Zurich</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>20</strong></td>
<td><strong>5</strong></td>
<td><strong>25</strong></td>
</tr>
</tbody>
</table>

The questionnaire itself was composed of three segments:
1. An introductory explanatory note, which is more concise and improved version of that of the East Midlands pilot.
2. PART I: Service assessment for the participant's airport to provide a 'reference datum' and prepare participants to answer PART II.
3. PART II: Service assessment for a hypothetical airport with an annual throughput of around two million passengers. Since participants actually represented different airports in different countries, it would not be possible to get consistent results using these airports. That is, the resulting P-R models would be trivial because each reply is based on the expert's personal experience with his own airport only and with its specific operational conditions. So, to get a consistent P-R model information from this kind of panel, a hypothetical airport was assumed for all the participants to consider. Participants would then take the airports they are associated with as a 'reference datum', then try to assess service condition for the hypothetical airport accordingly.

Facilities included in this survey are all the processing facilities both for arrivals and departures. P-R models were then built for those facilities for a hypothetical two million-airport. Figures A.5, A.6, A.7, and A.8 are P-R models for departures at this hypothetical airport for ticketing/check-in, security check, passport control, and all departure processing facilities, respectively. Figures A.9, A.10, A.11, and A.12 are P-R models for arrivals at the airport for inward immigration, baggage claim, customs (Red Channel), and all arrival processing facilities, respectively.

Furthermore, based on those P-R models, a level of service framework could be set. It is derived from experts' judgement and perception of operational and service conditions for a hypothetical airport. As presented in Table 9.3, this framework is expressed in terms of delay time values (T1 and T2) that define the three regions of service: good, tolerable, and bad.

The main outcomes and conclusions drawn from the panel of experts survey were:
### Table 9.3
Level of Service Framework for Arrivals and Departures
Hypothetical Airport (2.0 Million Annual Passengers)

Delay in Facility (Minutes rounded to nearest half-minute)

<table>
<thead>
<tr>
<th>FACILITY TYPE</th>
<th>P-R Model Figure No.</th>
<th>T 1 Good/Tolerable</th>
<th>T 2 Tolerable/Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEPARTURES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check-In</td>
<td>Figure A.5</td>
<td>6.5</td>
<td>11.0</td>
</tr>
<tr>
<td>Passports</td>
<td>Figure A.6</td>
<td>4.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Security</td>
<td>Figure A.7</td>
<td>3.5</td>
<td>6.5</td>
</tr>
<tr>
<td>All Processing Facilities</td>
<td>Figure A.8</td>
<td>17.0</td>
<td>26.0</td>
</tr>
<tr>
<td><strong>ARRIVALS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immigration</td>
<td>Figure A.9</td>
<td>7.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Baggage Claim</td>
<td>Figure A.10</td>
<td>12.0</td>
<td>19.0</td>
</tr>
<tr>
<td>Customs (Red)</td>
<td>Figure A.11</td>
<td>6.0</td>
<td>11.0</td>
</tr>
<tr>
<td>All Processing Facilities</td>
<td>Figure A.12</td>
<td>18.0</td>
<td>31.0</td>
</tr>
</tbody>
</table>

1. Although considerable emphasis was put on explaining that delay is the service measure used, it became quite clear that the term delay was unclear even in the minds of experts. This fact gave the concrete evidence that justified the deletion of delay as the service measure and replacing it by total time spent in a facility, for all subsequent P-R model information collection, particularly in the main passenger survey.
2. Noticeable variation in the resulting service standards of Table 9.3 were largely due to the fact that this survey was conducted only to demonstrate the alternative approach to P-R model construction. Two important aspects contributed to these variations. First, the fact that a hypothetical airport was in consideration. Hence it would not be expected to yield consistent and homogenous results. Secondly, each participant took his own airport (with its distinct characteristics, operational procedures, and unique service conditions) as the 'reference datum', which implied that each participant assessed service conditions of the hypothetical airport in terms of those of his own.

3. Nevertheless, the points mentioned above should not affect the view that this approach is applicable and perfectly feasible, especially when representation in the panel is homogenous, where participants are associated with a particular airport, or group of airports with quite similar operational procedures and service conditions.

4. Information of PART I of the questionnaire: service assessment of own-airports, was not included in analysis, because each reply represented a particular airport. In this sense, this part was virtually redundant, except for the fact that it was needed to establish an 'adaptation level' for the participants and prepare them to complete PART II, by considering a 'reference datum' for them to use.

9.3 MANCHESTER AIRPORT STUDY

Manchester International Airport (MIA), is the third largest airport in U.K. (after Heathrow and Gatwick) and the biggest independent airport (not under the British Airports Authority). It serves the north western conurbations of England, especially the metropolitan regions of Greater Manchester, Merseyside, South Yorkshire and West Yorkshire. MIA handled around 5 million passengers in 1983, with an increase of 49 % on 1978(194). Plans
are currently under way to bring capacity to 9 million passengers annually by 1990 (195, 196), following the rising importance of the airport within the British airport network, where the share of MIA of total U.K. traffic has steadily increased from 6.5% in 1978 to 7.9% in 1981, and to 8.3% in 1983 (104, 194).

Characteristics of traffic at the airport is typical of a British regional airport with around 65% charter and 35% schedule traffic split- 68/32 in 1981 (104) and 65/35 in 1983 (194). The percentage of foreign residence passengers is comparatively low (195)- 7% in 1981, including non-British EEC passengers. Figures 9.1-9.3 portray MIA's traffic patterns; Traffic is peaky in relation to annual throughput (195), with August being the busiest month of the year carrying 14% of annual terminal passengers, while February carried only 4%. This could be seen in Figure 9.1, which shows annual traffic at MIA as monthly throughputs for arrivals, departures, and total terminal passengers. Relation between Peak and SBR values are as follows (195):

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ARRIVALS</th>
<th>DEPARTURES</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
<td>SBR</td>
<td>Peak</td>
</tr>
<tr>
<td>1980</td>
<td>1634</td>
<td>1226</td>
<td>1706</td>
</tr>
<tr>
<td>1981</td>
<td>1668</td>
<td>1176</td>
<td>1408</td>
</tr>
</tbody>
</table>

Figure 9.2 shows the busiest week traffic pattern during the peak period of 1981, from which it could be seen that the peak occurs at weekends, with Sunday being the busiest day of the week. Figure 9.3 shows the daily pattern of passenger traffic on the peak day, presented as hourly throughputs for arrivals, departures, and total terminal passengers. Two distinct peaks are noticed: a morning peak (from 7 to 10 a.m.), and an afternoon peak (from 1 to 5 p.m.). There is a less important evening peak (from 8 to 10 p.m.).
Figure 9.1 MANCHESTER INTERNATIONAL AIRPORT - Annual Traffic Pattern.

MONTHLY TERMINAL PASSENGER THROUGHPUTS - 1981

TERMINAL PASSENGERS
Figure 9.2 MANCHESTER INTERNATIONAL AIRPORT - Weekly Traffic Pattern.
Figure 9.3 MANCHESTER INTERNATIONAL AIRPORT- Daily Traffic Pattern.
In the attempt to obtain a suitable environment for applying the proposed methodology, MIA airport authority was approached. Subsequently, approval was granted to have access to information of a survey conducted in Summer 1983 by Directorate of Planning and Development of MIA to explore attitudes of departing passengers to service conditions at the terminal, and to try to assess service standards at the airport's facilities. This opportunity was immediately exploited to conduct the first practical application of the methodology (in its two procedures) for a real-world condition. The survey consisted of a self-administered questionnaire (shown in Appendix B-3), that was handed by survey assistants to randomly selected passengers when entering the terminal building. Passengers were then requested to answer the questionnaire and later return it while in the departure lounge or gates. Information from this survey was used to construct P-R models for the processing facilities of the departure channel (i.e., airlines check-in, and outbound official controls). So, only information of parts 1 and 2 of the questionnaire were actually used for that purpose.

After closely examining the questionnaire, certain criticism have arisen on some of its aspects, particularly the way in which it was designed and structured:

1. Again, and as previously discussed elsewhere, delay is an emotive expression unsuitable to use as the service measure.
2. Statement of wait (delay) at each facility is not technically appropriate, because the amount of wait marked at the top of the boxes was not well-graded, which would eventually lead to somewhat crude P-R models. Service levels extracted from such models might not be so accurate, especially for upper range values. Specifically, certain clarifications on MIAA questionnaire (Appendix B-3) had to be made in order to facilitate the proper construction of P-R models;
   - NEGLIGIBLE, is the region (0-1) minute, with median = 0.5
   - LESS THAN 5, is the region (1-5) minutes, with median = 3.0
   - 5 TO 10, has a median = 7.5
- MORE THAN 10, is the region (10-15) minutes, with median = 12.5
- 100% passengers found (0) delay as good service conditions, and 0% passengers found and graded (0) delay as bad service conditions.
- 100% passengers found and graded delay of more than 15 minutes (with median of 20) as bad service, while 0% of the passengers surveyed found that delay as good or tolerable.

3. It was apparent from the way the questionnaire was worded, that the prime purpose of this survey was mainly to compare service at MIA with other airports (any airport regardless of nature of demand and irrespective of operational characteristics of that particular airport).

4. Although it might not seem so obvious, the underlying tendency in designing this questionnaire, in terms of its wording and general layout, lead responding passengers to concentrate on lower ranges of the P-R models with short delays, thus leaving upper ranges with longer delays open. This fact combined with improper graduation and layout of the delay scale, would result in some inconsistencies in establishing level of service framework.

9.3.1 P - R MODELS

The aforementioned features of the questionnaire had certain implications on accuracy and overall quality of the resulting P-R models. Nevertheless, a level of service framework for the processing facilities of the departure channel at the airport could be conveniently established, based on these models. Facilities included were airline flight check-in, and outbound official controls, both broken down into: charter, schedule-long haul, and schedule-European (Figures A.13-18). Figure A.19 shows P-R model for total departing passengers going through outbound official controls. A point worth mentioning here is that the sample size for various categories did comply with limits set earlier in Section 7.8.
Table 9.4 summarizes the level of service framework that would be derived from the P-R models, stated in terms of lower (T1) and upper (T2) limits on delay for the middle service region (i.e., T1 represents limit on delay for good/tolerable service level, while T2 represents limit on delay for tolerable/bad service level), all rounded to the nearest half-minute.

Generally, level of service framework shown in Table 9.4 seems reasonable, and reflects anticipated behavioural characteristics of the passengers of these categories. Except in the case of schedule-European passengers in outbound official controls (the upper range of service standards (T2)), where generally, schedule-European passengers, being mostly on business trips, are much less tolerant of long delays than other passengers.

9.3.2 PERFORMANCE MODELS

In order to build the performance models for facilities under consideration, description of those facilities is first presented, based on information extracted from Manchester International Airport Authority reports, or through personal observations.

1. AIRLINE FLIGHT CHECK-IN

According to a MIAA report, there were 40 check-in desks available to the airlines during 1982, equally divided between two handling agents; Service Air- the local handling agent, and British Airways- the national handling agent. The handling agents provided service to the following categories of flights:
- Schedule-European (medium haul).
- Transatlantic and intercontinental (schedule-long haul).
- European charters (Inclusive Tours).
- Common Travel Area.
- Domestic.
### Table 9.4
Level of Service Framework for Departure Channel
MANCHESTER INTERNATIONAL AIRPORT

Delay in Facility (Minutes rounded to nearest half-minute)

<table>
<thead>
<tr>
<th>FACILITY TYPE</th>
<th>P-R Model</th>
<th>T 1</th>
<th>T 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Figure No.</td>
<td>Good/Tolerable</td>
<td>Tolerable/Bad</td>
</tr>
</tbody>
</table>

A. CHARTER I.T.:

- Check-in: Figure A.13 3.0 14.0
- Outbound: Figure A.14 2.5 13.0
- Official Controls:

B. SCHEDULE-LONG HAUL:

- Check-in: Figure A.15 2.5 13.5
- Outbound: Figure A.16 2.0 8.0

C. SCHEDULE-EUROPEAN:

- Check-in: Figure A.17 2.0 9.0
- Outbound: Figure A.18 1.5 8.5

D. TOTAL DEPARTING PASSENGERS:

- Outbound: Figure A.19 2.0 13.0
- Official Controls:
However, only international traffic was included in this study. Those flight sectors could be readily characterized by the two fundamental input parameters, arrival distribution, and service times distribution.

**Arrival distribution:** For a particular flight category, the arrival distribution of passengers to airport facilities (especially check-in for departures, which is the first facility in the terminal to which passengers report) is of prime importance. Arrival distribution could effectively portray the behaviour of passengers on different flights. It also has a distinct influence on operational characteristics (including capacity), because it actually reflects the time-varying demand on terminal facilities. Figure 9.4 shows the arrival distributions of international passengers for the three categories of flights considered, and their behaviour with respect to arrival at check-in, at the departure lounge, and leaving for the pier (gates). As described earlier, arrival distributions are effectively interpreted within the simulation process by defining values of interarrival times (times between creation of entities) for each 20-minute time interval that would resemble the particular arrival distribution in consideration for the whole period the check-in facility is open and operational.

**Service times:** In practical situations, check-in service times are difficult to determine, especially when different flight categories, handling agents (and corresponding operational procedures), facilities, and group sizes are included. Initially, there are certain constraints stemming from restrictions placed on information collection in terminals. Furthermore, available information shows considerable variations between those times. According to MIAA(195), service times per passenger (in seconds) for check-in, for the three flight categories as recorded in 1981 were:
Figure 9.4 MANCHESTER INTERNATIONAL AIRPORT- International Passengers Movements Patterns.
<table>
<thead>
<tr>
<th>Flight category</th>
<th>National handling agent</th>
<th>Local handling agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule-European</td>
<td>77</td>
<td>82</td>
</tr>
<tr>
<td>Schedule-long haul</td>
<td>62</td>
<td>67</td>
</tr>
<tr>
<td>Charter I.T.</td>
<td>54</td>
<td>60</td>
</tr>
</tbody>
</table>

However, another MIAA report (197), gave the following service times for the charter I.T. sector in 1982 and 1983;

<table>
<thead>
<tr>
<th>YEAR</th>
<th>National handling agent</th>
<th>Local handling agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>56</td>
<td>37</td>
</tr>
<tr>
<td>1983</td>
<td>41</td>
<td>27</td>
</tr>
</tbody>
</table>

Moreover, service time values per passenger in group vary according to group size, because normally only one person in the group who would perform transactions required at the facility for all members of the group. Service times per passenger in groups of different sizes are bound to be different, and definitely non-linear. Figure 9.5, which is based on information for the local handling agent at MIA extracted from Table 9.5, demonstrates this fact by comparing the variation between group sizes and the corresponding service times per group, as well as passengers in a group, separately.

