A METHODOLOGY FOR THE COMPARATIVE ANALYSIS OF AIRPORT PASSENGER TERMINAL CONFIGURATION

by

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"Praise and glory and wisdom and thanks and honour and power and strength be to our God for ever and ever. Amen!"

Revelation 7:12

To my family

Sônia, Laís and Jonathan

ABSTRACT

The right choice between possible types of passenger terminal buildings is the key to a successful airport design project. Historically, in the earlier days of aviation the designer's concern was directed to aircraft and to the adequacy of the ground facilities which each airport provided. As the aviation grew, airport passenger buildings grew more complex and more expensive, to the point of being viewed as a key to the airports' economic performance. In this context, the process of selecting a Terminal Concept became fundamental for planning and designing airport terminal buildings. However, almost no methodology is available at the initial planning level for the selection of terminal concepts, and very little research has been done in this area.

This thesis looks firstly at the conventional steps for terminal planning and at traditional methods for facility sizing. Then it reviews the basic Terminal Concepts -- Linear, Pier, Satellite and Transporter -- placing the subject of terminal choice into context. Further it identifies and discusses the main factors involved in the process of selecting airport terminal configurations. The thesis then develops a single but effective new framework in order to assist in the choice between terminal configurations. It is based on an analogy of moment of inertia in Mechanics -- called here 'Moment of Transport' -- which allows a comparative analysis of different airport terminal building configurations. The approach builds upon detailed consideration of Moment of Transport as the core to balance three main attributes in dealing with choice of terminal building configuration: *physical* (geometry, static); *operational* (level of service, dynamic); and *economic* (capital and operational costs). The parametric analysis of a large number of theoretical terminal designs demonstrates that the Moment of Transport is able to synthesise the main attributes into this single indicator. Even so, further consideration still needs to be given to factors which cannot easily be incorporated in this type of static indicator.

KEY WORDS:

Moment of Transport, Airport Design, Terminal Sizing, Terminal Concepts, Terminal Configuration, Airport Planning, Radius of Transport.

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1. CHAPTER I The Research Topic

1.1 Introduction

Passenger terminals are complex systems that involve a great amount of investment, either private or public. Once established, an airport will serve the community for many years.

For more than half a century air transport has actually been an important social problem as well as an asset. From the beginning of this century, the aviation industry has grown from zero to accumulate more than one billion passengers a year. Today the industry is predicting that the demand for air travel in terms of the number of people wanting to travel round the world by air may double by the year 2005 [Moore (1988)]. This will, of course, require a dramatic increase in terminal capacity as the airports are to handle the extra traffic. The challenge facing airport planners is to increase the airport capacity. To accomplish this, the expansion or construction of new airports are necessary. However, the lack of a formal methodology for the choice of a terminal type, which will certainly define the success or failure of the project, is still a major deficiency in current airport planning and design. The result is that terminal types are usually conceived based on a high degree of subjectivity and intuition.

The purpose of the research is therefore to explore this problem of terminal configuration choice by firstly reviewing the current design process; then developing a tool for the design of theoretical terminal types that will form the basis for establishing the main variables necessary for the evaluation process; and finally suggesting a framework for the comparative analysis of different airport terminal configurations.

1.2 Airport Context

Once upon a time there was a will to fly. It seems that from old times the impetus to fly has always been a part of human nature. One might go back to ancient Greek mythology with Icaros [Petit (1966), Gibbs-Smith (1985)], through quotation in the Bible, many years BC, to the first drawings made by Leonard da Vinci in 1500 AD to try to find the root of mankind's dream. Freer (1986) quotes free ballooning as the beginning of civil aviation on 5 June 1783 at Annonay, France, where Joseph and Elienne Montgolfier launched the Globe Aérostatique. With many events from there on, it was not until 1884, that La France the fully steerable airship with propellers flew a round-trip pattern in 23 minutes. The first rigid airship came later, in 1900, by Graf von Zeppelin of

Germany. In 1901, Alberto Santos Dumont, built and flew a smaller airship in which he circumnavigated the Eiffel Tower. In 17 December 1903 the Wright brothers flew the first practical powered aeroplane. The heavier-than-air flight was 'conquered'. These are just a few events, to which the beginning of civil aviation may be ascribed.

According to Sir Colin Marshall (1992) contemporary civil aviation actually began based on a policy of prohibition. It developed from the Paris Convention in 1919 and the Chicago Convention in 1944, with the creation of ICAO, where the aspects related to each country's sovereignty gave birth to the Freedoms of the Air.

Although the origin of civil aviation can be ascribed to many events, the air transport industry actually started at the beginning of this century, when aeroplanes first started to be commercially used, and with it begun the history of airports. The world's first commercial air service, a series of mail flights between Hendon and Windsor, was established in Britain in 1910. In the USA a rudimentary airline service started in 1914 carrying passengers over a 21-mile route linking Tampa and St. Petersburg in Florida [Wiley (1986), Marshall (1992)].

By 1932, Lewis-Dale (1932) reported as a little more than a hundred the total number of aerodromes in Britain, including Landing Grounds, Seaplane and Airship Stations. In contrast, in America, by the same time there were over 1000 municipal and commercial aerodromes and 600 intermediate Landing Grounds, excluding many military establishments. Lewis-Dale's book is very interesting reading which helps to understand the state of the art in airport planning and design by the beginning of this Century. The book's preoccupation is with the aerodrome particularly viewed as a landing ground. The primary attention is devoted to aircraft and runways. Buildings are mentioned but details are given only of Hangars, to which 3 chapters are devoted. The following paragraph is quoted:

> "Position of Other Groups of Buildings. The main administrative block of an important civil aerodrome will naturally occupy a prominent and commanding position. It must be convenient of access both from the landing ground and from the landwards approach roads. It will probably group together under one roof the central management offices, booking-hall, waiting-rooms, customs hall, staff dining-rooms and other accommodation of similar kind.
>
> Workshops and stores will form another group of buildings, living and club accommodation a third group, and so on."

The principles of Planning with respect to a proposed aerodrome layout expressed Lewis-Dale's vision of the future. Regular overseas passengers, mail and freight services, with customs facilities, employing all types of aircraft; taxi services to other towns within the country; flying club with instruction facilities; and flying by individual aircraft owners were all foreseen as future airport developments. His principles listed below show that many of the current difficulties in the planning process such as phasing the airport construction, the development of commercial activities, flexibility, expandability and 'level of service' have been the designer's concern for many decades.

1. "The layout to be such as to allow of systematic development of the scheme from the smallest beginning until it reaches the final stage.

2. Each branch of activities, e.g. commercial, private flying, instructional flying, etc., to be capable of being developed independently of the others.
   The possibility, some time in the future, of having to develop commercial activity at the expense of some other branch of activity (which may have to be removed elsewhere) to be borne in mind.

3. At each stage of development, the scheme to be well balanced, efficient, and of good appearance.

4. The different branches to be separated as far as possible to avoid interference one with the other and congestion on the ground.

5. The safety of all kinds of operation to be ensured.

6. The comfort, convenience and well-being of passengers, operating staff, and all using the aerodrome to be studied thoroughly.

7. The siting to be so arranged that principal buildings can be architecturally dealt with to present a dignified appearance, expressive of their purpose, on approaching the aerodrome either by air or by land.

8. Individual buildings to be planned so far as possible to permit of being partially built, extended or altered, with the minimum amount of disturbance or pulling down of what has already been done.

9. The buildings to be arranged as far as possible in groups of like character, to project as little as possible into the landing ground, and to be sited on the lee side of the aerodrome. The spread and height of building to be reduced to a minimum consistent with other requirements.

10. Due regard to be paid to fire risks in the disposal of the various buildings, particularly with inflammable stores.

11. Economy with efficiency, in the broadest sense of the phrase, to be an important consideration throughout."

As the scheduled passenger service industry and the demand better interface facilities grew, the airport terminal progressed from a barn-stormer's fence in a farmer's field to the current jet terminal. In the beginning there were the airplane, the public and a single office in a farmer's field. Then, to the offices were added towers and aprons. Aircraft technology accelerated traffic growth, then gates and terminal extensions developed in many forms: fingers, multi-fingers, satellites. Airbridges connected the jets to the terminal and the larger aircraft increased gate distances which people movers tried to shorten. It seems that airport development has been pushed by the advances of the airline/aircraft industry, however, the regulation of technical aspects related to airport design has not followed the technological advance at the same pace.

Airport terminals have internally developed and adapted to the needs of the aircraft themselves in accordance with both the technological enhancement of aeroplanes and their increased capacity. Indeed, Lewis-Dale (1932) stated that "it is nevertheless a fact that, year in and year out, both pilots and machines spend far more time on the ground than in the air, and it is this which makes the provision of conveniently-planned and well-organised aerodromes stand out as a vital factor in future aviation progress and efficiency."

It is possible to categorise the historical development of Airport Design into the following categories:

- *Airports for pilots (- 1920)* - Only a landing ground was the image of an airport of that time: a square area of land used for landing and take-off, where buildings were considered secondary utilities. It was a time for heroes, where flying was an adventure and the involvement between aircraft and pilots was human in scale. Airfields were built for pilots. There were very few airports.

- *Airports for aircraft (1920 - 1940)* - Aerodromes and airports were becoming the focal points of civic development. The consideration of the needs of passengers started to become a concern, although the airport terminal was still a lean-to on the hangar. However there was an increasing concern with the design and construction of aerodromes, the selection of sites, architectural considerations, requirements of a landing field, and other general issues on the whole subject of aerodrome planning and design.

- *Airports for passengers (1940 - 1960)* - This period included World War II when airports were still built for aircraft. However the civil aviation established firmly from the Chicago Convention in 1944 brought in a new era for aviation. The internationalism of air transport was endorsed to stay. The hangar lean-to was overtaken by fast passenger traffic growth, giving place to a separate terminal building. As aircraft also grew bigger, the segregation of passengers and aircraft was required and airport designers began to look at devices which would take passengers directly from the terminal building aboard the aircraft and vice-versa. Passenger comfort became a concern.

- *Airports for architects (1960 - 1975)* - At this stage the jet age came into existence and the terminals grew in size and complexity. The development of larger aircraft led to the creation of different terminal types. The inception and the idea of terminal concepts was in the architects' mind. At the beginning of this stage the preoccupation was with form and appearance rather than with functions, but concern for the level of service was gradually introduced and the concept became one of design following function.

- *Airports for environment (1975 - 1985)* - The growing concern with the environment added a new perspective in both aircraft and airport planning and design. The ICAO Annex 16, Environmental Protection, was adopted in 1971, concerned with the advance in aircraft technology and the consequent influence in the airport environment. Environmental issues are still an increasing concern to the air industry.

- *Airports for shopping (1985 -)* - After the US Deregulation Bill passed into law in 1978, and with privatisation on its way, the airport operators have gradually focused on the terminal buildings as commercial entities. Concessions have provided not only amenities and service to passengers but also the main source of revenue for many airports.

- *Airport for the future* -. It is likely that the airports of the next century will resemble very little of the list above. It will probably be a mixture of strong concerns in every field of human knowledge, where technology might dictate the passengers' behaviour.

The International Civil Aviation Organisation (ICAO) was created out of the Chicago Convention, in 1944, to assure and expand the internationalism of civil aviation, and to develop and refine technical standards and procedures. At the same time, another international organisation that played an important role in post-1944 environment became reality: International Air Transport Association (IATA). The provisional titles of the Chicago Convention Annexes show that airport design standards were not a issue:

A. Airways Systems
B. Communication Procedures and Systems
C. Rules of the Air
D. Air Traffic Control Practices
E. Standards Governing the Licensing of Operating and Mechanical Personnel
F. Log Book Requirements
G. Airworthness Requirements for Civil Aircraft Engaging in International Air Navigation
H. Aircraft Registration and Identification Marks
I. Meteorological Protection of International Aeronautics
J. Aeronautical Maps and Charts
K. Customs Procedures and Manifests
L. Search and Rescue, and Investigation of Accidents

The titles and contents of some annexes were changed later and new annexes were added. The Annex 14 - Aerodromes - for example, was first adopted in 1951. The Annex 16 - Environmental Protection - was then adopted in 1971, concerned with the advance in aircraft technology and the consequent influence in the airport environment.

International Civil Aviation Organisation (ICAO) and International Air Transport Association (IATA) became the two main organisations for the provision of standards and recommendations for airport planning and design.

1.3 Design Solutions

Quoting de Neufville (1980): "... In trying to understand how to design terminals, we should recognise the limitations on our ability to define the best solutions."

In the process of evaluating a proposed project the capital and operational costs, time schedule of expenditures and the financial structure seem to be vital aspects which affects the decision making in most kinds of development. This is particularly true for the field of air transport now that privatisation, meaning competition, plays a major role in a great number of airports. Capital has become hard to attain and expensive, especially for those parts of the system which have been publicly owned.

On the other hand investment in airport terminals does not always need to represent a potential investment for the owners/government with the aim of obtaining a return on that project. This is particularly true in countries where airports are still considered public utilities and many of them are cross subsidised to maintain their operation. A simple calculation to determine the return produced by a proposed project might not be so vital for decision making in such cases and a thorough evaluation of an airport terminal may require more than the determination of the rate of return under the basic set of economic and operating conditions to define the feasibility of such a project.

An analysis of the possible causes of failure of an airport development may indicate the more effective procedures needed to achieve a successful project. Lewis (1990) pointed out two fundamental types of failure in transportation systems that can be correlated to airport terminal design:

- *capacity failure* - when there is a gap between demand and supply, after a new facility is opened. As example the M25 orbital motor-way around London was opened in the mid 80s and found to be heavily loaded at its opening. The excessive gap generated by over capacity may be just as bad. A terminal operating at half of its capacity and no signs of traffic growth might be considered in this category.
- *general planning failure* - when the design fails to properly address social, economic, environmental and aesthetic opportunities.

The first type of failure is a result of the uncertainties associated with future events and the forecast deficiency to detect these contingencies. The second type of failure is concerned with the difficulty in analysing required goals, setting objectives, and finally deciding on specific criteria for achieving those objectives.

Thus, the lesson from the first type is to recognise that forecasting is fundamental for the planning process to be effective. It determines whereby decisions may be taken on the development of new or existing airports. The establishment of an hierarchic and rational decision-making algorithm may help to solve the second type, yet may not guarantee it. A general example of the algorithm is as follows [Adapted from Lockwood (1976)]:

❶ Recognition of the problem or problems to be faced;

❷ Collection of all pertinent data and information;

❸ Classification and evaluation in terms of importance and priority of the problem or problems calling attention and analysis of their causes, setting of the goal to be achieved from the conditions presented;

❹ Inventory of the available or required means to face the emerging problem or problems, analysis of the skills required for design planning, decision-making and development of the problem solution;

❺ List of alternative courses of action (decisions), definition of overall objectives to reach the required goal;

❻ Evaluation of alternatives in view of the means disposable and the magnitude, importance and priority of problems to be faced, setting and defining criteria which enable appropriate objective decisions to be taken;

❼ Decision, choice and approval of an optimal solution proposal and design and decision-making to reach the optimal solution;

❽ Implementation; and,

❾ Follow-up.

The magnitude and desired level of accuracy of a solution to be investigated is determined by the amount of information, nature, scale, and level at which planning may be carried out. Figure 1.1 shows the relationship between estimated accuracy (suggested for each level of planning) and the engineering man-hours expended in arriving at such an estimate. This provides a guide to the expected magnitude of the project.

The number of man-hours is dependent not only on the above factors but also on the experience, sophistication and structure of the organisation preparing the estimate and whether computerisation is used. IATA (1995), for example, suggested an additional 10% over the values calculated from each formulae listed, to compensate for the uncertainty of the input variables.

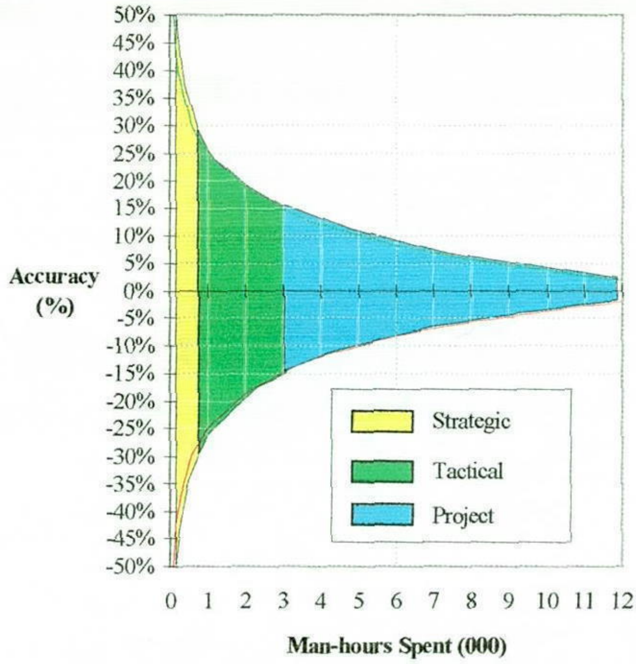


FIGURE 1.1: Man-hours Spent (000's) in Preparation of an Estimate
(Adapted from [Jones (1990)])

1.4 Passenger Distribution

From the 60's the practice in passenger terminal design has consisted largely of applying a fairly standard set of criteria to determine the space requirements of the various functions within the terminal. However, from the early 80's new approaches were introduced with regard to the concept of level of service. The process of design and capacity analysis has been the subject of increasing concern amongst the professionals in this area: Ashford, (1988); IATA & AACC (1990); Mumayiz (1985). Advances in the field of computer hardware and software have also allowed significant advance in the use of simulation procedures for use in passenger terminal evaluation, Pritsker (1986); NORR (1992).

The approaches for terminal analysis may be slightly different from country to country. The standard set of criteria may vary and some designers may evaluate a terminal based upon a single parameter or may even use simulation. However, the main point in terminal design has been the *provision of space* for the distinct passenger activities.

Generally speaking, not only *space* but also *form and order* are the components which have to be understood and analysed when evaluating terminal design. The determination of space, which is related with the standard set of criteria adopted, has been gradually changed from just a physical concept to a theory of social behaviour and personal space. The theory implies that space and social behaviour are identified with a particular group of people, thereby creating different space requirements for different cultures. The problem with the provision of space in terminal design is that, although detailed guidance for the design of each functional element of the terminal is available, there is relatively little attempt to assemble all such elements together.

Of course, form and order, i.e. the manner in which these spaces are arranged, generates formal characteristics, spatial relationships and contextual responses to the organisation of space. In terminal design these organisations are known as design concepts. There are a variety of concepts and a variety of combinations of concepts - configurations - available to the planner. Four basic concepts may be defined. These are *linear, pier, satellite and transporter*. These concepts are fundamentally different from each other and may be configured either exclusively or in a hybrid form.

In an airport development the main inputs to generate alternatives are usually constants, such as the forecast for traffic volumes (passengers/aircraft). The only change to these inputs may appear when different scenarios are considered. However, within each scenario, the alternatives are generated by a change in other factors rather than the inputs. The differentiating factor is generally form. Therefore the alternatives are mainly generated by varying this factor. The evaluation process originates with the selection of different configurations. The evaluation process in such cases has the purpose of permitting a decision to be taken on whether to choose one configuration/form or to decide which configuration/form is more advantageous.

The crux of the problem facing airport passenger terminal design is that the primary element to be defined is *form*. The experts agree that the terminal concept has to be determined at the first stage of the planning process. First, a rough approximation of the size must be determined and then a concept selected. However there is a lack of an accepted methodology in this area. There is no criteria which would allow the planner to determine the appropriate concept or combination of concepts in a given situation, both for current and future conditions. This work explores one approach to this problem of terminal concept by investigating the main factors with which may determine its choice.

An examination of different airports, for example Heathrow, Schiphol, Atlanta, Sao Paulo, indicates that configuration is not a simple matter to define, since most terminals have originally started as single form but have evolved to became hybrid types. However, what really differentiates one terminal concept from another seems to be their passenger distributions. Figure 1.2 suggests that the way passengers are distributed (in this case passenger distribution related to aircraft) is a characteristic of each terminal configuration. If all aircraft stands are occupied and all aircraft are departing simultaneously, the squares (red) represent the ultimate passenger arrangement. The same reasoning, if applied to the inside of a terminal building, would indicate for example that departure lounge layout is directly related to the passenger distribution within the terminal. This does not imply that the configuration is determined by its passenger distribution, on the contrary, the distribution is determined or is formed by the configuration which is adopted. However, the operational and cost efficiency of the system may well be attributed to the way passengers are distributed, i.e., changing the distribution by changing the configuration may produce a more efficient and plausible solution.

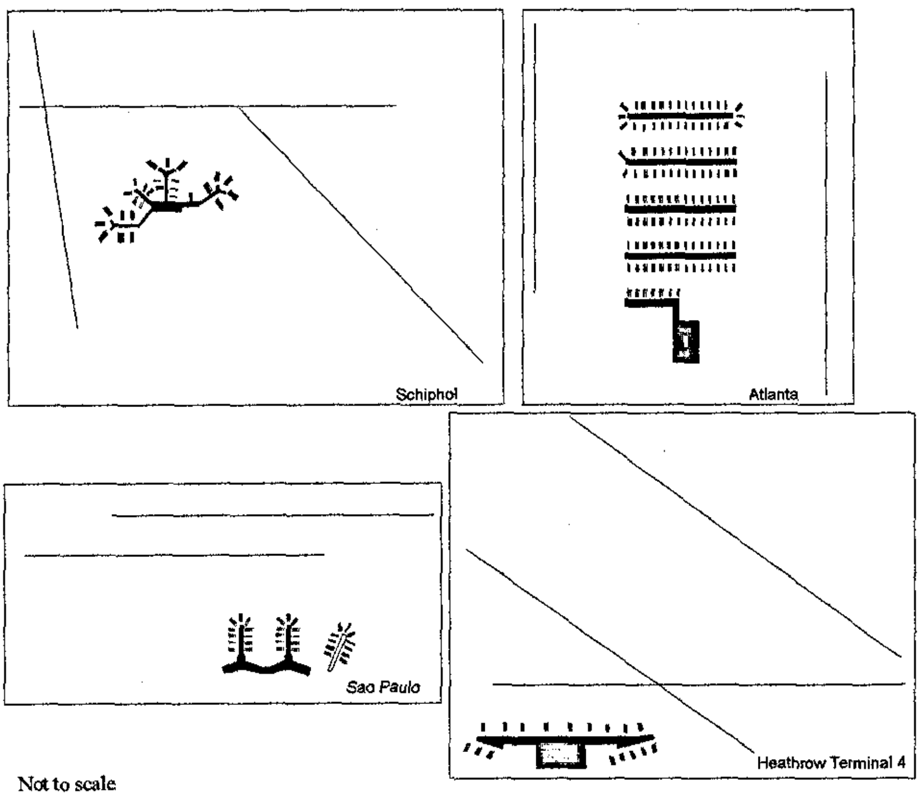


FIGURE 1.2: Examples of Passenger Distribution

Therefore it can be inferred that terminal forms are strongly interrelated with passenger distributions. The aim of this thesis is to discuss the procedures, and methodology needed to address issues involving different terminal configurations and to investigate the relationship between the most important variables and passenger distribution for the evaluation of terminal concepts.

1.5 Methodology

The process of airport sizing is fundamentally a matter of space provision or space definition, although the physical space is determined by operational conditions. The work conditions determine the form, quantity and necessity of space. Once that it is defined, the shape will certainly restrain and affect the operational conditions. The balance between demand and supply is represented by the most efficient use of the space used to provided to airline accommodation, commercial activities or passenger processing. Seasonally and daily variations of traffic volumes and respective standard requirements in the operational performance system are also important factors which must be taken into account.

The difficulty of gathering data in this area is an unquestionable reality. There is no uniformity in collecting it, i.e. each airport or airport organisation records information slightly differently from others. On one hand this occurs due to the necessity for a great amount of information to establish a correlation and also the great number of dependent variables in the system, on the other hand it adds to the lack of criteria in collecting and processing these data. This is true not only in the research field but also in the practice of executing any airport project. There will always be deficiency of data (lack of information, inadequate data collection or problem with data reliability). Even inside one airport organisation - Infraero for instance, the majority of its 62 airports have their own methods of collecting, processing and controlling their data, although a great deal of information is standardised as required by the enterprise headquarters.

After considering the available data a series of questionnaires was developed elaborated with the objective to evaluate and identify the main variables used in the design process.

Based on the difficulty in collecting data to evaluate the terminal spaces, coupled with the extensive number of variables, a different approach to analyse the airport terminal concepts was adopted. Instead of making an evaluation based on past experience and then attempting, through trial and error, to solve the problem using a heuristic approach, a different, though not new, strategy of analysis was seen to be necessary. A more theoretical methodology of research came into view:

namely, sizing fictitious or model terminals and submitting them to different model traffic volumes (passengers, aircraft and staff) to establish the functional balance and trade-off between the internal areas of the terminal.

The first step was the development of a tool that would enable the sizing of a terminal to allow flexibility and quickness in modifying the variables involved in the process (see Chapter 2). The results were obtained with a certain level of precision and twenty to thirty percent of variation was considered reasonable and acceptable at the beginning of the project, see Figure 1.1. This was materialised by implementing an expert system DSS "Decision Support System for Airport Design", which was the basis for the development of this new proposed methodology. Once the final results from the subject of this research were achieved, the methodology of space sizing was incorporated into the Expert System. The objective and methods in carrying out the DSS system are indicated in Chapter 3.

The first step in the Decision Support System for an Airport Planning project is to envisage a methodology or a powerful tool which allows the creation and analysis of distinct scenarios and different terminal types together, ending in a primary tool to help evaluate different terminal configurations.

Very little research evidence for the analysis of terminal concepts and configurations exists.. There is not even an agreed terminology that may be used to define the different airport terminal configurations, although there are many methodologies setting out procedures to verify project alternatives for airport terminals as a whole. Few studies link physical design (concepts), traffic characteristics (demand) and level of service (operation conditions) that would allow the definition of an approach to appraise terminal concepts. The only research evidence available was related to specific concepts which were viewed from single aspects, such as to consider the walking distances involved in processing a passenger within the terminal or just looking at a specific component of the terminal.

Three main concerns on project evaluation should be considered:

- *a technical analysis* involving physical design, shapes and geometry together with traffic characteristics;
- an *operational analysis* involving level of service and space standard conditions;
- an *economical analysis* considering the trade off between alternatives.

1.6 Objectives

The prime objectives of this research thesis were to:

- Identify the variables that may influence the choice of a specific terminal concept given certain particular characteristics of the boundary systems (exogenous factors) and internal relationships (endogenous factors). As a guideline, to try to adopt quantifiable variables rather than judgmental ones which may vary significantly from individual preferences. Theses variables should represent the corners of the main airport users: passengers, airlines and airport authorities;

- Analyse the aspects related to the form and geometry of the passenger terminal building for each one of the basic concepts;

- Establish assumptions over which variables should be used to evaluate the concepts and make sure that comparisons made are between similarly quantifiable concepts.

- Define the main differences between different concepts in terms of physical and operational conditions of individual facilities rather than simply point out the advantages and disadvantages of each concept.

- Derive comparison curves that may represent the relation between the variables adopted, e. g., capital costs versus passenger/aircraft throughput, see Fig 1.3.

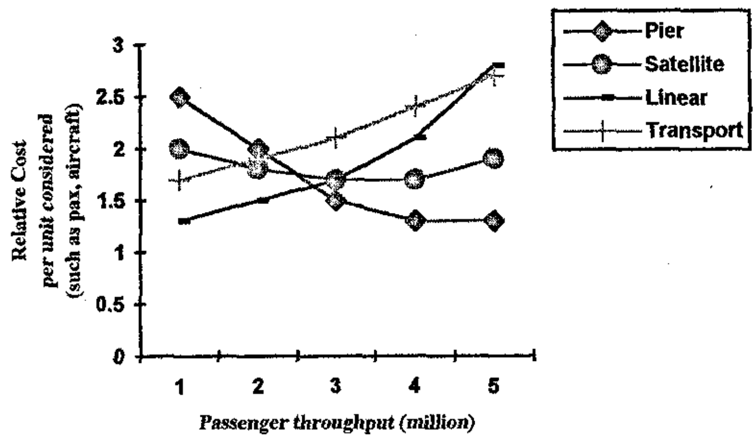


FIGURE 1.3: Example of evaluation procedure.

The methodology adopted to carry out this work was established in two stages. The first stage was to provide a tool to size and configure different types of terminals with a certain degree of approximation based on an expert system.

The second stage was the development of four distinct basic terminal concepts, combined with different scenarios and different passenger and aircraft demands (see Appendix D), to establish the relationship between a number of factors such as costs (capital & operational), flexibility and efficiency, and terminal configurations.

1.7 Organisation of Thesis

Having indicated the general aim of the thesis, the following chapters, from 2 to 5, will explore the field to establish the basis for the formulation of the framework suggested in Chapter 7. While Chapter 3 specifically describes the development of a tool for the design of airport terminals that was used for the design of 144 different terminals from scratch, comprising the basic types discribed in Chapter 4, Chapter 6 shows the outcomes of a parametric analysis carried out with these terminals, where *Shape, Size & Dimensions*; *Single Level or Multi-level* Terminals, *Centralised or Decentralised* passenger flows; *Circulation* spaces; *Walking Distances* and *Aircraft Characteristics* are identified and discussed as the main variables that should be considered in the choice process of a terminal configuration.

Chapter 2 (see also Appendix A) presents an introductory discussion of airport sizing methodology and describes the main steps adopted for conventional terminal planning. The discussion of each step is not limited to the information gathered from the literature review but also includes research and data analysis of many issues in the subject. Terminals whose facilities are not adequate at a specific airport, will most certainly pursue changes in their operation or exert influence and political pressure to develop their installations, therefore a thorough evaluation procedure for space provision and space management for airport terminal is also suggested.

In Chapter 3 a Decision Support System as a tool for airport design is presented. The decision or choice over the developments or expansions of facilities, in many countries dependent upon public investment, relies on professionals and their advice, which must be well constituted to be reliable. These professionals have to assess efficiency and factual performance of the airport facilities and, to be able to do that, they require a clear and definite methodology. Professionals are always looking at tools or methods that they can rely on and use as instruments for their work, yet, the attempt to elaborate a new methodology will not always guarantee, during the process of planning, an absolute, positive and assured result. Although the DSS in its final version has these objectives, the specific focus of Chapter 3 is on the provision of a tool for terminal sizing. This gives great flexibility for the design of a number of new passenger terminal buildings with four basic geometric forms, under different traffic loads, which will form the grounds for concept analysis.

In Chapter 4, the concept of different basic terminal types as it applies to airport design is identified and reviewed. Essentially in terminal design there are no formal procedures that will give the designer a unique direction and guidance to follow. However, Chapter 4 discusses these variables not only in terms of advantages and disadvantages, but also presents the conventional methods used generically for terminal evaluation and provides an empirical approach for terminal concept choice.

Chapter 5 focuses on terminal sizing. There are a number of empirical procedures and isolated criteria, such as the distance walked by passengers, the queue formed along the check-in,, that are used for sizing specific facilities, but it is far from forming a general method for airport terminal design. Despite having general rules established by international organisations, such as ICAO and IATA which give guidelines in the process of planning, the unique methodology that allow sizing the terminal (as a whole), is stated by Ashford (1992). In reality, airports are planned and sized by administrative organisations that are somehow linked to airports or by a few independent consultants. A complete lack of methodology in this area leads to an adoption of criteria that are unique to individual organisations. BAA and Aeroports de Paris are examples of that, having their own standards and direction for projects which is rather a complement than a discordance of the international standards recommended by these international organisations. This chapter emphasises the importance in the relationship between size and space. Space is viewed as the outcome from the design process and therefore deserves special consideration. A general discussion of each terminal facility is presented. The issue of space provision, addressing methods and procedures for terminal design, description of terminal design tools and current design technique for each of the main facilities is presented.

In Chapter 6, the parameters and attributes that should be considered in the terminal concept choice are identified and discussed in detail.

In Chapter 7, an attempt to develop a framework for the evaluation of a terminal concept is discussed. The way passengers are distributed within the terminal, their main routes and the respective aircraft stand allocation are closely interrelated. This interrelation is analysed in terms of a single relationship that encompasses the pertinent design factors discussed in Chapter 6. Moment of Transport is introduced and explained as the basis for the terminal concept evaluation. The moments are generated for each basic concept and analysed with respect to each factor.

Chapter 8 is a summary of the main findings related to the research work. A sensitivity analysis of individual facility sizes denote their influence upon the whole terminal. Some recommendations for future research are also included.

2. CHAPTER II The Airport Terminal Design Process

2.1 Introduction

There can always be a better solution for an old problem. The methods used in the past can be reviewed and improved. New methods can be introduced. Although, the study of history or past experiences can be either boring for someone and fascinating for others, there is always a singular opportunity to learn from others experiences. No one can allege that a particular problem or practice cannot be improved. This is true in any area of the physical and human sciences. Therefore it is factual in transportation systems. The evaluation of transportation systems is strongly related to human behaviour, social and political considerations, data manipulation, and decision making which involves also a human process amongst other things. This issue leads us necessarily to the point where it is essential to have the capability to accept the problems arising, learn from them and try new approaches to solve such problems *autonomously*.

Observing the past one can realise that the practice of planning and designing airport terminal buildings and related facilities is one problem which has not progressed at the same pace as technology and other advances made by the air transportation industry in general. The Concepts and methodology are almost the same as in the last two or three decades. There is a gap between the design and the operation phases. While the first preoccupation was with the buildings and attractive symmetries in the plan-views rather than their functionality, the operation of such terminals has been developed in many ways that are different from the primary intention of the designer. The lack of people who have participated at an early stage of designing and construction phases being involved in the operation of the terminal may enhance this issue. The gist of it is that planning and designing airports are complex matters involving distinct areas of human knowledge, consequently the need for procedures and techniques for resolving problems in this sphere is apparent. No matter whether the method for problem resolution is procedural, algorithmic or heuristic, it is necessary to understand the systems and to define problems relating to those systems first.

2.2 The System Approach to design

Most methodologies in airport design are concerned with models. The idea of using a mathematical model to describe the behaviour of a physical phenomenon is well established. The modelling process in transportation is a method of providing descriptions, design and analysis of systems. To consider the scope of a system two elements are important: its content and its boundaries. The contents - endogenous factors - are intrinsic to each internal element or sub-system. Boundaries - exogenous factors - are, and may be treated as, inputs to the system.

In this context, airports have been progressively considered as systems. However, whereas a system is a relative entity, an airport can only be a small part of a larger air transport system. It is primarily a sub-system. When it is the primary focus of interest it can also be considered as a system in itself. The contents of one system may be the boundaries of other systems, i.e. each subsystem can be analysed as a system. Depending on the scale, national, regional or local different planning levels can be established to carried out encircled and rather hierarchical systems, see Figure 2.1.

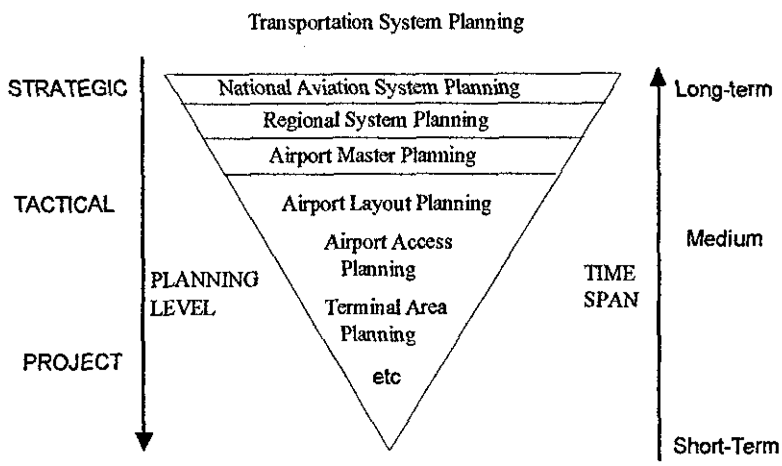


FIGURE 2.1: Airport Planning Process Levels related to time.

Planning can be understood as the decision process developed in relationship with an action that comprises a system of decision in an envisaged future situation. As a function of time and its magnitude three planning levels can be identified [Ashford, 1992]:

- *Strategic planning*, comprises a rather broad analysis to identify long term transportation needs, set up goals and objectives, establish policies and priorities, postulate scenarios and evaluate them, and select strategies for the subsequent planning levels. The strategies for planning indicate what can be done, subordinated to what has to be done in consonance with the goals and objectives and its temporal aspect. The decision to expand or build a new airport for instance is determined at this stage.
- *Tactical planning*, constitutes a more objective short and medium-term analyses by establishing best and proper courses of action for the attainment of the strategic plan goals and objectives. The 'tactics' indicates what will be done, subordinated to what can be done according to items established in the strategies. For instance, site selection (select preferred option) for a new airport may be treated at this level.
- *Project planning*, narrows the evaluation to a selected component established in the tactical plan in terms of a more detailed design. The project planning level indicates how the tactics will be executed. It implies definition, specification and succession of action in a period of time. An example of this level of planning is the preparation and execution of drawings for terminal buildings, runways and taxiways, etc.

Airports have also been divided into subsystems named landside and airside. The landside consists mainly of the passenger/cargo terminal buildings, apron, access roads, and parking. The airside consists of runways, taxiways, and aprons. Although these are usual terms among airport and aviation professionals, small variations in meaning may be common..

It is important to point out that a passenger terminal is a subsystem of the airport landside that is evaluated at the project planning level. Therefore it is influenced by and affects the other systems. It may be considered as the interface element between the landside and airside; they mutually interact to form the airport system. Although any complete evaluation must consider the airport system as a whole, starting usually from the top of the triangle in Figure 2.1, the passenger terminal will be viewed as the system itself, and the other systems - access, taxiways, runways, the exogenous elements - will be treated as generating the inputs to the passenger terminal. It is assumed that each component external to the terminal is in balance within the airport as a whole, therefore their study is not part of the scope of this paper. For example, the runway, taxiways system, notwithstanding being part of the airport system, is presumed to cope with the terminal requirements in terms of capacity and equilibrium. Capacity refers to the airport's capability to accommodate the demands of passengers, visitors, ground access vehicles, and parked or parking aircraft.

2.3 Traffic impact

History shows that many problems face airport planners. In the past two decades the traffic has doubled and there is a prediction that the demand will again double by the year 2005 - 2010 [Boeing, 1995]. This has seriously congested many existing passenger terminals at airports around the world. The most critical issue appears to be that of the provision of increased capacity to meet growing traffic. It seems that congestion, capacity versus demand, and delays, all related to landside constraints are a new problem in the transport industry, yet it is an old challenge that has been tackled since the mid 70's [Gosling, 1979; TRB, 1987; et al]. As the environmental issues increase it is also likely that the provision of additional capacity will converge on airport terminals rather than the expansion of runways, which may imply site enlargement and land acquirement. This is, of course, an increasingly difficult problem in developed, urbanised regions. One example is the construction of the fifth terminal in London Heathrow Airport that is being considered already and is likely to become a reality in a matter of time.

Terminal problems are becoming increasingly complex, but the solution is critical to the continued operation and expansion at many airports. This concern will emerge particularly in the concept of passenger terminals, which has already evolved considerably in the course of its brief history. In this matter there is no agreed methodology available at the initial planning level for the selection of terminal concepts for design. It is therefore relevant to examine the current methods of passenger terminal planning and design.

2.4 Current Methods in Terminal Design

The approaches for the design of airport terminals can be grouped in several ways [Mumayiz, 1985]: statistical analysis, economics-oriented, theoretical-mathematical, system and multi-discipline approaches. Diverse grouping for the design of airport terminals can basically be arranged into four distinct categories: deterministic, stochastic, heuristic and simulation methods. However, these methods all have shortcomings and there are several aspects that they individually do not address, even though they may be combined in some analyses.

Deterministic method

Although the variables involved are random quantities and the stochastic nature of the input parameters have to be considered, many facilities requirements are usually determined using deterministic methods; assuming that the functional relationships are known with certainty. These are analytical models based on formulae and concentrate on a single aspect of an airport terminal, such as departure lounges, or the walking distance of passengers in a terminal. Time variation is accounted for in most of the cases empirically by space factors based upon research from areas as diverse as psychology, human behaviour (perception of comfort), and is used to create a fairly standard set of criteria to determine the space requirements of the various functions within the terminal. Stochasticity, however, to some extent is ignored. For example, departure lounge space can basically be calculated by multiplying the number of passengers carried on the largest aircraft serving the departure gate, together with constants for the amount of space per passenger required for those standing and those seating. Another example is the gate requirement that is usually determined using deterministic methods [Hart, 1985]. The IATA terminal design program is a classic example, which sizes facilities based on the value provided by the designer for use in a number of direct equations. The IATA [IATA, 1991] program does not attempt to tie these equations together for each facility. The basic variables such as number of passengers can be altered without affecting other facility calculations. Each calculation is thus performed autonomously.

Probabilistic method

In this approach, the probabilistic aspects of demand and service rates are both taken into consideration; the uncertainty is incorporated. The method is based on steady-state queuing analysis Within the random fluctuations described by probabilistic processes or statistical functions, the average demand and service rates remain constant, at any time, during a certain period. A simple example of the queuing model is the check-in facility in a terminal. This method strives to incorporate the passenger's unpredictable behaviour using distributions rather than averages to analyse a facility.

Heuristic method

Heuristic methods are based around observed and practical data, gathered and analysed from actual circumstances, aiming to formulate the variables to duplicate the conditions observed in a given pattern, and to produce a good approximation instead of an exact prescriptive algorithm or mathematical formulation, which may be so complex that an analytical solution is nearly impossible. A heuristic solution relies on empirical rules leading to a preferred or refined solution by comparison with a previous one, it does not claim optimality for the indicated preference. The heuristic process provides, through the use of rules of thumb or another common-sense approach, a good approximate solution to a problem, but not necessarily the best solution. Heuristic methods involve trial-and-error procedures that try to move from one solution stage to another in such a manner as to improve the results with each successive move. An example of this process is the Ralph Parsons Report (FAA, 1976a) which can give sizes for various facilities in a terminal. The method is based on Equivalent Aircraft which represents the average number of passenger for a given mix of aircraft and was carried out in the mid 70's. All graphs and tables are purely empirical, and are inferred from data based on the USA experience in sizing airport terminals.

Simulation method

Simulation models have developed alongside the improvement in computer technology. In this sense computer simulation has been defined as the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer.

The crucial point in building a simulation model for the design of an airport terminal building is that it is a very complex technological system, and therefore difficult to model. For this same reason, simulation may potentially be the best method to evaluate the system, therefore many designers, researchers and consultants have developed simulation models for the movement and processing activities of passengers within airport terminal buildings over the last 30 years. Although the airport system may not be complex in itself, some factors that may account for this complexity were suggested by Eilon and Mathewson, (1973):

1) *The random pattern of traffic* (arrival and departure) aggravated by a superimposed randomness on the schedules due to delays (operational, engineering, etc..).
2) *Passenger characteristics*, as they have different needs and behaviour.
3) Conflict for resources (e.g. space) due to the *interaction between functions in the building*.

4) Rigid demand on some parts of the building due to *complex operating procedures* based on statutory requirements.

5) *Conflicting objectives* amongst the main actors that use the airport: passengers & visitors, airlines, airport authority and other bodies (Immigration, Customs, etc.); in view of the fact that all have their own objectives and criteria by which they judge operational performance at the airport. Lerner (1990, 1992) has tackled this problem suggesting that the solution would be a simulation framework to yield measure of value to decision makers.

Simulation programmes are applied to model the behaviour of proposed solutions and are generally used in the evaluation stage of the design process. This implies that first there must be a proposed design before the simulation can be applied. We usually design for a foreseeable future. Many of the variables and parameters are not known with certainty, and confers simulation models with a stochastic rather than a deterministic nature.

Optimisation is not the objective of a simulation model. Although a 'search mechanism' can be included in a model to provide an 'near-optimal solution', any optimisation that takes place must be done by the user varying the system parameters to obtain different sets of operating characteristics.

A number of different modelling approaches and uses can be adopted [Low, 1974]. There are basically three steps to building a model for an airport terminal building:

- Definition,
- Model formulation,
- Validation.

Definition, involves a number of activities which will establish the bases for the model. Terminal layout, data collection and input variables, system boundaries and the interrelationships between components of the system are the main features in this step.

Formulation is concerned with constructing the simulation model. At this point three alternatives are available:

a) a software package that has already been developed for this purpose, such as NAPA, by NORR, (1992); STEP - Transport Canada (1986); ALSIM [McCabe, 1982], by FAA, ARCTERM, (1994) by Aviation Research Corporation (Canada). etc.

b) Develop a general-purpose simulation computer programme using a simulation language such as GPSS [Schriber, 1974], SIMSCRIPT [Markowitz, 1963], SLAM [Pritsker, 1986] GERT [Pritsker, 1977], which provide timing mechanism and embodies many other features that greatly simplify simulation modelling. Furthermore, the use of a simulation language allows one to concentrate on the structure of the simulation rather than on aspects of programming.

c) Employ a general-purpose programming language such as FORTRAN, PASCAL, C++ to develop the simulation modelling from scratch. A great deal of programming effort is required for this alternative.

The choice is basically dictated by time and cost. As new technologies are introduced, new and faster computers, new special-purpose simulation languages and even new packages on the market, all indicate that simulation will become more widely employed and more widely available.

Validation is concerned with ensuring that the model adequately simulates the actual (real world) airport terminal system. The validation, widely agreed to be the most important step of any computer simulation model, is however the most difficult problem to solve. According to Dunlay Jnr. (1981) two fundamental checks should be included: the internal logic of the model and the validity of the assumptions (with inputs and outputs); and a comparison of model output with the corresponding actual data. Brant (1974) stated that "the measure of success of a simulation is the extent to which the real world events are duplicated".

It is actually the model of a system-in-use that should be evaluated rather than a new or theoretical airport, since that would be easier to validate and show how well the model fits observable data. Then the model can predict the behaviour of the actual airport in the future if correct assumptions are made. From this it is possible to infer that infer that simulation models can be a more powerful tool for the planning and management of operations or to define the need for expansion of an airport, than for the design of a new airport from scratch.

2.5 Main Steps in conventional terminal design

The above theoretical explanation of the planning and design process of an airport terminal building is rather academic, describing the intrinsic methods that one may use in the design process but it does not really lead to a grasp of the actual steps which one may adopt to design a terminal. On the other hand, an overview of the traditional approaches, carried out in Appendix A, gives the basis to outline the main conventional steps which are described in the following paragraphs.

Passenger terminals at airports are buildings constructed for people. They are a shelter to protect them and the services they receive. The terminal provides space and facilities where passengers and other airport users are processed, wait, spend time voluntarily, and work. The terminal integrates surface and air transport.

The first element involved in this process is people. This may be viewed either as a straight forward physical relation with space or a more complex human behavioural relation when subjective factors such as psychological and emotional characteristics are included. Expressions like 'over-design', 'congestion', 'crowdedness', 'delays', 'aesthetic', 'level of service'. are inherent when people are related to the space provided.

The second element involved in terminal design is space. Space may be viewed in its simple planar relation such as a square meter or account for its spatial properties including ambiental characteristics: thermal, acoustic, aesthetic and visual.

Therefore it can be inferred that the most rudimentary thought in the designing process is that of providing space for people. Implicit in the design process is the provision of equipment (furniture, machinery, etc.) which determines the appropriate use of the space. Although there are a multiplicity of factors involved in the relationship between these elements: space and people; the general principle must be to allocate space in proportion to the number of persons who are simultaneously in any particular place in the terminal. The logical steps for laying out a terminal can be outlined as follows:

1) Determination of the type and number of terminal users,
2) Definition of the space required by those users,
3) Specification of the relationship between users and space,
4) Determination of the required space, and
5) Configuration of space.

In reality this is more or less a standard process for the design of passenger terminals at airports in almost all the literature reviewed (see Appendix A).

2.5.1 Determination of type and number of users.

When any kind of transportation mode is being evaluated for design purposes there is a tendency to consider the concept of 'passengers' rather than users. The users can usually be divided into three groups [Horonjeff, 1984; Ashford, 1992]: passengers, visitors & greeters, and workers. The last two groups may be derived from the first, usually in terms of proportion or ratio. Passengers, on the other hand, can be sub-grouped according to trip purpose, flight type, trip type, and access mode [Ashford, 1992]. This distinction is an important issue when considering individual elements of a terminal. For instance, many facilities are applicable only to departing passengers (check-in) or only to arriving passengers (baggage claim) or to international passengers (immigration, customs) or even common use (toilets). On the other hand traffic may grow at different rates or may also happen differentially for distinct categories of passengers even where they use exactly the same facilities. Figure 2.2 shows an example of this breakdown.

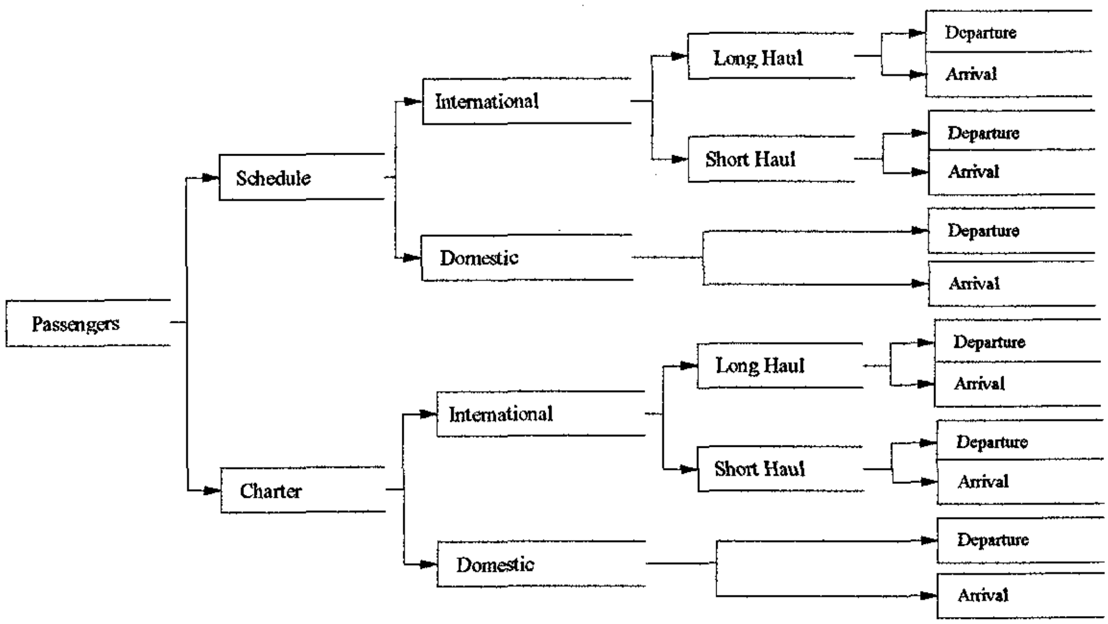


FIGURE 2.2: Example of Passenger Traffic split.

The number of users is always counted per unit of time, annually or monthly or daily or per hour. The knowledge of demand per unit time is important for the estimation of specific parameters. For example, estimation of potential revenues can be calculated using annual passenger movement figures; and the number of gates can be calculated using design hour volume for arrivals and departures. The most widely used design unit parameter is Peak Hour.

Forecasting

The forecasting process used or forecasting itself is debatable. It is both the most essential and the weakest point in transportation. Firstly, because it is the basic input to any process of planning and design. According to Wiley (1986) "forecasts are the origin and heart of the planning process". Furthermore, because forecasts are always inaccurate. There is still no magic crystal for predicting the future. It will always be a guess, no matter which methodology is used or the amount of information available. One process may be more or less accurate than another, however the results are uncertain. The number of assumptions that have to be made is per se a weaknesses in this process when forecasting for ten or fifteen years hence. It is sufficient just to have a look at any retrospective analysis comparing forecasts to what actually occurred in order to realise how different from reality they are.

This should not suggest, however, that forecasting is not an acceptable practice or whether forecasting models are useful or not. Exactly the contrary, the challenge of the forecaster is to improve the available estimating methods so as to minimise error. The choice of the appropriate forecasting technique and the preparation of forecasts are most essential prerequisites.

In reality failure in current airport terminal design is largely due to a combination of two main factors: forecast and project criteria. The designers used the wrong criteria, though the forecasts were accurate, or the designers have used no criteria, or the designers have used the correct criteria but the forecasts were far from reality.

Despite all the uncertainty the future might bring, forecasting of traffic levels has been the instrument that has provided the basis for the actual design for airport terminal buildings.

The challenge for planners is to provide a terminal layout that is flexible enough to be adapted as the circumstances change or become different from what was originally envisaged and to adopt the correct forecasting methodology taking into account the available resources and the desirable level of accuracy. The estimation of probable future peak-hour volume is a complex task and involves much uncertainty, but it is still essential to transportation planning.

Taneja (1979) states that the methods of forecasting can be divided into three broad categories:

Quantitative method comprises:

Time-Series Analysis - Ratio Analysis, Trend Projection, Moving Averages, Spectral Analysis, Adaptive Filtering, Box-Jenkins;

Causal Methods - Regression, Econometric, Simulation, Bayesian, Spatial Equilibrium.

Qualitative is divided in:

Judgement
Delphi
Technological

Decision Analysis is expanded to:

Market Research
System Dynamics
Heuristic
Probabilistic

Ashford (1992) states that the conventional methods of forecasting include Judgement, Survey of Expectation (Delphi analysis), Trend Forecasting, and Base Forecasts on Ratios of National Forecasts. The modelling procedure of these methods can be further divided into four consecutive steps: generation → distribution→ modal split, and →assignment, each one generating distinct models.

The methodology can be very complex in mathematical and computational terms. The controlling factor however is not one of mathematical technique but of predicting how the industry will react to change in the light of different constraints. Any methodology must recognise this fact and be able to handle it. As the model becomes more sophisticated, the accountability and the understanding of the process may improve. However, data requirements, complexity of the computation, insight of what is happening in the process of forecasting and number of parameters required to forecast may make the process worse. In addition to this, there is certainly no guarantee that with a more sophisticated model the accuracy of forecasts will increase. The probable differences in the outcomes in these methods of forecasting are due mainly to the forecast values of the input variables rather than the methods themselves.

Despite all possible difficulties, forecasting is still the starting point in the planning process. The success of a project is certainly rooted in an accurate forecast.

Peak Hour

Problems of 'Peak Hour' or peak time are a very common phenomenon in many fields such as hydrology, electricity supply, telecommunications, transportation. It is one of the most significant measures to establish as a criterion in facility planning and design. Although subject to criticism, the conversion of traffic forecast (annual volumes) into peak-hour forecasts is an important aspect of airport transportation planning studies.

The FAA uses the TPHP (Typical Peak Hour Passenger), where the recommended relationships are adopted as a percentage of annual flows and are an estimate of a figure that may be exceeded for only very short periods. The FAA tries to reflect the peak hour of the average day of the peak month. An airport may have peak hour operations as high as 12% to 20% of daily total operations. If passengers could be evenly distributed over 16 hours of the day, theoretically there would be an absolute low of 6.25% of the daily total operations.

European countries use a similar approach based on the concept of the standard highway engineering practice of designing for the thirtieth highest hour.

The Standard Busy Rate (SBR), which allows the passenger volume to be overloaded for a limited number of hours of operation is one measure that is used. Schiphol Airport in Amsterdam uses the twentieth highest hour, while Aeroports de Paris prefers the fortieth highest hour. The British Airports Authority (BAA) adopted the thirtieth highest hour for some years and then adopted the 5 percent Busy Hour Rate (BHR), a modification of the SBR, which means that only 5 percent of the passenger volume may exceed physical and operational capacity. The reason for BAA's use of the BHR measure was that it adapts well with service standards and varies proportionally to the size of the airport, as the SBR is found to give an incorrect measure for smaller airports. Figures 2.3 to 2.7 show these relationships graphically.

Ashford, 1984 describes other methods such as Busiest Timetable Hour (BTH) and Peak Profile Hour (PPH). Busiest Timetable Hour uses existing or projected timetables in conjunction with average load factors to calculate the peak hour. The method is not accurate. The Peak Profile Hour (PPH) is the largest hourly value computed from the average hourly volume in the average peak day. This value is very close to the Busy Hour Rate, as Fig. 2.3 shows. The Port of Authority of New York used a different relationship for peak hour based on an estimate coefficient indexes applied to annual passengers , average monthly flow, average daily flow and peak daily flow [Johnson, 1974]. The results are shown in Fig 2.3.

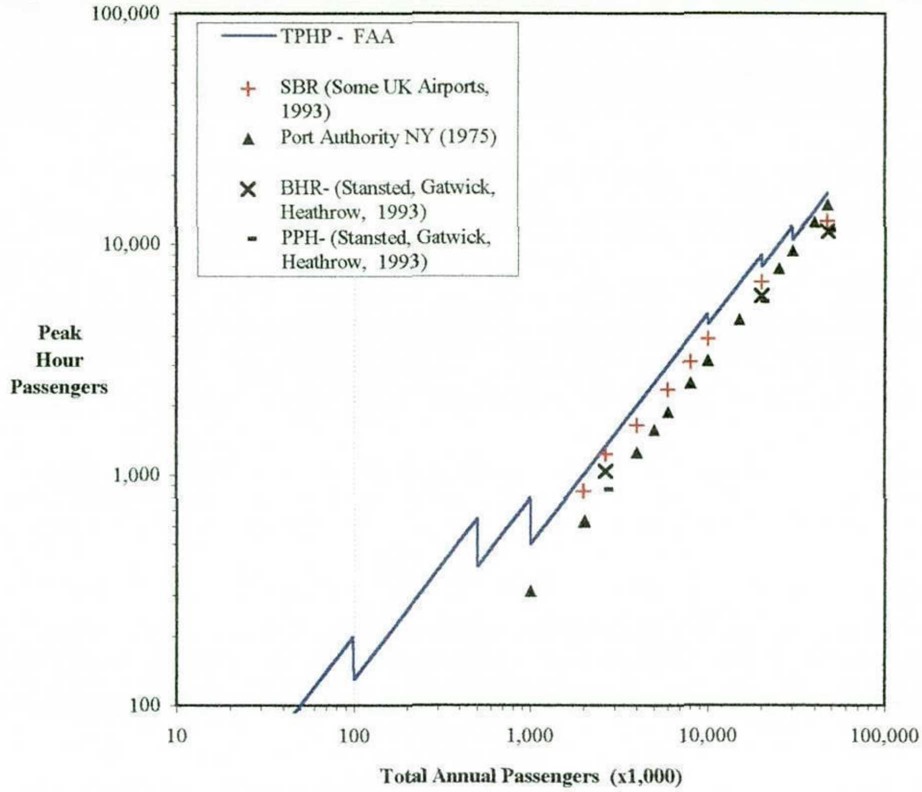


FIGURE 2.3: Relationship between Peak Hour and Annual Volumes.
Typical Peak Hour Passengers (TPHP)-, Standard Busy Rate (SBR), Busy Hour Rate (BHR), Peak Profile Hour (PPH) and Port Authority of New York method. (Source FAA, BAA and [Johnson, 1974])

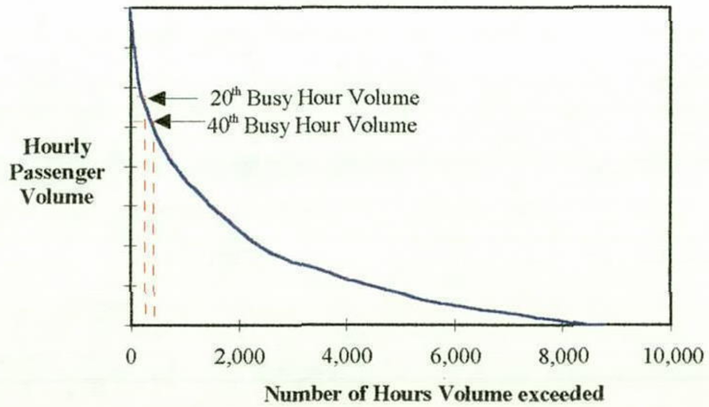


FIGURE 2.4 - Standard Busy Rate (SBR)

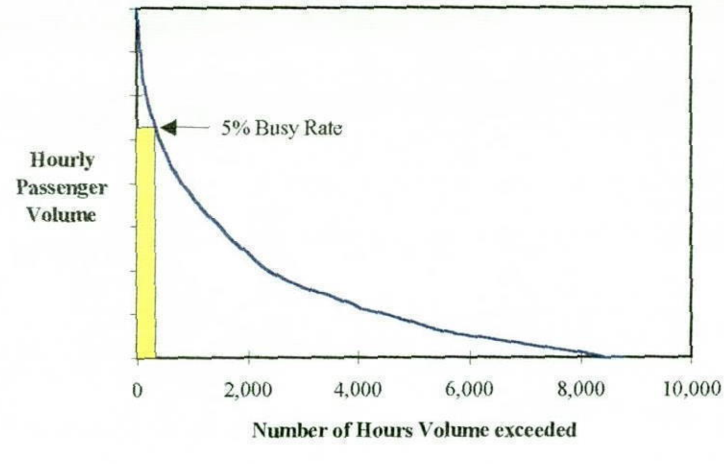


FIGURE 2.5: Busy Hour Rate (BHR)

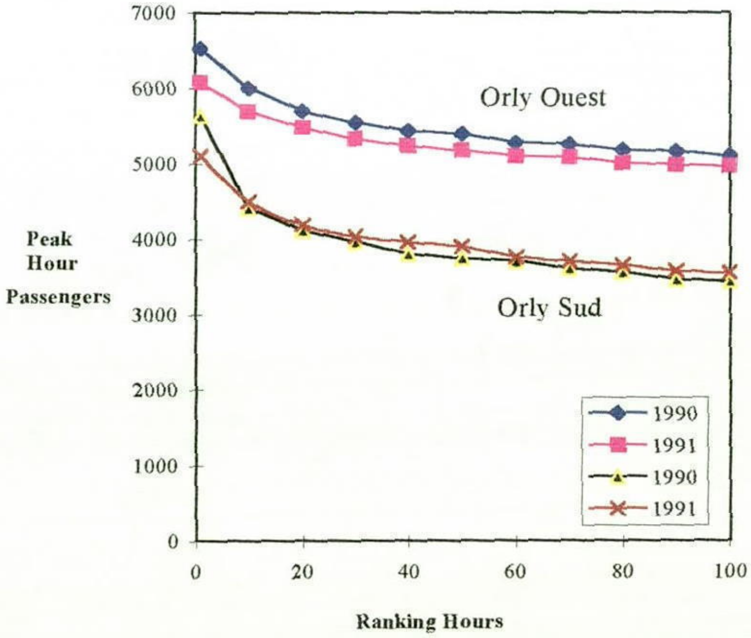


FIGURE 2.6: - Standard Busy Rate (SBR) 40th peak-hour.
The 100 hours Peak Passengers at Orly Ouest and Orly Sud - Paris, 1990 - 1991
(Source: ADP - Aeroports de Paris)

The importance of the peak hour approach cannot be overemphasised, but the opposite is also true. The criticism of the use 'Peak Hour' is that may not represent the actual passenger flow through at certain facilities. It is also recommended that the planner should be judicious in the use of peak traffic volumes. de Neufville (1980) goes beyond this in pointing out that the most common mistake is to use the peak hour passengers for the design day as the number of simultaneous occupants in a facility. It is actually the amount of time spent in a particular area (termed dwell time) that is the determinant factor for sizing a facility rather than the absolute peak hour. Infrastructure needs are usually based on peak demand, thus creating a need to study peaking patterns throughout the terminal.

Peak-Hour and Annual Flows

To compute peak hour volumes is not difficult as they are usually extracted or converted from estimates of aggregate traffic volumes (annual total) for the "design year" for which a new expanded or modified terminal is being designed. It is difficult to produce bases and extrapolate empirical ratios of these estimates to annual traffic figures as it is necessary to understand the quantitative relationships between various measures. There must also be an accurate peak hour forecast. Annual volumes are satisfactory for long-range planning, since the ultimate objective is the provision of facilities. For short range planning, however, peak-hour volumes are essential as an input to terminal design.

Airports collect and record data with regard to monthly, daily and hourly passenger and aircraft peaks. Although these peaks are interrelated, the absolute peak hour will not necessarily occur in the peak day of the peak month. However, the focus should not be on absolute peak-hours. That is the reason why planners try to find the best measure for peaks. These peaks are often computed as a ratio to the average day or to the average month or a coefficient converted from annual volumes as mentioned above.

To understand these peak relationships assume that the traffic volumes are uniformly distributed along the months of the year, days of the months and hours of the day and compute the peaks. The result is the minimum values for the peaks and the average values. Thus, the minimum monthly peak is 8.33% of the annual total, or the ratio of peak to the average month equals 1. An operation of 12 months, 30 days per month and 12 hours per day has a minimum peak hour of 0.023% of the annual flow, which is represented graphically in Figure 2.7. As the monthly peak increases with regard to concentration of traffic in one month or lack of operation in some months the peak hour coefficient as a percentage of monthly movement also increases.

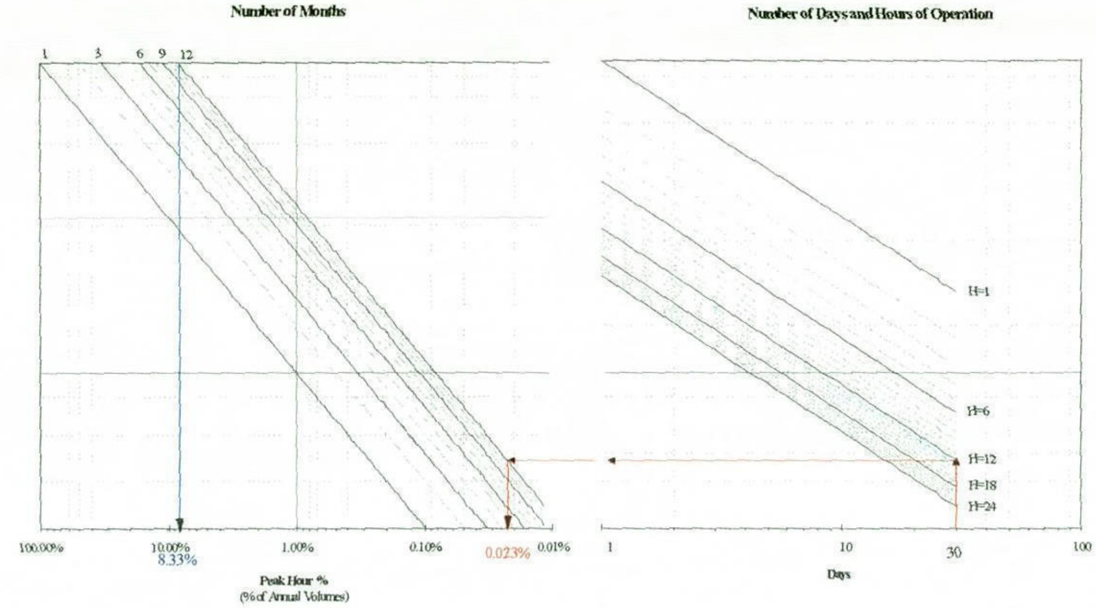


FIGURE 2.7: Relationship between the effective period of operation and Peak Hour as a percentage of the Annual volume.

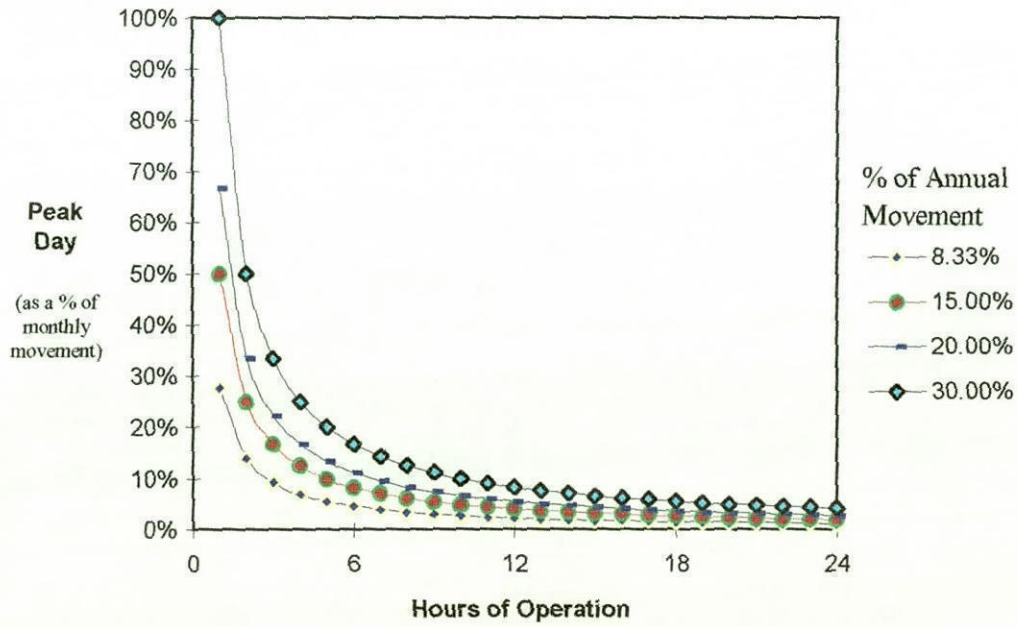


FIGURE 2.8: Peak Day as a % of monthly volumes considering number of hours of operation per day.

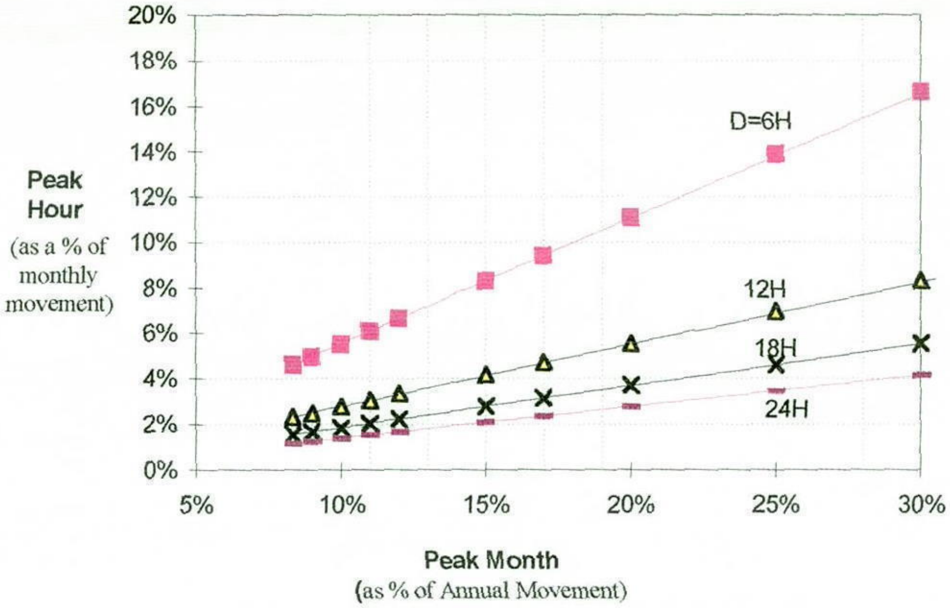


FIGURE 2.9: Minimum Peak Hour as a function of Peak Month and hours of operation.