Although more accurate simulations could have been achieved with more realistic results, if frequency distributions of group sizes for arrivals to check-in was made available, nevertheless, the final values of service times that would be used in simulations were obtained as averages from Figure 9.5. This was accomplished by determining the average service time per passenger for the average group size in each sector. Average group sizes were: 1.63 for schedule-European, 2.18 for charter I.T., and 2.30 for schedule-long haul (197).

So, service times actually used in simulations were based on all pieces of information that could be made available with some logical assumptions and as follows:
CHECK–IN SERVICE TIMES FOR DIFFERENT GROUP SIZES

AVERAGE GROUP SIZE:

SCHEDULE–EUROPEAN = 1.63
SCHEDULE–LONG HAUL = 2.30
CHARTER I. T. = 2.18

Figure 9.5 MANCHESTER INTERNATIONAL AIRPORT- Service Times for Passenger Groups at Airlines Flight Check-in.
CHARTER I.T.- service times per passenger are negative exponentially distributed with a mean that ranges between 0.60 to 0.73 minute per passenger.

SCHEDULE/EUROPEAN- service times per passenger are negative exponentially distributed with a mean that ranges between 0.66 to 0.83 minute per passenger.

SCHEDULE/LONG HAUL- service times per passenger are negative exponentially distributed with a mean of 0.73 minute per passenger.

Table 9.5
Service Times for Airlines Flight Check-In Facilities
MANCHESTER INTERNATIONAL AIRPORT

<table>
<thead>
<tr>
<th>HANDLING AGENT</th>
<th>National</th>
<th>Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP SIZE</td>
<td>1  2  3 4  5  6</td>
<td>1  2  3 4  5  6</td>
</tr>
<tr>
<td>FLIGHT TYPE</td>
<td>Domestic(&amp;CTA)</td>
<td>Sch.-European</td>
</tr>
<tr>
<td></td>
<td>83 131 175 257 373 -</td>
<td>91 126 175 240 373 -</td>
</tr>
<tr>
<td></td>
<td>59 97 130 160 342 -</td>
<td>75 86 97 140 184 -</td>
</tr>
</tbody>
</table>

After specifying the main input parameters to the simulation process (i.e., arrival distributions, service times, and number of servers- which in the case of check-in is one), simulation runs are made for varying demand levels. For airline flight check-in, because it is a batch-oriented facility, demand levels are better expressed in terms of number of passengers on flights.
The main service measure is waiting time (delay). Maximum queue length is also included as an auxiliary service measure, which could prove to be very useful, particularly to architects and facility designers, because it is more relevant to the physical design of the facility, since it would assist in determining space requirements—space need to be provided in front of counters to accommodate maximum number of waiting passengers without affecting operational standards.

The resulting performance models are shown in Figures 9.6-9.8 for the three flight categories. These models are constructed from synthesized data generated from simulation runs for the whole range of demand levels for specific demand pattern of the particular sector.

Finally, the significance and usefulness of this methodology could be demonstrated by the concluding step of applying service standards previously derived by means of P-R models onto the performance models. For airline flight check-in facilities that are operated by the local handling agent at MIA, Table 9.6 summarizes the resulting levels of operational service for different demand levels as delineated by service standards that are actually perceived by passengers at the airport. Figures of Table 9.6 seem reasonable and realistic in light of operating conditions that actually existed and prevailed in the airport. Thus, operating conditions could be graded as good for the three flight categories. Since actual demand levels (in 1983) for these sectors were close to those indicated, with the probable exception of long haul flights which normally use wide-body aircrafts on those flights. Maximum queue length values seem reasonable, keeping in mind that values stated do not necessarily refer to passengers actually queueing, but rather passengers waiting close by with only group leaders waiting in queue.
Figure 9.6 MANCHESTER INTERNATIONAL AIRPORT - Performance Model for Charter I.T. Check-in.
AIRLINES FLIGHT CHECK-IN: SCHEDULED EUROPEAN PERFORMANCE MODEL for SCHEDULED EUROPEAN COUNTERS

SERVICE TIMES: EXPONENTIAL 0.66 / 0.83

Figure 9.7 MANCHESTER INTERNATIONAL AIRPORT- Performance Model for Schedule/European Check-in.
AIRLINES FLIGHT CHECK-IN: SCHEDULED LONG-HAUL
PERFORMANCE MODEL for SCHEDULED LONG-HAUL COUNTERS
SERVICE TIMES: EXPONENTIAL 0.73

Figure 9.8 MANCHESTER INTERNATIONAL AIRPORT- Performance Model for Schedule/Long Haul Check-in.
Table 9.6
Levels of Operational Service for Airline Flight Check-in
MANCHESTER INTERNATIONAL AIRPORT

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER I.T.</th>
<th>SCHEDULE LONG HAUL</th>
<th>SCHEDULE EUROPEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I.T.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Demand Level*</td>
<td>130#</td>
<td>150</td>
<td>70#</td>
</tr>
<tr>
<td>0</td>
<td>Delay (min.)</td>
<td>3.0</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>D</td>
<td>Max Passengers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waiting</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>TOLERABLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Demand Level*</td>
<td>260#</td>
<td>260</td>
<td>140#</td>
</tr>
<tr>
<td>A</td>
<td>Delay (min.)</td>
<td>14.0</td>
<td>13.5</td>
<td>9.0</td>
</tr>
<tr>
<td>D</td>
<td>Max Passengers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waiting</td>
<td>60</td>
<td>42</td>
<td>30</td>
</tr>
</tbody>
</table>

* - In Passengers on Flights.
# - Average value of demand for the two service time curves in the corresponding performance model.

2. OUTBOUND OFFICIAL CONTROLS

According to MIAA(195), plans to bring the airport's annual capacity to 9 million by 1990, necessitated several changes on passengers handling facilities of the airport. Security check units were upgraded and transformed in early 1982 from a manual search system with an hourly capacity ranging from 1400 to 2000 passengers to a conveyorized X-ray and Magnometer system comprising of 4 units with an estimated nominal capacity of 1800 to 2400 passengers per hour. Also, the number of passport control counters was raised to 4 (however, only 3 were normally operational then).

Service times for outbound official controls as used in simulations were:
SECURITY CHECK—processing times for each unit ranged between (0.10-0.13) minute per passenger, so, being a newly introduced system, mean processing times of 0.13 minutes per passenger was chosen.

PASSPORTS CONTROL—for this facility, processing times was more difficult to obtain, because governmental agencies normally treat such information with confidentiality. However, after discussions with airport personnel, supplemented by limited and discrete spot checks, a mean service time of (0.12) minute per passenger was chosen.

Facilities of the outbound official controls, unlike the batch-oriented check-in, are subjected to continuous flow of passengers. In this sense, arrival distribution to these facilities essentially follow the fluctuations of demand on the departure channel. Since departure throughputs at MIA had showed a two-peak pattern (Figure 9.3), looking at those two peaks separately and constructing a performance model for each, would help in examining the performance of facilities under different operational conditions more accurately. But considering whole-day patterns (and respective performance models) would not change results significantly, because the process is consistent in either situation. In Figure 9.9, which is based on MIA simulations of flow through outbound official controls(196), each peak period is divided into 20-minute intervals, and the corresponding times are then included in the simulations. It should be noted here that since the security check precedes passport control, the arrival distribution is assigned only to security check. Arrival of passengers at passport control is assigned automatically initiated by the simulation model as the departure distribution from security, and as such it is implicit within the process.

Figures 9.10 and 9.11 show the performance models for the morning and afternoon peaks respectively. Because of the continuous-flow nature of this facility, the demand level in the model is
MANCHESTER INTERNATIONAL AIRPORT
FLOW THROUGH OUTBOUND OFFICIAL CONTROLS
SUMMER SUNDAY, 1983

Figure 9.9 MANCHESTER INTERNATIONAL AIRPORT - Flow Through Outbound Official Controls.
MANCHESTER INTERNATIONAL AIRPORT – MORNING PEAK

PERFORMANCE MODEL for OUTBOUND OFFICIAL CONTROLS

SECURITY CHECK: 4 UNITS – SERVICE TIMES / EXPONENTIAL 0.13
PASSENGER CONTROL: 3 SERVERS – SERVICE TIMES / EXPONENTIAL 0.12

Figure 9.10 MANCHESTER INTERNATIONAL AIRPORT – Performance Model for Outbound Official Controls (Morning Peak).
MANCHESTER INTERNATIONAL AIRPORT – AFTERNOON PEAK

PERFORMANCE MODEL for OUTBOUND OFFICIAL CONTROLS

SECURITY CHECK: 4 UNITS – SERVICE TIMES / EXPONENTIAL 0.13
PASSPORTS CONTROL: 3 SERVERS – SERVICE TIMES / EXPONENTIAL 0.12

Figure 9.11 MANCHESTER INTERNATIONAL AIRPORT- Performance Model for Outbound Official Controls (Afternoon Peak).
expressed as an average volume (in passengers per hour) over the period in consideration. Equally, demand level could also be expressed in terms of peak hour demand, by introducing peak/average demand ratio that would facilitate the conversion of average demand volume over the period in consideration, to peak hour demand volume. Since the demand pattern is controlled throughout the procedure by the Simulation Index (SI) to retain a specific shape and pattern, this will indirectly retain peak/average volume ratio as constant or kept within a narrow margin of variation. Simulation output showed that peak/average ratio for the morning-peak simulation runs ranged between (2.03-2.11) with an average of 2.07, while for afternoon-peak runs it ranged between (1.85-1.93) with an average of 1.88.

Application of the service standards to the performance model yields the information contained in Tables 9.7 and 9.8. The levels of operational service are delineated in terms of the measures indicated, in light of service standards perceived by passengers, that were previously derived from P-R models (i.e., values of delay in Tables 9.7 and 9.8 are those contained in Table 9.4).

Keeping in mind that the flow of passengers through outbound official controls and to the international pier in MIA represents around 70% of the total departing passenger throughputs at the airport (for all piers), peak hour values seems comparable to those specified by the airport authority. Generally, the information contained in Tables 9.7 and 9.8 is realistic. This suggests that values obtained for operational conditions are consistent with actual situation prevailing at the airport then, and also indicate that operational service could be graded 'Good'. However, some inconsistencies are bound to arise, because service times were basically estimations and not actual observations statistically verified. This fact should be realized, and any inconsistencies should be regarded with some tolerance.
Table 9.7
Levels of Operational Service for Outbound Official Controls
MANCHESTER INTERNATIONAL AIRPORT / Morning Peak

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER</th>
<th>SCHEDULE</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I.T.</td>
<td>EUROPEAN</td>
<td>LONG HAUL</td>
</tr>
<tr>
<td>G</td>
<td>-Average Volume*</td>
<td>800</td>
<td>750</td>
<td>770</td>
</tr>
<tr>
<td></td>
<td>-Peak Hour</td>
<td>1656</td>
<td>1553</td>
<td>1594</td>
</tr>
<tr>
<td>D</td>
<td>Delay(min.)</td>
<td>2.5</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Max. Passengers:</td>
<td>15</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>-Security</td>
<td>65</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>-Passports</td>
<td>1020</td>
<td>940</td>
<td>920</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2111</td>
<td>1946</td>
<td>1904</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.0</td>
<td>8.5</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Max. Passengers:</td>
<td>90</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>-Security</td>
<td>150</td>
<td>120</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>-Passports</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* - In Passengers per hour for the peak period.
<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER</th>
<th>SCHEDULE</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I.T.</td>
<td>EUROPEAN</td>
<td>LONG HAUL</td>
</tr>
<tr>
<td>G</td>
<td>Average Volume*</td>
<td>850</td>
<td>800</td>
<td>820</td>
</tr>
<tr>
<td></td>
<td>Peak hour</td>
<td>1598</td>
<td>1504</td>
<td>1542</td>
</tr>
<tr>
<td></td>
<td>Delay(min.)</td>
<td>2.5</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Max. Passengers</td>
<td>10</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>D</td>
<td>Security</td>
<td>58</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Passports</td>
<td>220</td>
<td>170</td>
<td>180</td>
</tr>
</tbody>
</table>

TOLERABLE

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER</th>
<th>SCHEDULE</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I.T.</td>
<td>EUROPEAN</td>
<td>LONG HAUL</td>
</tr>
<tr>
<td>B</td>
<td>Average Volume*</td>
<td>1080</td>
<td>980</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Peak hour</td>
<td>2030</td>
<td>1842</td>
<td>1880</td>
</tr>
<tr>
<td></td>
<td>Delay(min.)</td>
<td>13.0</td>
<td>8.5</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Max. Passengers</td>
<td>58</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>220</td>
<td>170</td>
<td>180</td>
</tr>
</tbody>
</table>

* - In Passengers per hour for the peak period.
Birmingham International Airport (BHX), is located on the eastern outskirts of Birmingham- Britain's second largest city, and serves the West Midlands Metropolitan Region and neighbouring counties of Central England and northern Wales, with excellent connections to the national land transport network as seen in Figure 9.12. Historically, it is a 45-year old pre-war airport with its old terminal building still standing as an architectural monument typical of airport design of that era. In contrast, the new terminal complex (including access, parking facilities, and other facilities) was put into operation on April 4th 1984, while the formal Royal inauguration took place on May 30th.