This explains mathematically the tendency of the peak hour to decrease as traffic grows and distribution over the unit of time is considered. Again it is easy to reach this conclusion from Figures 2.8 and 2.9.

It is apparent that the peakiness characteristics in transportation problems, and many other areas of human activity, are due to changes in the patterns of the variable under study.

Traffic Variations

Traffic variation is caused by: Seasonal variation, International and Domestic passengers, long haul and short haul, arrival and departure, transfer passengers, business and leisure passengers, scheduled and charter flights, aircraft punctuality, unexpected events, and airport location. Peak hour movement generally follows the variation of the traffic movement as indicated in Figure 2.10.

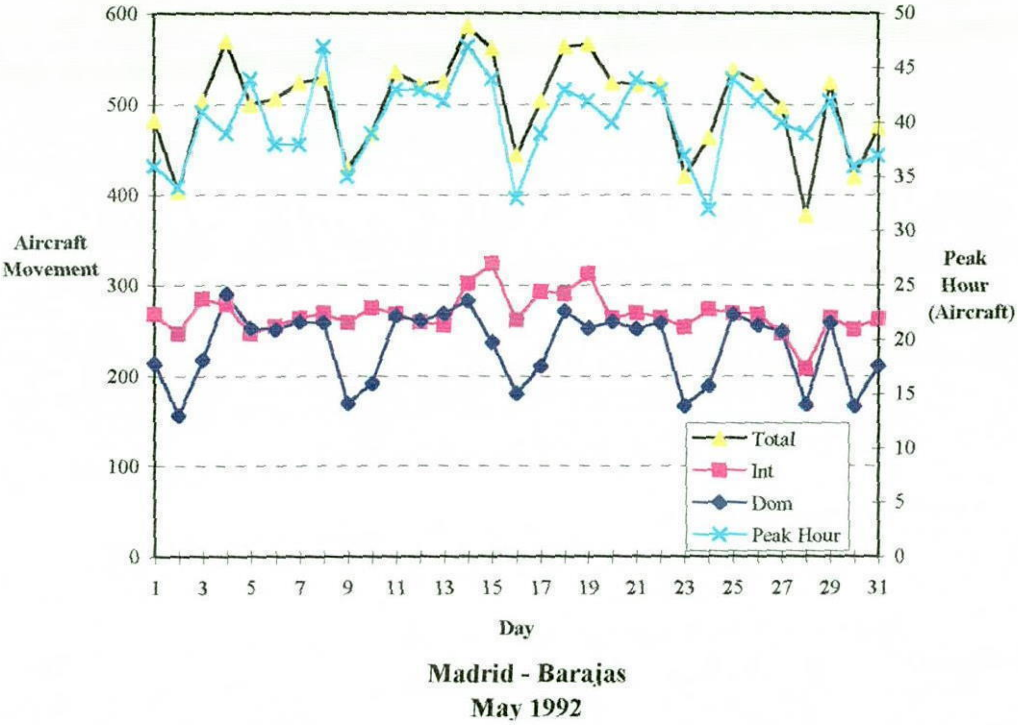
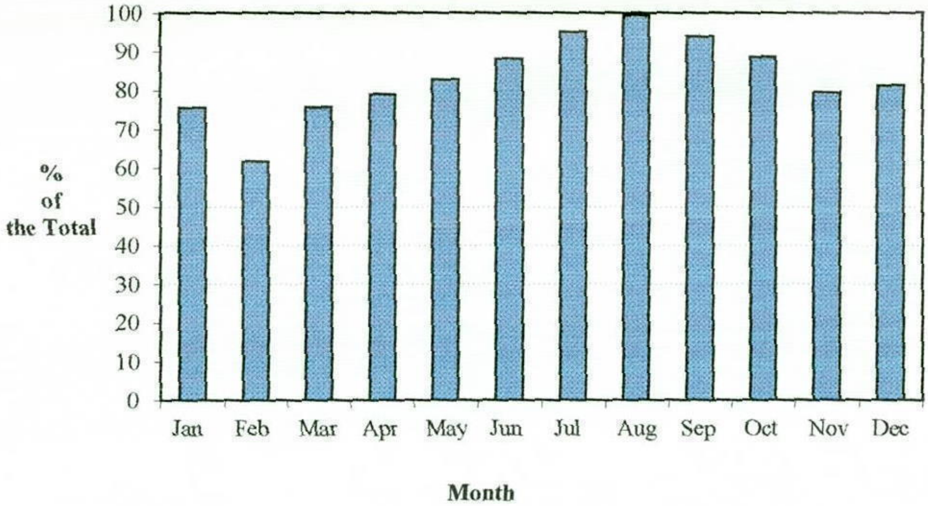
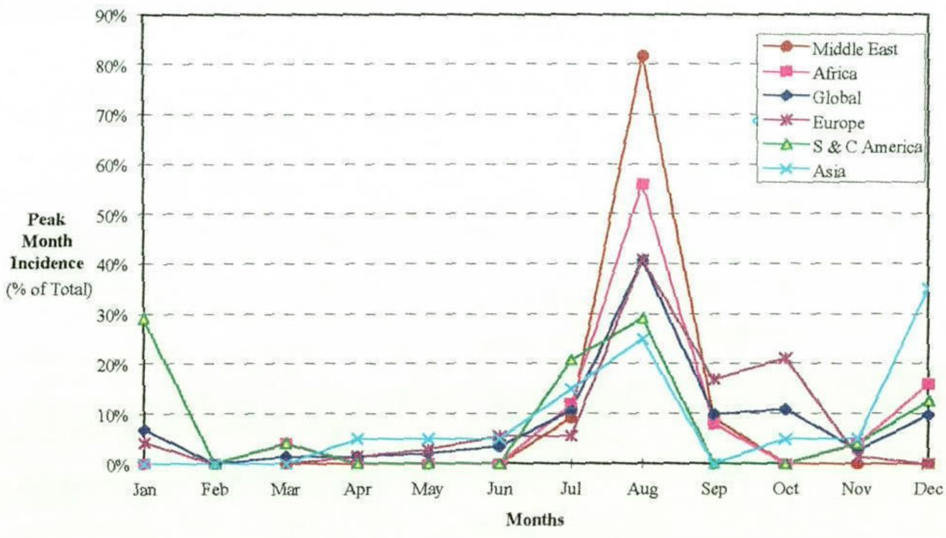


FIGURE 2.10: Variation between Peak Hour and total movement.
Madrid - Barajas Airport - May 1992
(Source Barajas Airport)

A well known fluctuation characteristic is that traffic distribution for the arrival and departure of domestic and international passengers usually is concentrated in distinct periods of time, as shown in Figure 2.11, which is a compilation of data from 160 airports located in Europe, Africa, South and Central America, Asia, and Middle East for the year 1991. Graph (a) shows the average passenger distribution over the months of the year. August was found to be the busiest month of the year in the majority of the airports considered as graph (b) shows. Another example of this fluctuation tendency is shown in Figure 2.12 (a), which reveals that 84% of the total passenger traffic arrives at Honolulu International Airport between five o'clock in the morning and one o'clock in the afternoon. Figure 2.12 (b) shows the separation between peak domestic and international passengers at Sao Paulo International Airport.

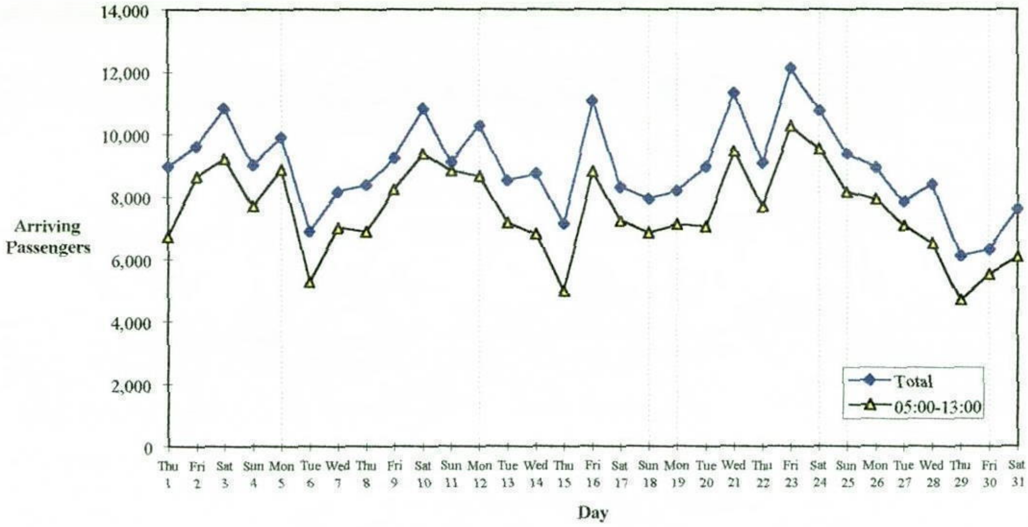


a) Monthly Passengers Average Distribution

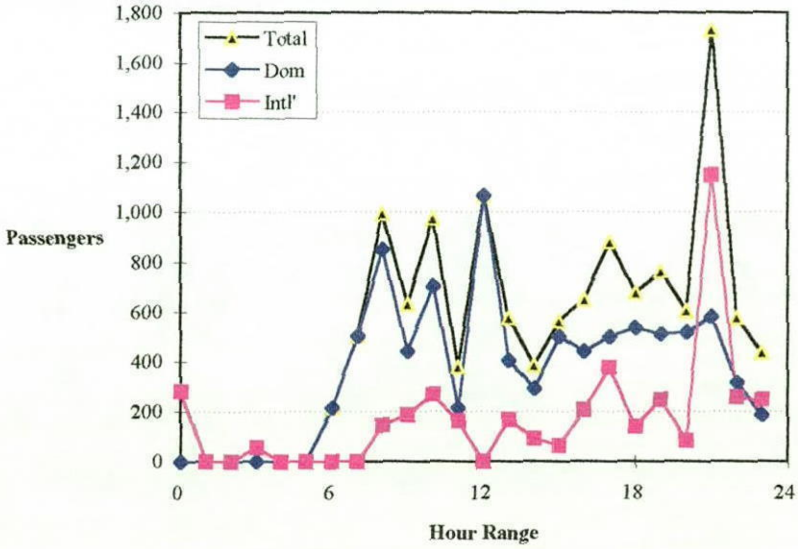


b) Rate of occurrence of the Peak Month along the year.

FIGURE 2.11: Passenger Distribution from 160 Airports around the world for the year 1991.
(Source: ICAO statistics).



a) Total Arriving Passengers - Peak Month, August 1991.
Honolulu International Airport.



b) Hourly fluctuation in traffic
21 Dec. 1990 - S. Paulo Intl. Airport

FIGURE 2.12: Examples of traffic variation.

Peak patterns are weekly based. This factor is often overlooked by airport planners. For example, Figure 2.13 for S. Paulo International Airport shows that the peak days are coincident with the weekends, Friday, Saturday and Sunday. This is also the pattern for many other airports. This weekly characteristic should be accounted for when analysing peaks. This would in many cases change the conception of the usual methods for determining peaks.

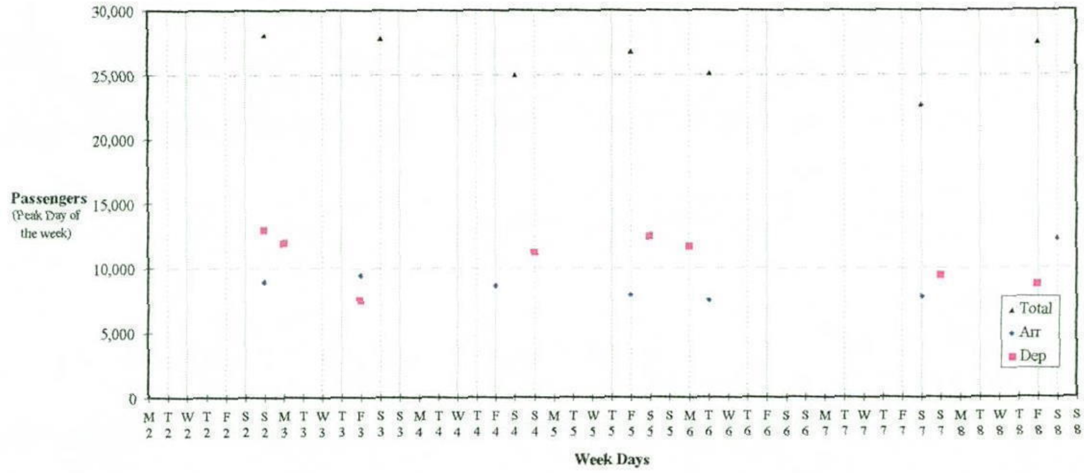


FIGURE 2.13: Passenger Distribution - Peak Days of the weeks from 04 Jan to 21 Feb 1993
S. Paulo International Airport (Week 2 to 8).

2.5.2 Definition of the Space required by the users

Terminal space requirements vary according to many factors such as traffic volumes, airport characteristics, airline characteristics and flight characteristics. As a result it is possible to identify different categories of users with similar and different needs. For example, an airport serving international routes has to provide space for federal inspections. This space is not necessary for a domestic airport. However toilets are necessary for both. The main facilities and respective factors that may influence their choice for a particular airport or situation are summarised in Table 2.1. Table 2.2 summarises the facilities for the main references in airport sizing. This is not an exhaustive list. Many other facilities and attributes could be included, moreover, the qualitative attributes can in some cases be quantified and the quantitative characteristics may be viewed in a qualitative sense in others. It is, for example, more important provide a mosque in the terminal in Islamic countries than to provide a VIP lounge. In other places it would be more important to provide special security facilities. Each airport needs to be considered individually.

Table 2.1: TERMINAL FACILITIES AND ATTRIBUTES

FACILITIES	ATTRIBUTES	
	QUALITATIVE	QUANTITATIVE
1. Departure Kerb Arrival Kerb	Exposure to weather; Systems and Signs; Security; Availability; Cleanliness;	Number of originating/terminating passengers; Proportion of pax per vehicle type; Number of traffic lanes; Transport mode; Stopping & dwell regulations; Average occupancy of vehicles by type; Kerb Length per vehicle type; Number of people per vehicle;
2. Lobby & Ticketing (Reservation & Information)(Departure Concourse)	Convenience; Security; Cleanliness; Information systems and signs;	Length of counter frontage; Queuing space; Space for lateral circulation; Number of people (passengers, visitors, etc.); Space per person;
3. Lobby Waiting Area (Departure) (Departure Concourse)	Seating arrangement; Convenience; Privacy; Amenities; Comfort; Airline service characteristics;	Number of seats; Waiting area geometry; Space per person; Terminal Configuration; Flight schedule; Number of people (passengers, visitors, etc.); Dwell Time;
4. Airline Ticket Counters (Reservation, Information) (Check-ins)	Comfort; Convenience; Airline procedure and staffing (courtesy of personnel); Counter use policy;	Length of counter frontage; Processing time; Number of passengers (arrival distribution pattern); Number and type of position; Contact Ratio; Area for queuing; Amount of baggage; Space per person;
5. Airline Ticket Office & Support (Airline Back Offices)	Service goals of individual airlines; Counter use policy;	Number of employees; Number of passengers (arrival distribution pattern); Contact Ratio; Space per employee;
6. Outbound Baggage (Outbound Baggage Room) (Baggage System, Make-up Area, Sortation Area, store/transfer area)	Convenience; Comfort; Technology	Number of acft/type departing; Number of passengers; Bags per passenger; Number of airlines; Lead-time standards for sorting bags into container/carts; Type and number of containers/carts; Space per containers/cart; Terminal Concept
7. Bag Claim (Baggage Claim Area) (Baggage Claim and Baggage Breakdown and Off-Loading Area)	Convenience; Complexity of procedure; Comfort;	Number of acft/type arriving; Terminating passengers; Checked bags per passenger; Type, layout, feed mechanism; Rate of baggage display; Relation of wait area to display frontage; Number of airlines;
8. Airline Operations and Support Areas	Airline policy (service goals of individual airlines, handling policy)	Aircraft mix (number of aircraft departing & arriving); Number of employees;
9. Security	Type, equipment sensitivity; Airline/Airport policy; Building layout; Convenience; Courtesy of personnel; Centralised/ Decentralised;	x-ray capacity; Number of passengers to be processed; Number of hand luggage; Processing time;
10. Departure Lounges *Gate Hold Rooms*	Boarding method; Passenger behavioural characteristics; Convenience; Comfort;	Number of passengers; Number of seats provided; Waiting area geometry; Dwell time;
11. Other Airline Spaces (Cabin Service or Commissary, Ramp Service Personnel, Aircraft Line Maintenance, Office Area, Locker Rooms, Flight Op. Facilities, etc.)	Airline Policy	Number of aircraft (aircraft fleet); Number of employees); Number of passengers;

Table 2.1: TERMINAL FACILITIES AND ATTRIBUTES

FACILITIES	ATTRIBUTES	
	QUALITATIVE	QUANTITATIVE
12. Arrival Concourse (Lobby Claim)	Convenience; Comfort; Amenities;	Flight schedule - Terminating passengers; Waiting area geometry; Space per person; Terminal Configuration; Dwell Time;
13. Food and Beverage (Restaurant, Coffee Shops, etc.)	Courtesy of personnel; Services provided; Amenities;	Number and type; Location and size; Number of users; Amount spent per passenger; Ratio of seats per passenger;
14. Other Concessions and Terminal Services (Concessions & Amenities: Hotel reservation, car hire, Post Office, Banks, shops, etc.)	Courtesy of personnel; Services provided; Amenities;	Number and type; Location and size; Number of users; Amount spent per passenger; Ratio of seats per passenger;
15. Other Rental Areas	Case-by-case	Case-by-case
16. Other Circulation Areas	Pedestrian density; Security; Comfort;	Pedestrian density; Walking distance; Terminal Configuration; Space available; Commercial activities; Stairs, escalators; Number and direction of people; Amount of hand-bags;
17. Heating Ventilating Air Conditioning and Other Mechanical Areas		Percentage of total gross area;
18. Structure	Aesthetic	Percentage of total gross area;
19. Duty Free	Courtesy of personnel; Convenience;	Number of passengers; Amount spent per passenger; Ratio of seats per passenger;
20. Public Health (Arrival Health Check)	Courtesy of personnel; Convenience; Complexity of procedure;	Average processing time; Number of arriving passengers; Space and configuration;
21. Immigration Control Departure Passport Control Arrival Passport Control	Courtesy of personnel; Convenience; Complexity of procedure; Efficiency	Average processing time; Number of International arriving passengers; Space and configuration; Number of positions;
22. Customs Arrival Customs	Courtesy of personnel; Convenience; Complexity of procedure; Efficiency	Average processing time; Number of International arriving passengers; Number of channels: red/green; Number of bags per passenger; Space and configuration;
23. Agriculture	Courtesy of personnel; Convenience; Complexity of procedure;	Number of passengers to be inspected; Number of counters; (case-by-case basis)
24. Visitors Waiting Areas (Visitor/Greeter Areas) (Arrival Concourse)	Seating arrangement; Convenience; Comfort; Amenities;	Number of seats; Room waiting area geometry; Space per person; Flight schedule; Visitor/passenger ratio;
25. Circulation Baggage assembly (Customs area: utilities, walls, partition)	Aesthetics; Comfort; Complexity of procedure; Efficiency;	Equipment configuration; Staffing practices; Baggage Loads; Number of Passengers;
26. VIP/CIP Lounges (VIP Very Important Person) (CIP- Commercial Important Person)	Seating arrangement; Convenience; Comfort; Amenities; Privacy; Airline service characteristics; Airport Policy;	Number of seats; Lounge-area geometry; Space per person; Flight schedule; Passenger load;
27. Airport/Station Administration Areas (Airport/Airline Administration Offices, staffing, etc.).	Airport/Airline Policy	Number of employees; Traffic Volumes(case-by-case basis)

TABLE 2.2: Airport Terminal Sizing Facilities

IATA (1995)	IATA PROGRAM [IATA, 1991]	BLOW (Function) (1991)	ASHFORD/PARSONS-FAA (1992)	HORONJEFF (1962)	HART (1985)
1. Departures Kerb	1. Departure Kerb	1. Arriving by car or bus at the terminal		1. Curb - arrivals	1.
2. Departures Concourse	2. Departure Concourse	2. Waiting in landside public concourse	1. Lobby & Ticketing 2. Lobby Waiting Area (Departure)	2. Domestic lobby 3. International lobby	2.
3. Check-in desks: Reservation Information 4. Airline Offices 5. Airline Operations Area	3. Check-in Desks	3. Checking-in, with or without baggage	3. Airline Ticket Counters 4. .Airline Operations and Support Areas 5. Airline Ticket Offices & Support 6. Other Airline Spaces	4. Ticketing counter	3. Ticket Counters
6. Baggage System (make-up area, systems)		4. Baggage handling	7. Outbound Baggage Room	5. Baggage check-in	4. Baggage Rooms and Systems 5. Outbound Baggage Dimensions and Criteria, Automated Systems
7. Passport Control - Departure 8. Security Check	4. Departure Passport Control 5. Security Check	5. Outbound immigration check 6. Pre-departure security check	8. Immigration	6. Security control	6. Security Checkpoints
9. Departure Lounge 10. Gate Hold Room	6. Departure Lounge 7. Gate Hold Rooms	7. Waiting in airside public concourse	9. Departure Lounges	7. Assembly	7. Passenger Departure Lounges
11. VIP/CIP Lounge		8. CIP and VIP facilities		8.	8.
12. Health	8. Arrivals Health Check		10. Public Health	9. Health	9.
13. Passport Control - Arrival	9. Arrival Passport Control	9. Inbound immigration check		10. Immigration	10.
14. Duty Free		10.			11.
15. Arrivals Customs	10. Arrival Customs - red/green channel	11. Inbound customs clearance	11. Customs 12. Circulation, Baggage assembly, Utilities, Walls, Partitions	11. Customs	12.
16. Baggage System (breakdown, claim, store, transfer, lockers/deposit, systems)	11. Baggage Claim Area 12. Number of Baggage Claim Devices	12. Reclaiming baggage	13. Bag Claim 14. Lobby Bag Claim	12. Baggage claim	13. Inbound Baggage
17. Visitor / Greeter Area			15. Visitors Waiting Rooms	13. Visitors Waiting Rooms	14.
18. Enquiry Counter					15.
19. Arrival Concourse Waiting Area	13. Arrival Concourse	13. Waiting in landside public space	16. Lobby Bag Claim	14. (Included in 2.,3.)	16.
20. Arrivals Kerb	14. Arrival Kerb	14. Leaving the terminal by car or bus	17. Agriculture	15. Curb - departures	17. Terminal Curb
21. Public Terminal Services Areas (Concessions & Amenities hotel reservation., car hire, Post Office, Banks, restaurants, shops, toilets, etc..)	15. Restaurant Seating Capacity		18. Food and Beverage 19. Other Concessions and Terminal Services 20. Other Rental Areas	16. Amenities	18. Concessions
22. Non-Public Services Areas (Station Administration Operation, crew, staff, storage, police security, etc..)			21. Structure 22. Heating, Ventilating, Air Conditioning and Other Mechanical Areas		19.
23. Transit and Transfer Passengers 24. Airside Corridor 25. Loading Bridges		15. Transit and transfer facilities 16. Facilities for the disabled	23. Other Circulation Areas		20. Public Corridors and Concourses

2.5.3 Specification of the relationship between users and space

This is a matter that explicitly or implicitly has been accounted for in almost all different methodologies used for designing and sizing an airport terminal. Even in the simple straight relationship between space and individuals, although not stressed in many methodologies, there are implicitly included subjective elements such as social, visual, spatial, thermal and aural interference.

The role of Space

The total area of a terminal is usually a sum of the individual facilities. These facilities can be grouped according to three main functional areas: operational, commercial, and administrative. The commercial and operational areas are the main concern for airport terminals design and operation, because most of the administrative space can be placed outside the main building.

Commercial facilities, almost a decade ago, were just the essential for supplying basic needs for passengers for most of the airports. However, as change is inevitable, a new vision is taking place in the way airports do business. In a addition to the traditional fees and charges made to Airline companies to generate revenue, Airport authorities now are much more aware of the commercial possibilities available. The design of terminal building must now emphasise the growing need to provide space in accordance with the authorities commercial interests on the ground. The conventional questions of the type of business, How priorities are decided, Who the primary customers are, What new products or services should be provided to meet customer needs, have been asked to overcome the obstacles of tradition and resistance to change. These changes have created space shortages in many airports.

The operational perspective has been a long standing issue dictating space requirements. Some events may exemplify this:

a) the uniform and continuing growth of traffic levels;

b) a new entrant airline at the airport with the possibility of another (small/major) airline in the future;

c) the realisation that the maximum airside capacity may be reached; or

d) the perception that the maximum terminal and landside facilities may be reached in the relatively near future; etc.

Many airports have experienced one or other of the above events which had had a dramatic impact upon its future.

These changes in traffic patterns, airlines, mergers and other conditions are challenges to the airport authority, managers, and planners. Because opportunities for expansion are limited and expensive the position to be adopted is that all future terminal development must be as flexible as possible to meet the likely changes. It is understandable that the interest of minimising additional capital construction costs, and maximising the efficient use of available facilities are the principal aims to be achieved in any development.

As traffic continues to grow, space in the terminal is expected to become more valuable, scarce and complicated to administer. Therefore there is a need to plan such spaces from the earlier stages of the design process.

The potential space shortages can be predicted and it is possible to anticipate and avoid the more serious problems by addressing the following questions:

- What new facilities are most needed at the airport?;
- Where should they be located?;
- How to locate them?;
- Who will be using them?;
- When should new facilities be constructed?

In any case, the airport manager should understand the methodology of space planning and management, including techniques for analysing space needs, establishing reasonable space standards and level of services, arriving at reliable space requirements, determining alternative solutions and selecting a proper action.

It is important to undertake a careful analysis of facility and space requirements for physical and operational functions, because the quality of service depends directly upon the internal efficiency of each facility. Efficiency is promoted by a good physical plan. It is equally important for the airport manager to be conscious of the objectives involved in space evaluation and space planning decisions.

Space Concept

The notion and perception of space are inherent to human beings and architectural design remains largely about man and his spatial needs. Dimensional and spatial measures are part of the planning process relating to most human activities. From early times artists and scientists have been concerned with dimensions and proportions.

The argument for space management as it is in any process of planning or rational decision making is the recognition of a problematic condition and the decision to find a solution to it. The realisation that provision of space is a problem to be faced in planning an airport terminal is unquestionable and the solution of this problem is rather more complex than a single mathematical relationship. Although an equation, a formulae or a set of standard dimensions may be used to represent the amount of space required for a particular purpose, such a relationship certainly includes other factors which are not so apparent.

Hall (1969) suggested that the provision of space ('territory') satisfies not only our physiological needs but also our psychological ones such as contact, privacy, experience (involving all our senses, activity, play, to be capable of orientation, to identify oneself with something in one's environment, and aesthetics (stimuli of what is considered beautiful). These psychological needs are related to four environment components: dimension, arrangement, location, and sensory stimuli. It can be seen that these components are intrinsic determinants of space in its broadest sense.

On the other hand, the extent to which space can modify an individual's behaviour or whether the psychological needs can be explained simply in terms of space alone is far from settled. Whether the space is determined basically by physiological or psychological needs, or a fairly even mixture of the two remains obscure. But certainly there are various attempts to explore human needs and conceive his personal space, not only but mainly, as a product of social behaviour.

Space is the core of any building designing process. To make space really work, it is necessary to understand how humans feel about space and how they interact within it.

When the terms 'overcrowded terminal' or 'capacity problem' are used, the queuing problem is the one most readily brought to mind. People easily imagine long queues being formed or a overcrowded lounge. This terminal space problem is centred around people. Personal space is a problem long before it gets to be a crisis and the image of a long queue or an overcrowded room becomes reality.

Space Management

The main objective of space management is to provide a consistent and equitable systematic procedure for evaluating airport terminal space to improve function and access and to maximise the utilisation of terminal facilities (for details on these procedures see Chapter 5).

This can be accomplished by:

1) Evaluating and documenting existing conditions, including space deficiencies and constraints:
2) Projecting space requirements to a pre-determined future date;
3) Establishing the appropriate level of service or standards that allows the manager to convert space inadequacies into meaningful space requirements.
4) Assessing the existent facilities/space ability to meet present and future requirements;
5) Establishing alternative means for providing adequate terminal facilities/space; and
6) Selecting and implementing from the alternatives a proper course of action(s).

The Role of Space Management

There are at least five primary roles for a space management approach at airport terminals that have strong architectural implications.

1. Passengers need a well-designed facility/space for transferring them from one transport mode to the other. They still want a secure, comfortable and easy way to accomplish this process.
2. Traffic is likely to grow and changes will occur from the beginning of any terminal development. For instance, an airport may face in its near future different split between domestic and international traffic, causing serious space distribution problems.
3. New technologies and new types of aircraft will come in to use, posing new requirements for space planning and a new generation of innovative service based on the new information technologies that will change the processing procedures at terminals.

4. Commercial activities will become more and more important for the airport as a source of revenue, completely changing the space arrangement inside the terminal. Space between operational and commercial facilities will need to be balanced.

5. The terminal area will continue to be the sum of spaces for public/visitors access and use, for staff, for commercial and service activities and for processing passengers.

Although the standard set of criteria to design or evaluate a facility may vary, the primary issue in an airport development should be the provision of space for passengers and its support activities.

The space plan, form and order are the components which have to be understood when defining space. The amount of space, which is related to the standard set of criteria adopted, has gradually changed from just a physical relation between man and space to a Level of Service approach, which is based on the theory of social behaviour of personal space and 'territoriality' [Hall, 1969], where the organisation of space by human beings is said to have originated in and can be accounted for by a universal, biologically determined impulse in individuals to claim and defend a clearly marked 'territory', from which others will be - at least selectively - excluded [Hillier, 1984]. It asserts by implication that space and social behaviour are identified with a particular group of people, therefore creating different space requirements in different cultures.

Of course, form and order, i.e. the manner in which these spaces are arranged generates formal characteristics, spatial relationships and contextual responses to the organisation of space. These may become very complex when the interaction between man and equipment and a three dimensional workspace are included.

Personal Space

Personal space has been defined as areas comprised of concentric circles surrounding a person's body, each one defining a region for certain types of interaction, where interference (entry into each space) may not be allowed. According to Diffrient (1981) these spaces can be divided into four zones:

(1) Intimate space. Usually reserved for family members, lovers and extremely good friends.

(2) Personal space. Reserved for friends. At the closer limits, it will be possible for one person to touch another.

(3) Distant personal space. This is the space to conduct business or some more formal relationship.

(4) Public space. Here the fine details of the other person are no longer visible.

Hall (1969) named these personal space zone as: intimate, personal, social and public distance, and later Oborne (1979) gave the following values for these as two 'phase' distances: close and far.

	Close phase (cm)	Far phase (cm)
A - Intimate Distance	0 to 15	15 to 46
B - Personal Distance	15 to 76	76 to 122
C - Social Distance	122 to 210	213 to 366
D - Public Distance	213 to 760	+ 760

The Social Distance tends to be used by people working together. The Close or Far phase distance in these circumstances will depend upon the kind of interaction between the workers. Oborne (1979) also drew attention to the fact that there are many variables that affect the distance of the different space zones which a person may create. These include personality, sex, age, culture and the status of the individual.

A similar concept was utilised by Fruin (1971) in what he has termed the 'body buffer zones', when considering the level of service standards for queues.

Clearly there are social constraints that may intervene to reduce the efficiency of the system even if the physical space is provided.

The concept of level of service

Since the beginning of the last decade there has been strong emphasis on the concept of level of service in design and capacity analysis of transport facilities. It is a measure for the relationship between users, space and capacity. This concept was introduced by Transport Canada (1979) and adopted by AACC & IATA (1981), based on a framework similar to that used in highway traffic engineering to describe and determine the capacity of highways, which is a framework of six levels of quality of service, from *A* to *F* in descending order: Level *A* being excellent service, free flow, no delay, direct routes, excellent level of comfort and *F* being system breakdown, unacceptable congestion and delays. Some examples of Level of service standards recommended by IATA are tabulated in Table 2.3.

TABLE 2.3: IATA Level of Service and Space Standards (Source: AACC & IATA, 1990)

	Level of Service Standards (m^2 per Occupant)					
Sub-System:	**A**	**B**	**C**	**D**	**E**	**F**
Check-in queue area	1.8	1.6	1.4	1.2	1.0	
Wait/Circulate	2.7	2.3	1.9	1.5	1.0	
Holdroom	1.4	1.2	1.0	0.8	0.6	
Bag Claim Area (Excluding claim device)	2.0	1.8	1.6	1.4	1.2	
Government Inspection Service	1.4	1.2	1.0	0.8	0.6	

A Excellent Level of Service; condition of free flow; no delays, excellent level of comfort.
B High level of service; condition of stable flow; very few delays; high level of comfort.
C Good level of service; condition of stable flow; acceptable delays; good level of comfort. (Below "C", dwell time should be added)
D Adequate level of service; condition of unstable flow; acceptable delays for short periods of time; adequate level of comfort.
E Inadequate level of service; condition of unstable flow; unacceptable delays; inadequate level of comfort.
F Unacceptable level of service; condition of cross-flows, system breakdown and unacceptable delays; unacceptable level of comfort.

The Level of Service approach focuses on trying to understand how passengers would perceive, interact and react within the space provided, considering as many variables as possible. Although there are no generally agreed standards by the airports, a set level of service criteria is necessary before starting any designing process, though it is difficulty to establish the causal effects of the subjective variables, between themselves and between time and available space. Mumayiz (1985), proposed a level of service framework based on a perception-response model in which a survey was carried out asking passengers to indicate their level of satisfaction with service in terms of a rank between good and bad. Table 2.4 shows other attributes that may be applied.

The effective assessment of airport 'level of service' has to relate distance, comfort, and convenience of airport users. In this relationship time is a major factor. This can be represented in Figure 2.14, where the variables comfort, convenience and distance are interrelated to demonstrate that time is a primary variable in level of service, and is directly affected by the space required. Conversely comfort, convenience and distance can be affected by the space provided and depend upon the occupancy time. If the dwell time is increased maintaining the ABC space unaltered, one or all of the other variables would probably worsen, as shown by the dotted points in the triangle, e.g. a passenger would have a sense of discomfort by spending longer time in a facility.

TABLE 2.4: Subjective attributes that may interfere in Level of Service

Pair of Attributes		Pair of Attributes	
1. agitating	calm	18. mitigating	activating
2. careless	careful	19. nasty-smelling	fragrant
3. cold	hot	20. negative	positive
4. conservative	radical	21. noisy	silent
5. depressing	elevating	22. passive	active
6. dirty	clean	23. simple	exclusive
7. discouraging	stimulating	24. stale	fresh
8. disturbing	peaceful	25. ugly	beautiful
9. dreary	daring	26. uncomfortable	comfortable
10. harsh	idyllic	27. unfriendly	friendly
11. heavy	light	28. unhealthy	healthy
12. idle	energetic	29. uninteresting	interesting
13. impersonal	personal	30. unpleasant	pleasant
14. inadequate	adequate	31. unsuitable	suitable
15. irrational	rational	32. untidy	tidy
16. irritating	relaxing	33. useless	useful
17. leaves me unaffected	engaging	34. worthless	precious

Another significant relationship between user and space is concerned with *demand* and *capacity*. These two measures have been related to the spatial arrangements by expansion of terminals, runways and terminal control areas.

The simple definition of 'capacity' as the amount that something can hold or contain, or the amount that something can produce, is not enough to explain an acceptable understanding of the term in the context of an airport terminal. According to different elements of the terminal with its distinct functions, capacity should be viewed as a variable measure.

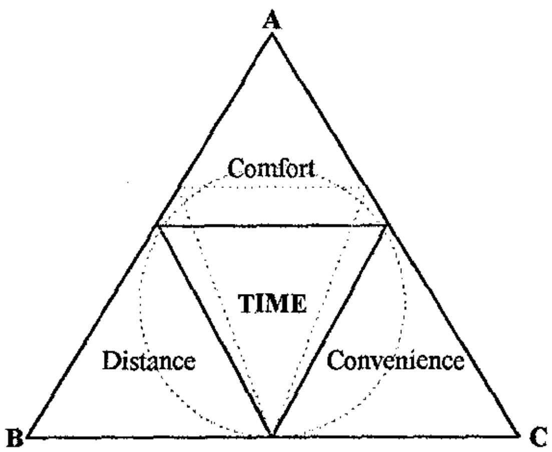


FIGURE 2.14: Space ABC of Level of Service.

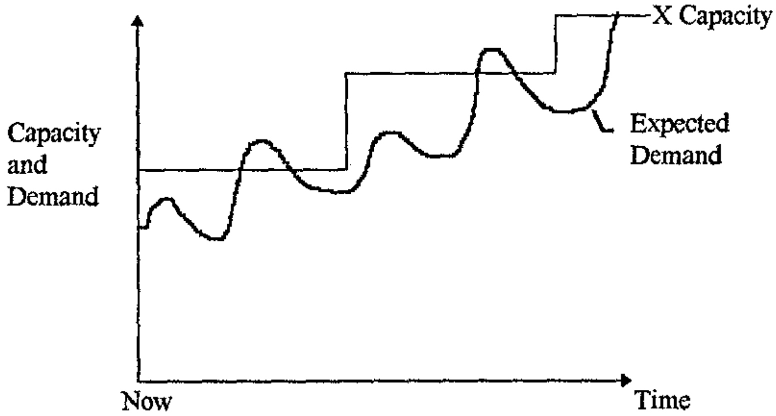
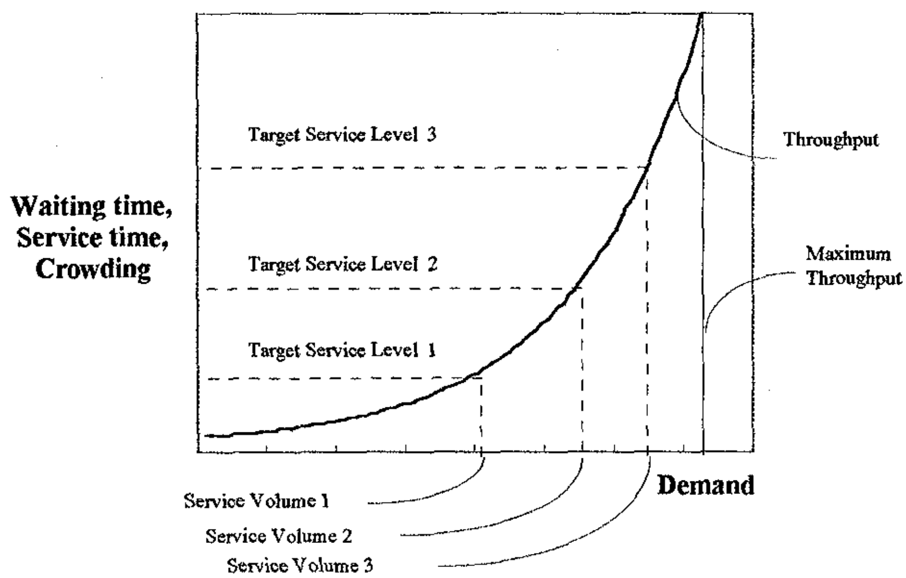
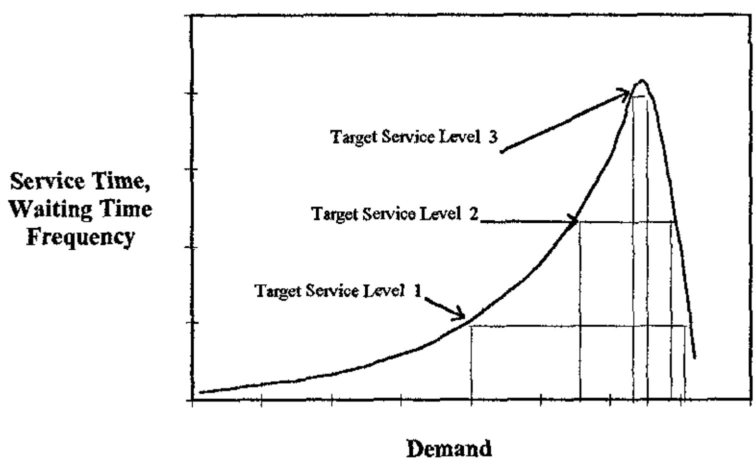


FIGURE 2.15: Relationship between Capacity, Demand and Time.

Capacity should also match the entire terminal/airport system to which it is linked. The capacity of a facility is therefore a reflection of the amount of resources available for the realisation of its function. However, *demand* is usually regarded as the number of passengers that will use the terminal at some future date, or as the need or the requirement that must be met or the ability and willingness of people to travel. Therefore capacity should be provided to meet demand, as shown in Figure 2.15, where the determination of capacity requires an understanding of the strategy for meeting demand fluctuations. Here, there is also a strong interdependence with *time* and *level of service*. In this context the capacity of a facility is directly related to its efficiency of processing the passengers in a particular interval of time under a specified condition or level of service. One small terminal with efficient systems may cope with a larger number of passengers, while a large terminal with inefficiency may have congestion and delays. Figure 2.16 shows the relationship between these variables.



a) Curve of cumulative values



b) Curve of frequency

FIGURE 2.16: Representation of Demand and Capacity with different levels of service.
(Adapted from [TRB, 1987])

In determining capacities, account should be taken of the fact that it is not practicable economically to provide facilities on a scale that ensures the highest level of service is always met, i.e., that no passenger ever receives sub-standard service. So the capacities depend not only on the numbers of hourly passenger flows but also on their demand characteristics, such as the timing of passenger arrivals at the airport, age, trip purpose, fare paid, baggage carried or checked, etc. The pattern of the daily/weekly/monthly schedule is also important depending upon whether it produces a single pronounced peak or a relatively steady profile.

2.5.4 Determination of the required space

When all other elements, relationships and variables are identified the determination of the space required can be calculated. The process is usually carried out calculating individual facilities. The total space requirement is given by the sum of each of the functions of single areas, by using one of the methodologies described by Parsons [FAA, 1976a], IATA (1991), or Ashford (1992). The necessary inputs to perform the calculations are indicated in Table 2.5. For the detailed layout of the terminal, due to the rough area approximation given by these methods, some additional evaluation of the spaces required should be undertaken, in terms of analysing the flows through the terminal to be able to identify the interaction between facilities. Queuing theory and simulation have consistently been applied in this procedures.

2.5.5 Configuration of space

At the early stage of the design process the planner should define an approximate layout of the building in study.

To accomplish this, the starting point is the passenger flows. The dominant passenger flow pattern identifies the nature of the intakes, the activities required to convert these into outputs, and the human and physical resources required to provide or to develop the required functions. The next step is to discover the discontinuities or the interfaces in the process that mark the physical boundaries of the building. Each part of the building has its own primary task or function and requires its own organisation. The organisation of the whole has to provide for the need to integrate the arrangement of its parts. The boundaries, however, are not always physical barriers. More commonly technological changes tend to alter these boundaries between facilities. The two external boundaries or interfaces are of extreme importance and are the main constraints which determine the configuration of the building. From one side there is the ground transportation represented by cars, buses, etc. and from the other side, the aircraft.

TABLE 2.5: TERMINAL FACILITY INPUTS

ASHFORD [1992]/PARSONS-FAA [1976a]	IATA PROGRAM [1991]	BLOW [1991] (Function:)
	Departure Kerb / Inputs: (Common to all facilities: Peak Hour Originating Passengers, Peak Hour Terminating Passengers, Peak Hour Transfer Pax processed Landside, Performance Standards) Proportion of pax per car, taxi, coach Number of pax per ... Kerb occupancy time per... Kerb length per ...	Arriving by car or bus at the terminal Hourly passenger flows Visitor ratio Estimated dwell time Modal split: car , taxis, bus
Airline Ticket Counters Equivalent aircraft Percentage of originating passengers Percentage of arrivals and departures Airline Ticket Offices & Support Equivalent aircraft Percentage of originating passengers Percentage of arrivals and departures Airline Operations and Support Areas Percentage of airline area Other Airline Spaces	Check-in Desks Check-in Process Common (y,n) Short-haul/Long-haul data (y,n) Proportion of PHT by Company Agent/Company # 1,2,...n Proportion of Flights S-H/L-H Processing time/pax ... Average # of seats/acft ...	Checking-in, with or without baggage Hourly passenger flows Visitor ratio Estimated dwell time Percentage of passengers using gate check-in Space per person
Outbound Baggage Room Equivalent aircraft Equipment technology		Baggage handling
Bag Claim Equivalent aircraft in peak 20 minutes Percentage of arriving passengers terminating locally Equipment technology	Baggage Claim Area Space required per person Average waiting / pax Proportion of pax arriving by acft narrow/ wide body N. of pax per acft ... Average claim device occupancy time... Number of Baggage Claim Devices	Reclaiming baggage Hourly passenger flows Processing rate Estimated dwell time Number of checked-in bags per passenger Pax split per narrow/wide-bodied aircraft Space per person
Departure Lounges Aircraft mix with average numbers of seats Area per person	Departure Lounge LH/SH pax occupying the dep. lounge (y,n) Peak Hour transits Peak Hour all transfers Space required per person Proportion of pax SH and LH Average wait (min) in lounge SH and LH Gate Hold Rooms Maximum n. of seats on large. acft handled at gate Average Load Factor (%) Proportion of pax for which seating is to be provided Space required p/ seated pax & standing pax	Waiting in airside public concourse Hourly passenger flows Estimated dwell time Space per person CIP and VIP facilities
Lobby & Ticketing Equivalent aircraft Lobby Waiting Area (Departure) Equivalent aircraft Seats required	Departure Concourse Space required per person Proportion of pax (resident / foreign) Well wishers (...) Average wait in concourse	Waiting in landside public concourse Hourly passenger flows Visitor ratio Estimated dwell time Space per person
Lobby Bag Claim Equivalent aircraft in peak 20 minutes Percentage of arriving passengers terminating locally Equipment technology Linear feet of claim display	Arrivals Concourse	Waiting in landside public Space Hourly passenger flows Visitor ratio Estimated dwell time Space per person

TABLE 2.5: TERMINAL FACILITY INPUTS

ASHFORD [1992]/PARSONS-FAA [1976a]	IATA PROGRAM [1991]	BLOW [1991] (Function:)
Food and Beverage Annual passengers enplanements		
Other Concessions and Terminal Services Annual passengers enplanements	Restaurant Seating Capacity Maximum number of seats on largest acft handled at the airport	
Other Rental Areas Annual passengers enplanements		
Other Circulation Areas Percentage of total area		
Heating, Ventilating, Air Conditioning and Other Mechanical Areas Percentage of total area		
Structure Percentage of total area		
Public Health Number of arriving international passengers Area per person	Arrival Health Check Average Service Time Maximum n. of seats on largest acft Target time for clearance of acft	
Immigration Number of arriving/departing international passengers Area per person	Departure Passport Control Separate passport control foreign/res. (y,n) Proportion of pax resident/foreign Processing time/pax Security Check Security centralised/decentralised Hand baggage / pax Capacity of x-ray unit Time of arrival of first pax >hold Room Time last pax should board Arrival Passport Control Proportion of pax resident / foreign Processing time resident / foreign	Outbound immigration check Hourly passenger flows Processing rate Area per desk Pre-departure security check Hourly passenger flows Processing rate Inbound immigration check Hourly passenger flows Processing rate Area per desk
Customs Number of arriving international passengers Area per person	Arrival Customs Red / Green Channel Average Processing Time Proportion of pax passing red channel Proportion of green channel pax being inspected	Inbound customs clearance Hourly passenger flows Processing rate Estimated dwell time Area per person
Agriculture Number of arriving international passengers Area per person		
Visitors Waiting Rooms Percentage of total area		
Circulation, Baggage assembly, Utilities, Walls, Partitions Percentage of total area		
	Arrival Kerb Proportion of pax using car, taxi coach Number of pax per ... ... Kerb occupancy time per ... ... Kerb length per	Leaving the terminal by car or bus Hourly passenger flows Visitor ratio Estimated dwell time Modal split: car , taxis, bus
		Transit and transfer facilities Hourly passenger flows Processing rate Estimated dwell time Facilities for the disabled

Having established the relationships between facilities, the construction of a Adjacency Diagram can be produced to show the relationship between the main parts of the building as in Figure 2.17. This can be worked up into a sketch layout, but at this point the basic concept is missing.

The basic shell or form of the building must be determined first, i.e., what will be the width and depth, number of levels and its basic structure (space of columns, ceiling height, light). This will allow on the other hand the analysis of the constraints that the building may impose on laying out the facilities, and on the other, study of the interfaces between the building and aircraft, and between the building and the ground transportation vehicles.

Although this is a technical decision, this matter is not always decided by the planner or architect and is often just a matter of what the client wants. The process is more an intense discussion with the client and with the users - the airlines and other users - to establish the ultimate solution.

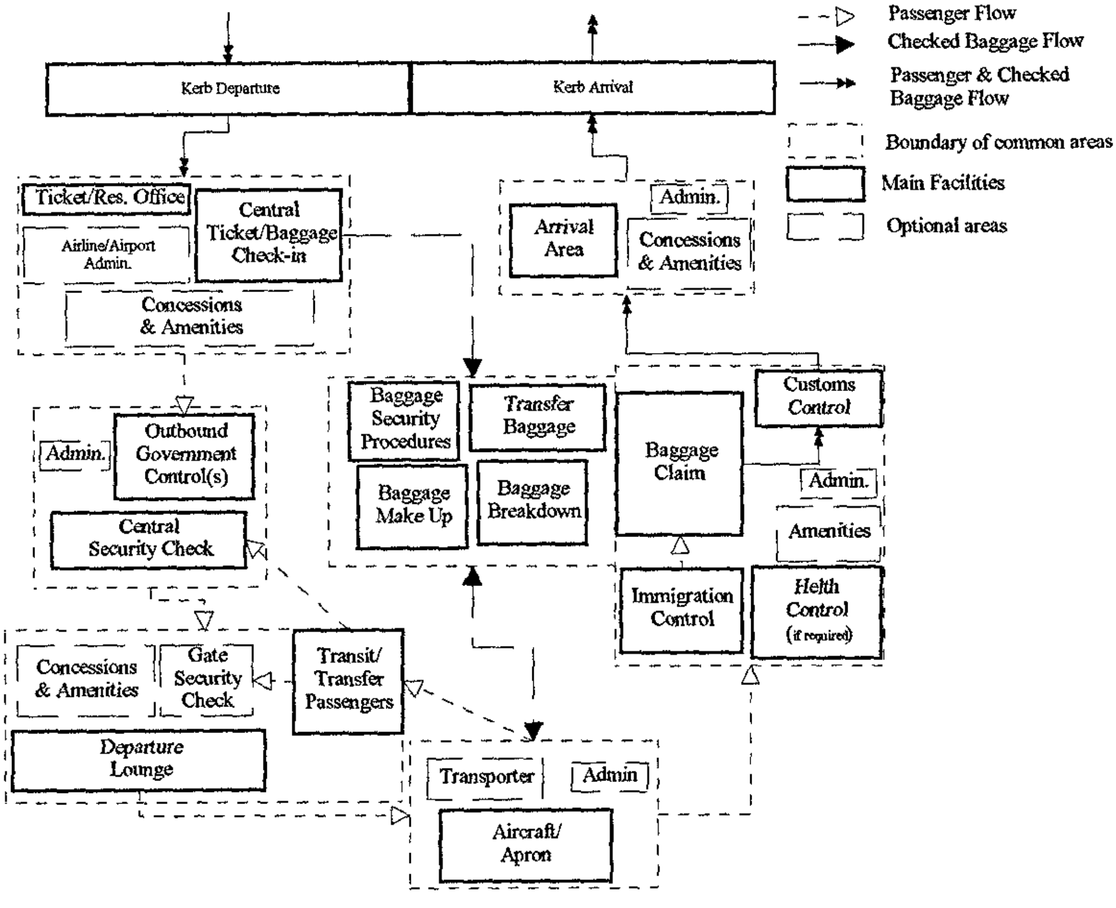


FIGURE 2.17: Example of a Passenger and Checked Baggage main flows and Adjacency diagram depicting interaction between facilities

Three other characteristics need to be considered:

modularity,

flexibility and

expandability.

The layout should be as modular and flexible as possible and allow for expansion. These three characteristics seem to be part of a circle where one is dependent upon the other two to be effective. They are also fundamental to another step the *phasing* development of the project.

2.6 Summary

This chapter provided a preview of the main steps followed by planners in the design of an airport terminal. It stated with an attempt to group the theoretical approaches to the designing process. A summary of the more practical and main steps as formulated and disclosed in technical literature which stresses the main issues related to the matter, was then presented as a guideline to back up the theory in the following chapters.

What is most interesting in this examination is that notwithstanding the fact that almost all authors have mentioned or referred to terminal concepts either superficially or in detail, no one has clearly stated where the choice of a concept should be included in the chain of the designing procedures. A probable reason for this could be the lack of an exact framework to evaluate the concepts or maybe the evaluation is so complex that can not be cleared defined.

Concept choice, as one of the steps within the design methodology, was discussed.

Some experts advise construction and use of scenarios analysis in some circumstances, particularly those characterized by a high level of uncertainty, on the basis that scenario analysis has a broader view with less emphasis on the quantification and precision aspects. The idea is to develop a solution which is sufficiently flexible to cope with any scenarios or mixes of scenarios which might occur in the future. However this procedure is said [Pearman, 1988] to be more useful in projects involving medium and long-term planning, where the underlying circumstances of the social and economic situation are unpredictable and the conventional forecasting models are presumably ineffective. Moreover this procedure is more adequate when considering strategic issues. A justification for the use of scenario analysis in transportation is well documented elsewhere [Pearman, 1988].

The need for *phasing* the construction is a further step that should be included in the design process. It is closely related to the nature of the future demand, i.e., passenger and aircraft mix, type of airlines, schedules. Particularly important is the expected traffic growth rate, which at first may define the numbers of terminals to be built and certainly the way to phase the expansion. The airport terminal plan should therefore be designed so that it can be implemented in stages according to needs arising from traffic demand. The way to achieve this is to design the passenger terminal in modules which can be extended when necessary, with a minimum of disturbance to normal operations.

The main steps for the airport design process are redefined as:

1. Determination of the inputs. Determine the type and number of terminal users,: forecasting annual passenger throughputs, aircraft, 'the busy hour', other users (such as visitors and staff), etc.
2. Provision of facilities necessary to handle the particular envisaged traffic.
3. Establish the relationship between the users and the facilities.
4. Determination of the space required.
5. Concept Choice: determine the basic shell, the external form and shape of the terminal.
6. Configuration of space, based on the main passengers flow and on the relationship between facilities, and
7. Phase the development on the basis of the forecast growth of the input elements.

3. CHAPTER III - A TOOL FOR TERMINAL SIZING

3.1 Introduction

Over the last few years, particularly in the field of terminal design and operation, a number of computer models have become available, mainly dealing with simulation, although some computer software appeared at the beginning of this decade trying to fill the gap on terminal capacity and sizing. The IATA (1991) airport terminal capacity programme also known as CAPASS, is a programme that has been developed to assist airport planners and managers in solving problems related to the throughput capability of existing airport terminals and also to determine the sizes of various individual terminal facilities. The programme is based on simple formulae which have been used successfully in evaluating airport terminals over many years. It is written around dBASE IV and is designed to run on a Personal Computer. The formulae uses the equivalent peak hour flows as the base for sizing most of the facilities. Although an easy-to-use software due to its simplicity, there are limitations as the programme only examines individual elements of a terminal building and does not take account of interactions between them. The main limitation is on sizing an airport terminal element where the output of a few facilities consists of a floor area, even though that area is the net usable area for a particular facility. All other areas required must be assessed separately, including circulation, service cores, offices, equipment rooms, toilets, concessions, etc.

Another computerised method, not commercially available, was developed at the Department of Aeronautical and Automotive Engineering and Transport Studies at Loughborough University. The LUTERM model is a menu driven spreadsheet, programmed in Excel 4.0 software. It is an oriented model for airport terminal sizing similar in function to the IATA model. It is a computer model of the graphic method described by Ashford (1992) in his book 'Airport Engineering' and FAA/ Parsons report (1976). The manual method is laborious and prone to inconsistencies when compared with the LUTERM model. The derived formulae for sizing most of the individual facilities are predominantly based on a demand level during the peak period known as the Equivalent Aircraft Factor (EQA), see Chapter 5.

Parallel to the advance in computer technology a large number of techniques have developed and are being developed for knowledge processing which may indicate that an alternative approach for sizing an airport terminal is lacking: an approach based on several design scenarios rather than just one set of operating conditions. Notably this is a proposition that would be flexible enough to account for three distinct operational conditions: common condition, a situation to be found in any terminal; comparable condition, a situation to be found in other terminals; and a condition under different set of assumptions.

This chapter outlines the work undertaken by this author and T. Foster to define an alternative approach to terminal design using a decision support system shell based technology. Although the overall system is able to give knowledge based guidance through several modules as depicted in Figure 3.3, the main focus described here is related to the Facility Sizing Module which it is an attempt to combine the only two available methods for sizing airport terminals: the IATA Airport Terminal Capacity Programme and the LUTERM spreadsheet or FAA/Parsons method.

3.2 An Expert System for Decision Support

The transmission of knowledge by printed and spoken words has been for long the main means of human communication. However these media of knowledge transfer have severe limitations being difficult and lengthy processes to acquire information, with problems of coding and decoding the messages. Computer technology on the other hand has been changing the way to store and apply knowledge in a wider range of expertise. Knowledge here is *information* [Shannon (1974)] and *expertise* is the ability to store and retrieve directly applicable knowledge in the form of an intelligent computer system. Information to be translated into action must be decoded and interpreted before it can be applied; and expertise is the kind of resource that directly contains applicable knowledge performed by computer technology, including expert systems. Information is retrieved to communicate knowledge and expertise is retrieved to apply knowledge. According to the ability to store and retrieve expertise and knowledge, two contrasting forms can be found: the conventional programme as opposed to artificial intelligence. It can be further expressed as numeric and algorithm as opposed to symbolic and heuristic, respectively. An expert system is therefore expressed as an extensive set of symbolic and heuristic knowledge about a specific subject, but also with some numeric and conventional programming incorporated.

The idea of developing an expert system for sizing a airport terminal building was based on the high potential presented in air transport for development of knowledge-based expert system as a useful tool for practising airport planners and engineers [Yeh (1986)].

The development of knowledge based expert systems (KBES) was introduced in the field of artificial intelligence (AI) during the mid-70's. Artificial intelligence is defined [Winston (1984)] as the study of intelligence using the ideas and methods of computation. Its central goal is to make computers intelligent. These systems are interactive computer programs that employ a collection of thinking or interactive modes such as judgement, experience, rule-of thumb and intuition, combined with inferential methods to apply this knowledge to provide expert advice to a variety of tasks, to reach the level of performance of a human expert in a specific professional domain; in this case airport planning and design.

The Decision Support System (DSS) is an expert system that has been designed for end users who may not be necessarily computer literate. The system is also provided with inference mechanisms by which knowledge can be processed together with different tools. Several items of software have already been developed, such as SIMMOD, IATA and NAPA. An interface is provided allowing the integration of these models for use in the DSS and vice-versa.

The basic objective of such a modelling support system is to assist a planner in deriving and simulating in a single software environment, a decision support for airport terminal planning and design. The modelling support system should possess the capability of quickly deriving sizing configurations for a new terminal and should describe the crucial problems affecting existing terminals. The idea of for this model borrows from the concepts given by Odoni (1992) which characterise a model that is flexible, fast and not precise. The model must be flexible to permit reconfiguration of the spaces, patterns flows. The model must also be fast enough to allow for estimation and evaluation of performance under all the combinations of conditions that might reasonably arise. The model may also give precision at the level of traffic to within 30%, see Chapter 1.

A general architecture of the Decision Support System model as originally conceived by this author is shown in Figure 3.1. The model is divided into three main components:

- the Knowledge Base Structure
- the Expert System Co-ordinator
- Internal Database System, User Interface, Outputs, External Packages.

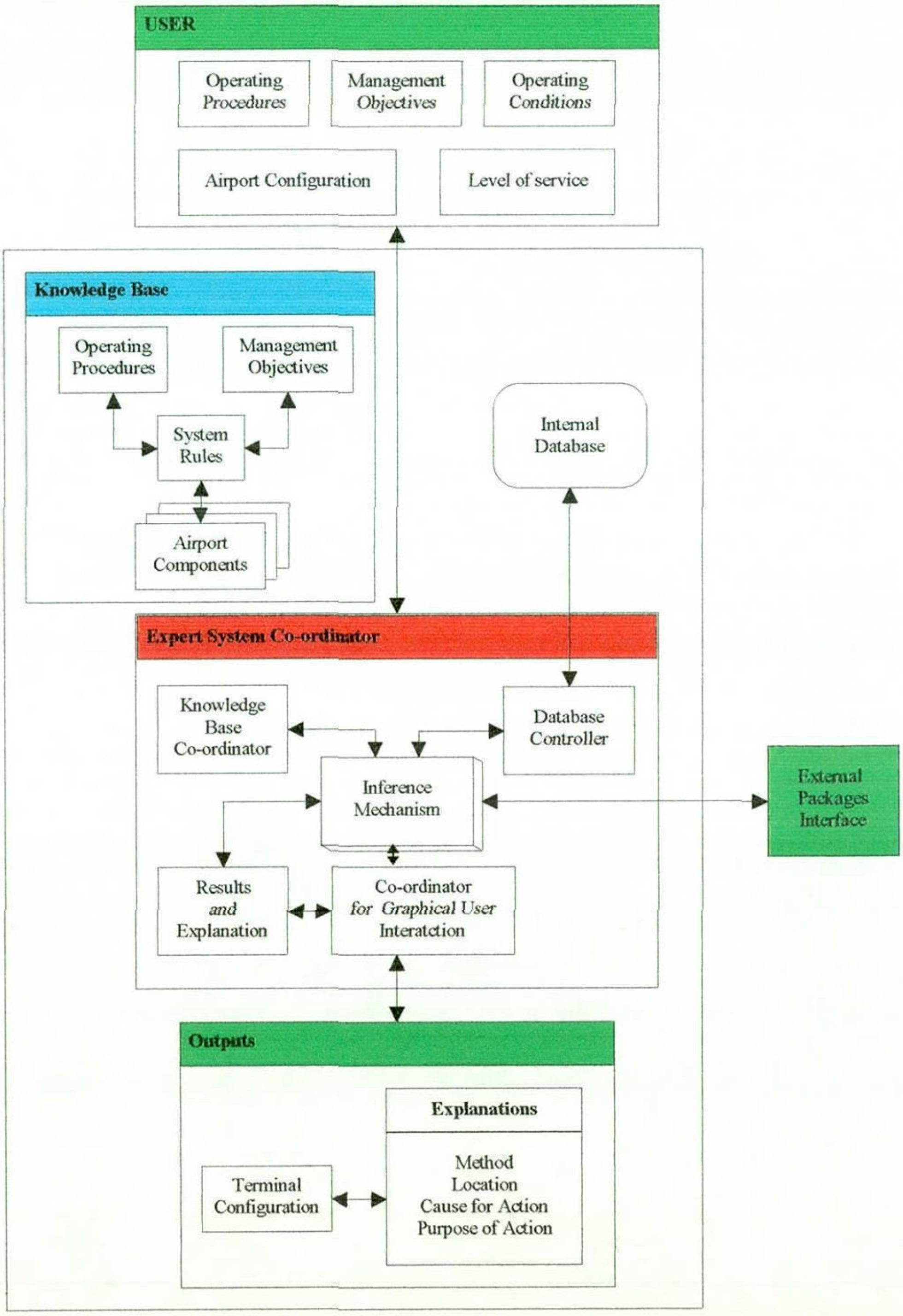


FIGURE 3.1: Decision Support System Architecture.

As a basis for representing Knowledge about the structure of a modelled system the Knowledge Base is subdivided into airport facilities and its respective rules for designing, operating procedures and management objectives. These features are formed together to establish criteria for the evaluation of performance of each terminal facility.

The Expert System Co-ordinator can be considered as a modular system whose main architectural elements are the Inference Engine, Controllers (Database and Knowledge base) and Results/Explanation. The Co-ordinator will provide for the integration and transfer of data from outside models to the internal Database system, which handle data retrieval, as well as the general control of the system. Users can query the database and request an analysis or report using the Expert System Co-ordinator, which is transparent for them.

The inputs to the system are the schedule data base, existing or predicted, layout of the terminal and airport, operational procedures and management objectives. The airport layout is important for information about the exogenous factors or the boundaries of the terminal system such as apron, access, runway.

The outputs of the system are given by either the results and layout for a new terminal facility or by highlighting any problem in the current terminal and suggesting layout solution through a block graph display together with textual explanation of the cause of the problem/solution. This can be in various formats and levels of detail depending upon the needs of the user.

The major task in building an expert system is to transfer the expertise and knowledge acquired from one or more experts to a computer program. This knowledge acquisition is the bottle neck of the entire expert system development process, therefore is of capital importance to identify the area, concepts, and characteristics of the problem and solution. Another and different problem is the software architecture needed to support the various sources of knowledge required, with many interfaces integrated to the main system. So, due to its well-integrated and easy-to-use development environment the Kappa-PC tool was chosen to implement the DSS, see Foster (1995).

3.2.1 Kappa-PC

Kappa-PC is a knowledge based systems software, designed to run in Microsoft Windows. The software is an object-oriented programme using objects as the main form of knowledge representation. Physical entities or abstract concepts are grouped into a hierarchical structure of parent classes having children which may be either parent classes themselves or end nodes which have no children and are called instances. These classes and subclasses are broken down into a set of slots which describe the properties and type of information of a particular class. The program also enables direct association of procedural code with objects as 'methods' and with slots as 'monitors'. This allows certain actions to be taken or slot values changed, or further messages sent to other objects. Detailed information on this tool can be found elsewhere [Lydiard (1990), Foster (1995)]. An important feature available is the provision of several ways to access external data files and possibilities to integrate external programs. Kappa-PC can read data from ASCII, dBASE, and Lotus files, and can execute external routines in C, FORTRAN, Pascal, and CAD packages. Although the applications with their rules, functions, and methods are written using KAL (the Kappa Application Language), the close integration with C allows for further expansioon of the program's capabilities. For example, the end-user interface of the DSS with simulation models such as SIMMOD and NAPA can be built using C.

Most of the functionality required by the expert system co-ordinator for controlling the interaction between the different sub-modules in the design support system and for the presentation of results to the user can be provided by the expert systems shell KAPPA-PC which will provide access to a knowledge base structure, graphic interfaces to the user and interfaces to external packages, see Figure 3.2.

The interfaces to the user are extremely important and should provide flexibility between the interactions of inputs and presentation of results. The user feeds the information into the system about a particular project. This information is processed and passed back to the user for further manipulation in order to equate or alter the results for a different scenario. The ability to import information from external packages in order to avoid duplication of database and extensive data manipulation is advantageous. This task may be very complex due to the need for writing and translating programs and this suggests that the provision of some kind of standard translation system is required. Kappa-PC provides ways for such integration.

The final conception of the application using Kappa-PC incorporated several modules defining the interaction diagram as illustrated in Figure 3.3. These modules are designed as stand alone systems. However, they can communicate information to a common data store, corresponding to the class/instance hierarchy, which can then be read by the other modules in the system.

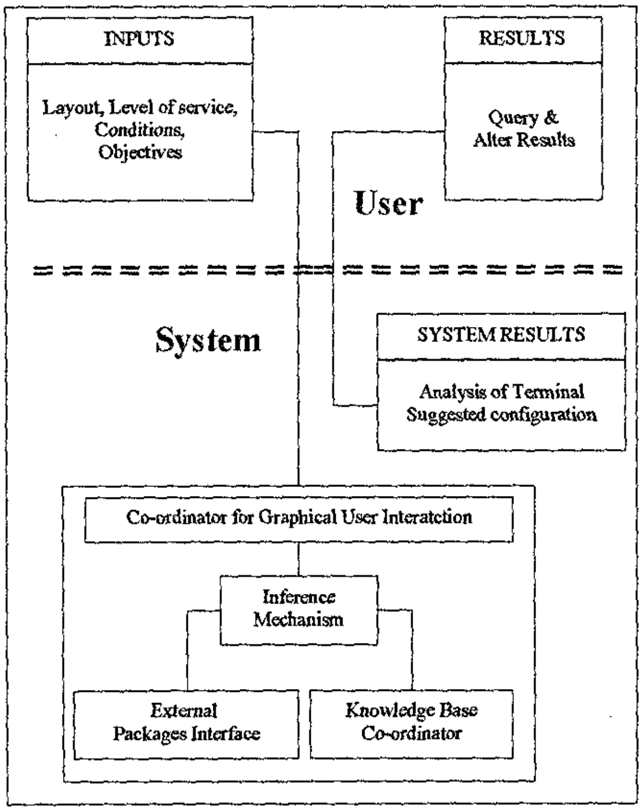


FIGURE 3.2: User Input Format.
Adapted from [Foster (1995)]

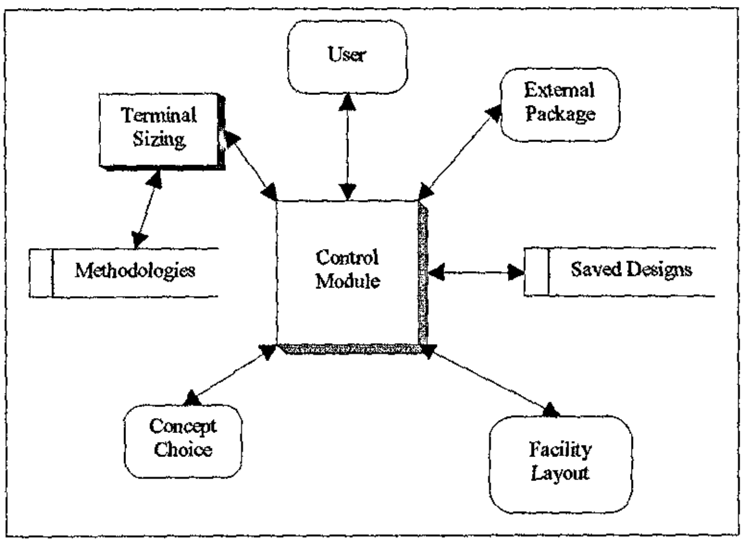


FIGURE 3.3: Interrelationship between DSS modules.