According to CAA statistics(194), Birmingham Airport handled 1.31 million passengers in 1978 and 1.56 million in 1983, an increase in passenger traffic of 19.5 %. The share of BHX of total U.K. traffic stands at 2.6 %. Since the opening of the new facilities, accompanied with complete administrative reorganization, operational services have been substantially upgraded. These improvements were anticipated to initiate traffic growth and increase Birmingham Airport's share of U.K. traffic (especially when BHX will be Britain's first Freeport). Characteristics of traffic at the airport are similar in many ways to these of other British regional airports, but with a higher percentage of schedule traffic. CAA statistics(194) indicated that charter/schedule traffic split was in 1981 and 1983 56/44 percentage of international traffic.

Again, annual traffic pattern at BHX (Figure 9.13), shows typical British regional airport mid-summer peaking behaviour. Specifically, the last two weeks of July is the peak period of the year, and as Figure 9.14 reveals, the busiest days of the week are the weekend-days: Saturday and Sunday. BHX daily traffic patterns show some resemblance to that of Manchester's. Figure 9.15 shows peak hourly pattern of departures, with its two-peak
Figure 9.12 Birmingham International Airport - Geographic Location.
Figure 9.13 BIRMINGHAM INTERNATIONAL AIRPORT- Annual Traffic Pattern.
Figure 9.14 BIRMINGHAM INTERNATIONAL AIRPORT—Weekly Traffic Pattern.
behaviour. Figure 9.16 is the peak hourly pattern for arrivals, with a less representative behaviour that shows two peaks (however, for analysis purposes, arrivals peaking pattern is considered as single-peaked, because the trough between the two appearing peaks is comparatively narrow, and it had most probably occurred for the indicated day only). So, BHX peaks are from 6-7 a.m. (morning peak) and from 1-5 p.m. (afternoon peak) for departures, and from 1-7 p.m. for arrivals.

Prior to the administrative reorganization following the recent development programme at the airport, availability of information on various planning, operational, and financial aspects was, unfortunately, very limited and scarce. The absence of an active and efficient body responsible for collection and handling of planning, operational, and statistical data, greatly contributed to that situation, and necessitated looking for other sources of information on BHX.

In pursuit of an opportunity to undertake a total and comprehensive implementation of the proposed methodology, BHX Airport Authority was contacted and negotiations were initiated to have their approval and cooperation in conducting a study in the new terminal of the airport. Eventually, agreement was reached to run a passenger survey for arrivals and departures at the airport during the peak period of summer 1984. The Airport Authority approved to grant access to the airport and furnish whatever information needed that could be made available.

Preperations got underway to carry on with BHX Passenger Survey, as the major part of the demonstration of the methodology application. Subsequently, literature in related topics, past experience, and lessons learned from previous exercises were reviewed to eliminate risks of possible setbacks and potential difficulties that might adversely affect the passenger survey. Several meetings were held with the airport's Planning Department to discuss important issues concerning the passenger survey, such
Figure 9.15 BIRMINGHAM INTERNATIONAL AIRPORT—Daily Traffic Pattern (Departures).

BIRMINGHAM INTERNATIONAL AIRPORT—DEPARTURES PEAK DAY
SUNDAY, JULY 22, 1984

TERMINAL PASSENGERS

0 5 10 15 20 25
HOUR OF DAY

0 100 200 300 400 500
Figure 9.16 BIRMINGHAM INTERNATIONAL AIRPORT—Daily Traffic Pattern (Arrivals)

BIRMINGHAM INTERNATIONAL AIRPORT — ARRIVALS PEAK DAY
SATURDAY, JULY 28, 1984

[Graph showing hourly traffic pattern with peak times indicated]
as timing and scheduling of the survey, positioning of stations used as questionnaires delivery points, liaison with other organisations and agencies in the airport found appropriate to inform or contact, and other issues related to general context of questionnaires. From these meetings the following was realized:

1. Timing of the survey was finalized to be during the last two weeks of July, coinciding with the industrial summer holidays, where tourist traffic is expected to reach its peak.

2. Operational information related to passenger throughputs and hourly traffic during survey period were to be made available from handling agents and airlines directly, and not from the Planning Department. Airlines and handling agents agreed to provide such information from their daily records and work-sheets, but on the condition that this information is to be collectively used to generate passenger throughputs and traffic data, and should not be disaggregated so as to reveal the share of each in airport traffic or give any indication of their performance, which might affect their public image or influence market competitiveness.

3. It became evident that it was not feasible to get useful operational information on baggage handling in the airport, because of the commercial and industrial-related sensitivity of such information to the competing handling agents at the airport. Also, such information is so diverse and variable between different situations, that it would be impractical to collect, and later difficult to analyse for the purpose of constructing the performance model for the baggage claim facility.

4. It was realized that the only possible location where the surveyor can effectively approach the arriving passengers was at the terminal end of the International Pier just prior to queueing for inward immigration. Since being positioned there, was absolutely vital to the success of the survey, the Airport Authority agreed to grant the surveyor access to the airside, where he could effectively approach passengers.
5. Response rates of the passenger survey were discussed to try to come up with a reasonable range that would be used to determine number of questionnaires need to be distributed. Based on experience and knowledge of Airport Authority personnel, values between 10% and 25% were thought to be reasonably realistic, in light of characteristics and behaviour of passengers in the circumstances of the survey.

6. Questionnaire preparation, design, and production would be the responsibility of the surveyor, and that questionnaires and all survey material would have the joint heading of BHX and LUT. In addition, questionnaires would be self-administered by the passengers, but distributed to passengers (both arriving and departing) by the surveyor himself.

Planning of passenger survey, design and production of questionnaires, and the theoretical interpretation of the outcomes of the survey were carefully considered; thoroughly studying and examining major aspects and principles of each, frequently consulting available literature on this topic, and occasionally discussing and taking advice of experts and specialists in this area. Instructions, recommendations, rules, and practical tips on effective planning and running of such surveys, including efficient questionnaire design, were all taken into consideration and adopted in the process. Realizing its importance and contribution to the efficiency and success of the survey, both theoretically and practically, collective discussion on all these aspects were purposely elaborated on in Chapter Seven.

9.4.1 PLANNING OF THE SURVEY

Basically, BHX Passenger Survey incorporated the distribution of self-administered questionnaires to arriving and departing passengers inside the terminal. The main objective was to collect necessary information required to construct P-R models for the
processing facilities of the two channels, broken down to the major traffic (passenger/flight) categories, so as to arrive at disaggregated operational service standards for those facilities. Considering outcomes of previous studies, especially regarding the inappropriateness of delay, service measure adopted by the survey was decided to be total time spent in each facility. Total time spent in a processing facility is an expression that is composed of actual processing time plus any delay encountered by a passenger waiting for service. Compared to delay, total time spent is a service measure that is less emotive and easier to view and interpret. Also, it is more conveniently manipulated in the level of service procedure, and would not bear any unwanted harmful effects or to the capacity procedure.

Field implementation of the survey was as follows:

Departures: Departure questionnaires were to be delivered to passengers on pre-selected flights (flights thought to be representative of its category, or those that have special impact or weight on airport traffic). In order to control response rate, questionnaires were delivered to passengers who acted as group leaders, not to every passenger in each group, and particularly not to children, the aged and handicapped, or passengers (or groups) who showed disinterest or seemed uncooperative. Delivery of questionnaires was done at 'departure-questionnaires delivery station', positioned at the entrance of 'International Departure Lounge D' just prior to security check (Figure 9.17a). Selection of this station was favoured because:

1. Convenience provided to the surveyor trying to establish rapport with passengers whilst verbally briefing each group of what the survey is all about, and what they are supposed to do.
2. Mid-way location between check-in and outbound official controls, which ensures that passengers' encounters in both facilities would be still fresh in their minds when they attempt answering the questionnaire.
(a) Departures.

(b) Arrivals.

Figure 9.17 BIRMINGHAM INTERNATIONAL AIRPORT- Questionnaire Distribution Stations.
3. Its location so close to departure pre-inspection, gave the impression to passengers that the surveyor has an official task to perform that should be responded to seriously. After receiving the questionnaire and being briefly informed about the nature of the survey, passengers would then go through security check and passport control, before proceeding to the departure lounge, where they stay for some time awaiting their flight departure announcement. The departure questionnaire was to be answered while passengers were waiting in the lounge for a period of time that was more than sufficient for them to read the questionnaire, understand it, and then enter their replies. When they finally left the departure lounge to the gates, passengers deposited the questionnaires in a well-marked box situated at the exit of the departure lounge, as instructed by the questionnaire's introductory note. To monitor response rates, this box was to be emptied and questionnaires collected on daily basis.

Arrivals: It was planned that arriving passengers coming down from the International Pier (airside) prior to inward immigration processing, would be handed sealed envelopes (containing the arrivals questionnaire with a FREEPOST return-addressed envelope) with a printed message displayed of brief yet clear instructions. These instructions would direct the attention of passengers towards particular information sought by the questionnaire, and to inform them to try to observe and monitor specific aspects of operation while in the terminal. This was found to be most appropriate, because of the fact that passengers do not have enough time to spare for reading, understanding, and then answering the questionnaire while waiting for service inside the terminal. Once they clear customs, all want to leave the terminal either alone or with friends and relatives, get a taxi, or rent a car, as soon as they can. When they try to fill in the questionnaire later, they probably would not be able to recall the required information. By instructing the passengers in advance and briefly informing them what they are expected to be
asked about, they could be able to record such information without necessarily reading the whole questionnaire enclosed. Later, after reaching their final destination (home or office), they would have no problem in entering their replies on the questionnaire, before dropping it in the mail, to be posted to the surveyor free of charge.

However, very soon before commencement of the survey, the surveyor was briefed by airport authority that he can no longer enter the airside. Permission to access the airside of the airport had been withdrawn, because of newly-implemented tighter security measures with immediate effect. Fortunately, this problem was overcame by distributing the arrivals questionnaire at the exit of H.M. Customs and Excise (Figure 9.17b) directly after leaving the customs (landside) and before they had the chance to meet greeters. This alteration necessitated only a minor change (deletion of 'will') on the printed instructions.

9.4.2 QUESTIONNAIRE DESIGN

In the process of designing survey questionnaires, discussion raised previously in Section 7.6.4 was considered. The structure of the arrivals and departures questionnaires consisted of three main parts:
1. Concise introductory and explanatory note that has the function of a covering letter for the survey, describing in few words the purpose of the survey, asking for passengers cooperation and participation, and what to do with the completed questionnaire. To give the questionnaires official and authoritative status, the covering letter was signed by LUT's Department of Transport Technology. The tone of this covering letter was a logical compromise between pleading, authoritarian language, and excess politeness. It was imperative that all questionnaire information and material, should be contained in
only one paper, because lengthy and multi-papered questionnaires would probably reduce chances of taking them seriously by passengers, hence reducing the response rate.

2. PART I, which was designed to be as brief and short as possible, had two main functions. The first, was to provide sample information that would facilitate categorization according to flight sector and passenger type. The second, was to check and verify synthesized information generated by simulating operational conditions in each facility, as compared to those recorded by respondents as the actual operational conditions that existed during survey period.

3. PART II, the most important part of the questionnaire, which contains information necessary to construct P-R models. It starts with a message in big bold letters to passengers to carefully read the instructions before attempting to answer. These instructions include a description of circumstances and conditions that respondents would be required to consider in their answers, and the grading system they should use and comply with in assessing those conditions. Questions are arranged in the form of a spectrum or range of time spent in each facility in consideration, and empty boxes to be filled by the respondent with the level of satisfaction estimated in light of general operational and service conditions that actually existed during that particular trip. The last question of this part should give some indication of respondent's general outlook to overall time spent in terminal processing, however, it would not contribute to assessment of operation at particular facilities.

Wording of questionnaires was very carefully studied, and chosen so as to ensure better understanding and efficient completion of them, as well as building communications and establishing rapport with the passengers. This was hoped to increase possibilities of response and would secure success of the survey. Several practical measures and techniques to increase response rates were adopted in the final form and layout of questionnaires (shown in Appendix B-4), they are:
1. BHX and LUT title heading and logo were displayed on all survey material to give the added influence on passengers of sponsorship and authority.

2. Different paper colour of questionnaires was used for two purposes: easier handling with better recognition of each channel's questionnaires by the surveyor during distribution and sorting, and the added effect of 'importance and prestige' of the survey to passengers.

3. Questionnaires graphic design incorporated use of different character sizes and types to properly and nicely arrange the three parts of questionnaire.

4. For departures, questionnaires (blue) were handed-out to passengers folded, but for arrivals, questionnaires (pink) were enclosed along with a FREEPOST mail-back envelope, in a sealed envelope with printed instructions. These instructions, bearing the joint title heading and logo of BHX and LUT, were carefully worded so as to be concise, and very clear. FREEPOST (Business Reply) return-addressed envelopes to mail back arrivals questionnaires, was used as a measure of increasing response rates for the arrival channel, where passengers reply and mail the questionnaires back free of charge. Samples of questionnaires, envelope-printed instructions, and the business reply envelopes are shown in Appendix B-4.

9.4.3 P-R MODELS

Information compiled from BHX Passenger Survey was processed and analysed, either manually or by means of a computer statistical package (MINITAB General Statistics Package was used). The next step was to construct P-R models for processing facilities of arrivals and departures channels.

For departures, P-R models were constructed for airline check-in, outbound official controls (security check and passport control considered separately), and overall departure processing
facilities, disaggregated for flight categories that used the international departures channel. Figures A.20-A.23 show P-R models for charter I.T. flights, Figures A.24-A.27 for schedule-long haul flights, Figures A.28-A.31 for schedule-European flights, and Figures A.32-A.34 are P-R models for total departing passengers on all international flights. Table 9.9 summarizes level of service framework that is derived from these models, stated in terms of lower (T1) and upper (T2) limits on total time spent (as the service measure) for the middle (tolerable) service region, rounded to the nearest half-minute.

Table 9.9 shows that for schedule-European flights, service standards had a diminished middle (tolerable) region. This means that schedule-European passengers treated with much less tolerance any lowering in service resulting in longer time spent at various facilities, than other passengers. This was realistic, and was actually felt by the surveyor during conduct of survey. This fact probably reflects the behaviour of passengers on business trips, since passengers of this category are mostly on business. Other observed facts concerning schedule-European passengers traffic, is that passengers usually enter the departure lounge in the last possible opportunity convenient to them, which would leave them virtually no time in the departure lounge sufficient enough to fill the questionnaire. This behaviour, typical of business passengers, was responsible for the comparatively low response rates for departures for this flight category (as noted in Table 9.12). Sample sizes, as indicated on the P-R models, were generally, in line with standards set earlier in Section 7.8.

For arrivals, P-R models were constructed in sets of inward immigration, baggage claim, customs, and all arrival processing facilities combined, disaggregated for flight categories of the international arrivals channel, namely, charter I.T., schedule-long haul, schedule-European, and Common Travel Area passengers. Traffic from Ireland and the Channel Islands
Table 9.9
Level of Service Framework for International Departure Channel
BIRMINGHAM INTERNATIONAL AIRPORT

<table>
<thead>
<tr>
<th>FACILITY TYPE</th>
<th>P-R Model</th>
<th>T 1 Good/Tolerable</th>
<th>T 2 Tolerable/Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. CHARTER I.T.:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check-in</td>
<td>Figure A.20</td>
<td>11.0</td>
<td>21.0</td>
</tr>
<tr>
<td>Security</td>
<td>Figure A.21</td>
<td>6.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Passports</td>
<td>Figure A.22</td>
<td>6.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Overall</td>
<td>Figure A.23</td>
<td>22.0</td>
<td>34.0</td>
</tr>
<tr>
<td>Departure</td>
<td>Figure A.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B. SCHEDULE-LONG HAUL:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check-in</td>
<td>Figure A.24</td>
<td>15.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Security</td>
<td>Figure A.25</td>
<td>9.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Passports</td>
<td>Figure A.26</td>
<td>7.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Overall</td>
<td>Figure A.27</td>
<td>23.0</td>
<td>37.0</td>
</tr>
<tr>
<td>Departure</td>
<td>Figure A.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C. SCHEDULE-EUROPEAN:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check-in</td>
<td>Figure A.28</td>
<td>7.5</td>
<td>14.0</td>
</tr>
<tr>
<td>Security</td>
<td>Figure A.29</td>
<td>6.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Passports</td>
<td>Figure A.30</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Overall</td>
<td>Figure A.31</td>
<td>21.5</td>
<td>21.5</td>
</tr>
<tr>
<td>Departure</td>
<td>Figure A.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>D. TOTAL DEPARTING PASSENGERS:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td>Figure A.32</td>
<td>6.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Passports</td>
<td>Figure A.33</td>
<td>6.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Overall</td>
<td>Figure A.34</td>
<td>23.0</td>
<td>34.0</td>
</tr>
<tr>
<td>Departure</td>
<td>Figure A.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(designated as the Common Travel Area) was treated by H.M. Customs and Excise like other international traffic, and was subjected to customs regulations and taxation. As such, it shared the use of the same channel (for arrivals only) with international traffic, except for inward immigration. For this fact, which was only realized after the survey had already started, it was decided to include CTA traffic in the passenger survey, but for arrivals only. However, because of the belated decision, sample size for the Common Travel Area traffic was relatively small and below the limit of the standards set for sample size. Service standards established for CTA should therefore be regarded with more tolerance than others. Figures A.35-A.38 show P-R models for charter I.T. flights, Figures A.39-A.42 for schedule-long haul flights, Figures A.43-A.46 for schedule-European flights, Figures A.47-A.49 for Common Travel Area traffic, and Figures A.50-A.53 are P-R models for total arriving passengers. Table 9.10 summarizes level of service framework, the service standards of which were derived from P-R models previously mentioned. Service standards stated in Table 9.10, seems realistic, reasonable, and consistent with the characteristics and typical behaviour of passengers of the flight categories included. However, service standards for the schedule-European flights showed a noticeably different behaviour. Apart from the narrow margin of tolerent region (not diminished as was previously noticed for departures), service standards for baggage claim and customs had significantly lower (T1) and (T2) values. Again, this fact is greatly contributed to the predominantly business passengers on these flights, who in most instances, carry only cabin hand-baggage, hence do not need to use the baggage claim facility, or customs. This fact was actually observed and verified on site by the surveyor during the conduct of survey. Sample size as indicated on P-R models, are generally in line and in comformity with the standards set, except for CTA traffic for reasons mentioned earlier.
Table 9.10
Level of Service Framework for International Arrivals Channel
BIRMINGHAM INTERNATIONAL AIRPORT

<table>
<thead>
<tr>
<th>Time Spent in Facility (Minutes rounded to nearest half-minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACILITY</td>
</tr>
<tr>
<td>TYPE</td>
</tr>
</tbody>
</table>

**A. CHARTER I.T.:**
- Immigration: Figure A.35, 6.5 | 15.0 |
- Baggage Claim: Figure A.36, 13.0 | 23.5 |
- Customs: Figure A.37, 6.5 | 13.0 |
- Overall: |
  - Arrival: Figure A.38, 24.0 | 40.0 |
  - Processing: |

**B. SCHEDULE-LONG HAUL:**
- Immigration: Figure A.39, 7.0 | 16.0 |
- Baggage Claim: Figure A.40, 16.5 | 25.0 |
- Customs: Figure A.41, 6.0 | 12.0 |
- Overall: |
  - Arrival: Figure A.42, 23.5 | 44.0 |
  - Processing: |

**C. SCHEDULE-EUROPEAN:**
- Immigration: Figure A.43, 6.0 | 12.0 |
- Baggage Claim: Figure A.44, 10.0 | 17.5 |
- Customs: Figure A.45, 5.0 | 7.0 |
- Overall: |
  - Arrival: Figure A.46, 20.0 | 28.0 |
  - Processing: |
### Table 9.10 (cont.)

<table>
<thead>
<tr>
<th>FACILITY TYPE</th>
<th>P-R Model</th>
<th>T 1 (Good/Tolerable)</th>
<th>T 2 (Tolerable/Bad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. COMMON TRAVEL AREA TRAFFIC:</td>
<td>Figure No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baggage Claim</td>
<td>Figure A.47</td>
<td>12.5</td>
<td>21.0</td>
</tr>
<tr>
<td>Customs</td>
<td>Figure A.48</td>
<td>6.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Overall</td>
<td>-</td>
<td>20.0</td>
<td>34.0</td>
</tr>
<tr>
<td>Arrival</td>
<td>Figure A.49</td>
<td>20.0</td>
<td>34.0</td>
</tr>
<tr>
<td>Processing</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. TOTAL ARRIVING PASSENGERS:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immigration</td>
<td>Figure A.50</td>
<td>6.5</td>
<td>14.5</td>
</tr>
<tr>
<td>Baggage Claim</td>
<td>Figure A.51</td>
<td>12.5</td>
<td>22.5</td>
</tr>
<tr>
<td>Customs</td>
<td>Figure A.52</td>
<td>6.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Overall</td>
<td>-</td>
<td>23.0</td>
<td>37.0</td>
</tr>
<tr>
<td>Arrival</td>
<td>Figure A.53</td>
<td>23.0</td>
<td>37.0</td>
</tr>
<tr>
<td>Processing</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The degree of success of the passenger survey could be known by monitoring and analysing response rates of passengers to the survey questionnaires. Actual response rates should be compared with those initially predicted during meetings with BHX Planning Department. It was anticipated that response rates would be somewhere between 10% and 25%, and on this particular assumption the number of questionnaires to be delivered was set so as returned questionnaires would conform to the minimum sample size standards set earlier in Section 7.8. Returned questionnaires were classified according to the date of delivery as entered by the passenger (and verified with the flight schedules) and flight category. Tables 9.11 and 9.12 show that...
actual response rates were within the target—29.2% for departures, and 25.1% for arrivals. Table 9.11 monitors response rates on daily basis for the duration of survey period, while Table 9.12 furnishes details of response rates according to flight category.

Table 9.11
Daily Response Rates of BHX Passenger Survey

<table>
<thead>
<tr>
<th>DAY/MONTH</th>
<th>DEPARTURES</th>
<th>ARRIVALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deliver</td>
<td>Retrieved</td>
</tr>
<tr>
<td>20/7</td>
<td>100</td>
<td>18</td>
</tr>
<tr>
<td>21/7</td>
<td>105</td>
<td>20</td>
</tr>
<tr>
<td>22/7</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td>23/7</td>
<td>100</td>
<td>18</td>
</tr>
<tr>
<td>24/7</td>
<td>99</td>
<td>26</td>
</tr>
<tr>
<td>25/7</td>
<td>100</td>
<td>36</td>
</tr>
<tr>
<td>26/7</td>
<td>102</td>
<td>39</td>
</tr>
<tr>
<td>27/7</td>
<td>99</td>
<td>25</td>
</tr>
<tr>
<td>28/7</td>
<td>105</td>
<td>42</td>
</tr>
<tr>
<td>29/7</td>
<td>98</td>
<td>27</td>
</tr>
<tr>
<td>30/7</td>
<td>100</td>
<td>39</td>
</tr>
<tr>
<td>31/1</td>
<td>100</td>
<td>37</td>
</tr>
<tr>
<td>1/8</td>
<td>93</td>
<td>37</td>
</tr>
</tbody>
</table>
Table 9.12
Flight Categories Response Rates of BHX Passenger Survey

<table>
<thead>
<tr>
<th>CHARTER</th>
<th>S C H E D U L E</th>
<th>C T A</th>
<th>INCOMPLETE</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.T.</td>
<td>LONG HAUL</td>
<td>EUROPEAN</td>
<td>TRAFFIC</td>
<td>REPLIES</td>
</tr>
<tr>
<td>---------</td>
<td>----------------</td>
<td>---------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A. DEPARTURES:
# Retrieved 307 30 35 - 8 380
% Delivered 23.6 2.3 2.7 - 0.6 29.6
% Retrieved 80.8 7.9 9.2 - 2.1 100.0

B. ARRIVALS:
# Retrieved 148 36 87 13 54 338
% Delivered 11.0 2.7 6.5 0.9 4.0 25.1
% Retrieved 43.9 10.7 25.7 3.8 15.9 100.0

Finally, it was thought initially at the questionnaire design stage, that information obtained from PART I of questionnaires on the time spent in each facility as estimated by the passengers themselves could be useful to verify the operational conditions with actual conditions that prevailed during the survey. However, it became evident later that estimated time values could not be efficiently utilized for that purpose, although in principal, it generally seemed to reflect relative conformity with existing trends as anticipated beforehand. The level of accuracy of these values as obtained by means of simulation, and as estimated by passengers were not compatible. Since passengers' replies on PART I are expressed in terms of numbers (time values), it can be easily affected by the passengers' opinions. Also, the time-estimating capability of each individual plays an important role in formalizing the replies of individual passengers, and the resultant average values for groups of passengers. As presented previously in Chapter Seven, socio-psychologic factors influence
passengers' opinions, and contribute to variations encountered in their replies and in stating their estimates of times spent in various facilities. This implies that there is some degree of variation between the actual values of time, and values of time that were perceived and recorded by the passengers. Variance between the two values can be expected, because previous research by Clark (198) had shown that the perception of urban travellers to travel time is likely to be non-linear function of actual values of travel time, and as described by this relation that is based on 'Stevens Law':

\[(\text{Perceived Value}) = a.(\text{Actual Value})^b,\]

where \(a\) and \(b\) are coefficients related to some particular characteristic of the environment.

Nevertheless, when values of the coefficients \(a\) and \(b\) of Clark's study were applied to the estimated values of time spent in facilities, the difference was found to be negligible for the practical purposes of our study.

9.4.4 PERFORMANCE MODELS

Synthesized operational information generated by means of simulation was used to construct performance models for arrivals and departures processing facilities in BHX. However, it should be stressed here, that due to the fact that basic input information required for simulation was so scarce and difficult to obtain for the case of BHX, the majority of those input data were either assumed or data of Manchester Airport were used instead. This situation should be regarded with consideration in light of degree of availability of airport-related information in current circumstances. Brief description of each facility modelled will be presented along with input parameters used in the simulation.
1. AIRLINES FLIGHT CHECK-IN:

It was mentioned earlier that airlines and handling agencies at BHX agreed to provide operational and traffic information on the condition that it would not be used in any way that would reveal information concerning their performance. Abiding by this condition meant that airline flight check-in, being a batch-oriented and flight-related facility, could not be included or their performance models built. On the other hand, common properties with great similarities in nature of traffic and characteristics of operations of the local and national handling agencies at Birmingham and Manchester airports had been observed to exist. These similarities made comparisons of performance models previously constructed for MIA airline flight check-in facilities, with P-R models established for BHX, somewhat suitable. It is true that the service measure used for MIA performance models was delay, while for BHX P-R models it was total time spent, but since processing times (which together with delay form total time spent) are all comparatively low (less than one minute), as compared against two-digit delay times, this comparison would seem to be reasonably practical to conduct, provided higher tolerance margins are adopted (e.g., plus or minus one minute).

Table 9.13 shows the levels of operational service for airline check-in for charter I.T., schedule-long haul, and schedule-European flights. The results of Table 9.13 seem logical except for charter I.T. flights, which seem under-estimated. The standard load factor (demand level) for Inclusive Tour flights ranges between (110-130) passengers(197). Figures for the other two categories do comply with actual situation that prevailed during survey period at BHX.
Table 9.13
Levels of Operational Service for Airline Flight Check-In
BIRMINGHAM INTERNATIONAL AIRPORT

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER SERVICE</th>
<th>I.T.</th>
<th>SCHEDULE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LONG-HAUL</td>
<td></td>
<td>EUROPEAN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Demand Level*</td>
<td>205</td>
<td>265</td>
<td>120</td>
</tr>
<tr>
<td>O</td>
<td>Time Spent (min.)</td>
<td>11.0</td>
<td>15.0</td>
<td>7.5</td>
</tr>
<tr>
<td>O</td>
<td>Max Passengers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Waiting</td>
<td>32</td>
<td>48</td>
<td>20</td>
</tr>
</tbody>
</table>

TOLERABLE

| B                | Demand Level*   | 260             | 310  | 160      |
| A                | Time Spent (min.) | 21.0             | 25.5 | 14.0     |
| D                | Max Passengers  | Waiting         | 60   | 72       |

*- In passengers on flights.