Of utmost importance for the object of this chapter is the Terminal Sizing Model. By means of comparison with an ideal design to more closely match certain pre-established standards or level of services, an existing terminal can be evaluated and assessed for the extent by which it may be improved by suggesting alterations or expansions. A new terminal can also be sized using the information from the global knowledge base, a daily or weekly flight schedule, or a given *facility sizing methodology*. The Terminal Sizing Module interaction is depicted and highlighted in Figure 3.4. Other features and module descriptions in the DSS system can be seen elsewhere [Foster, 1995]. The Terminal Sizing Module is internally the same as the Kappa-PC characteristic and structure, although the sizing methodology was developed based on conventional programming. The module allows the equations to be implemented inside the program and to perform the calculations involved in facility and terminal sizing. In general any method that has incorporated an algorithm in it with definite equations which can be translated to formulae can be stored in this module.

3.2.2 Facility Sizing

The solution of allowing any sizing methodology to be created and edited into the program, by which the sizing of individual facilities can be accomplished , is an alternate method of coping with the lengthy and difficult task to hard code all possible methodologies into the design support system. This provides a generic framework that is flexible enough to support different methodologies or a combination of several methodologies in order to create a new one incorporating areas from the distinct set of equations. The edit module needs to provide the possibility for the user to both:

- create new sizing methodologies, and
- edit existing sizing methodologies.

New ones may be created by building entirely new facility size algorithms, or by extracting values from existing methodologies. The possibility of combining different sizing methods through a particular equation or mathematical calculation, or even by calling to an external package to extract a value is the strength of this module. The weekness of the existent tools for terminal sizing is that they are all in some way incomplete. Other softwares that are based on simulation techniques such as ARCTERM and NAPA [ARCTERM (1994), NORR (1992)] can indirectly derive a size for a terminal, even though the results only account for the accumulation of passengers and probable queue lengths of each facility rather than the space required. The manual procedures for terminal sizing such as the FAA and Ashford's methods [Ashford (1992)] also lack information. They give, for example, the total area for international facilities which are calculated based on rules of thumb, however the number of desks or positions required are omitted. Sometimes facilities are looked at from a different approach either by their inputs or by the outputs required to size them. A methodology which combines these distinct aspects of different models is ideal for sizing a terminal.

Terminal Hierarchy

The initial structure of a series of standard facilities to be found within a terminal building, (see Chapter 2), was built and divided into four classes according primarily to passengers flows: Arrivals; Departures; General; and Airline facilities. Those classes were further divided according to three passenger characteristics: International area; Domestic areas; and Common areas. The former division takes into account that arriving and departing passengers generally use separate areas throughout the terminal building during their respective processing. Airline space on the other hand is exclusive for the use of airlines in their operation. All other areas of the terminal, such as commercial, administrative areas; building structure; circulation, etc., are attached to General Areas. For the sub-division, international and domestic areas are grouped facilities which are unique to either international or domestic passengers, whilst common areas may be attached to those facilities that can be used by both international and domestic passengers.

Although this hierarchy structure has been pre-defined it can be altered by the user to reflect any particular requirement. What is important in the initial structure is that it breaks down into actual facilities with which the methodology has its foundation. The terminal is composed of a number of individual facilities that when sized and arranged define the terminal. The decision support system is able to read data directly from other computer models and also provides a means for designers to enter values directly, therefore creating or editing a methodology a particular facility through 'equation' or may be a mathematical calculation, or a call to an external package in order to extract a value.

Facility Sizing Module

This module provides the mechanism to either evaluate or size a terminal. Traditional methods for sizing have their calculations based on peak hour volumes. However, there is a tendency now toward a method that is established and supported by flight schedules rather than only peaks. This module, therefore, provides a schedule integration and an editor for the construction of facility sizing methodologies. Figure 3.4 shows the interrelationships between these modules. The modules allow the user to choose the methodology to be used, which may have its own internal set of facility definitions, or have existing facilities with new sizing equations. This requires that a methodology be divided into a set of facilities and equations which gives a conventional feature to the system. The equation to be used is selected by a division of the methodology into distinct levels of service, and has one equation per level.

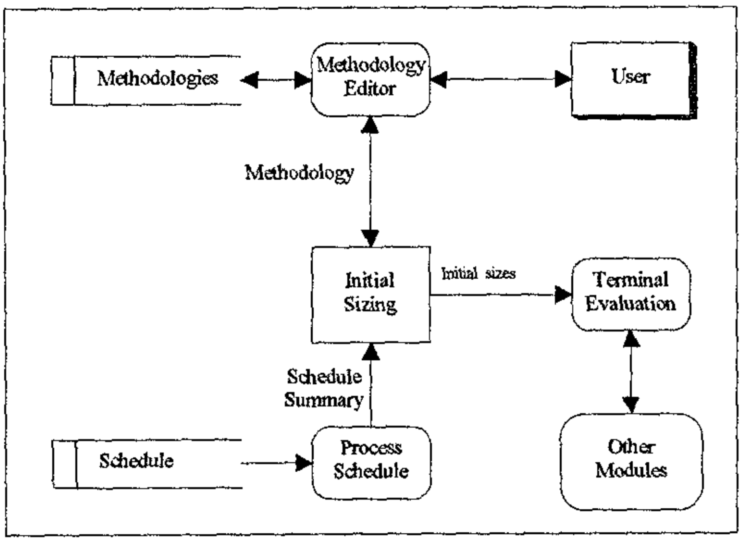


FIGURE 3.4: Main interactions of facility sizing module.

The variables stored in the system are those pertinent to each method, however they are commonly used and different methods can access the same variables. When a terminal is being sized for the first time the variables should be initialised. This may be done by either reading the values from a file, or asking the user to specify values directly. After all the relevant variables are entered an initial sizing is then presented to the user as a summary of the main areas. This may then be broken down into the constituent areas. The individual areas may be subsequently re-sized by adjusting the values of some of the variables used.

Once an initial terminal size has been calculated and displayed the user is presented with a list of the possible variables they may use to change the terminal size, allowing for the fine adjustment of the terminal. In order to do this a window is displayed showing the overall terminal area, together with that of a given facility. Alongside this are various controls for the manipulation of values with sliders and buttons. These controls act directly on the variable concerned and trigger a method within the image definition which automatically re-sizes the terminal as the variable is manipulated.

Editing Equations

Two separate modules were used to allow the creation of a new methodology and the editing of equations as shown in Figure 3.5 and 3.6. The instance 'methodologies' contain definitions for each methodology in terms of the levels employed, facilities used, and equations to be called. The editing of equations is common to both the creation of new methodologies and the editing of old. The variables displayed for use in the equations are divided into four groups in the system:

- Terminal variables, the top level variable in the system which may be used by any methodology,
- Local variables, that are local to the currently designed facility
- Schedule variables, that are specifically attributed to the schedule module.
- Facility names, equations can be constructed using the size of another facility in the terminal hierarchy, and any newly defined facilities or variables

The equations themselves are stored in the terminal hierarchy structure and the facility concerned has a method defined corresponding to the equation to be called up.

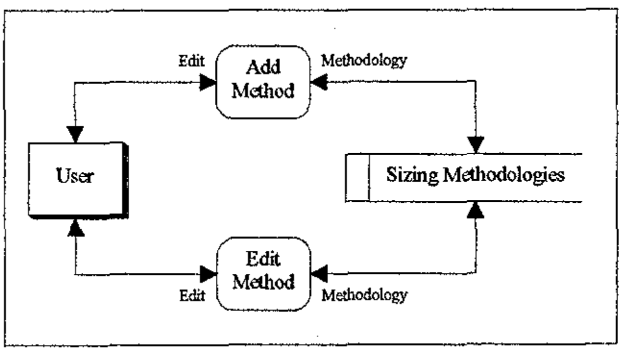


FIGURE 3.5: Structure of method editor.

The system has an internal consistency to make sure that the equation is correctly defined. This is accomplished by the final check on the validity of the codes, e.g. "var. +" is allowed, but needs another variable to be complete.

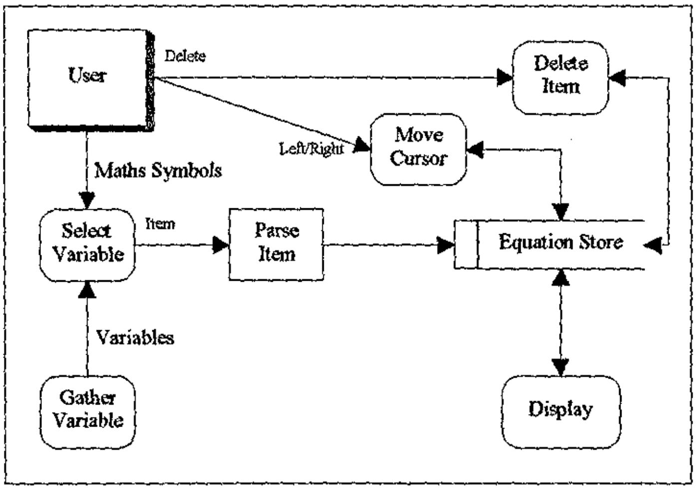


FIGURE 3.6: Editing equations.

Once the equations have been edited or created, they can be included in the methodology and be sorted into discrete levels of service. Each equation has associated with it a facility and each level has a list of facilities. In this way the concept of level of service can be incorporated into the system.

In a similar way, the creation of a new methodology or the edition and alteration of an old methodology can be done. A special routine searches through the facilities to find all the pertinent sizing equations irrespective of which methodology it is currently used in, and add to a new method the facility and equation being edited or created. As indicated before, facilities and equations from several different existing methodologies can be combined in a newly created methodology, thus encompassing the possible effectiveness of some of the equations of one method, creating new ones and leaving out others. Figure 3.7 shows a diagram of this procedure. Therefore the Terminal Sizing Model and sub-models should allow the user to be able to add new terminal facilities; create equations for new and existing facilities in the system; select a facility that indicates to the system which equations, whether new or existing, are to be associated with the facility in the designed methodology; sort these equations into different levels of service in order to complete the methodology design; and, select, create and edit methodologies. In synthesis the system has been built with a complete editor for the manipulation and formulation of facility sizing, methodologies and set of pertinent equations. A methodology can therefore be used to size a given set of facilities each one having a proper equation. Flexibility is also provided for the initialisation of variables used in terminal sizing through primitive file import or through direct input.

The final attribute embodied into the system and connected with the Terminal Sizing Module is the possibility of integrating the sizing results to an external design package such as a CAD program, allowing the user to perform a detail terminal layout. Nevertheless, the system also has a module to suggest an alternative and simplified layout, which automatically positions facilities based on the flow pattern and information about the likely positions of these facilities.

The knowledge representation in the software system acts as a frame structure, but there are no provisions for machine learning algorithms in the design, so the system cannot learn from previous designs in order to produce better new designs.

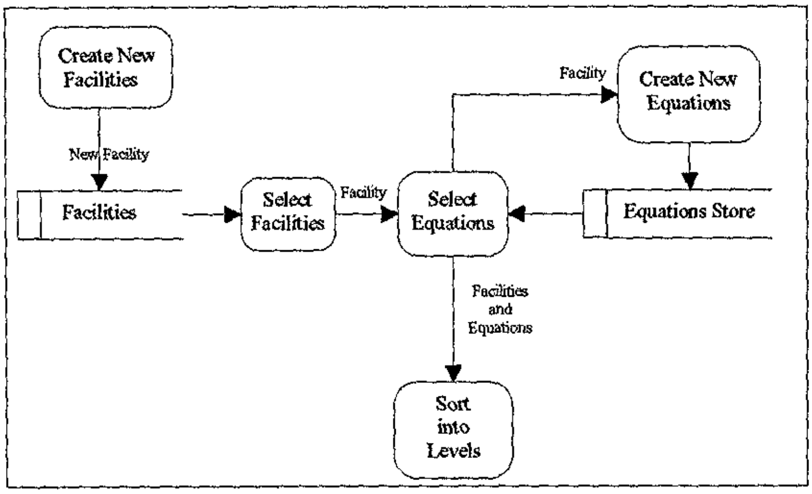


FIGURE 3.7: Top Level Organisation for Adding new Methodologies.

3.3 IATA and LUTERM methods combined.

Having provisionally decided which software structure to use, the next step was to devise a set of equations to input into the system that would effectively enable a terminal to be sized. It became necessary to ask whether it should be done by using the sizing equations from IATA (1995) Airport Development Reference Manual, the equations from LUTERM model, or by some other methods. The result implications of the different possible methods needed to be assessed and what type of output was necessary to have a whole picture of the terminal being sized.

These two methods are somewhat incomplete in terms of sizing the terminal as a whole. In both methods there is a lack of information which is necessary for sizing a terminal, and also a lack of some complementary information that is necessary for layout development. For example, the IATA programme gives only the net usable area for a particular facility (where this is applicable). The FAA method on the other hand includes areas such as circulation, structure and HVAC. The IATA gives only the number of baggage claim devices required, and the FAA/Ashford method provides the total area required for a particular baggage claim device technology, but does not give the number of devices required. The IATA gives the number of check-in positions, and the FAA/Ashford method gives the total area. Some facilities are not included in the IATA model but are included in the FAA/Ashford model. Both methods have quite different approaches, but have a similar objective: sizing an airport terminal. To some extent it might be possible to combine these different approaches.

The IATA method is deterministic, based on equivalent peak hour volumes as its main input, which incorporates the conversion of an actual flow into an equivalent flow based on the passenger throughput during a peak period within the peak hour, rather than the average throughput taken over the whole peak hour. Such time is referred to as 'Performance Standard'. The programme is based on relatively simple formulae, though it requires a great number of input variables and several levels for decisions, which is dependent on whether or not a complete set of input data is available. For example, the sequence of data entry screens related to the check-in facility sizing function may lead to a series of different data entry screens, dependent on whether the user answers yes/no to the two questions related to the check-in processing characteristic (common/dedicated), and if there is data available on short-haul and long haul flights. The great advantage is that the formulae are well known and have been used successfully by airport planners for many years. The main drawbacks are the limited number of airport terminal elements, the input or output consisting of the net usable area for a particular facility, and the lack of area for some facilities.

The FAA/Ashford method is empirical and is based on data gathered in the 70's. It is, therefore, rather out of date. Furthermore it was developed for American domestic airports. It was also developed before the airline deregulation in the USA and did not take into account the theory of hub-and-spoke airport. The main model input is the Equivalent Aircraft, which corresponds to the seating capacities and number of aircraft in a given peak period. (See Table 2.5 in Chapter 2 for the inputs required in both methods).

In addition to the above 'disadvantages', it is not clear whether the results from the model can be currently used. These negative points are the main reasons indicating that the method is out of date. However, the fact that some airports like Chicago, Atlanta and Dallas Fort Worth had a high percentage of connecting traffic even before deregulation [Kanafani (1985)], may be a contra argument in the FAA/Ashford method for not considering conceptually hub-and-spoke airports, but they were somehow empirically included, even though the transfers were largely interline rather than on-line. Furthermore, this author compared the actual areas of Dublin, Newcastle, Leeds, Sao Paulo, and East Midlands airports, with the total terminal area obtained with LUTERM model, and the results were found to be very similar. There is a strong indication that this model is still valid for terminal sizing and could be used into the DSS system.

The IATA formulae is based on vast experience of expertise in the subject of airport planning and has been used in airport developments world-wide for many years, therefore seems to be more 'reliable' or less controversial than the FAA method. But in spite of its reliability the method is still incomplete; some additional formulae are necessary, which suggests that a combination of methods would be more appropriate.

It was decided in this research project to use the IATA formulae as the basic method for the DSS system and to incorporate any missing information from the LUTERM model.

To investigate further the validity of the FAA method, and the possibility of combining it with the IATA method, they were compared using the LUTERM and IATA programmes. As the inputs for both methods are different, a very close set of assumptions was adopted. For example, the EQA aircraft used in the LUTERM method was determined by the actual peak hour passengers used in the IATA programme, including the load factor (see Chapter 5, EQA). The same level of service, the same proportion of international and domestic traffic, etc., were allocated to both methods. The results of the LUTERM programme were corrected to give an approximation of the net usable area for each facility.

Some differences were found for a few individual facilities as exemplified in Figure 3.8. However, the overall results indicated a high degree of compatibility between both methods. For example, Figure 3.9 shows that the results obtained for the total areas are very similar for both methods. Part of the individual discrepancies were observed and corrected by adjusting the level of service in the IATA model. However, the higher value for the IATA check-in area in Fig 3.8 can be explained by the fact that, for this particular facility, used a level of service *A*, which is not explicit in the LUTERM method.

The formulae used in the IATA programme are those contained in the IATA Airport Development Reference Manual [IATA (1995)] and the equations used in the LUTERM have been defined from a series of graphs, originally given in FAA (1976a). The LUTERM programme follows the diagram depicted in Figure 3.10.

In order to combine both methods into the DSS, the problem of transforming the Equivalent Peak Hour (*EPH)* to an equation which is given in the IATA Airport Terminal Capacity Programme - User's Handbook in the form of two graphs had to be overcome. In Equivalent Peak Hour, the main value used in the calculation, is the number which corrects the actual peak hour (*PH*) for a variation of the arrival pattern in the form of a given Performance Standard (*PS*) in minutes, considering the arrival pattern as a Poisson distribution, which, when large numbers are involved, can be approximated by a Normal distribution. The mean throughput based on the adopted *PS* is given by:

$$Mean = \frac{PH \times PS}{60}$$

and the Standard deviation (S_d)by:

$$S_d = \sqrt{Mean}$$

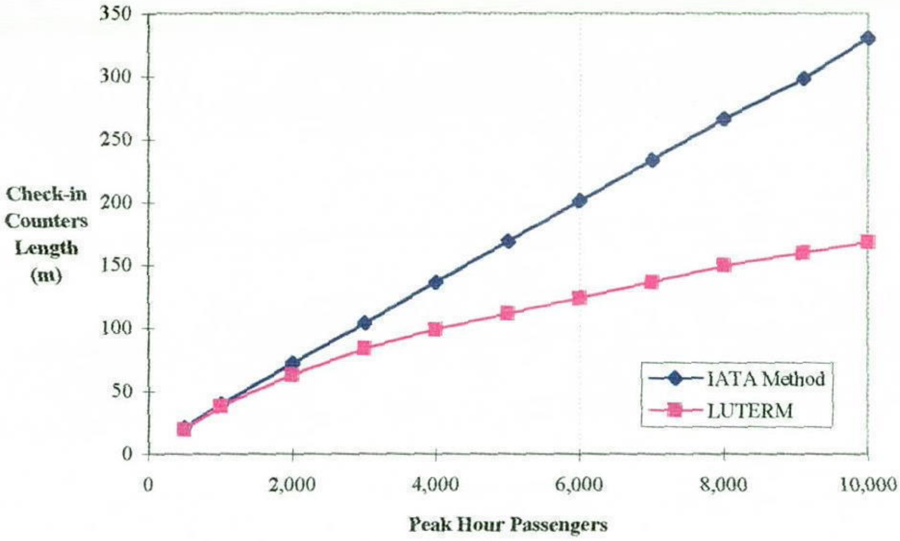


FIGURE 3.8: Check-in length, comparison between LUTERM and IATA programme.

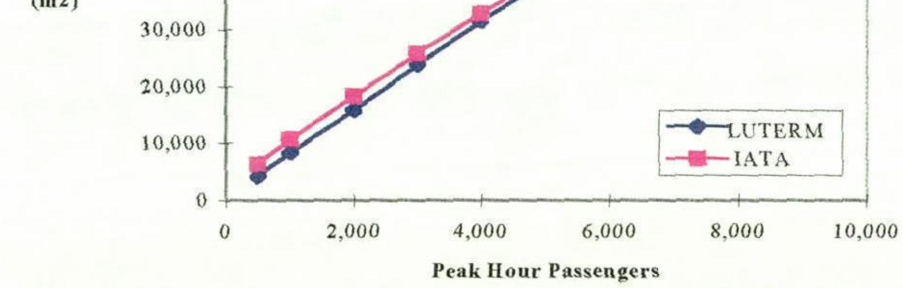


FIGURE 3.9: Comparison between IATA and LUTERM sizing methods.

Considering the property of the Normal distribution that 95% of all 'observations' will be within the limits of the mean ± 2 times the standard deviation, the *EPH* equation can be defined as:

$$EPH = PH + 15.5\sqrt{\frac{PH}{PS}}$$

This is the main formula input for the calculation of most of the facilities in the IATA model.

The IATA formulae were adopted as the basis for the standard sizing methodology in the DSS Sizing Module, including also the formulae for queuing relative to each facility. The programme based on those formulae calculates sizes for the elements of the terminal building that are included in the diagram depicted in Figure 3.11.

There was also a need to add other main facilities to the system, once all areas required for ancillary facilities such as concessions, service, equipment rooms, offices, toilets, HVAC, structure, and circulation are not included in the IATA programme.

The other important information lacking in the IATA programme shown in Figure 3.11, is that only five of the thirteen facilities state the required area. For the other eight facilities the programme output is number of positions, number of x-ray units, etc., rather than area. The completion was given by the LUTERM module and by the individual facility methodologies described in Chapter 5. For example, the main circulation spaces were added by using the formulae indicated in Section 5.3.

By inserting a standard sizing procedure into the DSS Sizing Module in an attempt to join the two methods, the system was provided with flexibility for accepting new equations or combining new methodologies.

The possibility of integrating the Facility Sizing Model with the Layout Model through an external CAD design tool is one important characteristic of the DSS system, which was not completed at the time of using the former module for sizing the terminals object of the methodology of this thesis. Therefore the layout of the theoretical terminals was carried out by inserting manually the results from the Sizing module into a CAD program. An example of a set of the drawings elaborated in CAD software is presented in Appendix D.

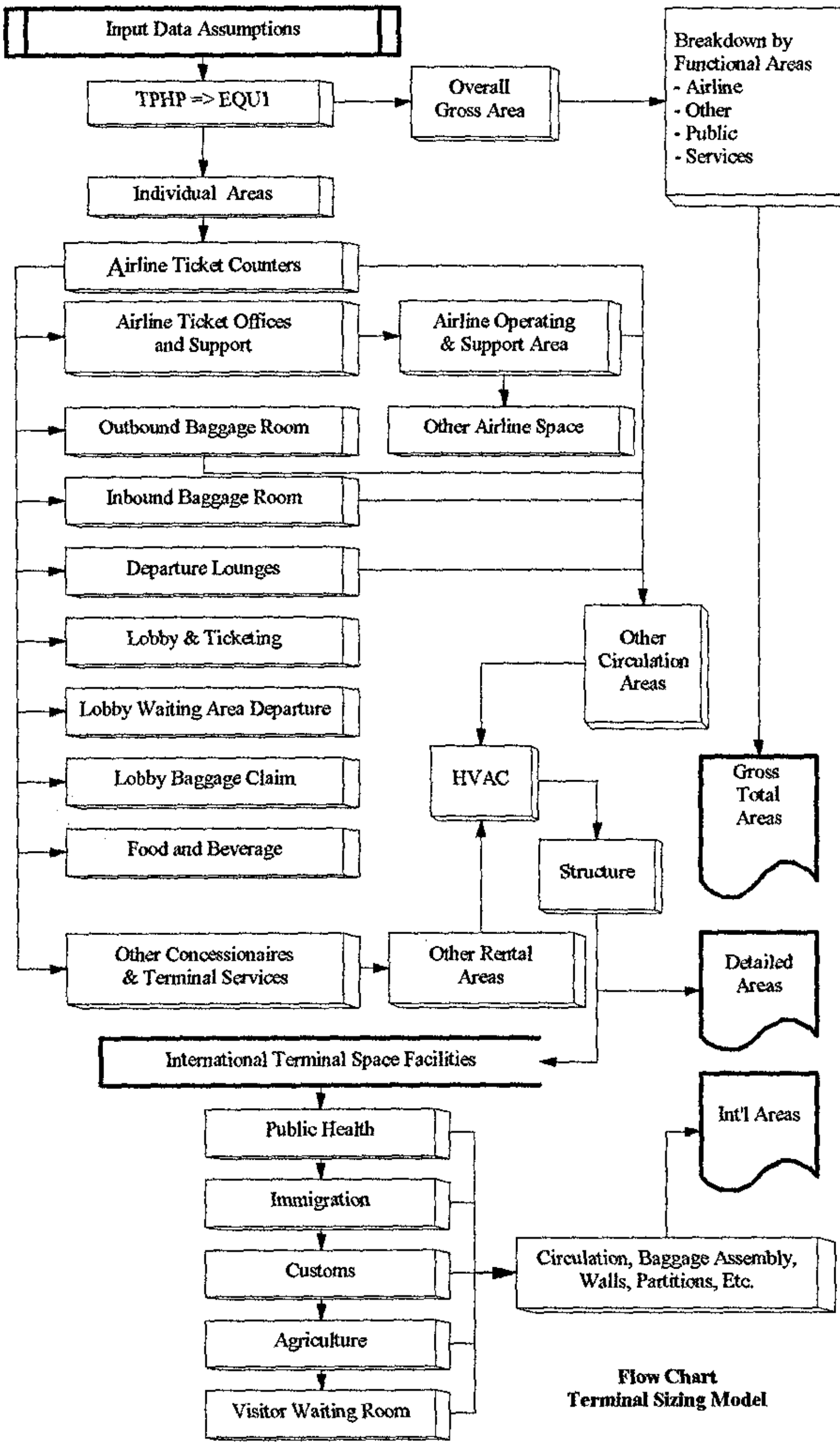


FIGURE 3.10: LUTERM sizing diagram.

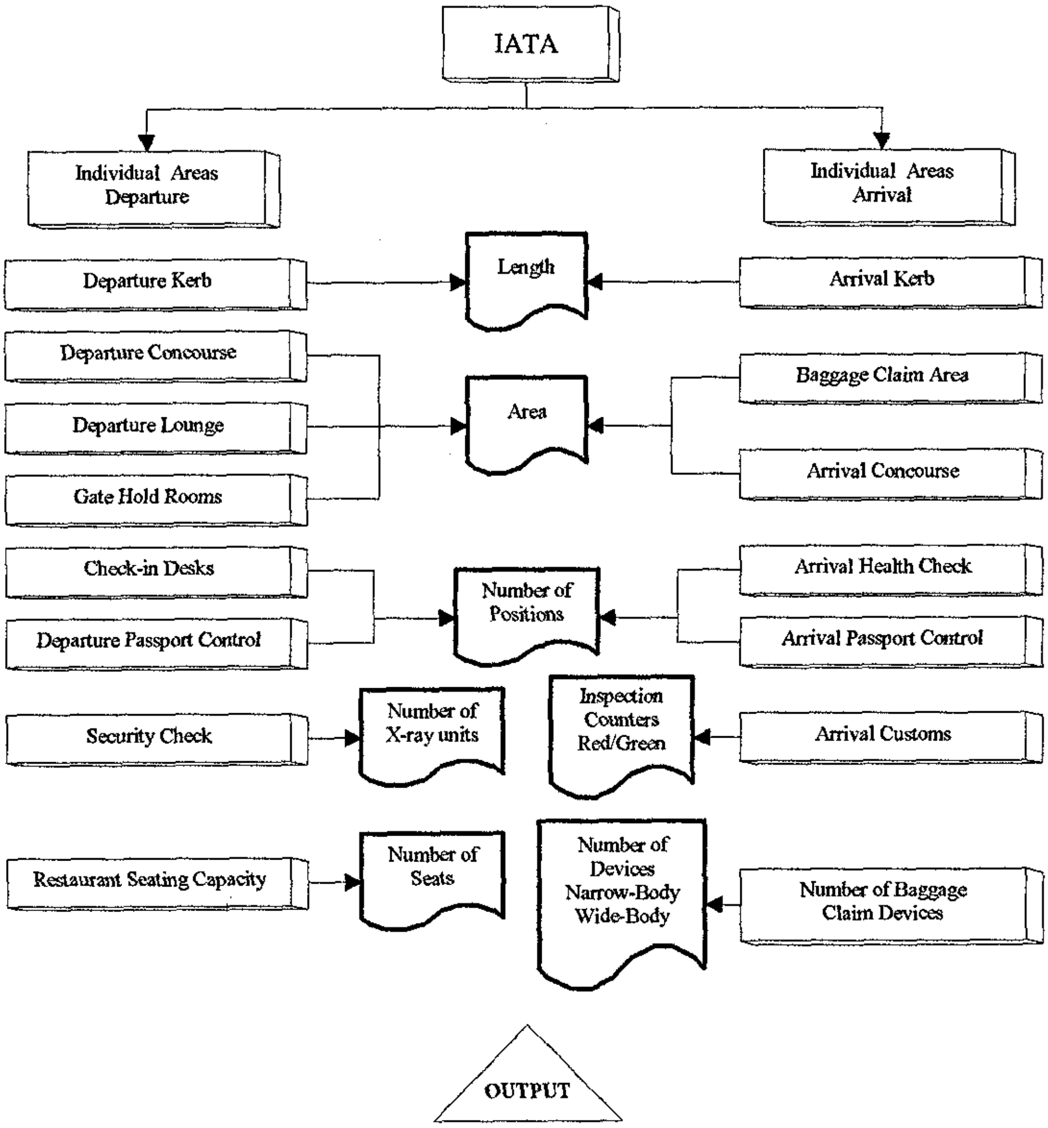


FIGURE 3.11: IATA Programme sizing facility outputs.

3.4 Summary

In this chapter a partial solution for the development of a tool to assist the designers in planning and design of an airport terminal was discussed. It described the implementation of a software system which could act as an aid in the terminal design process by exploring the use of decision support and expert systems technology known as the DSS - Decision Support System for Airport Terminal Design. Although the system is quite comprehensive, the focus was directed to the Sizing Module.

The Expert System for Decision Support was found to have many other functions in addition to sizing, including the flexibility to integrate many other external packages to satisfy the requirements of a strategic planning tool for airport designers. It was also found to be compatible with existing design models, such as NAPA, SIMMOD, ARCTERM. These functions and system characteristics are described in detail in Foster (1995).

The standard method included into the Facility Sizing Module of the Decision Support System for Airport Terminal Design, a computerised tool that allows sizing a set of terminal facilities was discussed. The chapter concluded with a description of a combination of different and well known methods that have been used in the field of airport terminals for many years coupled with the experience of the author acquired in ten years working in this area and three years of research.

4. CHAPTER IV Terminal Concepts

4.1 Introduction

The preceding chapter explained the development of a tool for terminal sizing, but before following the sizing procedures it is interesting to look at the implications that different shapes may or may not impose upon this process.

Although an airport terminal used to account for only one quarter or less of the cost of an airport, nowadays individual terminals can be extraordinarily expensive. For this reason de Neufville (1980) emphasised that terminals should be designed with the utmost care. Considering the *shape* of a terminal, his view is that a hybrid of pure concepts is most suitable for an airport terminal design. He pointed out that planners have been using intuition rather than a systematic analysis as the deciding factor in this selection process.

Some authors and experts claim that the choice of the apron terminal geometry must be made at the first stage of sizing an airport terminal. Nevertheless, there is no explicit method or criteria to establish the concept applicable. Furthermore, it seems to be a paradox trying to chose a form which will certainly dictate the success or failure of the whole process, at a stage of the project when not enough detailed information may be available. The problem facing the planners of a design at this stage certainly varies as projects vary in size, quality and complexity, location, cost, and urgency, therefore it seems that no single detailed procedure can be applicable to all.

The common ground for terminal design is that every project involves a chain of decisions which starts from the decision to build, then passes to a decision where site finance and other resources are thought as adequate to meet the requirements. It thence passes to decisions on a particular scheme, on the details of design and construction, and finally to decisions on the design or choice of the specific fixings. Among the main stages in the chain decision is the feasibility stage where the configuration has to be chosen ensuring that it is feasible, functionally, technically and financially. The weight that each requirement, such as site conditions, physical aspects, external or internal constraints and costs lay upon the project, as necessary to reach decisions, vary from different circumstances. Nevertheless costs seem to play a significant role in the majority of designs, as well as being a factor of decision making.

In the light of the variables involved in the design process, a common framework can be established to define the choice of the main configurations and should be considered as a major decision. Once the basic configuration is chosen, the planner will be able to use it as a guideline for any hybrid configuration that might be subsequently adopted.

The vocabulary of terminal architecture such as shape and form, concept and configuration needs to be defined. They are all used quite synonymously, but what exactly is meant by these terms in this context needs to be clarified.

Shape is the outer form of a terminal. It is usually viewed in a two dimensional sense. Some shapes are essentially geometrical: regular figures such as rectangles, squares, triangles, or circles; others are more complex composed of mixed lines; and some are totally irregular. The shape of a building is directly related to its efficient functional arrangement and economical construction. Reekie (1976) states that "... a good design is a mosaic of tidy, well-shaped pieces, each contributing smoothly to the overall effect". Shape is the principal identifying characteristic of *form* and results from the specific arrangement of a form's surfaces and edges. Although defined as a synonym of shape, *form* is usually used in a three-dimensional sense.

Concept by its definition is an idea or a principle. A 'Terminal' concept therefore is a taxonomy based on the criteria of *form*. The different types of terminal buildings that form the present classification do exist because they each manage to fulfil a specific function. In the design process form follows function. They are the result of a historical process that began with the inception of the air transport industry at the beginning of this century and which has continued to the present.

The word '*configuration*' is used here to describe the arrangements of the different terminal basic concepts. For example, a unit terminal can be an arrangement of several pier terminal concepts put together or a pier and a satellite. Some authors use the term 'terminal configuration' to mean terminal concept.

Horonjeff (1994) and Ashford (1992) suggest that the design concepts are fundamentally based upon the way passengers are physically arranged and processed. They describe passenger processing as either *centralised* or *decentralised* processing; but even so, they use *form* as the way of grouping and representing the different configurations. Hart (1985) identifies the dominant feature to define concept as the *link* that connects an *aircraft gate configuration* with a terminal. Blow (1991) conceives the terminal concepts as a taxonomy of *aircraft terminal forms* with organisational properties and with *bio-forms* characteristics, which add a dynamic aspect to the terminal-aircraft relationship. Blankenship (1974) states that the basic concept is determined through the effects of various *interactions* between systems inside and outside the terminal. IATA

(1995) emphasises the degree of *centralisation* of the processing activities as the main factor in the process of developing a terminal concept.

Looking at the building characteristics, it is the terminal *form* that reveals its *concept.*

4.2 A Concept review

de Neufville (1980) states that, one of the dominant issues in aircraft planning concerns the *shape* and *function* of terminals. The *shape* of the terminal is largely the most important requirement in airport terminal design. It can satisfy the multiplicity of different kinds of demands efficiently, and establishes the flexibility that the uncertainty of the future requires. The shape is certainly one of the most important criteria to look at in the design process. The *shape* will probably establish the best balance between capacity and demand, efficiency and economy, comfort and costs, and between a terminal under-utilised most of the year or being too crowded for almost half the days of any month, due to the seasonality and fluctuation of an unbalanced traffic distribution.

Nearly all authors, referring to concepts of terminals, stress its importance in the context of terminal planning and design, describing its characteristics, advantages and disadvantages. Although there are few stated methodologies, theories, and even a speculative approach to how to proceed in the design process to select a terminal concept, there are a variety of design concepts available to the planner.

The Apron-Terminal Complex, prepared for Federal Aviation Administration by Ralph M. Parsons Company in 1973, is a very comprehensive document that describes the four basic concepts of terminal form: linear, pier, satellite, and transporter, and indicates their suitability to specific airport situations, considering traffic levels, physical constraints, and airline station characteristics.