2. OUTBOUND OFFICIAL CONTROLS

In BHX, outbound official controls are arranged as follows: one security check unit consisting of a conveyorized X-ray baggage scanner and Magnometer personal searching frame, similar to MIA's, directly followed by a one-server passport control counter. Although both facilities are included in one simulation model, operational data were generated for each separately. Processing times were considered as similar to those of MIA; 0.12 minute per passenger for passport control, and 0.15 minute per passenger for security check, which is slightly higher than MIA's
figure because the facility (unit and operating staff) was in the shakedown period of the early months of operation. Performance models for the outbound official controls were built for the two peaks—morning and afternoon. Demand levels were expressed in terms of average volume (pax/hr), but equivalent peak hour demand could be easily derived by applying the peak/average conversion ratio. Simulation output showed that this ratio ranged from 1.82 to 2.00 with an average of 1.90 for the morning peak, and from 1.50 to 1.59 with an average of 1.56 for the afternoon peak. Performance models for outbound official controls, including both security and passport, are shown in Figure 9.18 for the morning peak, and Figure 9.19 for the afternoon peak. An interesting feature of these models is the behaviour of passport control curve. Since the arrivals to passport control is totally dictated by departures from security check, and because mean processing time for security is slightly higher relative to that of passport control, passengers would not be expected to spend considerable amount of time or queue awaiting service at passport control. So, the maximum value for average time spent in passport control, obtained from the performance model, was around 0.5 minutes, while corresponding value of maximum number of passengers waiting ever reached there was around 15. These observations were found to be realistic and were actually monitored (rather discretely) by the surveyor during the survey. Tables 9.14 and 9.15 show levels of operational service for the security check for morning and afternoon peaks, respectively. Since the security check completely governs the behaviour of the passport control process, levels of operational service for the latter need not be delineated.
BIRMINGHAM INTERNATIONAL AIRPORT - MORNING PEAK

PERFORMANCE MODEL for OUTBOUND OFFICIAL CONTROLS

SECURITY CHECK: 1 UNIT - SERVICE TIMES / EXPONENTIAL 0.15
PASSPORT CONTROL: 1 SERVER - SERVICE TIMES / EXPONENTIAL 0.12

Figure 9.18 BIRMINGHAM INTERNATIONAL AIRPORT- Performance Model for Outbound Official Controls (Morning Peak).
BIRMINGHAM INTERNATIONAL AIRPORT — AFTERNOON PEAK

PERFORMANCE MODEL for OUTBOUND OFFICIAL CONTROLS

SECURITY CHECK: 1 UNIT — SERVICE TIMES / EXPONENTIAL 0.15
PASSPORTS CONTROL: 1 SERVER — SERVICE TIMES / EXPONENTIAL 0.12

Figure 9.19 BIRMINGHAM INTERNATIONAL AIRPORT — Performance Model for Outbound Official Controls (Afternoon Peak).
Table 9.14
Levels of Operational Service for Security Check
BIRMINGHAM INTERNATIONAL AIRPORT / Morning Peak

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER I.T.</th>
<th>SCHEDULE LONG-HAUL</th>
<th>SCHEDULE EUROPEAN</th>
<th>TOTAL PASSENGERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Demand Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Average Volume*</td>
<td>235</td>
<td>250</td>
<td>235</td>
<td>238</td>
</tr>
<tr>
<td>O</td>
<td>-Peak Hour</td>
<td>447</td>
<td>475</td>
<td>447</td>
<td>450</td>
</tr>
<tr>
<td>O</td>
<td>Time Spent (min.)</td>
<td>6.0</td>
<td>9.0</td>
<td>6.0</td>
<td>6.5</td>
</tr>
<tr>
<td>D</td>
<td>Max Passengers</td>
<td>85</td>
<td>125</td>
<td>85</td>
<td>90</td>
</tr>
</tbody>
</table>

TOLERABLE

<table>
<thead>
<tr>
<th>Demand Level</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>-Average Volume*</td>
<td>254</td>
<td>260</td>
<td>238</td>
</tr>
<tr>
<td></td>
<td>-Peak Hour</td>
<td>483</td>
<td>494</td>
<td>452</td>
</tr>
<tr>
<td>A</td>
<td>Time Spent (min.)</td>
<td>10.5</td>
<td>12.5</td>
<td>6.5</td>
</tr>
<tr>
<td>D</td>
<td>Max Passengers</td>
<td>150</td>
<td>162</td>
<td>95</td>
</tr>
</tbody>
</table>

* In passengers per hour for peak period.

The results shown in Tables 9.14 and 9.15 seem reasonably realistic, and the conclusion they convey is that for total passengers, operational level of service for security check at BHX during the survey could be considered as 'bad' during the morning and afternoon peaks. They confirm the observations made during the survey, that the queue of passengers waiting for the security check was excessively long extending to and
sometimes through the seating area of the terminal's main bar and cafeteria, particularly for long-haul flights. This aspect demonstrates the usefulness of the methodology when used for the physical design of terminal facilities, by identifying crowding areas and predicting expected queue lengths. For that particular case, space in front of the entrance of the International

Table 9.15
Levels of Operational Service for Security Check
BIRMINGHAM INTERNATIONAL AIRPORT / Afternoon Peak

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>I.T.</th>
<th>LONG-HAUL</th>
<th>EUROPEAN</th>
<th>TOTAL PASSENGERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Demand Level</td>
<td>-Average Volume*</td>
<td>290</td>
<td>308</td>
<td>290</td>
</tr>
<tr>
<td>D</td>
<td>-Peak Hour</td>
<td>452</td>
<td>480</td>
<td>452</td>
<td>456</td>
</tr>
<tr>
<td>E</td>
<td>Time Spent (min.)</td>
<td>6.0</td>
<td>9.0</td>
<td>6.0</td>
<td>6.5</td>
</tr>
<tr>
<td>F</td>
<td>Max Passengers</td>
<td>107</td>
<td>150</td>
<td>107</td>
<td>110</td>
</tr>
</tbody>
</table>

**TOLERABLE**

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>I.T.</th>
<th>LONG-HAUL</th>
<th>EUROPEAN</th>
<th>TOTAL PASSENGERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Demand Level</td>
<td>-Average Volume*</td>
<td>315</td>
<td>322</td>
<td>292</td>
</tr>
<tr>
<td>H</td>
<td>-Peak Hour</td>
<td>491</td>
<td>502</td>
<td>456</td>
<td>491</td>
</tr>
<tr>
<td>I</td>
<td>Time Spent (min.)</td>
<td>10.5</td>
<td>12.5</td>
<td>6.5</td>
<td>10.5</td>
</tr>
<tr>
<td>J</td>
<td>Max Passengers</td>
<td>170</td>
<td>190</td>
<td>110</td>
<td>170</td>
</tr>
</tbody>
</table>

* - In passengers per hour for peak period.
Departure Lounge D, where the security check unit is situated, was not sufficient for the expected number of people that could be queueing for service at peak periods, which was around 120-150 passengers.

3. INWARD IMMIGRATION

Inward immigration control in BHX, is composed of two sections: EEC passport control (4 counters), and non-EEC passports immigration (2 counters), and it is the first processing facility in the arrival channel. Due to that fact information concerning governmental agencies was virtually unobtainable, mean processing time values for both sections used in simulations, were derived by logical assumptions based on collective opinions and personal judgement of airport personnel, supported by information that could be collected from other sources. Mean processing times were decided to be: (0.50) minute per passenger for EEC passports, and (2.00) minutes per passenger for non-EEC passports. Performance models derived were based on total passengers, whose percentage consistuents were obtained from the passenger survey itself. Those percentages, as indicated on P-R models shown in Figures A.35, A.39, A.43, and A.50, are:

<table>
<thead>
<tr>
<th></th>
<th>EEC</th>
<th>Non-EEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charter I.T.</td>
<td>100.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Schedule-European</td>
<td>74.0</td>
<td>26.0</td>
</tr>
<tr>
<td>Schedule-Long Haul</td>
<td>93.3</td>
<td>6.7</td>
</tr>
<tr>
<td>Total passengers</td>
<td>94.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Arrival distribution to the facility follows the pattern of arrivals peak shown in Figure 9.16. Demand levels are expressed in the performance model as average volume (pax/hr.). Peak/average ratio that could be used to convert demand levels from average volume to equivalent peak hour ranged from 1.45 to 1.57 with an average of 1.51. Shown in Figure 9.20 is the performance model of inward immigration control at BHX for total
passengers based on an EEC/non-EEC split of 94/6%. In the performance model, the average time spent in the facility is expressed as the average of times spent by total passengers in both sections, while the maximum number of passengers waiting is presented for each section separately. From Table 9.16, it could be concluded that service conditions at inward immigration during survey period was 'Good'. But on the other hand, provided that the mean processing times assumed were realistic enough, it seems that number of EEC counters need to be increased in order to match imposed demand, and the split of counters in each section be compatible with nature and characteristics of traffic.

4. BAGGAGE CLAIM

This facility was not included in simulation, hence no performance model was derived for it, because of the realization mentioned earlier, where it was recognized during meetings at BHX, that it was practically infeasible in current circumstances to obtain and gather proper information to successfully simulate operations at this facility. Constructing the performance model for this facility would require the collaboration of all associated parties, and much more dedication involving a separate research effort directed towards the accurate and realistic analysis of operations at the facility taking into consideration all controlling factors, contributions, and influence of parties involved. Moreover, if favourable results are to be achieved, a well-planned purposely-designed information collection programme should be staged. Nevertheless, in this methodology, P-R models for baggage claim were included and built, as shown in Figures A.36, A.40, A.44, A.47, and A.51.
BIRMINGHAM INTERNATIONAL AIRPORT

PERFORMANCE MODEL for INWARD IMMIGRATION CONTROL

E E C PASSPORT HOLDERS: 4 SERVERS – SERVICE TIMES / EXPONENTIAL 0.50

NON–E E C PASSPORT HOLDERS: 2 SERVERS – SERVICE TIMES / EXPONENTIAL 2.00

Figure 9.20 BIRMINGHAM INTERNATIONAL AIRPORT- Performance Model for Inward Immigration Control.
Table 9.16
Levels of Operational Service for Inward Immigration
BIRMINGHAM INTERNATIONAL AIRPORT

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER I.T.</th>
<th>SCHEDULE LONG-HAUL</th>
<th>SCHEDULE EUROPEAN</th>
<th>TOTAL PASSENGERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Demand Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Average Volume*</td>
<td>400</td>
<td>405</td>
<td>395</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>- Peak Hour</td>
<td>604</td>
<td>612</td>
<td>596</td>
<td>604</td>
</tr>
<tr>
<td></td>
<td>- Time Spent (min.)</td>
<td>6.5</td>
<td>7.0</td>
<td>6.0</td>
<td>6.5</td>
</tr>
<tr>
<td>D</td>
<td>Max Passengers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- EEC</td>
<td>38</td>
<td>40</td>
<td>35</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>- Non-EEC</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>TOLERABLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Demand Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Average Volume*</td>
<td>438</td>
<td>445</td>
<td>425</td>
<td>435</td>
</tr>
<tr>
<td></td>
<td>- Peak Hour</td>
<td>661</td>
<td>672</td>
<td>642</td>
<td>657</td>
</tr>
<tr>
<td></td>
<td>- Time Spent (min.)</td>
<td>15.0</td>
<td>16.0</td>
<td>12.0</td>
<td>14.5</td>
</tr>
<tr>
<td>A</td>
<td>Max Passenger</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- EEC</td>
<td>65</td>
<td>70</td>
<td>52</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>- Non-EEC</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

* In passenger per hour for peak period.
5. CUSTOMS CONTROL

This is the last processing facility in the arrival channel at BHX for terminating passengers. The number of Red Channel counters (with customs officials) was four, while the number of Green Channel (units) was considered as one, being the corridor passengers should walk with their baggage to the exit of customs hall from the baggage claim area. To facilitate the simulation of operating conditions at this facility, certain assumptions had to be made. The number of (units) of the Green Channel was determined based on the fact that the width of the corridor at its end (exit) can hardly accommodate two baggage trollies abreast. As far as processing times are concerned, again any information regarding processing times (in Red Channel) could not be made available. So, although it is highly variable and really difficult to predict, mean processing time in the Red Channel was assumed to be (3.00) minutes per passenger. The decision on the assumption of mean processing time for the Green Channel was carried on more realistically and systematically. The distance passengers should walk is 25-30 feet, and the average walking speed of passengers based on Fruin's findings(51) is 200-250 ft/min (IATA standards(8) for terminals is 75 m/min). Therefore processing (self-service, i.e., walking) time needed for clearing the Green Channel ranges between (0.10-0.12) minutes per passenger. Performance model, shown in Figure 9.21, was constructed for customs based on average time spent in the facility by all (total) passengers, and maximum number of waiting passengers in Red and Green Channels seperately. Since the percentage split of Red/Green passengers was virtually impossible to obtain from official sources, percentages obtained from the passenger survey itself was used- 96 % Green, and 4 % Red. Demand levels are expressed as average volume (pax/hr), and in order to convert these levels to equivalent peak hour, the peak/average ratio, which ranged from 1.46 to 1.51 with an average of 1.49, was used.
BIRMINGHAM INTERNATIONAL AIRPORT

PERFORMANCE MODEL for ARRIVALS CUSTOMS CONTROL

GREEN CHANNEL: 1 UNIT - SERVICE TIMES / EXPONENTIAL 0.11
RED CHANNEL: 4 SERVERS - SERVICE TIMES / EXPONENTIAL 3.0

Figure 9.21 BIRMINGHAM INTERNATIONAL AIRPORT - Performance Model for Customs Control.
Table 9.17
Levels of Operational Service for Customs Control
BIRMINGHAM INTERNATIONAL AIRPORT

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>SERVICE MEASURE</th>
<th>CHARTER SCHEDULE</th>
<th>I.T.</th>
<th>LONG-HAUL</th>
<th>EUROPEAN AREA</th>
<th>C. T. TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>-Average Volume*</td>
<td>445</td>
<td>450</td>
<td>440</td>
<td>455</td>
<td>455</td>
</tr>
<tr>
<td></td>
<td>-Peak Hour</td>
<td>678</td>
<td>671</td>
<td>656</td>
<td>678</td>
<td>678</td>
</tr>
<tr>
<td>O</td>
<td>Time Spent (min.)</td>
<td>6.5</td>
<td>6.0</td>
<td>5.0</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>D</td>
<td>Max Passengers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- GREEN</td>
<td>160</td>
<td>150</td>
<td>130</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>- RED</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TOLERABLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Demand Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Average Volume*</td>
<td>505</td>
<td>495</td>
<td>460</td>
<td>515</td>
<td>485</td>
</tr>
<tr>
<td></td>
<td>-Peak Hour</td>
<td>752</td>
<td>738</td>
<td>685</td>
<td>767</td>
<td>723</td>
</tr>
<tr>
<td>A</td>
<td>Time Spent (min.)</td>
<td>13.0</td>
<td>12.0</td>
<td>7.0</td>
<td>15.0</td>
<td>11.5</td>
</tr>
<tr>
<td>D</td>
<td>Max Passengers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- GREEN</td>
<td>300</td>
<td>275</td>
<td>178</td>
<td>320</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>- RED</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* In passengers per hour for peak period.
From Table 9.17, it could be seen that service condition at BHX customs control during the survey period was, in general, 'Good'. However, the performance model indicated that there was a mismatch between number of units of the Red and Green channels, resulting from the inappropriateness of Green Channel in dealing with the imposed demand. Since processing Green Channel passengers is actually a self-serve activity whose outcome is basically influenced by the capacity of the corridor (i.e., its width), increasing the number of Green Channel units could be accomplished simply by increasing the width of the corridor and exit from customs. Pile-up and queueing of Green Channel passengers was actually monitored by the surveyor, where acute congestion was repeatedly observed at exit of customs (Figure 9.17), for two main reasons:

1. Internal, namely the inadequacy of corridor and exit to accommodate the large number of passengers leaving customs.
2. External, caused by the pressure of visitors greeting arriving passengers, which occasionally blocked the exit forcing passengers to stop and wait for those in front to clear the way. In many instances, way was cleared only after direct intervention of Airport Police.

This particular situation is another example of how useful the methodology can be for physical design of terminal facilities through exposing potential bottlenecks and predicting locations of congestion points.

9.5 SUMMARY

This chapter presents practical applications of procedures of methodology to real-world conditions. Aspects of applications are discussed in detail and in conjunction with knowledge and information elaborated on in previous chapters. This includes assumptions made, sources of information used, comparisons of outcomes with observed and actual situations, different aspects of implementation, interpretation of results and findings, and
finally, conclusions drawn. Being a practically-oriented methodology, it basically demonstrates various features of the methodology, explores its applicability as a planning and management tool, and manifests the role it can play as a bridge between planners and architects, and airport managers.
Outcomes of this research are not restricted to immediate scientific findings typical of similar academic exercises, but are also related to important aspects of the wider issues of research, availability of knowledge, and applied practices in the field of airport terminals planning and operations. Throughout this research, certain facts were realized and conclusions reached, that could be of some assistance to future researchers dealing with the 'realities' of airport terminal's environment. Moreover, practical techniques developed would hopefully enhance current practices and provide useful knowledge to practitioners as well as to academics. These conclusions include:

1/. Methodology proposed herewith can provide a realistic and applicable means of assessing operations and performance of processing facilities in airport terminals, both for the purposes of planning and operations management. In light of restrictions and substantial difficulties associated with acquisition of information and the general lack of knowledge concerning certain operational aspects in this field, information required for applying this methodology in real-word conditions was found to be manageable and reasonable with straightforward implementation.

2/. There are serious difficulties associated with gathering data inside airports. This is a major obstacle and a stumbling block to research in improving and enhancing current planning practices and management techniques, and widening scope of available
knowledge in the field of airport operations. Those difficulties, which were actually experienced in many occasions throughout this research, are primarily caused by the sensitivity of the system and conflicting economic and political motives and objectives of parties involved. However, if these problems are solved, this methodology would be highly suitable for 'internal' use by the parties associated with operations.

3/. There is an evident absence of comprehensive and systematic practice and procedures in airport terminals, that could be efficiently and flexibly used for planning, design, and operations management of terminals at different environments.

4/. Systematically devised service standards for airport terminals are lacking. There is a need to establish publically recognized and professionally approved airport service standards that are based on sound principles and follow clear definitive procedures.

5/. Most research programmes associated with studying airport terminal operations had concentrated mainly on establishing tools for analyzing and describing operations (i.e., simulation models), and have spent exhaustive time and resources on perfecting and validating those models. They eventually neglected the objective of devising techniques for improving operations management using those tools.

6/. The most relevant factor that could define operational service levels in terminals is delay, which is the major outcome of congestion in servicing. However, due to the difficulty of obtaining perception of users to this predominantly emotive factor, overall time spent in a processing facility was more conveniently implemented.
7/. Consequently, level of service framework, which is essential to the process of planning and operations assessment of airport terminals, could be practically and conveniently erected through the successful implementation of P-R models. In this way, service standards for different processing facilities, at various conditions, and for any environment, can be set.

8/. The concept of P-R models has good prospects for use not only with time as the service measure selected in this work, but with any other service measure, or combination of measures, that could be adopted to describe different service conditions and could be perceived by people to formulate an attitude towards its various values.

9/. Processing time, in terms of processing rate and distribution, is a vital and essential piece of information in understanding and analysing operations of airport terminal processing facilities, because it is the main factor and basic element that would eventually dictate capacity and hence the performance of facilities. Nevertheless, current practices fail to recognize this importance; no guidelines are set for defining service rate threshold values and processing distributions, no classification is carried out of processing facilities into distinct categories, or even provide sufficient knowledge on characteristics of the processing (servicing) activity.

10/. Capacity of processing facilities could be defined through the use of 'performance model' that describe supply-demand relations of the particular facility with definitive operational parameters based on the particular demand pattern prevailing. Defining capacity, and assessing operations must be performed in conjunction with an appropriately set level of service framework. Performance models could be derived by implementing an appropriate simulation technique, whereby various aspects of operations are described in detail with important variables are monitored more closely and efficiently.
CHAPTER ELEVEN

RECOMMENDATIONS FOR FURTHER RESEARCH

1/. It is believed (yet could not be appropriately investigated or proven in this work because of limitations and restrictions on information collection) that prevailing passenger perception to service, which effectively dictate the service standards, vary with demand levels. This means that service levels extracted from P-R models hold only for the demand level when and where the passenger survey took place, because it is thought that passengers respond to different activity levels differently. In partial recognition of this fact, IATA adopts two-tier service standards for normal and peak conditions. This argument suggests that service standards vary with change in demand levels, with the service levels taking a slightly curvilinear pattern increasing with higher demand levels. In this work, however, it was assumed that prevailing passenger perception and response to service was constant for different demand levels.

2/. In this work, values of time as perceived by passengers are directly used to construct P-R models. Actual time spent in different facilities as recorded by the passengers was also included in the main passenger survey. However, it was found that passenger estimation of time actually spent was not very accurate. Psychological theory of perception that was previously implemented in a study by Clark(198) to try to model urban traveler's perception to travel time, suggested that perceived values of time are likely to be non-linear functions of actual values (see Section 9.4.3). Nevertheless, applying values of the
parameters arrived at in that study to our case study showed negligible effects on values of the service measure adopted (time). So, further research into the relationship of perceived to actual values of service measures in the airport environment is required to understand the situation more fully. This will be most helpful to deriving service standards more accurately and on a more realistic basis.

3/. Throughout this work, certain assumptions were made regarding facilities' processing times, primarily for the sake of simplification, or for lack of necessary information. Check-in processing times were obtained by using the weighted average processing time per passenger according to average group size observed for the particular flight sector. All other processing facilities were assumed to handle passengers on a one-in-group basis, where processing times were assumed per passenger processed. However, it would seem more realistic and accurate if processing times were assigned during operation on a group basis according to prespecified frequency distribution, rather than on an individual passenger basis. Evidently, the effect of group size (and its corresponding frequency distribution) on overall processing (in terms of processing times) is quite significant and undoubtedly influences the behaviour of the performance model and capacity. Research is thus required to provide a better knowledge and understanding on this important issue.

4/. It was frequently indicated in this work, that the substantial difficulties of obtaining operational information within airports, were mainly contributed to the reluctance of responsible parties and authorities to provide information, or at least give their consent to its collection by others. This attitude, which seems universal, is a considerable obstacle if not a real threat to efforts of general research associated with airport operations. All parties should now recognize the adverse effects this behaviour has on the present and future of this vital transport system at all levels: regionally, nationally, and
internationally. The argument invariably presented by those parties as the excuse, is the unique and sensitive situation of the airport system—operationally, commercially, and socio-politically. There should be a coordinated effort to organise research and information collection programmes in airports. It should be implemented systematically with the responsibility shared between the parties involved, preferably under the supervision of specialized government-related organisations. When introduced, this arrangement would be in the general interest of airports and the air travelling public, and of benefit to related parties associated with the system.

5/. In this work, P-R models were built with time as the service measure. But for the purpose of defining space requirements, this measure (time) would not be applicable directly. However, this work has demonstrated that space standards can be obtained indirectly through performance models that use time as well as space (expressed in terms of maximum queue length) as the service measures. Nevertheless, although perception of people to space might be interpreted less accurately by them in comparison with time, a research that would develop space service standards based on P-R models that adopt space as the service measure, would complement this work, and could throw more light on this particular issue.

6/. Using the level of service procedure with service measures other than time to build P-R models that would express different kinds of service of airport terminals. These measures may include: walking distance, occupation density, economic parameters (airline ticket fares, access trip fares, airport tax, and concessions and services prices), frequency of flights, ...etc.
7/. Since this work excluded baggage claim facility largely because of insufficiency of information, research should be conducted on analysing operations of the baggage claim facility in detail. This methodology can be applied to achieve that purpose.

8/. This methodology is suitable if adopted in research to better understand and uncover previously unknown features of the "Super-peaking" phenomenon. Super-peaks are operational conditions where the system is subjected to acute levels of utilization resulting from extremely high levels of demand for sustained periods of time, but only for short durations.
REFERENCES


55. Transport Canada; "A discussion Paper on Level of Service Definition and Methodology for Calculating Airport Capacity", Air Services Branch, Tp 2027, Canadian Air Transportation Administration, Ottawa, April, 1979.


185. Battelle Memorial Institute; "Computer Program Description: Airport Demand/Capacity Analysis Methods", Battelle-Columbus Laboratories, Columbus, September, 1974.


APPENDIX A

P - R MODELS

1. EAST MIDLANDS AIRPORT Pilot.


3. MANCHESTER INTERNATIONAL AIRPORT.

4. BIRMINGHAM INTERNATIONAL AIRPORT.
EAST MIDLANDS AIRPORT PILOT SURVEY
P - R MODEL for DEPARTING PASSENGERS
No. of Samples = 25

Figure A.1 EAST MIDLANDS AIRPORT - P-R Model for Charter Flights Check-in.
Figure A.3 EAST MIDLANDS AIRPORT- P-R Model for Security Check.
Figure A.4 EAST MIDLANDS AIRPORT- P-R Model for All Departure Processing Facilities.
Figure A.5 Panel of Experts - P-R Model for Airlines Flight Check-in.
Figure A.6 Panel of Experts - P-R Model for Security Check.
Figure A.7 Panel of Experts- P-R Model for Passports Control.
Figure A.8 Panel of Experts- P-R Model for All Departure Processing Facilities.
PANEL OF EXPERTS SURVEY
P - R MODEL for TOTAL ARRIVING PASSENGERS
No. of Participants = 25

Figure A.9 Panel of Experts- P-R Model for Inward Immigration.
Figure A.11 Panel of Experts- P-R Model for Customs (Red Channel).
PANEL OF EXPERTS SURVEY
P - R MODEL for TOTAL ARRIVING PASSENGERS
No. of Participants = 25

Figure A.12 Panel of Experts - P-R Model for All Arrival Processing Facilities.
MANCHESTER INTERNATIONAL AIRPORT SURVEY
P - R MODEL for CHARTER I.T. CHECK-IN
No. of Samples = 497

Figure A.13 MANCHESTER INTERNATIONAL AIRPORT- P-R Model for Charter I.T. Check-in.
MANCHESTER INTERNATIONAL AIRPORT SURVEY
P - R MODEL for CHARTER I.T. PASSENGERS
No. of Samples = 497

Figure A.14 MANCHESTER INTERNATIONAL AIRPORT- P-R Model for Outbound Official Controls
(Charter I.T. Passengers).
MANCHESTER INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: LONG HAUL PASSENGERS
No. of Samples = 41

Figure A.15  MANCHESTER INTERNATIONAL AIRPORT- P-R Model for Schedule/Long Haul Check-in.
Figure A.16 MANCHESTER INTERNATIONAL AIRPORT- P-R Model for Outbound Official Controls (Schedule/Long Haul Passengers).
MANCHESTER INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: EUROPEAN PASSENGERS
No. of Samples = 52

Figure A.17 MANCHESTER INTERNATIONAL AIRPORT- P-R Model for Schedule/European Check-in.
Figure A.18 MANCHESTER INTERNATIONAL AIRPORT- P-R Model for Outbound Official Controls (Schedule/European Passengers).
MANCHESTER INTERNATIONAL AIRPORT SURVEY
P - R MODEL for TOTAL PASSENGERS
No. of Samples = 590

Figure A.19 MANCHESTER INTERNATIONAL AIRPORT - P-R Model for Outbound Official Controls (Total Departing Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for CHARTER I.T. PASSENGERS
No. of Samples = 268