Blankenship (1974) also describes these four basic terminal concepts illustrating qualities inherent to each one of them. He suggests that *flexibility* is the most important attribute. The selection of a terminal type is based on interaction between elements within the terminal system and may be defined therefore through comparisons of the effects that are produced as a result of those system interactions. His analysis of terminal configurations observed the following factors:

a) total acreage;
b) total square footage;
c) curb availability;
d) expansion capability;

e) aircraft manoeuvring capability;

f) construction cost;

g) relationship to adjoining terminals or satellites; and

h) common hold room aspects.

The critical parameters in the terminal system evaluations are described as those associated with congestion and delays.

An interesting classification is made by Shen (1988) that divides the concepts into: designs before Automated People Mover (APM); and designs with APM Systems. Before APM he classifies the common basic concepts: Linear, Pier, Satellite, Unit Terminal, and Transporter. Concepts with APM Systems are: Remote Satellites, Remote Piers and Unit Terminal.

An attempt was made by Braaksma (1976, 1979) to design concepts systematically, based on an heuristic modelling technique with the objective of minimising area and transportation costs. Using an heuristic algorithm, he produced a theoretical concept through finding the 'best' spatial arrangement. Circles were used to represent the area and shape for both, aircraft and passenger loads, see Figure 4.1. The problem was broken down into three parts:

(1) Facility sizing;

(2) Flight assignment; and

(3) Facility layout.

The objective was to find the minimum amount of space required and the best possible assignment of passengers and aircraft to facilities and produce a geometric configuration respectively.

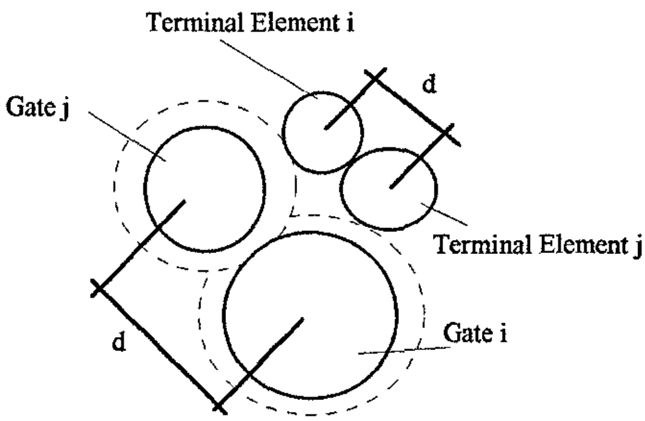


FIGURE 4.1: Theoretical Concept. (Source: [Braaksma, 1976, 1979])

His method uses what he called a bridge to link two theoretical and actual plans. From two parameters to describe a concept (*decentralisation* and *shape*) through two correlated indices (decentralisation index and compactness index) the final objective is defined by the indices that characterise the theoretical concept. Then, by matching them with indices of an actual concept, the most suitable concept can be identified. Although these two pieces of work could be considered as a complete methodology for arriving to a terminal concept definition, problems arise from the comparison with actual terminals. Two parameters are not enough in themselves to represent and contain all factors influencing the multiple aspects of an airport terminal in operation. He summarises the concept in terms of level of service, economy of design, and flexibility as in Table 4.1.

Table 4.1: Evaluation of Basic Terminal Concepts

Terminal Concept	Level of Service	Economy of Design	Flexibility
Centralised			
Finger	poor	good	good
Satellite	fair	good	fair
Remote	good	very good	excellent
Partially Centralised			
Connected	fair	good	good
Unit	fair	fair	good
Aeroquay (Toronto Airport)	very good	good	poor
Decentralised			
Linear Modular	fair	poor	very good
Spinal Cluster (Dallas Ft.-Worth)	fair	poor	very good

[Source:Braaksma, 1975]

Mumayiz (1985), Beinhaker (1975) and Blankenship (1974) attempted to group the different configurations in three historical time periods:

First generation: from pre war to late forties early fifties, which includes the *linear terminal* (simple terminal).

Second generation: from the fifties up to the mid sixties, which includes *linear, satellites, piers and transporters* (open apron).

Third generation: since mid sixties, including *linear decentralised* (gate arrival units), *remote satellites, remote piers, remote apron.*

Table 4.2 summarises the most common taxonomy of airport terminal concepts.

The basic agreed concepts are: Linear, Pier, Satellite and Transporter and they are detailed in the following paragraphs.

TABLE 4.2: Terminal Concepts Classification

Concepts	References (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Simple							x		
Basic Terminal with remote aircraft			x						
Linear		x	x			x	x		
Open Apron or Linear	x								
Linear/Gate Arrival				x					
Gate Arrival	x				x				
Pier		x							
Piers: single or multiple			x						
Central Terminal with Pier Fingers	x								
Pier Finger				x	x	x	x		
Satellite		x		x		x	x		
Satellites: single or multiple			x						
Central Terminal with Pier Satellites	x								
Pier Satellite					x				
Central Terminal with Remote Satellites	x								
Remote Satellite					x				
Transporter		x					x		
Basic Terminal with mobile lounges			x						
Remote Apron or Transfer or Transporter	x								
Open Apron				x					
Mobile Conveyance					x				
Unit Terminal							x		
Multiple linear units			x						
Multiple island piers			x						
Central Terminal with Remote Piers	x								
Compact Module Unit Terminal						x			
Before APM Systems (Linear, Pier, Satellite, Unit Terminal and Transporter)									x
With APM Systems (Remote Satellite, Remote Pier, Unit Terminal)									x
First Generation (simple)								x	
Second Generation (Linear, Pier, Satellite, Open Apron)								x	
Third Generation (Gate arrival Remote Satellite, Remote Pier, Remote apron)								x	
Hybrids: Combinations of forms			x						
	8	**4**	**8**	**4**	**5**	**5**	**6**	**3**	**2**

References

(1) Ashford, (1992)
(2) Blankenship, (1985)
(3) Blow, (1991)
(4) de Neufville, (1980)
(5) Horonjeff, (1994)
(6) IATA, (1995)
(7) ICAO, (1987)
(8) Mumayiz, (1985)
(9) Shen, (1988)

4.2.1 Linear Forms

The oldest terminal concept is the single building housing all terminal functions with the aircraft parked against the terminal. Aircraft usually are parked in a single line at a corridor or concourse connecting with other functional elements of the terminal. Another usual practice is that of passengers walking or using buses to get into and out of aircraft parked on an open apron.

The linear concept is an extension of the single concept with small terminals arranged in a linear procession, each with a complete set of systems for each isolated terminal. As the major functions such as outbound, inbound baggage may not lead to centralisation, the building depth of a linear terminal may usually be shallow. At Dallas Fort Worth, the building depth varies from 23 to 37 m. At Kansas City International Airport the building depth is 20 m. At Manchester Terminal II, on the other hand, the building depth is 125 m; at London Heathrow Terminal 4 is 90 m; and at London Gatwick North Terminal is 125 m.

The linear concept can assume different geometric forms. Although the conventional idea of the linear terminal is a long straight building, the description has a wider application and today can also refer to a series of buildings laid out in a line, though the plan of the buildings may be curved. Dallas Forth Worth Airport, Rio de Janeiro International Airport and Charles de Gaulle - Module A & B are examples. Circular linear units, for instance, like Kansas City Airport, have drawbacks in the apron design where large areas between the taxiway system and the terminal may remain unused.

One advantage is the direct integration of airside terminal facilities with landside access/egress activity. As individual segment is provided with all functions, congestion may be kept to a minimum. However, the cost of decentralisation processing may outweigh the advantages in certain cases.

Ashford (1992) conversely describes the linear concept as the most centralised of all arrangements. It is frequently used for low traffic volume airports. They are appropriate for airports with traffic volumes up to 200,000 annual enplaned passengers. Between 200,000 and one million annual enplaned passengers, linear, pier and satellite concepts are more appropriate as the linear concept begins to exhibit an increasing degree of decentralisation. Above one million, according to old methodologies this concept is not applicable.

A linear concept terminal design with than one million passengers requires a sophisticated signing and graphics system for identifying airlines, gate positions, arrival concourses, etc. Hart

(1985) remarked that this concept demonstrates unfavourable conditions that prevent it from being applicable to airports with more than 1,000,000 enplanements and more than 30% transfers. He also pointed out that due to the uncertainty of the future, one may question whether an airport with more than 1,000,000 enplanements and less than 30% transfers should adopt a linear concept at all.

The called Gate Arrival Concept is an extension of the linear concept. It is arranged in such a manner that the traveller can park his car at a point opposite to his departure gate, and if he/she is lucky will arrive back at the same gate. Munich II has a similar concept using alternative arrival and departure modules linearly arranged.

Linear arrangements usually provide ease of access and relatively short walking distances. Average walking distance may be reduced to the width of the terminal provided that passengers are delivered opposite the desired gate. Although the walking distances may be kept to a minimum for originating and terminating passengers, for transfer or intraline passengers this configuration can be quite unattractive.

The linear terminal may be expanded by adding unit terminals. An example is Munich II Airport. The most important aspect of this concept is the flexibility, in that there is no necessary interference with aircraft and terminal movements during construction. Furthermore the construction cost may also be less than other concepts as the structure may be kept very simple. The concept definition may then be named as Multiple Linear Units.

The implementation of linear unit terminals (or multiple linear units) naturally requires separate baggage handling check-in facilities and security controls. This significantly increases the number and cost of the equipment and staff needed to serve passengers. As was mentioned this configuration may become unacceptable for transfer passengers. The expansion capability exists by simply lengthening the building as necessary. Unfortunately linear terminals have a basic problem. This is the ripple effect caused when more than one airline use the facility. When one airline wants to expand, if it happens to be anywhere but on the end of the building, everyone else has to move in order to allow them additional room. One alternative for that airline is to build an entirely new space on the building end. However, if another airline wants to expand, an operational problem may be created [Downey, 1971]. The concept then becomes highly inflexible and certainly unfeasible from an economic point of view. To overcome this problem the Unit Terminal configuration, generally dedicated to one airline, offers the solution, provided that its capability to expand is not restrained by the next unit terminal.

IATA (1995) points out that this concept is mainly used if there is only confined space available between the landside road system and the aircraft ramp.

Figure 4.2 shows examples of some forms of linear terminals.

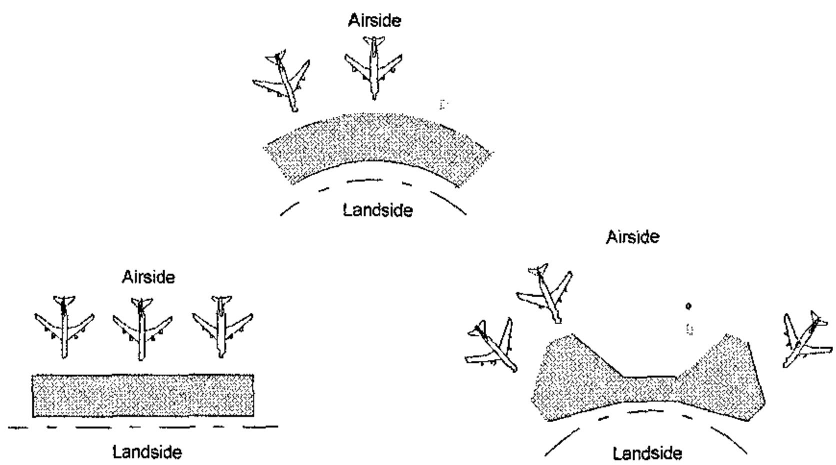


FIGURE 4.2: Linear Forms.

Some main advantages and disadvantages can be summarised as follows [Adapted from IATA, 1995]:

Major advantages	Major Disadvantages
• Minimum walking distance, if check-in facilities are decentralised.	• Longer walking distances for transfer passengers.
• Building depths are shallow.	• Long walking distance if passenger processing is centralised and the pier system (airside corridor) is extend.
• Easier passenger orientation; Separation of arriving and departing passengers is relatively easy using airside corridor.	• In a decentralised terminal a more extensive flight information display system is required.
• Simple construction of the main terminal; If decentralised, relatively easy incremental expansion.	• If system is decentralised, will require duplication of terminal facilities/amenities (restaurant, duty free) & personnel.
• If required, separation of arriving and departing passenger is relatively easy using airside corridor.	• Special logistic may be required for handling of transfer baggage depending upon size of building.
• Adequate curbside length.	• Reduced compatibility of building/apron geometry and future aircraft design development.
• If a decentralisation system is used reduced cost of baggage conveying/sorting systems.	• High capital operating and maintenance cost if centralised passenger baggage processing facilities are employed.
• Reasonable check-in and close out times.	

4.2.2 Pier Forms

This is the most common shape to be found at airports, as shown in Table 4.2. This concept first appeared in the 50s and was a direct result of the increase of aircraft size, i.e., the necessity to increase the terminal frontage correspondent to the increase in aircraft wing span. It also occurred as a result of airline processing changes, separating passengers holding facilities for each flight. The airline changed from a centralised processing check-in to a decentralised processing of passengers at individual departure lounges, immediately adjacent to aircraft parked along the pier.

Accommodation for a greater number of aircraft gate positions may be achieved by adding piers to the main building maintaining the increase of the total floor area to a minimum. Aircraft are parked along these piers extending from the main terminal area. There is no direct linear relationship between curb length and aircraft.

Expansion is more difficult as the walking distances may increase substantially. Expansion may be accomplished by linear extension of an existing structure or by multiplying the numbers of pier-terminal units with connectors. Unless this expansion is expressly planned it is often impracticable to extend piers due to infringement of space occupied by taxiways, other piers or other constraints.

Piers are usually two stories high, whereas the terminal enplaning and deplaning may be either on single or multilevel. The two levels offer the possibility for separating all systems associated with the various enplaning and deplaning functions, yet the ground level at the pier extension is usually used for airline operation space rather than for separating flows. This is usually accomplished by corridors at the first level of the pier.

The pier configuration has serious drawbacks. It is generally limited to a maximum size in terms of its passenger walking distances without the use of people moving devices. Blankenship (1974) noted that "the limitations of expansion innate in pier configuration extend also to apron areas and taxiways between piers, which being fixed cannot move apart to allow for increased sizes of aircraft and to enplaning and deplaning curbs, which usually can only be effectively expanded as far as the main terminals to which they are related can be lengthened".

This scheme generally is said to require less total space as, for example, for aprons, buildings, than other configurations and tends to be more compact (all services may be in one area), therefore it also tends to be most economical in terms of capital and operational expenditure.

Pier configurations are appropriate for airports with traffic volumes above 200,000 annual enplaned passengers and also allow centralised terminal operation. Ashford (1992) states that pier finger terminals can be very efficient for annual passenger volumes up to approximately 35 million annual passengers for domestic operation only, and 25 million annual passengers for international operation. At higher volumes there will be problems with passenger walking distances, as with larger gate requirement, the pier scheme increases the perimeter of the terminal to allow aircraft to be served.

The average walking distance of a pier terminal may vary significantly from 150 m to more than 400 m depending on terminal width, pier length, or whether people moving devices (travelators) are provided or not.

A different configuration of pier terminal design is pier satellite terminals, such as Tullamarine in Melbourne and Dublin Airport in Ireland. Pier satellites are a move toward decentralisation of the pier finger concept. As the terminal becomes more complex, or the satellite facilities become more elaborate, the economies of the design disappear.

The pier in its simplest shape is very efficient, although it can be arranged in various configurations which have certain advantages and disadvantages.

Hart (1985) described three of them as: a) 'Y' configuration; b)'T" configuration; and c) Parallel versus Radial, see Fig 4.3 c), d) and f).

a) Y configuration. This form is said to be efficient when a terminal complex is surrounded by multi-directional runways/taxiways, though the angles outside and inside the Y cause constraints in aircraft gate movements and flexibility in gate assignments. The finger may become quite long, more than 300 m. Kingsford Smith Airport in Sidney, Frankfurt Main in Germany, Amsterdam in Holland and Chicago O'Hare in USA are examples of this shape.

b) T configuration. This form is one alternative for lateral expansion of the finger, when maximisation of the terminal unit is preferred over the construction of an additional unit or there may be constraints in its length. As this expansion creates quadrants of 90 degrees opposite gates, the efficiency and utilisation of these spaces are compromised and may be very low. This may cause a large area of concrete to be useless. There may also be a problem at the top of the 'T' with aircraft movements interfering with the taxiways. Dusseldorf, Boston-Logan International, Miami International, and Philadelphia International are examples of airports where this shape is found.

c) Parallel versus Radial. In terms of apron utilisation, piers arranged in a parallel configuration appear to be more effective than in a configuration where piers are placed radially, forming angles between piers, with the objective of shortening walking distances in the terminal. The problem with radial configuration is that an unpaved triangular apron area may be formed, depending on the distance between opposite piers ends. Another problem may be the manoeuvrability of aircraft types (larger/smaller) operating at the airport, as the dimensions at the end and at the base are different causing different clearance distances along the pier. Depending on the traffic mix this may become a serious problem.

Figure 4.3 shows examples of pier terminal configurations.

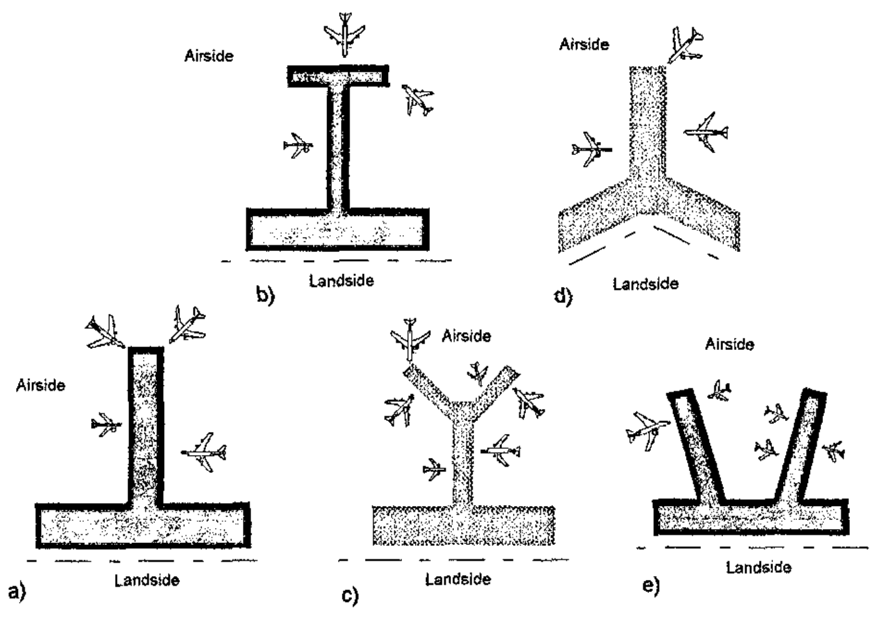


FIGURE 4.3: Examples of Pier Forms

Some main advantages and disadvantages can be summarised as follows [Adapted from IATA, 1995]:

Major advantages	Major Disadvantages
• Economic to build • Centralisation of airline and Government Authority processing personnel.	• Possible long walking distances. This is aggravated for interlining passengers in configurations with multiple piers.
• Permits centralisation of terminal facilities and amenities (i.e., restaurants, duty free, etc.).	• Curbside congestion in peak hours. Yet this can be common in other configurations.
• Permits use of relatively simple flight information display system.	• Limited expansion capability of main terminal due to the complex building geometry.
• Accommodate future larger aircraft toward the end of piers in a radial form without major changes.	• Reduced aircraft circulation & manoeuvrability; limited compatibility with future larger aircraft design development.
• Possibility of separation of arriving and departing passengers if required.	• Separation of arriving/departing passengers, if required, must be by different level (3 level finger).
• Facile control of passengers, if required.	• Early check-in and close-out times.
•	• High capital, operating and maintenance costs for passenger moving & baggage conveying sorting systems; potential for baggage mishandling.

4.2.3 Satellite Forms

Satellite configurations were introduced to provide airside flexibility through increased aircraft manoeuvrability and parking space by placing in most cases the passengers' access below the apron. It really consists of a building surrounded by aircraft normally parked in a radial position around the satellite, which is separated from the main terminal and is usually reached by an underground, surface, or above-grade connector. This arrangement also allows the aircraft to be concentrated about a point, therefore facilitating the sharing of equipment and service facilities. According to Ashford (1992) Satellite terminal design is a modification of the basic pier concept and represents a move toward decentralisation of the pier design as it permits ticketing and security functions be carried out at the aircraft gates.

The passenger walking distances may be kept to a minimum if people mover or mechanical systems are employed to transport passengers between the terminal and satellite, otherwise it may be maximised for all gates around a satellite. The average walking distance may vary depending on terminal and satellite dimensions. In this form also there is no direct relationship between curb length and aircraft wing span.

Expansion, mainly in number of gates, may be accomplished only by adding new satellite modules. This, in some ways, limits its capabilities of growth. If the connection is underground it may provide an excellent area for manoeuvrability for aircraft. On the other hand such connections are usually expensive to construct. If the connection is above ground, although less expensive, the advantages in aircraft manoeuvrability will be lost. Although aircraft manoeuvrability is usually increased, necessary pavement areas may be greater than in other configurations. It is noteworthy that a rectilinear form is structurally easier to expand than a circular, hexagonal or pentagonal configuration. Hart (1985) emphasised that expansion of a satellite can only be accomplished in two ways:

a) by constructing a larger concentric circle, which is costly and disruptive to implement; or

b) by adding rectangular areas, which seem to be awkward and unconventional.

Hart (1985) also stated that originally satellites were circular and were approved of because a maximum number of aircraft could be accommodated in such a configuration and yet occupy a minimum apron area at each gate position for a minimum building area. Satellite terminal may also assume other forms rather than just circular. Remote Satellites are often connected by some mechanised form of transport like Orlando, Tampa, Paris-Charles de Gaulle. Rectangular satellites (usually known as Remote Piers) parallels or with their long sides perpendicular to the terminal are good for high volume airports with considerable amount of domestic transfer and interlining passengers. Parallel alignment of the piers assures efficient use of the apron space. Examples of Remote Piers are London - Stansted and Atlanta Airports.

Figure 4.4 shows examples of satellite forms.

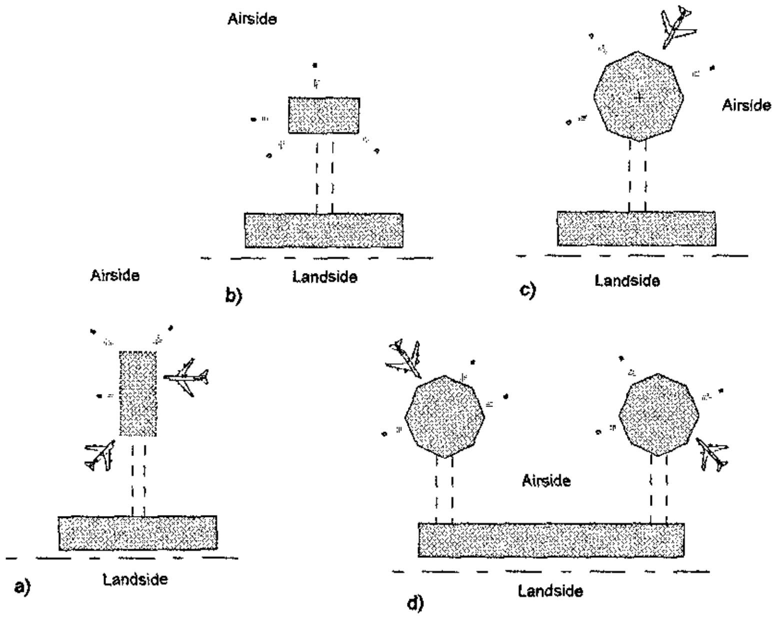


FIGURE 4.4: Example of Satellite Forms.

Some main advantages and disadvantages can be summarised as follows [Adapted from IATA, 1995]:

Major advantages	Major Disadvantages
• Normally provides for the centralisation of airlines and government authorities processing personnel.	• High capital, operating & maintenance costs of the transporter or travelator system between the main terminal and satellites.
• Has capability for concession areas and other amenities near gates (Can be true for other forms as well).	• High capital, operating & maintenance costs of baggage conveying/sorting systems; potential for baggage mishandling.
• Permits relatively simple flight information display system.	• Curbside congestion in peak hours.
• Facilitates control of passengers, if required.	• Limited expansion capability of the terminal due to complex building geometry.
• Additional satellites can be designed to accommodate future aircraft design developments	• If required, separation of arriving and departing passengers is difficult without construction of an additional level or the development of specialised facilities.
• Satellites, with aircraft positions clustered, are very suitable to the provision of common lounge areas.	• Apron area occupied by ground handling equipment serving adjacent aircraft may overlap.

Major advantages	Major Disadvantages
• Allow common or separated departure lounges.	• Future aircraft with larger wing span must be positioned farther from the centre, creating problems with loading bridges and apron manoeuvrability • Due to lengthy distances, increased minimum connecting times between flights in different satellites are mandatory. • Early check-in and close-out times.

4.2.4 Transporter Forms

In the Transporter concept the aircraft are parked away from the main terminal and use a connecting vehicle to transport passengers to and from the aircraft. For the passengers the transporter terminal functions are very much like any centralised terminal equipped with devices to reduce walking. The difference is that all passengers must use the transporter.

The Transporter concept in its purest form was first introduced at Washington-Dulles Airport in 1962. It was not until 1975 that a second airport, Montreal - Mirabel, introduced a similar concept. Although a great number of airports uses buses or a combined transport system to convey passengers due to demand for additional aircraft positions without fixed facilities, the major innovation in this concept is the use of large 'mobile lounges', which serve as gate holding rooms, to move entire plane loads of passengers from the main terminal to the aircraft parking in a remote stand and vice-versa This mobile lounge may be either a non-elevating vehicle that permits enplaning and deplaning at apron level at the aircraft and at the terminal; or an elevating vehicle that permits direct enplaning and deplaning to the aircraft and terminal by moving the passenger cab vertically to match the height of the terminal building floor or the aircraft door sill.

As aircraft are parked away from the main terminal allowing self manoeuvring (taxi-in, taxi-out) operations and eliminating towing operations, flexibility for aircraft parking becomes the great advantage of this configuration. The major disadvantage is the length of time required between the departure of the lounge from the terminal and the departure of the aircraft. This tends to be greater than the time usually required for a late-arriving passenger, as well as a probable poor level of service given by mobile lounges. Hart (1985) stated that in the transport concept the total scheduled flight time probably increases 10 to 15 minutes due to the operation of the transporter vehicles associated to the waiting for the last minute passenger.

This concept has a very flexible expansion capability related to mobile lounges and the main terminal and apron may be expanded without interruption of aircraft or terminal movements.

The transport concept becomes inappropriate when the airport has a high percentage of transfer passenger, since this scheme may cause inefficiencies resulting from transferring passenger and baggage between aircraft. Hart (1985) assumes that this concept is not operationally suitable for airports with more than 15% of transfer traffic. The FAA recommend it when the airport originates more than 75 percent of its passenger traffic.

Transporters become more economical than fixed gates when the rate of utilisation for the facilities becomes relatively low, particularly when the airport is used only a few hours a day or a few months a year. Some cost aspects can be expressed as follows:

Advantages: 1) The transporter concept does not require a connecting building or corridor;

2) Loading bridges are not required;

3) A push out operation may be not required.

Disadvantages 1) Transporter incurs maintenance and operating costs;

2) Support buildings are required at the aircraft flight line;

3) A transporter concept may requires a larger apron area due to power out operation;

4) Utilisation of staff baggage handling extended travel distance for baggage carts,

5) The need for buses for crew transportation between the terminal and remote parking.

Figure 4.5 shows example of a terminal transporter configuration.

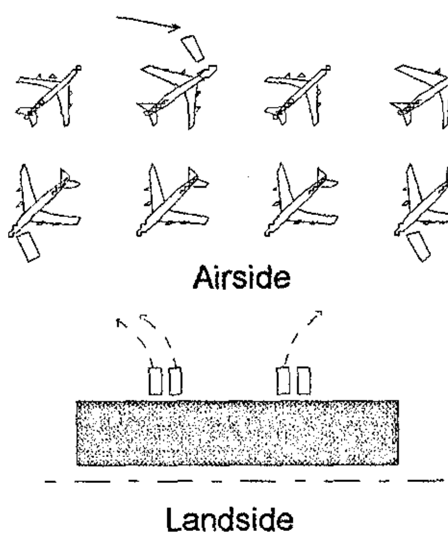


FIGURE 4.5: Example of Transporter Form

Some main advantages and disadvantages can be summarised as follows [Adapted from IATA, 1995]:

Major advantages	Major Disadvantages
• Constant compatibility of terminal/apron geometry and future aircraft development.	• Delays passenger because of poor level of service in loading/unloading process.
• Ease of aircraft manoeuvrability (i.e., power in, power out operation), due to the separation of the aircraft apron from the terminal.	• Very early close-out times required, very limited last minute embarkation capability.
• Simplified passenger movement/ orientation; reduced walking distances.	• High capital, maintenance and operation cost for the required number of transporters.
• Ease of expansion capability for aircraft stands.	• Susceptible to industrial dispute by vehicle drivers which could effectively close the airport operation.
• A more simple and smaller central terminal	• Requires right of way/control of transporter due high collision potential of transporters and aircraft.
• Separation of arriving and departing passenger if required, can easily be achieved	• Curbside congestion in peak hours.
•	• Additional cost of larger number of ground vehicles for crew and baggage transportation.
	• Due to slow transport between aircraft and terminal, increased minimum connecting times.
	• Additional airline staff required.

The rationale for the acceptance of this concept is not so evident. There are serious doubts that it is a solution that should be adopted at all. Although theoretically it seems to have, in certain circumstances, many advantages over other concepts, in practice it may be considered not very successful. A strong evidence of its drawback is Dulles International Airport, which will totally change concept before the turn of the century. Designed by the Finnish architect Eero Saarinen, after completion in 1962, it lay nearly dormant for more than two decades [Reingold, 1994], unable to prove its concept efficiency. Since then, the traffic has increased to 11 million passengers in 1993, which is about 20% of the airport total projected capacity.

Looked at from the point of view of both the airport operator and the user, the design concept has failed, yet from another angle, the designers have provided enough flexibility to adapt to unforeseen conditions. Unexpectedly for the designers, one of these conditions is the complete change of the original concept in the very near future. The mobile lounge will be around for some time yet. However, they will be gradually replaced by underground people movers and eventually eliminated. According to Reingold (1994) this is a firm idea of the Metropolitan Washington Airports Authority faced with growing passenger complaints about the mobile lounges operation.

It must be emphasised that the philosophy of operating remote positions by normal buses is a common practice in the majority of the airports and should be distinguished from the Transporter Concept that is a design policy, where almost all operations are served by the Transporter Vehicles.

Operation of Remote Stands

As one can realise, parking aircraft on remote stands is a very usual practice and its role may vary from airport to airport. The remote positions are mainly provided in airports where the main stands are served by loading bridges (gate stands). They are used as a buffer for supplying extra capacity and include the following uses:

1. When the airport is approaching maximum capacity, in peak hour occasions, the number of positions with loading bridges may not be sufficient to accommodate all the aircraft. Therefore the remote stands in conjunction with conventional airport buses and airstairs are needed.
2. For parking aircraft that are not required at gate positions, i.e., used in terminating or originating flights that are not scheduled to load for some hours.
3. For parking aircraft that need expending some time in routine maintenance, i.e., when an expected greater time is necessary.
4. For overnight staying in supplement to the gate stands. There are airports that have different price policy whether the aircraft stays on gate stands or remote stands.
5. For security reasons, such as security risk or special flights that need a safe distance from other aircraft and buildings.
6. As a design policy -- as it is the case of Transporter concepts served by Mobile Lounges.
7. For additional capacity in conjunction with Mobile Lounges.

Although remote stands are a necessity in almost all airports, there is a tendency against their indiscriminate use. Manchester Airport for example has a policy of allowing only 5% of total aircraft operations to be allocated in remote positions. Sao Paulo Airport, although has no pre-established target, and has a policy of maximising the use of loading bridges. The passenger aircraft are assigned to remote stands only when a gate position is not available. The overall gate utilisation (with loading bridge) varies from 85% to 95%.

4.2.5 Hybrid Forms

Other forms that were mentioned can be seen to be combinations or variations of these four basic forms.

The combination of a linear and a pier or satellite form is not unusual as there are many airports that combine a satellite at the end of a pier shape.

Often the unit terminal consists of two or more separate buildings, each housing a single airline or group of airlines and having a particular characteristic, such as traffic split -- domestic terminal and international terminal; a terminal for long-haul flights and another for short-haul. Heathrow is a good example of this unit terminal configuration. The multi-pier and multi-satellite terminals are composed of two or more of the basic piers or satellites that are connected to central terminals. The remote piers and remote satellites are basically satellite concepts with more than one satellite with the difference that they usually are connected to a central terminal by some mechanised system of transport. Examples of this form are Atlanta, with an underground people mover connecting the remote piers and Orlando with connection to the remote satellites above the apron.

Most of the combinations of concepts are results of modification from the initial conception of the airport. Mainly in Europe, for example, where the airports were built around the first half of this century and most of them were simple terminals based on the linear concept. Growth of aircraft size, growth of traffic and the entry of new airlines have caused the initial pure conceptual form to be modified quite completely. The result is a diverse combination of form and geometry that is found in many airports in Europe.

These hybrid forms have intrinsic underlying advantages and disadvantages carried from its basic concepts. The extension of the benefits that these combinations have brought can be inferred from the proper need to adapt to the dynamic changes that an airport faces throughout its life-span. The main point is that changing conditions and altering needs dictate the adoption of combined concepts.

Figure 4.6 shows some examples of hybrid forms.

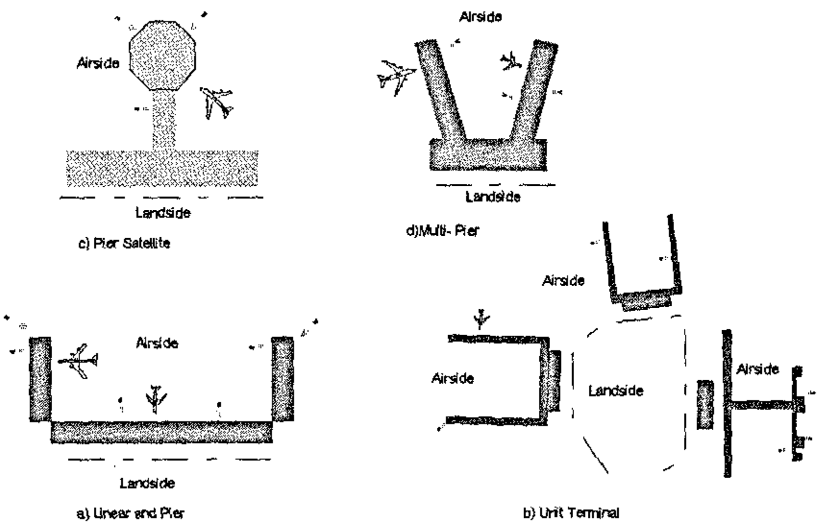


FIGURE 4.6: Examples of Hybrid Configurations.

4.3 Characteristics of Concepts

There are different points of view in considering the approach and variables involved in the process of evaluating terminal concepts. Parsons [FAA, 1973] determines the concept by comparison of different apron configurations and their resulting connectors. The connector is the element that joins the terminal to parked aircraft. By classifying the type of connector the concept is established. TRB (1987) states that concepts should perhaps be investigated within the context of relationships between terminal siting and runway configurations, whereas Blankenship (1974) defined them by way of comparing the effects that are produced as a result of the interactions between the functional elements of the terminal.