Legend
△ GOOD
× TOLERABLE
BAD

Figure A.20 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Charter I.T. Check-in.
Figure A.21 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Security Check (Charter I.T. Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for CHARTER: I.T. PASSENGERS
No. of Samples = 267

Figure A.22 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Passports Control
(Chart I.T. Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for CHARTER:I.T. PASSENGERS
No. of Samples = 266

Figure A.23  BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for All Departure Processing
(Charter I.T. Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: LONG HAUL PASSENGERS
No. of Samples = 35

Figure A.24  BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Schedule-Long Haul Check-in.
Figure A.25 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Security Check (Schedule-Long Haul Passengers).
Figure A.26  BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model For Passports Control (Schedule: Long Haul Passengers).
Figure A.27 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for All Departure Processing (Schedule-Long Haul Passengers).
Figure A.29 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Security Check. (Schedule-European Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: EUROPEAN PASSENGERS
No. of Samples = 27

Figure A.30 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Passports Control (Schedule:
European Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: EUROPEAN PASSENGERS
No. of Samples = 27

Figure A.31 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for All Departure Processing
(Schedule-European Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for TOTAL DEPARTING PASSENGERS
No. of Samples = 330

Figure A.32 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Security Check (Total Departing Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for TOTAL DEPARTING PASSENGERS
No. of Samples = 329

Figure A.33 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Passports Control (Total Departing Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for TOTAL DEPARTING PASSENGERS
No. of Samples = 328

Figure A.34  BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for All Departure Processing
(Total Departing Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for CHARTER I.T. PASSENGERS
No. of Samples = 147

Figure A.36 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Baggage Claim (Charter I.T. Passengers).
Figure A.37  BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Customs Control (Charter I.T. Passengers).
Figure A.38 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for All Arrival Processing (Charter I.T. Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: LONG HAUL PASSENGERS
No. of Samples = 36 : E E C = 74%, Non-E E C = 26%

Figure A.39 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Inward Immigration
(Schedule - Long Haul Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: LONG HAUL PASSENGERS
No. of Samples = 36

Figure A.42 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for All Arrival Processing
(Schedule - Long Haul Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY

P - R MODEL for SCHEDULE: EUROPEAN PASSENGERS

No. of Samples = 88; EEC = 93.3%, Non-EEC = 6.7%.

Figure A.43 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Inward Immigration
(Schedule - European Passengers).
Figure A.44  BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Baggage Claim (Schedule-European Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for SCHEDULE: EUROPEAN PASSENGERS
No. of SAMPLES = 88

Figure A.46 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for All Arrival Processing
(Schedule-European Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for COMMON TRAVEL AREA PASSENGERS
No. of Samples = 13

Figure A.47 BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for Baggage Claim (Common Travel Area Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for TOTAL ARRIVING PASSENGERS
No. of Samples = 283 : E E C = 94% , Non-E E C = 6%

Figure A.50 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Inward Immigration (Total Arriving Passengers).
BIRMINGHAM INTERNATIONAL AIRPORT SURVEY
P - R MODEL for TOTAL ARRIVING PASSENGERS
No. of Samples = 282 : GREEN CHANNEL=96% , RED CHANNEL=4%

Figure A.52 BIRMINGHAM INTERNATIONAL AIRPORT- P-R Model for Customs Control (Total Arriving Passengers).
Figure A.53  BIRMINGHAM INTERNATIONAL AIRPORT - P-R Model for All Arrival Processing (Total Arriving Passengers).
APPENDIX B

QUESTIONNAIRES

1. EAST MIDLANDS AIRPORT Pilot (3 pages).
3. MANCHESTER INTERNATIONAL AIRPORT (1 page).
4. BIRMINGHAM INTERNATIONAL AIRPORT (3 pages).
Dear Sir/Madam;

Your assistance and cooperation are highly appreciated, and would be valuable for future planning and design of airport terminals, which will eventually contribute to your comfort and satisfaction. All you have to do is to state your opinion and reaction to the time you anticipate spending inside terminals in DELAY.

Going through airport terminals, when traveling by air, you inevitably spend some time in delay. DELAY, is the time you unwillingly spend waiting for service (as in check-in, immigration...), or a call (as for boarding...). Delay does not include; time spent actually being serviced or processed (but NOT waiting for it), waiting for or being with family and friends, moving between various parts of the terminal, or time spent in concessions like duty free shop, restaurants, bars, ... etc.

Please, consider answering this questionnaire as regarding delays encountered in various parts of the airport terminal, by giving an assessment for DELAY according to your personal judgement and perception to delay encountered in the part of terminal under consideration. Replies would be in the form of grades you put for every period of delay stated in the particular question. The grading system has three levels:

1. DESIRABLE, where delay is short and comfortable..................mark(V).  
2. TOLERABLE, where delay is moderate but acceptable..................mark(V).  
3. UNACCEPTABLE, where delay is significantly uncomfortable and untolerable................................mark(X).

EXAMPLE: What is your perception to delay in AIRPORT BANK (currency exchange)?

Delay in minutes: 1 2 3 4 5 6 7 8 9 10 12 15 20

Thank you very much for your consideration and cooperation.
PART I SAMPLE INFORMATION

1. AGE: [ ] 0 - 19    [ ] 20 - 29    [ ] 30 - 39    [ ] 40 - 49    [ ] 50 - 59    [ ] over 60

2. SEX: [ ] MALE    [ ] FEMALE

3. BRITISH NATIONAL: [ ] YES    [ ] NO

4. PREFERENCE FOR AIR TRAVEL:
   - Do you like traveling by air?
     [ ] LIKE VERY MUCH    [ ] LIKE    [ ] LIKE A LITTLE    [ ] DISLIKE    [ ] INDIFFERENT
   - Do you feel comfortable and happy going through airport terminals?
     [ ] VERY MUCH    [ ] MODERATE    [ ] A LITTLE    [ ] NOT AT ALL    [ ] INDIFFERENT

5. FREQUENCY OF AIR TRAVEL:
   - How many times do you travel by air every year? ————

6. ORIGIN / DESTINATION OF THIS TRIP: ————
   [ ] DOMESTIC    [ ] INTERNATIONAL

7. PURPOSE OF THIS TRIP:
   [ ] BUSINESS    [ ] LEISURE    [ ] OTHER

8. FLIGHT:
   - Your flight number: ————
   - Flight class:
     [ ] SCHEDULED    [ ] CHARTERED    [ ] OTHER
PART II DELAY INFORMATION

Based on personal judgement, grade your perception to delay for the following (similar to example shown on page 1):

1. TICKETING / CHECK-IN:
   - Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
   - Grade:

2. SECURITY CHECK:
   - Delay in minutes: 1 2 3 4 5 6 7 8 9 10 15 20 30
   - Grade:

3. PASSPORT CONTROL (departures):
   - Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
   - Grade:

4. IMMIGRATION:
   - Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60 90
   - Grade:

5. BAGGAGE CLAIM:
   - Delay in minutes: 1 3 5 7 10 15 20 25 30 40 50 60 75
   - Grade:

6. CUSTOMS (RED CHANNEL):
   - Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
   - Grade:

7. OVERALL DELAY IN TERMINAL FOR AN ARRIVING FLIGHT:
   - Delay estimate in minutes: 5 10 15 20 30 40 50 60 75 90
   - Grade:

8. OVERALL DELAY IN TERMINAL FOR A DEPARTING FLIGHT:
   - Delay estimate in minutes: 5 10 15 20 30 40 50 60 75 90
   - Grade:
Please consider answering this questionnaire based on your own judgement as an expert in the field of airport operations involving passenger servicing. The objective is to indicate your judgement on different delay periods that passengers may possibly encounter while being serviced (processed) inside the airport terminal. Delay, here, is the time unwillingly spent by passengers awaiting service, and does not include; actual processing time, time deliberately spent with family and friends, or in concessions and amenities. What is required from you is to give your assessment (as a grade) to the passengers' perception and response to stated delay periods, at the processing facilities considered, and for varying levels of operational conditions, from the passengers viewpoint as experienced in your airport.

The grading system is as follows:

✓: **GOOD** service; delay stated is satisfactory and comfortably short to the passengers.

✓: **TOLERABLE** service; delay stated is moderate but still acceptable to the passengers, that it would not justify complaints.

✗: **BAD** service; delay stated is significantly long, and uncomfortable and intolerable to the passengers that it would justify complaints.

Thank you.
PART I:

* Airport you are associated with: ........................
* Annual passenger throughput of airport in 1982: ........................

A- DEPARTURES:

- **TICKETING / CHECK-IN:**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
  
  Grade:  

- **SECURITY CHECK:**
  
  Delay in minutes: 1 2 3 4 5 6 7 8 9 10 15 20 30
  
  Grade:  

- **PASSPORT CONTROL (departures):**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
  
  Grade:  

- **OVERALL DELAY IN TERMINAL FOR A DEPARTING FLIGHT:**
  
  Delay estimate in minutes: 5 10 15 20 30 40 50 60 75 90
  
  Grade:  

B- ARRIVALS:

- **DEPARTURE:**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
  
  Grade:  

- **BAGGAGE CLAIM:**
  
  Delay in minutes: 1 3 5 7 10 15 20 25 30 40 50 60 75
  
  Grade:  

- **CUSTOMS (RED CHANNEL):**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
  
  Grade:  

- **OVERALL DELAY IN TERMINAL FOR AN ARRIVING FLIGHT:**
  
  Delay estimate in minutes: 5 10 15 20 30 40 50 60 75 90
  
  Grade:  

PART II:

* Now consider the case of another airport similar in characteristics to your airport (PART I), but with an annual throughput of around 2.0 million passengers.

A- DEPARTURES:

- **TICKETING / CHECK-IN:**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
  
  Grade:

- **SECURITY CHECK:**
  
  Delay in minutes: 1 2 3 4 5 6 7 8 9 10 15 20 30
  
  Grade:

- **PASSPORT CONTROL (departures):**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
  
  Grade:

- **OVERALL DELAY IN TERMINAL FOR A DEPARTING FLIGHT:**
  
  Delay estimate in minutes: 5 10 15 20 30 40 50 60 75 90
  
  Grade:

B- ARRIVALS:

- **IMMIGRATION:**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60 90
  
  Grade:

- **BAGGAGE CLAIM:**
  
  Delay in minutes: 1 3 5 7 10 15 20 25 30 40 50 60 75
  
  Grade:

- **CUSTOMS (RED CHANNEL):**
  
  Delay in minutes: 1 3 5 7 10 12 15 20 25 30 45 60
  
  Grade:

- **OVERALL DELAY IN TERMINAL FOR AN ARRIVING FLIGHT:**
  
  Delay estimate in minutes: 5 10 15 20 30 40 50 60 75 90
  
  Grade:
In order to help the Airport Authority continue to improve facilities at the Airport, I should be grateful if you could answer the following questions. The form may be returned to the survey assistant who gave you the form or placed in the box in the Departure Lounge or gate.

D. P. Stanley
DIRECTOR OF DEVELOPMENT AND PLANNING.

1. CHECK-IN
Was your wait at check-in
How did this waiting time compare with other Airports

2. OFFICIAL CONTROLS
Were you held up in a queue at SECURITY PASSPORT CONTROL
How long in total
How did this waiting time compare with other Airports

3. AIRPORT FACILITIES
Please indicate your level of satisfaction with the following facilities if you used them.
CATERING (including Bars
DUTY FREE SHOP
OTHER SHOPS
BANK
TOILETS
SEATING AREAS
INFORMATION

How many people in your party do your answers apply to

Please give any further comments you have about the Airport here:

THANK YOU.
Dear Passenger;

We are undertaking a passenger survey to evaluate service standards at this airport, and how passengers respond to the time they spend in different parts of the terminal building.

We hope for your cooperation in participating in this survey, and should be grateful if you could answer the two parts of this questionnaire, which will not take you long to complete.

After completing it, please place the questionnaire inside the marked box just outside the departure lounge on your way to the departure gate, and thank you for your cooperation.

Department of Transport Technology
Loughborough University of Technology

PART I:

DATE:____________
FLIGHT No.:_____________ TO:______________

Please state the time (in minutes) you actually spent during this trip, in the parts of the terminal building indicated below:

1. AIRLINE CHECK-IN:_____________
2. SECURITY CHECK:_____________
3. PASSPORTS CONTROL:_____________
Now, assume that circumstances were different whilst proceeding to your flight, and you had to spend different amounts of time within each part of the terminal building.

If you were to spend the amount of time shown in the boxes below, what would be your judgement on the level of satisfaction you would experience in each case?

Please, indicate your level of satisfaction as A, B, or C according to the following grading system:

A - GOOD service; comfortably short time spent, which you would perceive as definitely satisfactory.

B - TOLERABLE service; moderately long time spent, but still perceived as tolerable, and would not justify any complaints.

C - BAD (POOR) service; significantly long time spent, which you would perceive as uncomfortable and intolerable to the extent that it would justify complaints.

[ PLEASE FILL ALL BOXES ]

1. AIRLINE CHECK-IN:
   - Time spent in minutes: 1357
   - Level of satisfaction for each time:
     \[ \frac{1}{2} \]

2. SECURITY CHECK:
   - Time spent in minutes: 1357
   - Level of satisfaction for each time:
     \[ \frac{1}{2} \]

3. PASSPORTS CONTROL:
   - Time spent in minutes: 1357
   - Level of satisfaction for each time:
     \[ \frac{1}{2} \]

4. OVERALL TIME IN 1, 2 & 3 ABOVE:
   - Time spent in minutes: 51015202530456090120
   - Level of satisfaction for each time:
     \[ \frac{1}{2} \]
Dear Passenger;

We are undertaking a passenger survey to evaluate service standards at this airport, and how passengers respond to the time they spend in different parts of the terminal building.

We hope for your cooperation in participating in this survey, and should be grateful if you could answer the two parts of this questionnaire, which will not take you long to complete.

After you finish, please mail this questionnaire back, using the FREEPOST envelope provided, and thank you for your cooperation.