It is also suggested that the point of transition of airport type is 1 million annual enplanements and that capacity issues become more important as traffic grows. Physical characteristics, regarded as the number of levels of the terminal, are also considered important.

FAA (1976a, 1988a) and Parsons (1973) underline the relevance of the relationship between capacity aspects of terminal concepts and its physical characteristics as shown in Figures 4.7 and 4.8.

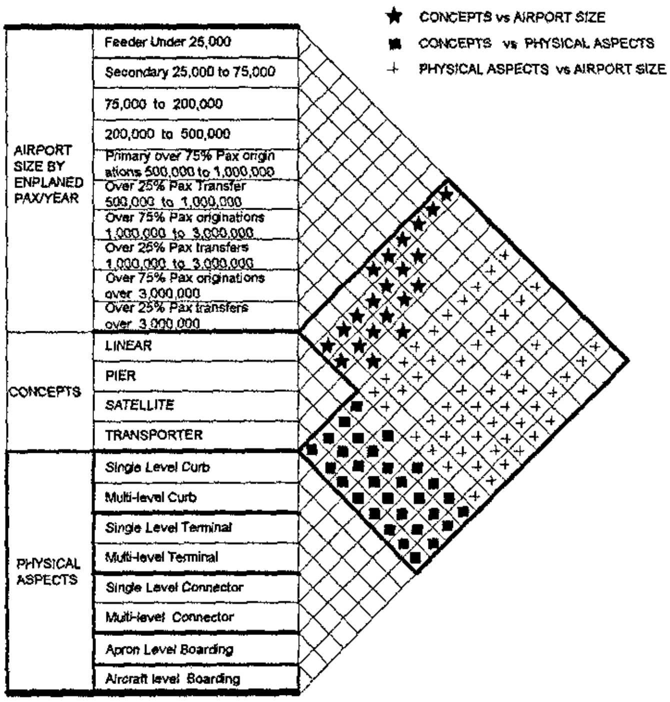


FIGURE 4.7: Relationship between Airport Size, Concept and Physical Characteristics.
(Adapted from [FAA, 1976a; Hart, 1985; Horonjeff, 1962])

The relationships in Figures 4.7 and 4.8 are considered broad indicators of generally accepted conventional wisdom to define terminal concepts. Tables 4.2, 4.3 and Figure 4.9, show a different reality in terms of terminal configurations. Approximately 70 percent of all airports around the world are simple or linear concept airport terminals. However, airports that still maintain the basic concepts can have traffic volumes up to around 10 to 15 million total annual passengers. The linear form, while being the most suitable for low-volume airports, actually has almost the same upper capacity as the other concepts. Furthermore if the hybrid configurations in terms of individual modules is considered, i.e., a pier or a satellite, their average annual traffic volumes also vary around 10 million passengers per year per pier or satellite. In practice, 10 to 15 million annual passengers represents a basic modularity of a terminal concept in terms of capacity.

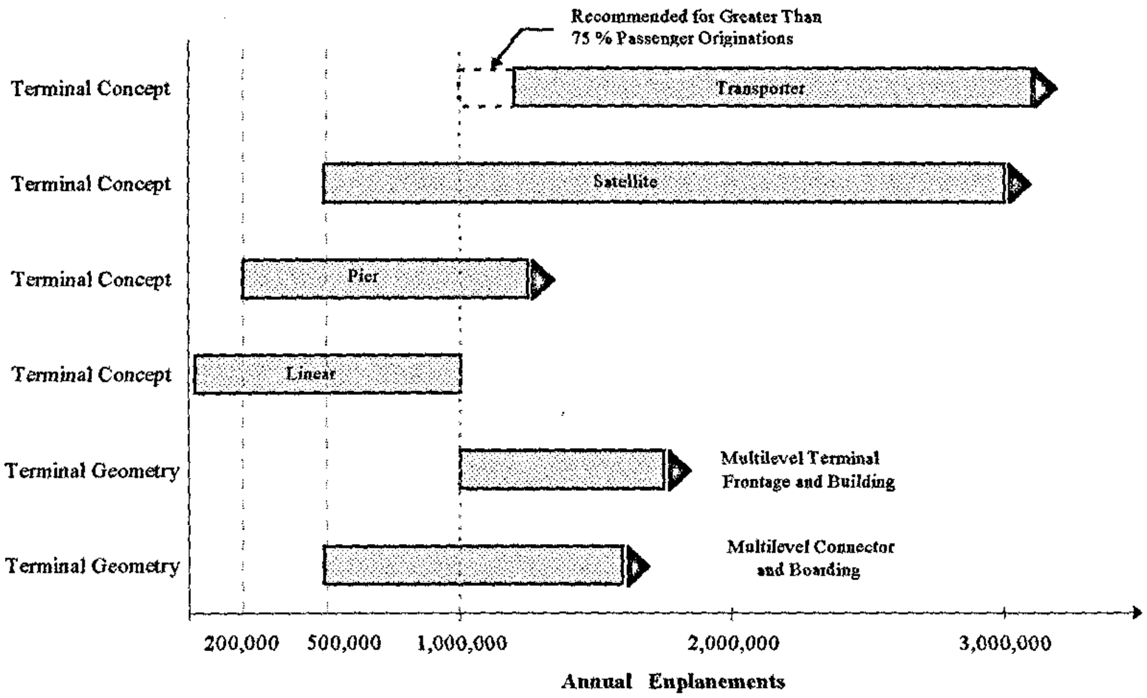


FIGURE 4.8: Concept Application by Annual Enplanements
(Source: [TRB, 1987])

The number of aircraft stands around pier or satellite terminals are usually between 7 to 15 aircraft, depending upon size and aircraft mix. In more complex shapes such as 'Y' piers these numbers may get up to 20 - 26 aircraft at most. Blow (1994) states that 50 aircraft is the maximum reasonable size of a terminal unit. It seems that these modularity are closely related to aircraft arrangement and walk distance.

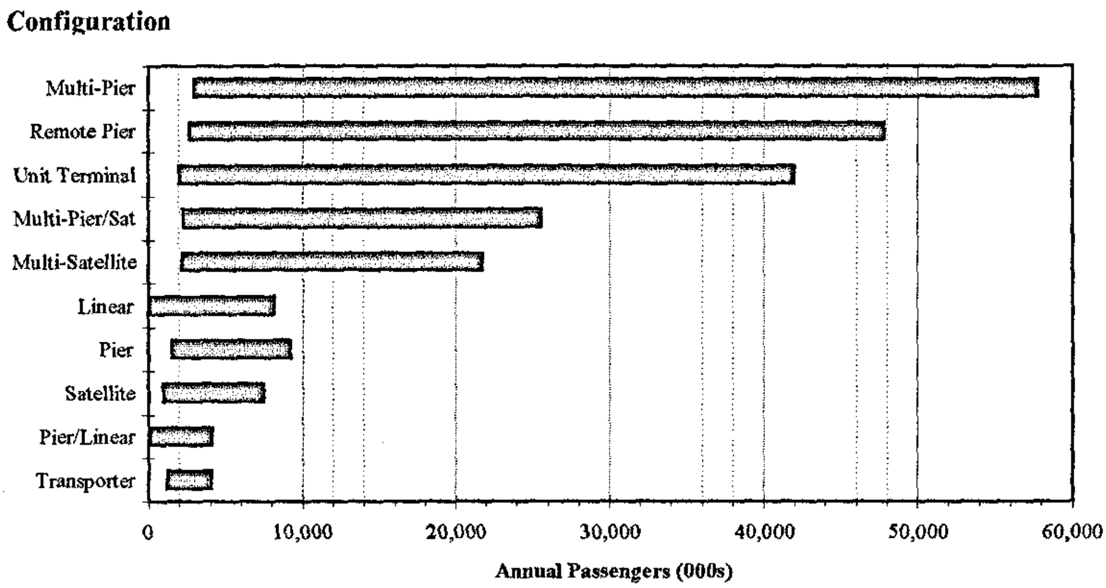


FIGURE 4.9: Terminal configurations in relationship to total Annual Passengers throughput.
(Data from Table 4.3 and 4.4)

Before going further the relationships that may be used to establish whether a particular concept is consistent with what has been inferred should be evaluated. Also the factors that influence the choice of a concept should be established. It is therefore necessary to ask what are those variables and factors, how they may be classified and what are their relevance in the process of terminal choice.

Table 4.3: Airport Configuration and Concepts at selected airports in USA and Europe.
(Source: [Wright, 1990, 1991])

AIRPORT	CONFIG.	CONCEPT	N. OF AIRLINES (Inc.. Tour Oper.)	MOVEMENT (1987/88)		Obs.
				Aircraft	Passengers	
1. Chicago O'hare	Multi-Pier	Pier/(Sat)		795000	54812000	5 Pier
2. Atlanta	Remote Pier	Satellite		787400	45191500	4 Satellites
3. Dallas-Ft. Worth	Unit Terminal	Linear		575936	39945326	4 Terminals
4. Los Angeles	Unit Terminal	Satellite/Pier		556400	38946000	9 Terminals
5. London (LHR)	Unit Terminal	Linear, Pier, Satellite	65	329977	35079755	4 Terminals
6. NY-JFK	Unit Terminal	Pier/Sat/Linear		286100	30200000	9 Terminals
7. NY-Newark	Unit Terminal	Satellite		400100	29433000	2 Terminals
8. San Franciscoo	Unit Terminal	Pier/Sat/Linear			28900000	6 Terminals
9. Miami	Multi-Pier	Pier-Linear		347000	23900000	8 Terminals
10. Frankfurt - Main	Multi-Pier/Satellite	Pier/(Satellite)	87	269,000	23300000	3 Piers
11. LaGuardia	Unit Term	Pier		350900	22195000	3 Term 6 Piers
12. Boston-Logan	Unit Terminal	Linear/Pier/Sat		364000	21863000	4 Terminals
13. Paris (Orly)	Unit Terminal	Linear, Pier	50	171200	20427000	2 Terminals
14. London (LGW)	Unit Terminal	Linear, Pier, Satellite	78	189202	19587281	2 Terminals
15. Paris (CDG)	Unit Terminal	Linear, Satellite	45	155100	16041000	2 Terminals
16. Washington National	Multi-Pier/Sat	Pier/Sat/Linear		318700	15400000	1 Pier 1Sat
17. Rome (FCO)	Multi Pier	Pier/(Linear)	74	143168	14169492	2 Piers
18. Houston	Unit Terminal	Sat/Pier			14000000	3 Terminals
19. Amsterdam	Multi-Pier	Pier	69	222284	13628000	4 Piers
20. Philadelphia	Multi-Pier	Pier			12800000	5 Piers
21. Orlando	Satellite	Satellite		182849	12544000	2 Sat (4 Sat)
22. Las Vegas	Multi-Pier/Sat	Pier/Sat			12303000	3 Pier/Sat
23. Stockholm	Unit Terminal	Pier	33	209816	11899832	2 Terminals
24. Copenhagen	Multi-Pier	Pier	48	191839	11781649	3 Piers
25. Phoenix	Multi-Satellite	Satellite		397500	11596000	3 Sat
26. Seattle-Tacoma	Multi-Pier/Satellite	Pier/Sat/Linear			11400000	2 Piers 2 Sat
27. Palma	Unit Terminal	Linear, Pier	73	89531	11300450	2 Terminals
28. Zurich (Kloten)	Multi-Pier	Pier	55	183344	10615015	2 Piers
29. Athens	Multi-Pier	Pier	88	112700	10247000	2 No air-bridges
30. Dusseldorf	Multi Pier	Pier	66	130725	9877595	3 Piers
31. Tampa	Multi-Satellite	Satellite			9200000	4 Satellites
32. Kansas City	Unit Terminal	Linear-circ.		208400	8300000	3 Terminals
33. Manchester	Unit Terminal	Linear, Pier	58	126305	8076250	2 Terminals
34. Milan (Linate)	Linear	Linear	30	96824	8076250	
35. Brussels	Multi-Pier/Satellite	Pier/Satellite	50	139000	6212000	2 Piers 1 Sat.
36. Helsinki	Linear	Linear	46	99300	5737787	
37. Oslo (Fornebu)	Unit Terminal	Linear, Pier	22	121954	5723385	2 Terminals
38. Geneva	Multi Satellite	Satellite	76	138089	5596659	3 Sat.
39. Berlin (TXL)	Hexagonal	Linear (Gate arrival)	10	67338	5278545	
40. Nice	Unit Terminal Linear	Linear	28	97878	4871075	2 Terminals
41. Vienna	Pier/Linear	Pier/Linear	39	62100	3999000	1 Pier
42. Dublin	Multi- Pier/Satellite	Pier/Satellite/Linear	28	60300	3522000	1 Pier 1 Sat.
43. Washington Dulles	Transporter	Transporter			2865120	
44. Cologne/ Bonn	Multi-Satellites	Satellite	32	97825	2313606	2 Sat
45. Milan (MXP)	Linear	Linear	11	14993	1629766	
46. Luxembourg	Linear	Linear	16	50653	944792	

Table 4.4: Airport Configuration and Concepts at selected Airports (year 1978).
(Source: [Wright, 1990, 1991])

AIRPORT	CONCEPT	CONFIG.	Stands/ Airbridg	N. OF AIRLINES (Inc.. Tour Oper.)	MOVEMENT (1978) Pax (000s)	Aircraft	Obs.
1. Heathrow	Linear/Pier	Unit Terminal	152	74	26992	269872	(3 Term)
2. Frankfurt	Pier/Sat	Multi-Pier	36+(79)	68	15883	207506	(3)
3. Osaka	Pier/Sat	Multi-Pier/Sat		17	15314	126681	(4)
4. Paris- Orly	Linear/Sat	Unit Term	116	63	13999	171348	
5. Toronto	Linear/Pier	Unite Terminal	72	20	11953	126872	
6. Rome(FCO)	Linear/Pier	Linear/Pier	52	70	11027	143006	
7. Copenhagen	Pier	Multi-Pier	43	42	9594	156342	(4)
8. Amsterdam	Pier	Multi-Pier	48	61	9468	143156	(4)
9. Paris CDG	Satellite	Unit Terminal	35+(58)	29	9280	103403	(2)
10. Gatwick	Pier	Multi-Pier	55	19	8060	102874	
11. P. de Mallorca	Linear	Linear	48	10	7877	78991	
12. Zurich	Pier	Pier	45	47	7729	98853	
13. Sydney	Linear/Pier	Unit Terminal	24+(6)	29	7474	127146	(3)
14. Montreal	Satellite	Satellite	28+(12)	12	6496	75498	
15. Dusseldorf	Pier	Multi-Pier	20+(14)	23	6360	84034	
16. Puerto Rico	Pier	Pier	26	22	5703	153838	(2)
17. Hong Kong	Linear	Linear	35	27	5441	50320	
18. Vancouver	Pier	Multi-Pier	39	9	5416	60695	
19. Melbourne	Pier	Multi-Pier	25+(14)	18	5388	98389	
20. Brussels	Pier/satellite	Multi-Pier/Sat.		39	4844	111085	(2) + (1)
21. Rio de Janeiro	Linear	Linear	12+(19)	23	4611	82928	
22. Hamburg	Linear	Linear	27	16	4159	63386	
23. Berlin	Hexagonal/Linear	Linear	32	9	4029	53315	
24. Marseilles	Linear	Linear	24	20	3605	45207	
25. Cairo	Linear	Linear	27	46	3487	50496	
26. Teheran	Linear	Linear		25	3456	59952	
27. Naha	Linear	Linear	13	11	3426	35136	
28. Bogota	Pier	Pier	18	15	3362	61494	
29. Nice	Linear	Linear	12	20	3270	45673	
30. Tenerife	Linear	Linear			2967	38472	
31. Calgary	Pier	Multi-Pier	22	6	2926	46032	(2)
32. Manchester	Pier	Multi-Pier	31	15	2902	46826	
33. Seoul(Kimpo)	Linear	Linear	22	10	2846	32694	
34. Vienna	Linear	Linear	21	33	2777	49231	
35. Helsinki	Linear	Linear	17	13	2711	48498	
36. Stuttgart	Linear	Linear	19	12	2635	49203	
37. Karachi	Linear	Linear	17	29	2422	30388	
38. Brisbane	Linear	Linear	7	17	2421	37769	
39. Algiers	Linear/Remote	Linear	14	21	2396	38001	
40. Dublin	Pier/Sat	Multi-Pier/Sat	22	10	2267	35724	
41. Cologne	Linear/Sat	Multi-Sat	30	29	2198	37121	
42. Lyon	Linear	Linear		22	2066	45432	
43. Prague	Linear	Unit Terminal	27	21	2029	50008	(2)
44. Winnipeg	Linear	Linear	18	7	1994	36605	
45. Luton	Linear	Linear	17		1951	20808	
46. Bahrain	Linear	Linear	4+(7)	27	1887	19863	
47. Dhahran	Linear	Linear	19	24	1862	30028	
48. Edmonton	Linear	Linear	4+(9)	7	1752	30337	Transporter
49. Brasilia	Linear	Linear	14	6	1572	99245	
50. Adelaide	Pier	Pier		8	1538	24071	
51. Buenos Aires	Linear	Linear	9	22	1470	21048	
52. Halifax	Linear	Linear	12	6	1351	24532	
53. Nagasaki	Linear	Linear	6	2	1317	11328	
54. Budapest	Linear	Linear	20	20	1301	28431	
55. Mirabel	Transporter	Transporter	28	25	1189	22431	
56. Calcutta	Linear	Linear	18	11	1136	20504	
57. Hanover	Linear	Linear	12+(12)	9	1097	36579	
58. Casablanca	Linear	Linear	16	21	1093	17056	
59. Nagoya	Linear	Linear	13	4	1062	20432	
60. Bridgetown	Linear	Linear	13	11	1059	22426	
61. Napoli	Linear	Linear	9	5	1010	15154	
62. Peking	Satellite	Multi-Sat	16				(2)
63. Narita	Satellite	Multi-Satellite	28+(52)				(4)

Variables and Factors

The factors that may exert some kind of influence upon a particular choice of a basic concept are listed without consideration of its degree of importance or where in the process they will be noticed or necessary The variables were identified from the advantages and disadvantages listed. What is really important to observe is that the number of variables can make the choice process very complex and influence the final basic terminal design. These variables are as follows:

- Centralisation, Decentralisation
- Walking distance
- Ease of Orientation, concerned to FIDS -- Flight Information Display Systems
- Separation of Arriving and Departing Passengers
- Expansion
- Simple Construction
- Construction Cost
- Curbside Length
- Cost of Baggage Systems
- Compatibility between Building/Apron Geometry
- Aircraft Circulation & Manoeuvrability
- Capital and Operation & Maintenance Costs
- Check-in Close-out Times
- Easy Control of Passengers
- Localisation of Concessions
- Connecting Times
- Terminal Size
- Flexibility
- Modularity
- Total Area
- Traffic Characteristics: Including station type, demand growth rates for air traffic, passenger characteristics and aircraft type.
- International Traffic
- Activity Level -- where the traffic volume is applied (the feeder, secondary and primary systems indicated in Fig. 4.7 are example of FAA airport classification system for terminals related to activity levels, which relates to traffic volumes).
- Relation to runways, taxiways, and cargo areas.
- Relation to the access mode.
- Physical Characteristics: Size, number of levels, and dimensions.
- Airport Size

From this list it can be seen that some variables are interrelated. There are variables that are quantifiable and others that are subjective and are difficult to compare. Although it is easy to determine the major quantifiable aspects for comparison, it is often the less obvious, less quantifiable ones that may influence the choice of one concept over another in a particular situation.

In an attempt to classify and give priority to the main variables that may influence choice of concepts, two steps were put forward to a group of experts in airport planning and design: Firstly, trying to identify from the point of view of the experts what would be the main variables and list them; and, secondly, asking them to give priority to that list. To find the list of variables was not so difficult. The problem came when trying to determine the order of importance of each variable. The main reason was quite obvious: the list was quite long and the 'weight' between the variables was clear in the mind of the experts. They were certain that the variables change their order of importance according to the specific situation being analysed. For example, in designing a hub terminal, the number of transfer passengers is more important than originating or destinating passengers. Conversely, airports that are the destinations of charter flights, for instance, have arriving and departing passengers as more significant than transfers. The following are 22 important factors to consider when choosing a terminal concept. This is not an exhaustive list but the opinion of some experts in airport design.

1) Passenger Characteristics
2) Airline Characteristics
3) Walking Distance
4) Aircraft Mix
5) Domestic/International Service
6) Traffic Volumes
7) Rate of Growth
8) Centralised/Decentralised
9) Number of Levels
10) Separation of Arrival/Departure
11) Runway Configuration
12) Number of Airlines
13) Site Constraints
14) Physical Constraints
15) Baggage Technology

16) Commercial Activities

17) Access Modes

18) Size

19) Passenger Orientation

20) Convenience

21) Comfort

22) Type of Financing

As it has been said, to rank 22 important features it is not an easy task. A Prioritising Grid as shown below was used, asking the experts to put the variables in order of priority comparing pairs of factors. They had to decide which was the more important variable of each pair, and tick the appropriate number each time.

Looking at the top row in the prioritising grid, there are two rows of numbers representing the variables on the variables list. The first pair is 1 and 2, corresponding to Passengers Characteristics and Airline Characteristics respectively. If one thinks that Passenger Characteristics is more important than Airline Characteristics for this pair, he or she should tick or circle number 1, which is shown bold in the Prioritising Grid. The process is repeated for pair 1 and 3, 1 and 4, and so on, then doing the same for the other rows. The final result is given by counting the number of times each number was ticked and then rewriting the list of variables in order of priority.

The order of precedence on different situations will certainly change, because some variables are inter-dependent, for example: passenger characteristics and domestic/international services, size and physical constraints, passenger convenience and walking distance. Therefore, an attempt was made to put the variables in a priority group. Table 4.5 shows the final result, which represents an average amongst the experts.

It must be emphasised that many other elements can be included in the above list. For example, for the Queen Alia International Airport near Amman, the capital of Jordan, expansion, security and *earthquake resistance* were the three factors that dominated the design considerations by virtue of that Amman is in a seismically active area. The overall terminal concept adopted was similar to the modular one used at the Dallas/Ft. Worth International Airport in Texas. For the Kansai International Airport, according to the selection committee -- formed by a nine-judge panel, Piano's design was chosen primarily because of its *aesthetics*. Taking into consideration the building's aerodynamic curves and boomerang-like surfaces, the committee regarded it as an appropriate concept for an airport for the 21st Century [Usui, 1988]. The new Pittsburgh International Airport basic idea accrued from 200 preliminary schemes to deduce that the most *efficient configuration for moving both aircraft and passengers* would be an 'X' surrounded by aprons and taxi-lanes.

Prioritising Grid

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	3	4	5	6	7	8	9	10	11	12	13	14	15	...
2	2	2	2	2	2	2	2	2	2	2	2	2	2	
3	4	5	6	7	8	9	10	11	12	13	14	15	...	
3	3	3	3	3	3	3	3	3	3	3	3	3		
4	5	6	7	8	9	10	11	12	13	14	15	...		
4	4	4	4	4	4	4	4	4	4	4	4			
5	6	7	8	9	10	11	12	13	14	15	...			
5	5	5	5	5	5	5	5	5	5	5				
6	7	8	9	10	11	12	13	14	15	...				
6	6	6	6	6	6	6	6	6	6					
7	8	9	10	11	12	13	14	15	...					
7	7	7	7	7	7	7	7	7						
8	9	10	11	12	13	14	15	...						
8	8	8	8	8	8	8	8							
9	10	11	12	13	14	15	...							
9	9	9	9	9	9	9								
10	11	12	13	14	15	...								
10	10	10	10	10	10									
11	12	13	14	15	...									
11	11	11	11	11										
12	13	14	15	...										
12	12	12	12											
13	14	15	...											
13	13	13												
14	15	...												
14	14													
15	...													
15														
...														
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Table 4.5: Terminal Concept Variables

Variable	Priority	Group
Traffic volumes	1	1
Walking distance	1	
Domestic/International Service	2	2
Centralised/Decentralised	2	
Number of Levels	2	
Separation of Arrival and Departure	2	
Aircraft Mix	2	
Size	2	
Rate of Growth	2	
Number of Airlines	3	3
Comfort	3	
Physical constraints	3	
Pax Characteristics	4	4
Airline Characteristics	4	
Commercial Activities	4	
Passenger Orientation	5	5
Access Modes	5	
Convenience	5	
Baggage Technology	5	
Type of Financing	6	6
Runway Configuration	6	
Site Constraints	6	

The key to make these and other variables actually represent the evaluation of a concept is to choose those factors that will meet the principal objectives -- sometimes mutually exclusive objectives -- of the airport, airlines, concessionaire, retail operators and the ultimate client, the passenger.

From the point of view of the design team the principal objectives may vary significantly.

The passenger terminal building is usually designed with passenger convenience in mind, so that it should be efficient, user-friendly and easily accessible. To achieve these and other objectives a Master Plan is essential. The possibility to expand should be planned. Schiphol Airport for instance, although 80 years old, prepared its first Master Plan in the middle of the 80s. One of the

Master Plan central issues was the efficient layout of facilities, since the airport had all the geographic capacity it needed do cope with the expected increase of traffic. Probably the actual layout would have been different if the airport had expected its growth at the beginning.

The choice of variables to achieve the main objectives is complex. This can be exemplified by looking into some design criteria and goals.

The Munich II Airport design criteria -- "Munich Model" -- for example were (Source: Munich Airport):

- Flexible use of land. The possibility of using the terrain flexibly, taking future extensions into consideration;
- Optimum noise prevention resulting from an appropriate runway system. Looking at environmental protection for the airport surroundings when laying out the runway system.
- Built-up zone between the runways. Arranging the handling facilities and other operational areas in a 'built-up zone' between the runways;
- Economical construction to make full use of the capacity according to the modular system;
- Decentralised handling system with convenience for the passengers by means of short distances in buildings in a straight line;
- Roads encircling the passenger handling area;
- Direct connection with the rapid transit rail system;
- Integration of the airport into the landscape.
- High passenger comfort.

The design team of the Pittsburgh Airport concluded that the primary focus for Midfield Terminal was on four strategic criteria (Source: Pittsburgh Airport):

- Passenger Convenience. Simplify the way a passenger moves through the airport. Provide direct access to parking areas and buildings. Minimal walking distances and ample room for circulation and queuing. Ability to transfer luggage expeditiously in a "hub" situation between on-line or intra-line connections. Provide shops, boutiques, restaurants, service facilities of all kinds to be available to the passengers.
- Operational Efficiency. This efficiency is achieved by the proposed "X" configuration, locating the Terminal Complex in the middle of the runways, which would facilitate aircraft access and manoeuvrability. High technological baggage handling system with state-of-the-art-equipment to identify problems.
- Expansion Capability. Design flexibility will enable the airside building to grow to accommodate as many as 25 gates per concourse arm, and room for an additional concourse connected by the extension of the automated guided transit system is also planned.
- Economic Effectiveness. This planned to be achieved by a continual follow up, check and updates of budget and costs as the scope of the project changed or expanded; by third party contracts for energy requirements; and bid certain items such as elevators, escalators, and transformers, as one-bid packages.

Another group of possible objectives can be outlined:

- State-of-the-art facility offering maximum efficiency and convenience for both passengers and aircraft;
- Highest standards of flight safety and airport security;
- Maximum operating efficiency and passenger management;
- Adequate capacity in all airport support systems;
- Flexibility to accommodate future change;
- Compatibility with the natural environment and surrounding communities; and
- Financial viability through appropriate investment planning.

or,

- Provide flexibility and adaptability in the arrangement and phasing of facilities to accommodate unforeseen changes in demand and technology;
- Minimise delays to passengers due to congestion;
- Recognise functional interrelationship affecting the facilities;
- Maximise continued utilisation of facilities;
- Match the capacities of various components of the airport system so that a balance of capacity and demand can be achieved throughout the whole system;
- Minimise airport and airline operating costs associated with utilities, vehicle operations, and maintenance functions;
- Effectively utilise available land resources; and
- Minimise the impact on environment.

and,

- The building should offer a high standard of comfort to passengers and visitors. Walking distances should be short; gate access should be by ramps and close to parking areas;
- Fast and simple passenger and baggage movement;
- Improved ground transportation. Terminal facilities should be structured to provide a smooth transition to efficient ground transportation; and
- Efficient transfer procedures. The terminal should provide fast, simple and convenient transfers of passengers and baggage.

The expansion of an existing terminal or the construction of additional terminal facilities to meet the forecast growth in air traffic on an existent airport also has its development principles and strategies to achieve.

Four basic principles guided the modernisation program for Boston Logan International Airport in the beginning of this decade:

- Retain Airport Size. The physical boundaries of the existing airport will not change.
- Develop Balanced Facilities.
- Preserve Future Flexibility. Design to accommodate a range of future demand scenarios being able to adapt to changing conditions.
- Use Prior Studies. In particular the Authority's 1976 Master Plan.

These principles were oriented on the following primary objectives:

⇨ Modernise Airport facilities, infrastructure, and roadways;

⇨ Provide facilities to accommodate the future fleet mix;

⇨ Parsimonious use of the Airport Land;

⇨ Provide for a balanced allocation of all types of essential aviation facilities on existing Airport lands;

⇨ Increase the level of service and passenger convenience throughout the reconstruction process;

⇨ Improve service;

⇨ Concern to the environment issues;

⇨ Assure the integration of Airport plans with other agencies.

The development of the second passenger terminal of Manchester International Airport was based on a number of assumptions and principles as follows [Public Enquiry, 1988, Wythenshawe Forum, Manchester]:

- Provide terminal capacity compatible with the capacity of the existing runway.
- Phase construction to keep pace with capacity demands. The first phase will be capable of handling approximately 6 million passengers per year. The final capacity is expected to be 12 million passengers per year.
- Planning options for the new terminal. Define whether:
- it should be a full facility with built in flexibility,
- it should be a seasonal or all year facility, and
- whether inbound and outbound passengers should be segregated vertically or laterally.
- Retain Airport total size.
- Full integration with the total airport complex. Terminal 2 and Terminal 1 will therefore need to be linked both airside and landside for both vehicles and passengers.
- Provide the most efficient arrangement of taxiways and aircraft stands for the airside layout.
- The landside layout should provide suitable areas for building, parking and landscaping, with an effective road layout linked to the public road system.

- The airside/landside boundary will be positioned to provide a balance between airfield operational requirements, security, safety and the needs of landside development. Similar considerations will determine the boundary within the terminal building.
- The size of the terminal itself will be determined by the floor-space requirements of passenger and visitor amenities, baggage handling, support facilities, office accommodation and services. Floor-space may be on various levels. Commercial facilities will be related to the use of the terminal likely passenger mix.
- The terminal development should incorporate measures to reduce the impact on the environment.

The terminal concept variables will certainly not encompass the origin for all the main objectives nor will the concept itself directly attain all the objectives. But configuration of spaces and ultimately the shape of the terminal will certainly influence or determine the means for expansion, modularity, economical construction, integration, walk distance, decentralisation or centralisation, flexibility, efficiency, and balanced capacity. They are all factors that are embodied in the main objectives and may constitute variables for the process of concept choice. In this consideration of some of the many factors mentioned in this evaluation procedure there are variables which are very difficult to measure. They are qualitative factors, which are subjective in essence. highly susceptible to personal influence and are based on judgmental criteria. These are Aesthetic, Airline Policy, Airport Policy, Amenities, Availability, Comfort, Complexity, Convenience, Efficiency, Passenger Behaviour Characteristics, Privacy, Safety, Flexibility, Modularity, Expansion, and Signage & Orientation factors.

The overall objective of the terminal system may be stated to achieve the efficient, safe and secure facilitation of passengers and cargo from point of arrival on airport to point of departure from airport in both ways. At the same time the requirements of the airport authority and airlines should also be met concerning passengers, operators and airlines. The terminal designer should strive to attain the variety needed for their basic needs. The passengers are looking for convenience, comfort, compactness and reliable service. The operators and airline are expecting an economical terminal system, with flexibility, functionality, operational efficiency and effectiveness, and corporate image. Lemer (1990, 1992) discusses these issues in more detail. Therefore, the principal objectives that the designer should be looking at are:

- A terminal that is compact, convenient and comfortable from the passenger point of view.
- A terminal that is operationally efficient and effective from airline and operator's point of view.
- A terminal that has flexibility and adaptability to be implemented in stages.

- A terminal that has enough flexibility and adaptability to accommodate unforeseen changes in demand and technology, and

- A terminal with cost-effectiveness in mind. Costs are usually defined in terms of all the resources necessary for the design, land acquisition, construction, operation and maintenance of the terminal system during its useful life. Effectiveness is the degree to which a design achieves its objectives.

4.4 Evaluation Procedures

The traditional approach for terminal concept evaluation has been based primarily on intuition and experience. It is claimed that this has been proved to be time consuming and costly, lacking in scientific and methodological support. On the other hand, no one can assure that concepts accomplished by other evaluation techniques, whether simple or complex, are any more successful than configurations selected by the traditional method.

The basic concepts shown in this chapter are mostly differentiated by advantages and disadvantages. However, it is not logically possible to rank items of these two parameters in correct order before all of the different alternatives have been correctly estimated.

Several other methods are applied in evaluating alternatives in transportation planning. They are documented elsewhere [Wright and Ashford, 1989] and include Engineering Economic Analysis, Cost Benefit Analysis, Goals and Objectives-Achievement Matrices, Planning Balance Sheet, Factor Profile, Plan Rank, Mathematical Programming Approaches, Design Synthesis Approach and Idealised Evaluation Procedure.

Winfrey (1969) states that Engineering Economic Analysis are mathematical procedures that have the common objective of "comparing the future streams of cost and benefits in such a way that for a specific future period of time the analysis will disclose the probable net return on the proposed investment or the most economical design required to produce the returns." The four methods of economic analysis are well known and are as follows:

- Net Present Worth
- Equivalent Uniform Net Annual Return
- Benefit/Cost Ratio

- Internal Rate of Return

The use of these methods for evaluation of terminal concepts have some limitations and in many instances may not be applicable. As the concept evaluation is traditionally carried out in the early stages of the design process, economic data may not be ready available.

Cost Benefit Analysis includes a wider point of view of the economy or society in general. It goes beyond financial aspects and evaluates externalities, intangible effect as such as the value of life or time, as well as other social considerations. In reality the CBA may comprise financial, economic or social view points. In the airport field, the selection of the Maplin site for the third London airport may be the best known example of CBA, yet it is a very controversial example, see Foster (1974).

The purpose of both Planning Balance Sheet and Goals and Objectives-achievement Matrices is to identify all relevant impacts and indicate their magnitude and importance in a way that makes possible for the planner trade-offs between different objectives. Examples of both are illustrated in Figures 4.10 and Table 4.5. The main difference between them is that Goals Achievement Matrices introduce weight to reflect the relative importance of goals and group of interests. For more detail in these methods see Lichfield (1968), (1975) and Hill (1968).

Factor Profile attempts to show on a visual scale the relative importance or level of effect of each individual factor. The conclusion for one of the options may not be straightforward. An example of this method is represented in Figure 4.11.

Plan Ranking as illustrated in Figure 4.12 differs from the other methods by using rankings rather than weightings. Both this and the preceding may be combined in an evaluation.

Mathematical Programming Approaches are typically represented by linear programming methods, in which the aim is to minimise or maximise an objective function, subject to one or more constraints functions. As the name suggests it supposes a linear relationship between the variables, which is a quite reasonable assumption looking at most variables included in airport design.