Department of Transport Technology
Loughborough University of Technology

PART I:

DATE:_____________ FLIGHT No.:_____________ FROM:_____________

NATIONALITY:__________________________

Please state the time (in minutes) you actually spent during this trip, in the parts of the terminal building indicated below:

1. PASSPORTS/IMMIGRATION:_____________
2. BAGGAGE CLAIM:_____________
3. CUSTOMS: (answer one as applicable)
   - GREEN CHANNEL (nothing declared):_____________
   - RED CHANNEL (something declared):_____________
Now, assume that circumstances were different whilst proceeding from your flight, and you had to spend different amounts of time within each part of the terminal building.

If you were to spend the amount of time shown in the boxes below, what would be your judgement on the level of satisfaction you would experience in each case?

Please, indicate your level of satisfaction as A, B, or C according to the following grading system:

A - GOOD service; comfortably short time spent, which you would perceive as definitely satisfactory.

B - TOLERABLE service; moderately long time spent, but still perceived as tolerable, and would not justify any complaints.

C - BAD (POOR) service; significantly long time spent, which you would perceive as uncomfortable and intolerable to the extent that it would justify complaints.

[ PLEASE FILL ALL BOXES ]

1. PASSPORTS / IMMIGRATION CONTROL:
   - Time spent in minutes: 1 3 5 7 10 15 20 25 30 45 60
   - Level of satisfaction for each time:

2. BAGGAGE CLAIM:
   - Time spent in minutes: 1 3 5 7 10 15 20 25 30 45 60
   - Level of satisfaction for each time:

3. CUSTOMS:
   (Tick either RED or GREEN channels as entered in PART I):
   - Time spent in minutes: 1 3 5 7 10 15 20 25 30 45
   - Level of satisfaction for each time:

4. OVERALL TIME IN 1, 2 & 3 ABOVE:
   - Time spent in minutes: 5 10 15 20 25 30 45 60 90 120
   - Level of satisfaction for each time:
PLEASE DO NOT OPEN NOW

BUT KEEP IN MIND

In this survey, you will be asked about the time you spent in each facility of the airport terminal.

Please, try to record the amount of time you spend in: PASSPORTS / IMMIGRATION, BAGGAGE CLAIM, CUSTOMS, then, enter those times in the enclosed questionnaire later. Thank you.
APPENDIX C

SIMULATION LISTINGS

1. Check-in Facility (2 pages).

2. FUNCTION USERF (1 page).

3. Outbound Official Controls at MANCHESTER and BIRMINGHAM (1 page).

4. Inward Immigration Control (1 page).

5. Customs Control (1 page).
C.1 Check-in Facility

```fortran
PROGRAM MAIN(INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, TAPE7)
DIMENSION NSET(14000)
COMMON QSET(14000)
DIMENSION NSET(14000)
COMMON/S001/ ATRI f, (100) , DD (100) , DDL (100) , DTNOW, II, MFA, MSTOP,
1NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100), SSL(100), TNEXT, TNOW,
2XX(100)
COMMON/U0OM/ NPAX
EQUIVALENCE (NSET(1),QSET(1))
NNSET = 14000
NCRDR = 5
NPRNT = 6
NTAPE = 7
CALL SLAM
END

SUBROUTINE INTLC
COMMON/SOCOM/ ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP,
1NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100), SSL(100), TNEXT,
2TNOW, XX(100)
COMMON/U0OM/ NPAX
XX(2) = 0.
CALL SCHDL(1,0., ATRIB)
RETURN
END

SUBROUTINE EVENT(I)
CALL ARVL
RETURN
END

SUBROUTINE ENDSV
COMMON /SOCOM/ ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP,
1NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100), SSL(100), TNEXT, TNOW,
2XX(100)
COMMON /UCOM/ NPAX
***COLLECT STATISTICS ON DEPARTING PASSENGERS
TINQ = TNOW - ATRIB(1)
CALL COLCT(TINQ,1)
***CHECK NO. OF WAITING PAX.
IF(NNQ(1) .GT. 0) GO TO 10
***IF NO PAX WAITING, SET AGENT TO IDLE, AND RETURN
XX(2) = 0.
RETURN
***AGENT IS FREE , SO SERVE FIRST PAX IN QUEUE
10 CALL RMOVE(1,1, ATRIB)
CALL SCHDL(2, EXPON(0.73,2), ATRIB)
RETURN
END
```
SUBROUTINE ARVL

COMMON /SCOM/ : ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP,
INCLNR, NORDER, NRRTN, NRNRN, INSET, NTAPE, SE(100), SSL(100), TNEXT, TNOW,
2XX(100)

COMMON /UCOM/ : NPAX

***** Cause next arrival, mark arrival time, and increment NPAX
IF (TNOW .LE. 20) GO TO 1
IF (TNOW .GT. 20 .AND. TNOW .LE. 40) GO TO 2
IF (TNOW .GT. 40 .AND. TNOW .LE. 60) GO TO 3
IF (TNOW .GT. 60 .AND. TNOW .LE. 80) GO TO 4
IF (TNOW .GT. 80 .AND. TNOW .LE. 100) GO TO 5
IF (TNOW .GT. 100 .AND. TNOW .LE. 120) GO TO 6
IF (TNOW .GT. 120 .AND. TNOW .LE. 140) GO TO 7
IF (TNOW .GT. 140 .AND. TNOW .LE. 160) GO TO 8
IF (TNOW .GT. 160 .AND. TNOW .LE. 180) GO TO 9
IF (TNOW .GT. 180 .AND. TNOW .LE. 200) GO TO 10
IF (TNOW .GT. 200 .AND. TNOW .LE. 220) GO TO 11
IF (TNOW .GT. 220) GO TO 100

1 XX(1) = 1.29
GO TO 100
2 XX(1) = 3.40
GO TO 100
3 XX(1) = 2.22
GO TO 100
4 XX(1) = 1.22
GO TO 100
5 XX(1) = 0.90
GO TO 100
6 XX(1) = 0.90
GO TO 100
7 XX(1) = 0.86
GO TO 100
8 XX(1) = 1.25
GO TO 100
9 XX(1) = 2.22
GO TO 100
10 XX(1) = 6.67
GO TO 100
11 XX(1) = 80.00
GO TO 100
12 XX(1) = 80.00
100 CALL SCID(1, EXPON(XX(1), 1), ATRIB)
ATRIB(1) = TNOW
NPAX = NPAX + 1

***** If agent is free...
IF (XX(2) .NE. 0.) GO TO 200

***** Then make busy (serve), and schedule end of service
XX(2) = 1.
CALL SCIDL(2, EXPON(0.73, 2), ATRIB)
RETURN

***** Otherwise place Pax in queue
200 CALL FILEMM(1, ATRIB)
RETURN
END
C. 2 FUNCTION USERF

FUNCTION USERF(I)
COMMON /SCOM1/ ATRI B (100), DD (100), DLL (100), DTNOW, II, MFA, MSTDP,
1NCLNR, NRDR, NrNRT, NNRUN, NNSRT, NTAPE, SS(100), SSL(100), TNEXT, TNOW,
2XX(100)
    I = 1
C****CHECK NEXT ARRIVAL...
    IF (TNOW .LE. 20) GO TO 10
    IF (TNOW .GT. 20 .AND. TNOW .LE. 40) GO TO 20
    IF (TNOW .GT. 40 .AND. TNOW .LE. 60) GO TO 30
    IF (TNOW .GT. 60 .AND. TNOW .LE. 80) GO TO 40
    IF (TNOW .GT. 80 .AND. TNOW .LE. 100) GO TO 50
    IF (TNOW .GT. 100 .AND. TNOW .LE. 120) GO TO 60
    IF (TNOW .GT. 120 .AND. TNOW .LE. 140) GO TO 70
    IF (TNOW .GT. 140 .AND. TNOW .LE. 160) GO TO 80
    IF (TNOW .GT. 160 .AND. TNOW .LE. 180) GO TO 90
    IF (TNOW .GT. 180 .AND. TNOW .LE. 200) GO TO 100
    IF (TNOW .GT. 200 .AND. TNOW .LE. 220) GO TO 110
    IF (TNOW .GT. 220 .AND. TNOW .LE. 240) GO TO 120
    IF (TNOW .GT. 240 .AND. TNOW .LE. 260) GO TO 130
    IF (TNOW .GT. 260 .AND. TNOW .LE. 280) GO TO 140
    IF (TNOW .GT. 280 .AND. TNOW .LE. 300) GO TO 150
    IF (TNOW .GT. 300) GO TO 160
10  XX(1) = 0.34
    GO TO 200
20  XX(1) = 0.21
    GO TO 200
30  XX(1) = 0.24
    GO TO 200
40  XX(1) = 0.14
    GO TO 200
50  XX(1) = 0.078
    GO TO 200
60  XX(1) = 0.057
    GO TO 200
70  XX(1) = 0.056
    GO TO 200
80  XX(1) = 0.048
    GO TO 200
90  XX(1) = 0.060
    GO TO 200
100 XX(1) = 0.090
    GO TO 200
110 XX(1) = 0.145
    GO TO 200
120 XX(1) = 0.24
    GO TO 200
130 XX(1) = 0.150
    GO TO 200
140 XX(1) = 0.180
    GO TO 200
150 XX(1) = 0.48
    GO TO 200
160 XX(1) = 0.90
C
C****GENERATE NEXT ARRIVAL, AND MARK ARRIVAL TIME.
    200 USERF = EXPON(XX(1),1)
    RETURN
END
I- MANCHESTER INTERNATIONAL AIRPORT

GEN, SAM, OFFICIAL CONTROLS, 1/5/84, 1;
LIMITS, 7, 2, 2000;

NETWORK;
  CREATE, USERF(1);
  ASSIGN, ATRIB(1) = TNOW;
  ASSIGN, XX(2) = XX(2) + 1;
  COLCT, XX(2), PAX ARRIVING;

SELS SELECT, SQQ, , , SEC1, SEC2, SEC3, SEC4;
SEC1 QUEUE(1);
  ACT/2, EXPON(0.13, 2),, SELP;
SEC2 QUEUE(2);
  ACT/2, EXPON(0.13, 2),, SELP;
SEC3 QUEUE(3);
  ACT/2, EXPON(0.13, 2),, SELP;
SEC4 QUEUE(4);
  ACT/2, EXPON(0.13, 2),, SELP;
SELP SELECT, SQQ, , , PAS1, PAS2, PAS3;
PAS1 QUEUE(5);
  ACT/3, EXPON(0.12, 3),, EXIT;
PAS2 QUEUE(6);
  ACT/3, EXPON(0.12, 3),, EXIT;
PAS3 QUEUE(7);
  ACT/3, EXPON(0.12, 3),, EXIT;

EXIT COLCT, INT(1), TIME IN CONTROLS, 20/0/0.5;
  TERM;
ENDNETWORK;

FIN;

II- BIRMINGHAM INTERNATIONAL AIRPORT

GEN, SAM, BHX DEPART CONTROLS, 1/6/84, 1;
LIMITS, 2, 2, 2000;

NETWORK;
  CREATE, USERF(1);
  ASSIGN, ATRIB(1) = TNOW;
  ASSIGN, XX(2) = XX(2) + 1;
  COLCT, XX(2), PAX ARRIVING;

SECT QUEUE(1);
  ACT/2, EXPON(0.15, 2),, Pasp;
PASP COLCT, INT(1), TIME IN SECURITY, 20/0/0.75;
  ASSIGN, ATRIB(2) = TNOW;
  QUEUE(2);
  ACT/3, EXPON(0.12, 3),, EXIT;
EXIT COLCT, INT(2), TIME IN PASSPORT, 20/0/0.5;
  TERM;
ENDNETWORK;

FIN;
C.4 Inward Immigration Control

GEN, SAM, BHK IMMIGRATION, 1/8/84, 1;
LIMITS, 6, 2, 1800;
NETWORK;
ENTER CREATE, 'USERF(1);
ASSIGN, ATRIB(1) = NOW;
ASSIGN, XX(2) = XX(2) + 1;
COLCT, XX(2), PAX ARRIVING;
ACT, 0.95, EEC;
ACT, 0.05, NEEC;
ECC SELECT, SQ, ECC1, ECC2, ECC3, ECC4;
ECC1 QUEUE(1);
ACT/2, EXPON(0.50, 2), EXIT;
ECC2 QUEUE(2);
ACT/2, EXPON(0.50, 2), EXIT;
ECC3 QUEUE(3);
ACT/2, EXPON(0.50, 2), EXIT;
ECC4 QUEUE(4);
ACT/2, EXPON(0.50, 2), EXIT;
NEEC SELECT, SQ, NON1, NON2;
NON1 QUEUE(5);
ACT/3, EXPON(2.00, 3), EXIT;
NON2 QUEUE(6);
ACT/3, EXPON(2.00, 3), EXIT;

EXIT COLCT, INT(1), IMMCR TIME, 20/0/1;
TERM;
ENDNETWORK
INIT, 0, 380;
MONTR, SUMRY, 0, 20;
FIN;
C.5 Customs Control

GEN.GAM.BIX CUSTOMS,10/8/84,1;
LIMITS,5,2,1800;
NETWORK;
ENTER CREATE,USERF(1);
ASSIGN,ATRIB(1)=TNOW
ASSIGN,XX(2)=XX(2)+1;
COLCT,XX(2),PAX ARRIVING;
ACT,,0.96,GREN;
ACT,,0.04,RED;
RED SELECT,SNO,,,CUS1,CUS2,CUS3,CUS4;
CUS1 QUEUE(1);
ACT/2,EXPON(3.0,2),EXIT;
CUS2 QUEUE(2);
ACT/2,EXPON(3.0,2),EXIT;
CUS3 QUEUE(3);
ACT/2,EXPON(3.0,2),EXIT;
CUS4 QUEUE(4);
ACT/2,EXPON(3.0,2),EXIT;
GREN QUEUE(5);
ACT/3,EXPON(0.11,3),EXIT;
EXIT COLCT,INT(1),TIME IN CUSTOMS,20/0/1;
TERM;
ENDNETWORK

INIT,0,360;
MONTR,SUMRY,0,20;
FIN;