The Design-Synthesis Approach and Idealised Evaluation Procedures are in fact descriptions of broad logical steps for plan evaluation, in which the impacts are identified, quantitative and judgmental values are put in the appropriate places and eventually one alternative is selected. These process are depicted in Figures 4.13 and 4.14.

There are other techniques such as Threshold Analysis and Cost-Effectiveness Analysis. Cost-effectiveness is usually applicable when dealing with non-quantifiable impacts or impacts that are subject to ordinal classification only [Stopher, 1976]. Threshold Analysis is often used on the assumption that the benefits of the alternative plans are approximately equal but that their costs may be different. In these circumstances a technique of cost minimisation is used. It is also used as a means of generating alternative plans, where the initial objective is to identify the costs of crossing certain thresholds to growth.

The drawbacks to conventional methods of evaluation of transportation alternatives are related to their ability to deal with the concepts of efficiency and effectiveness. The concept of efficiency stems from the ability to achieve an objective. In other words, how to obtain investment returns that are worthwhile. In general, most economic techniques of evaluation are concerned with measuring this characteristic. The concept of effectiveness or how the objective is achieved is the extent to which an alternative attains the objectives and is a measure of its effectiveness.

The suitability of these techniques for the evaluation of terminal concepts needs to be addressed. Any method used would certainly need to be adapted. Furthermore, each method has shortcomings. Some are limited in scope, others are more suitable for wider matters, and others need to much information, bringing doubts about the reliability of the analysis as far as terminal concepts are concerned.

On the other hand, looking again at the main list of factors that influences the concept evaluation procedure, it must be realised that the most important variables, *form* and *shape* or simply form, are not listed. The paradox is that this variable can be considered both as the dependent or independent variable contingent to the way the problem is analysed. The aim is to find the overall shape that will satisfy the principal objectives. In this sense the shape itself becomes a dependent variable.

Conversely most of the other variables are in fact constants for all alternative concepts. Once their values are determined at a point in time they will not change. For example, traffic volumes will not change while testing different shapes of terminals in a specific stage of the development -- yet, they are constantly changing with time. The number of passengers and aircraft will not presumably alter either. Nevertheless, traffic is still a factor that may influence the overall concept.

These traditional methods may be considered controversial because in most of the practical cases they were adapted for airport project appraisal as a whole and were not specifically designed for concept evaluation. The system approach adopted by Ashford and agreed by some experts in airport planning and design is in fact the first practical and logical guideline for the selection of a terminal concept that the author came across. The suggested algorithm of this approach is outlined in Figure 4.15. It is based on experience and examples of the actual operation of airports around world. It is also based on more recent solutions of new airport projects. There are also a number of 'rules of thumb' imbedded in the procedures. If one goes through the algorithm, will probably find that there is a number of steps that still need a close knowledge not only of the problem itself, but also of being familiar with the specific airport design process.

Actors	*Impact*	*Level of Impact*			
		Option I	*Option II*	*Option III*	*Option IV*
A. Airport Authority	1. Required Capital	$120m	$140m	$200m	$350m
	2. Benefit/cost ratio	2.4	3.2	2.3	3.3
	3. Skilled labour requirement	2200	3200	3000	3800
	4. Ease of operation	Low	Medium	Low	High
B. Airlines	5. Required Capital	$0.5m	$1.2m	$5m	$7m
	6. Annual aircraft operating cost	$2m	$3m	$5m	$4m
	7. Staffing requirements	15200	16400	20000	24000
	8. Adverse noise abatement procedures cost	$2m	$4.2m	$3m	$2m
	9. Ranking of Safety of noise abatement procedures	1	3	4	2
C. Air Traveller	10. Ranking of Ease of Using Terminal	3	2	1	4
	11. Ranking of Ease of Using Parking	4	1	2	3
	12. Estimated time required in terminal for departing passengers	85 min.	80 min.	65 min.	60 min.
	13. Estimated time required in terminal for arriving passengers	15 min.	20 min.	24 min.	15 min.
	14. Aesthetic level of terminal design	Low	Medium	High	Medium
	15. Estimated % of Transfer flights missed by bailing to make connection	2%	1.5%	1%	1.5%
	16. Average walking distance for embarking passenger	455 m	300 m	210 m	55 m
D. Non-traveller in Neighbourhood of Airport	17. Average increase in L_{dn} level	25	15	12	10
	18. Effect on average housing values	-$10,000	-$8,000	NIL	+$2,000
	19. % increase in road traffic on arterial routes and freeways	5%	4%	1%	2%
	20. Loss of amenity	High	High	Medium	Low
	21. Effect on local job market	Low	Medium	High	High
	22. Effect on local taxes/capita/annum	-$20	-$15	+$5	NIL
	23. No. of properties taken by eminent domain				
	24. Loss of public land (acres)	200	300	200	450
	25. Total land take (acres)	25	200	300	750
		300	600	750	3500

FIGURE 4.10: Example of a PBS -- Planning Balance Sheet -- for an airport development.
(Source: Lichfield, 1968 as cited in Wright and Ashford, 1989)

Table 4.6: Example of Goals Achievement Matrix

		Goal a, relative weight 2			Goal a, relative weight 3		
Incidence		Relative weight	Costs	Benefits	Relative weight	Costs	Benefits
Group	a	1	*A*	*D*	5	*E*	-
	b	3	*H*		4	-	*R*
	c	1	*L*	*J*	3	-	*S*
	d	2	-		2	*T*	-
	e	1	-	*K*	1		*U*
			Σ	Σ		Σ	Σ

The letters A, B ... are costs and benefits that may be defined in monetary or non-monetary units, or in terms of qualitative states.
(Source: [Hill, 1968])

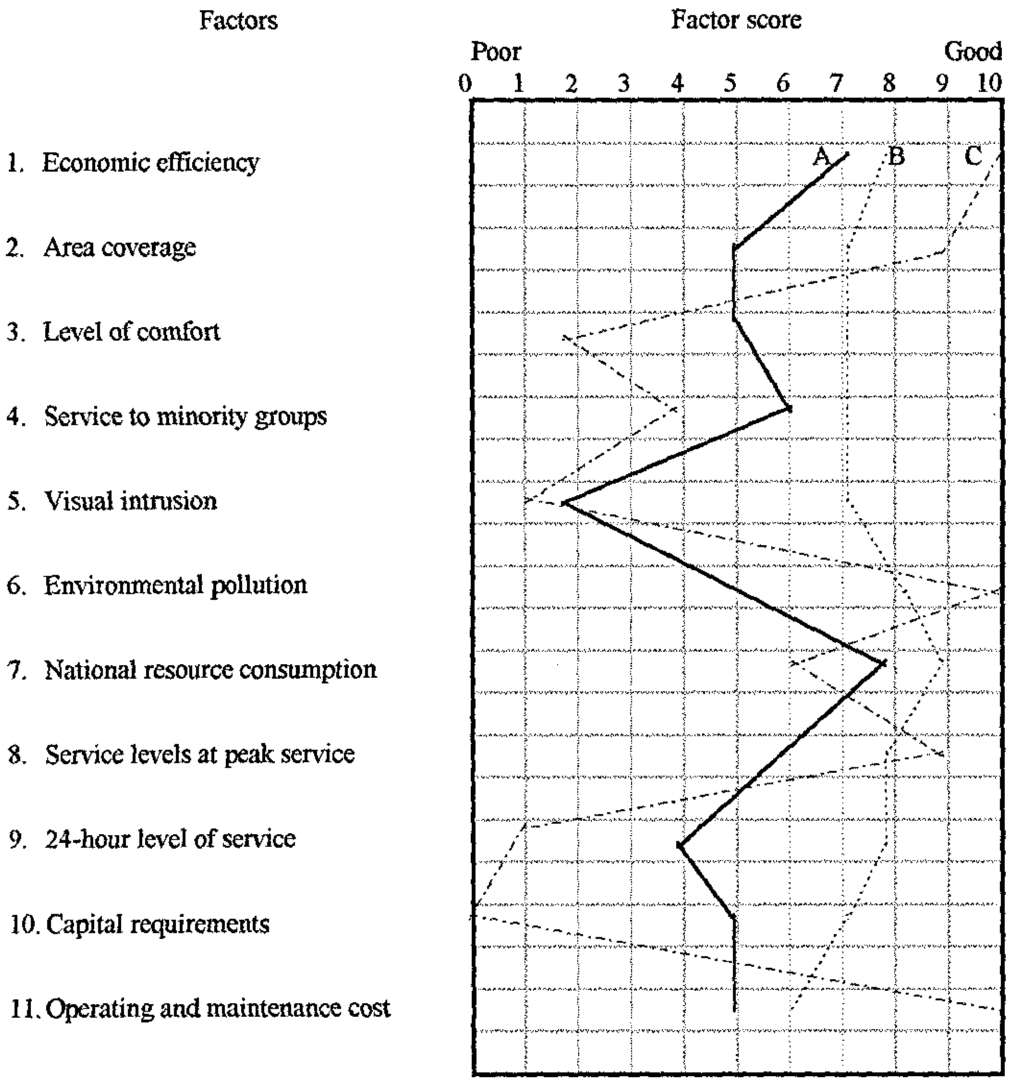


FIGURE 4.11: Example of Factor Profile Chart.
(Source: Oglesby, 1970 as cited in Wright and Ashford, 1989)

Plan	Probability of Implementation	Provide a Balance Transportation System	Provide for and Appropriate Spatial Distribution of Land Use	Economic Efficiency	Plan Value
		Rank Order of Objective n=2	Rank Order of Objective n=3	Rank Order of Objective n=1	$v = p\Sigma(n_1m_1+n_2m_2+n_3m_3)$
		Rank Order Value of Plan (m)	Rank Order Value of Plan (m)	Rank Order Value of Plan (m)	
Continue existing trends with controls	p=0.6	3	1	3	0.6[(2x3)+(3x1)+(1x3)]=7.2
Corridor development	p=0.5	2	2	1	0.5[(2x2)+(3x2)+(1x1)]=5.5
Satellite city concept	p=0.9	1	3	2	0.9[(2x1)+(3x3)+(1x2)]=11.7

FIGURE 4.12: Example of Rank Based Expected Value method.
(Source: Schlager, 1968 as cited in Wright and Ashford, 1989)

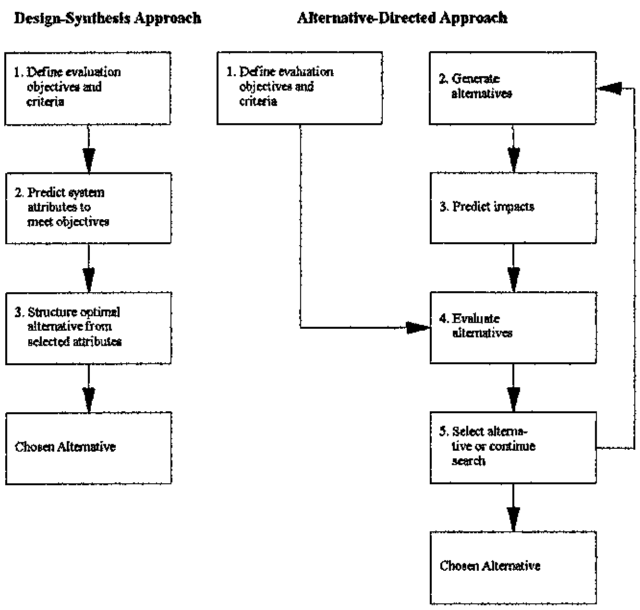


FIGURE 4.13: Design Synthesis and alternative-directed approach diagrams.
(Source: Scheibe, 1977 as cited in Wright and Ashford, 1989)

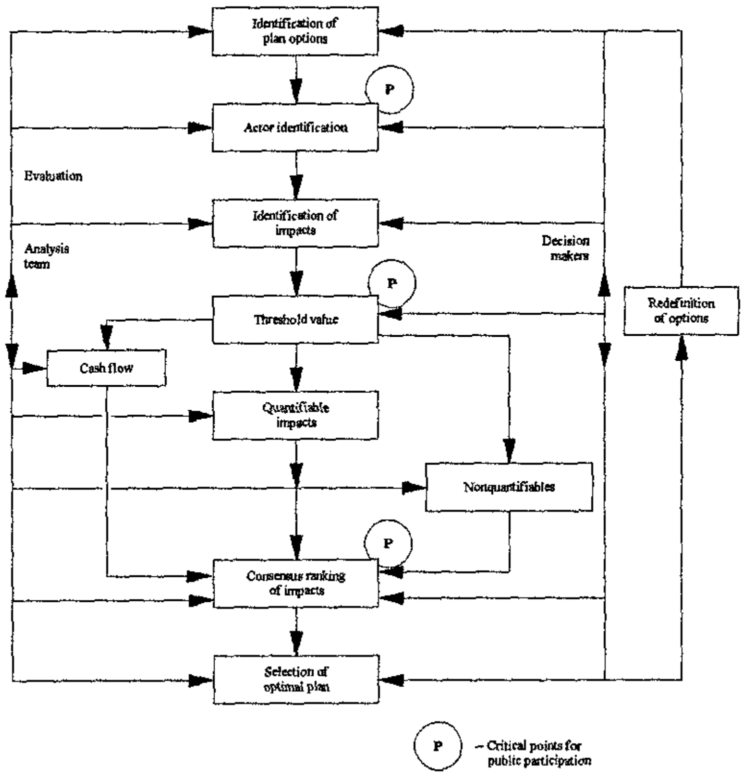


FIGURE 4.14: An idealised evaluation procedure.
(Source: Ashford and Clark, 1975 as cited in Wright and Ashford, 1989)

To a certain extent the algorithm is fairly self-explanatory. Even so, the prominent steps are summarised, see Fig 4.15.

1. Obtain the traffic volumes of passengers and aircraft.

2. Estimate the Peak Hour Passengers and Aircraft Peak Hour Movements.

3. Estimate the area of the terminal and in parallel determine number of gates and length required.

4. Using these values, dimension a terminal as a single level terminal.

5. If the terminal size is equal or less than 1 km long, one should adopt a Linear concept, which can be single or multi-level.

6. If the terminal size is more than 1 km long, then it has to be decided if a single terminal still being a option.
   If the answer is 'yes', and if the number of domestic & transfer passengers are less than 40 million a year and the number of international passengers are less than 25 million a year, it should be considered a pier terminal concept as the option. Otherwise, the choice is a multiple Unit terminal.

7. If the conditions satisfy the pier requirements, the length of the piers should then be computed. If the maximum walking distance is less than 700 m, the selection will be a Pier concept.
   If not, it is necessary verify if the terminal is located in the middle of the runways and airport site. If yes, the maximum walking distance for a cruciform arrangement that should be less than 700 m, should be calculated. If it is less, the selection will be a cruciform concept (Pier).
   If at any decision the answer is 'no', the solution is to go back to multiple unit terminal.

8. For the decision of a multiple unit terminal there are two options: a) A complete independent unit terminal; or b) A centralised terminal with satellites or remote positions. The parameters that may influence this choice are numerous, from passenger characteristics to government policy. This seems to be the obscure point in this algorithm or the most difficult to reach a decision.
   If the answer is 'yes' -- choice a) --, the process starts again with the annual movements split in whatever traffic separation should be made.
   Contrarily, the resultant concept can be or Transporter, or Remote Satellites or Remote Piers. See Fig 4.15. The decision for a Transporter terminal is reached by agreement with the airlines. This may also be an unclear point in the diagram, transferring to the subsequent steps lack of confidence in arriving to the right solution.

9. The further steps in Fig. 4.15 (cont.) lead to a detail design. It includes sizing the facilities interactively, using more than one method and refining the process through simulation.

A final consideration is that the diagram gives only general steps that should be adequately developed to meet the specific problem requirements. This development clarifies the points for each case being analysed.

TERMINAL LAYOUT SELECTION ALGORITHM

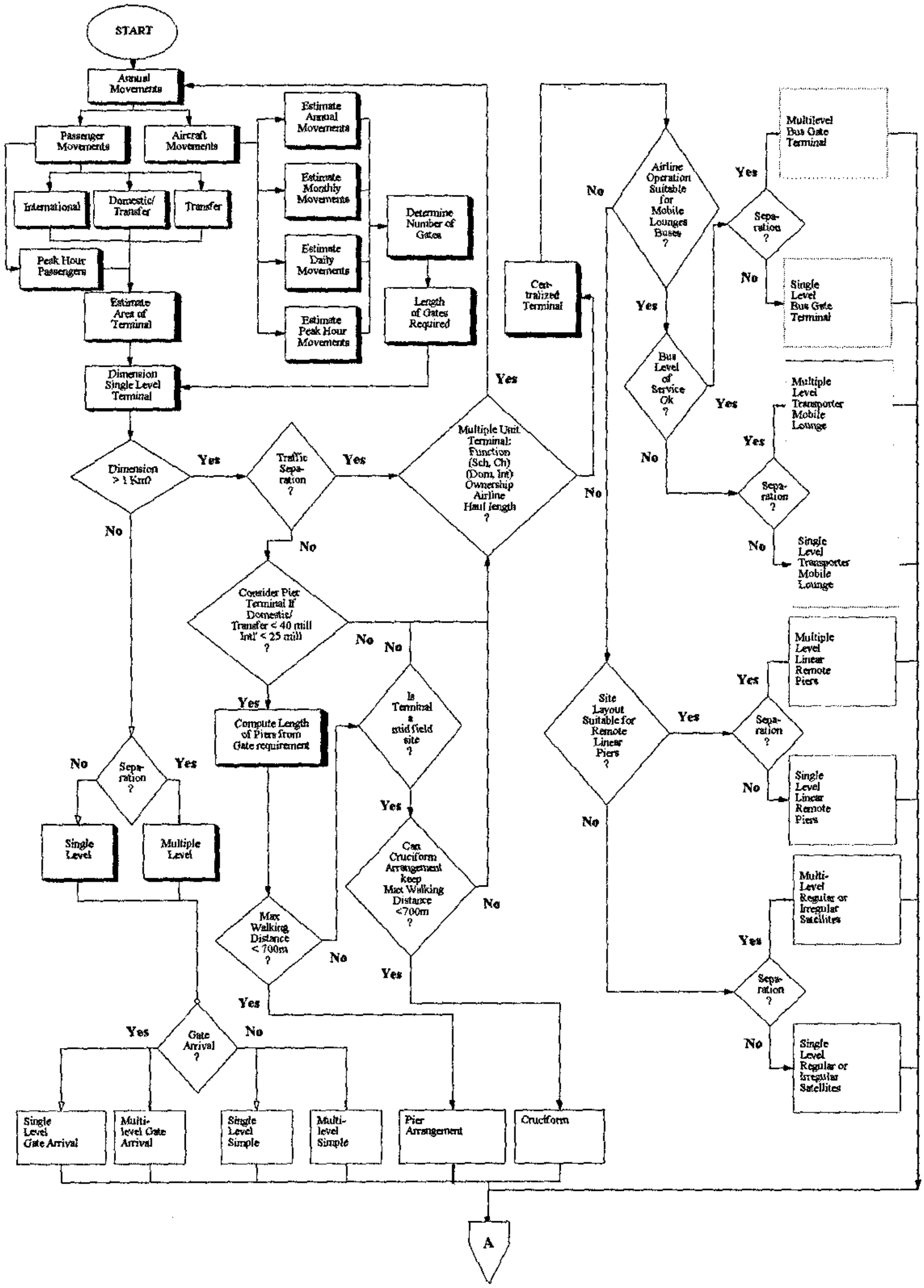


FIGURE 4.15: Terminal Concept Algorithm [*Ashford*]

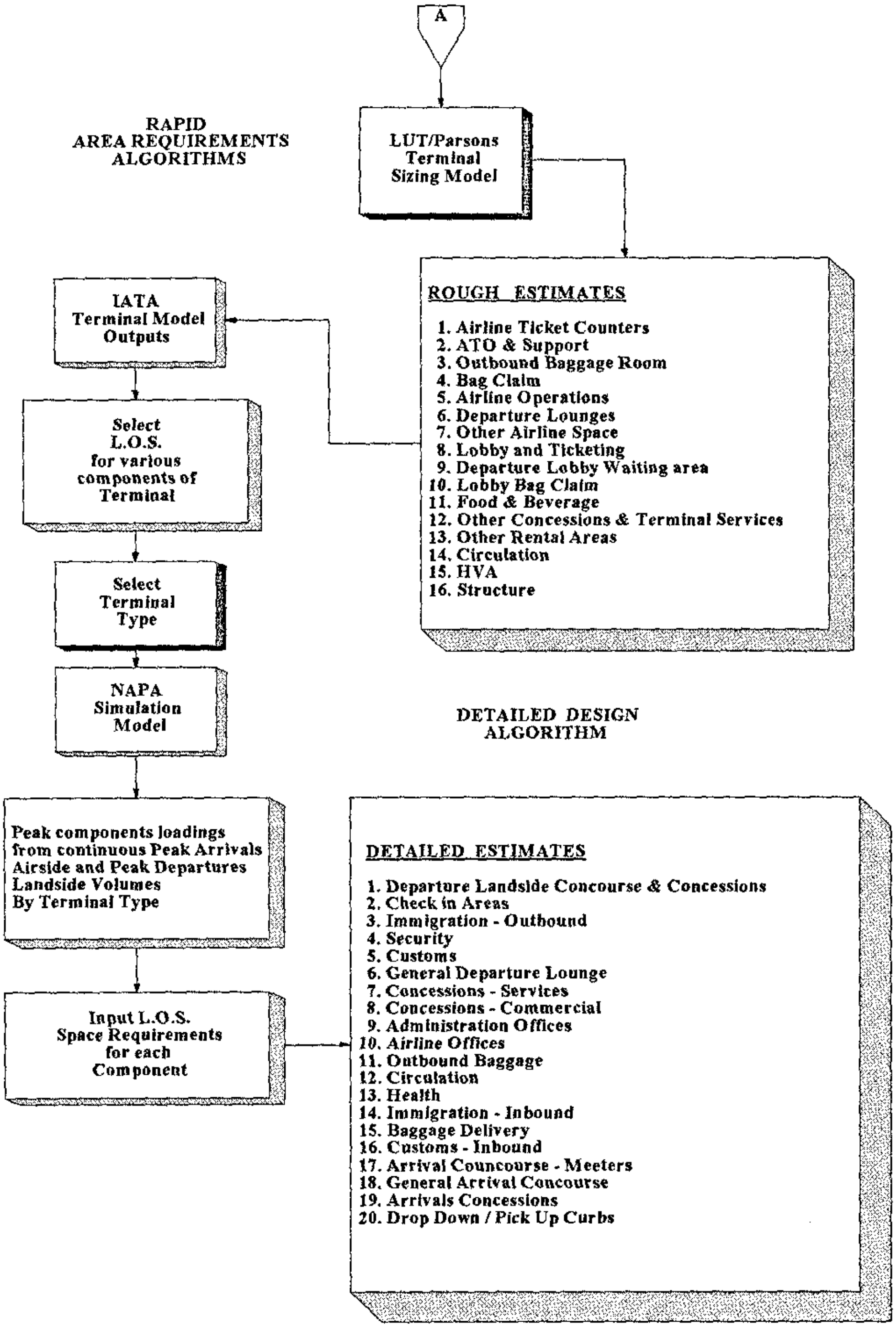


FIGURE 4.15: Terminal Concept Algorithm (cont.)

4.5 Summary

Concept is defined as an idea or a principle. As a primary definition, Terminal Concept is a taxonomy based on a conventional idea of form. It is also based upon centralised or decentralised passenger processing activities. It is the delineation of the link that connects an aircraft gate arrangement with a terminal or a taxonomy of aircraft terminal forms.

Although there is no agreed standard definition of terminal concepts among designers, the consensus is that the *basic forms* for terminal design are:

Linear

Pier

Satellite

Transporter

Other classifications vary from author to author and include hybrid forms. Some examples are mentioned: Open Apron, Gate Arrival, Central Terminal with Pier Fingers, Central Terminal with Remote Satellites, Multiple Piers, Unit Terminal, Mobile Conveyance, etc. see Table 4.1.

The concept evaluation should be based on a set of variables. The term variable meaning a quantity which does not have to be fixed, and that can take on any one of a set of values which falls within a range of values delimited by the set boundaries. A list of the main variables that may influence concept choice with order of priority is presented in Table 4.4. A simple procedure for prioritising alternatives is also illustrated.

The evaluation of different terminal concepts has been traditionally based on intuition and experience. Additionally, a number of techniques used in transportation planning are summarised, yet the possibility to adapt them in an attempt to evaluate concepts raises some doubts. Nevertheless, it is reasonable to suggest that a framework for evaluation is lacking in the system.

In this framework for evaluation, the analysis of alternatives should include the variables that are most effective for achieving the principal project goals. Such analysis should include *form* and *shape* as important variables in the process.

A Terminal Selection Algorithm is presented in Fig 4.15 This algorithm may well represent what can be called the traditional approach, which is based on knowledge and experience, yet is presented in a logical decision making structure. On the other hand, there is a series of loops in the algorithm associated with the Transport Concept that should be reappraised as the mobile lounge operation has been rejected by the majority of operators, not disregarding the fact that every airport is likely to have a need of additional aircraft stand positions served by buses as part of the apron complex.

5. CHAPTER V Terminal Sizing

5.1 Introduction

The previous chapters have discussed in general terms the designing process and the magnitude and interrelationship of the variables associated with the selection of basic terminal concepts. The necessity to understand the characteristics of the traffic using a passenger terminal, the provision of facilities to handle these passengers, establishing their flow patterns, and calculating the space required, before deciding about a terminal form has discussed in Chapter 2. This chapter addresses the details aspects of sizing an airport terminal, including the necessary assumptions and factors involved in the process that will allow the planner to idealise a proper concept.

The usual sizing methodology is based upon calculating individual facilities. The total area is then obtained by the summation of such single spaces. While these spaces are connected sequentially according to pre-defined passenger flows, the layout is mainly constrained by the shape given to the terminal. Since for each case only one form can be adopted and constructed the evaluation of Terminal Concept is quantifiable on theoretical grounds.

Whether or not a variable is important to this process, space is the resultant element. In other words, the provision of space is what one is looking for. The role of space is considered in Chapter 2, and before looking at individual elements of the terminal a framework for evaluating such spaces is discussed.

5.2 A framework for airport terminal space evaluation

The multiplicity of aspects involved in any process of planning and designing includes an analysis of spatial features of the environment rather than a simple plan/space relationship. It is certainly a three dimensional problem. Other interference related to personal space and its working conditions must also be accounted for.

Organisations like International Airline Transportation Association (IATA), Federal Aviation Administration (FAA) and British Airport Authority (BAA) have established standards for airport terminals in terms of individual space (area per person, per passenger, etc.), but which social or behavioural aspects were considered in their standard is not stated. Certainly there are some subjective aspects within their data though this is very difficult to ascertain. Mummayiz (1985) used a level of service approach based on passengers perception rather then basic standards to derive a methodology to analyse airport terminals. A good summary of Level of Service Standards is presented by Park (1995).

Level of Service has slightly varied definitions and a relatively different viewpoint among designers. It is considered to be a measure for capacity assessment, and expresses the quality and conditions of service of a processing facility, and is related to the amount of inconvenience experienced by passengers. Factors related to time (processing, waiting, dwelling, walking) and availability of passenger amenities for comfort and convenience are measures of Level of Service. Level of Service is also defined as a range of values or assessments of the ability of supply to meet demand, and combines both qualitative and quantitative assessments of relative comfort and convenience. Mumayiz (1985) considered Level of Service as a framework that would consist of temporal, spatial, econometric, and statistical measures. Temporal measures include: processing time, delay, total time spent, reporting time, flight arrival and departure delay. Spatial measures include: walking distance, occupation density (crowding). Econometric measures include: airline ticket fare, fare of airport access trip, pricing policies of airports, airlines and concessionaires. Statistical measures include: frequency of flights, number of airlines using airport.

5.2.1 Space Evaluation

Once the decision has been made to "do something" about space management at an airport terminal the following are some guidelines intended to lead the airport manager/planner through logical steps in planning and evaluating space or facilities within the terminal.

Step 1 - Inventory of All Terminal Areas

The first step of space management is the inventory of all terminal areas. A complete and thorough inventory of all terminal areas should be undertaken. In examining any terminal facility it is necessary to acquire and understand a recent and accurate floor plan, architectural drawing or blue print. Plans which are essential for evaluation of the building are those which include accurate marking of such permanent physical characteristics as walls, pillars, floors, and windows. Several elements must be considered, from the floors to the ceiling, mechanical conditions (wiring, electrical power and lighting, HVAC), furniture (desks, chairs, etc.), equipment (conveyors, scales, x-rays, computers, etc.). Then proceed to a visual inspection of all of the areas identified from the drawings, together with a collection of comparative statistics data of traffic volumes, and the identification of space characteristics from each facility, describing the purpose, functions, relationships, operations, physical properties and economics of a particular facility in terms of its space needs, functional relationships, environmental requirements and other relations.

The objective is to gather enough information to permit the manager to evaluate the degree of adequacy of each facility or terminal areas as well as the constraints, and the need for expanded or new spaces in the future. Collect data to project space requirements for a foreseen future of 3, 5, 10 or 15 years hence. Such information can be collected in a number of ways from internal and external sources, using observation, questionnaires, surveys, regular discussion and consultations with, airlines handling companies, commercial representatives, public sector; and local and national commercial and government information sources.

Step 2 - Level of Service & Standards

In this phase the emphasis should be on establishing the appropriate set of standards or level of service that will allow for an examination of the space the facility needs to meet present and future circumstances as well as to evaluate any serious deficiencies in the present terminal. Essentially, what is needed to make the area perform effectively and efficiently. The level of service and standards will be used as parameters forming a paradigm to compare the actual figures obtained from the inventory.

The effective assessing of space - including its characteristics described further on - have to relate comfort, convenience and time expended of airport users. Figure 2.15 represents the relationship between these factors, demonstrating that time is a primary variable to level of service. Time may directly affect the space required as well as comfort. Convenience and distance can also affect the space required in relation to the occupancy time. If any side of the internal triangle - time - is modified there will be a direct influence on the external triangle, which is representing the space. This means that if any variable changes, to maintain the same level of service, the space provided must be adjusted. Time is the major factor.

Step 3 - Establishment of Alternatives

With the information provided by the inventory, the airport manager should consider the various options for solving the space requirements. These may include:

- <u>Do nothing</u>. Sometimes political, economical or other factors may be the reason for the choice of doing nothing . Yet other alternatives should be evaluated.

- Reduce space requirements. If the space in study is under-utilised or if the inventory shows any other reason in this direction, reducing space may be a viable alternative.
- Change layout. Whether or not change layout represents an effective alternative depends upon the existing conditions, location, amount of space, efficiency and last costs.
- Expansion. This will depend mostly upon the building flexibility to allow expansion. However, this may be accomplished by shifting space with other facilities.
- Convert to for another purpose. Convert space to another use is more easily done when dealing with administrative spaces. With other facilities consideration must be given to make sure that this alternative is a viable and suitable one.
- Build a new space. Although this seems to be a natural solution, sometimes considered the most expensive one, a careful analysis should be carried out and the previous alternatives must be reviewed.

Step 4 - Action

The selection of one or more alternatives is the final phase. What is the best solution for the airport over the pre-determined period should be established. At this point a careful and objective investigation of the alternatives in terms of advantages and disadvantages for each facility and in terms of implication to the terminal as a whole must be completed.

In selecting an alternative the manager should be directed by certain attributes which should be embodied within any facility: a) flexibility, b) compactness, c) accessibility, d) extendability, and e) economic.

Flexibility

Flexibility in its figurative sense means to easily adapt to fit various conditions, in other words, being adaptable and able to turn easily from one situation to another or to be susceptible of modification or alteration. A capacity for ready adaptation to various purposes or conditions. It does not mean, of course, that the structure is flexible and will bend. A flexible facility is one which allows flexibility in the layout with space arranged to facilitate adaptability.

Flexibility is a prime requirement of a terminal building today. Not only do technological characteristics advance, but the shifting of traffic patterns may develop in unforeseen directions. In dealing with the future, the best approach would seem to be to recognise that traffic will change, shortage of space will occur, new approaches to problems will develop and all these factors need to be evaluated to be adapted to fit the new condition.

Compactness

The ease of movement of passengers means having the parts neatly or tightly arranged within a small space, not sprawled or scattered. A compact building theoretically will reduce walking distance to a minimum. The shape or physical properties here will play a significant role. A compact space on the other hand, should not compromise the comfort that is an adequate satisfactory space which is enough for one's needs - where level of service is implicit.

Accessibility

The quality of ease of access will allow an easy route to the entrance: and once inside, the user will be aware of the location of the principal elements of the terminal - check-in, arrivals, departures, information desk and the routes that should be strongly stated without an over-proliferation of signs and directions.

Terminal buildings are designed to be used and this use obviously implies traffic and accessibility to operate with a minimum of effort and minimum of disturbance is one of the essential attributes of a functional terminal.

Extendability

Extension should provide for increase in length or size. The space, as much as possible, should be able to become longer or larger. The terminal design should be capable of extension and land should be reserved for future expansion provided that the physical and operational arrangement will allow it. An organised and ordered arrangement of facilities will certainly 'better' the accessibility and functionality of the building. Simplicity in layout, arranged in an easily and understood way will facilitate the passenger flow inside the terminal and may well permit expansion.

Economic

Airport terminals are expensive buildings to build and they can be very expensive to run. Running costs may become a major financial consideration to airport managers. The inefficiency of space utilisation or the correct management of space may become the most important factor between the airport making a profit or a loss.

5.2.2 Space Evaluation Process

The diagram in Figure 5.1 shows the sequence and interaction between the four steps that are proposed to evaluate space requirements in airport terminal. The process must be iterative to cover not only individual facilities but the terminal as a whole. Nevertheless the process must be iterative due to the interdependence of each space and its attributes. This is better explained by analysing the space characteristics and the space management algorithm.

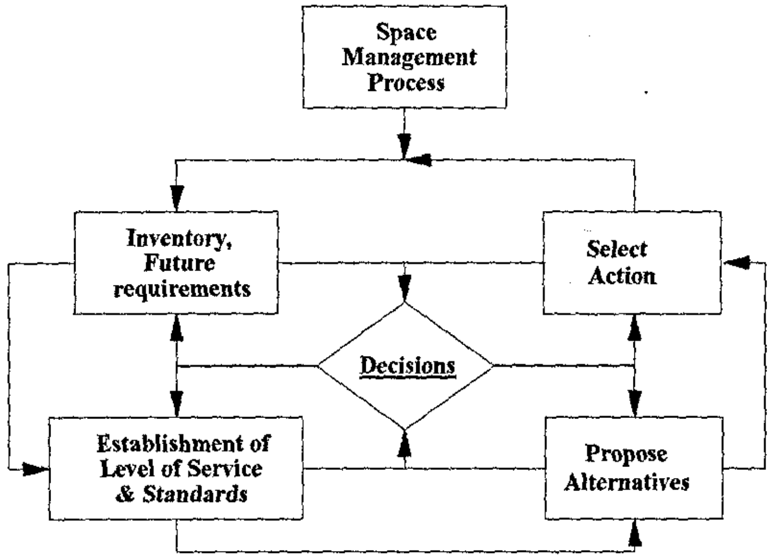


FIGURE 5.1: Space Management Process

Space Characteristics

There are four main characteristics that should be assessed when gathering information and evaluating facilities or space in airport terminals.

1) Functional;

2) Operational;

3) Physical: and

4) Legal/Economic.

These elements are included in the above management process and are shown in Figure 5.2 as a further expansion of the above diagram.

Functional

Two main elements should be identified at this stage: the *function/location* and its *user*, or more precisely the function of a space (facility) and its actual use.

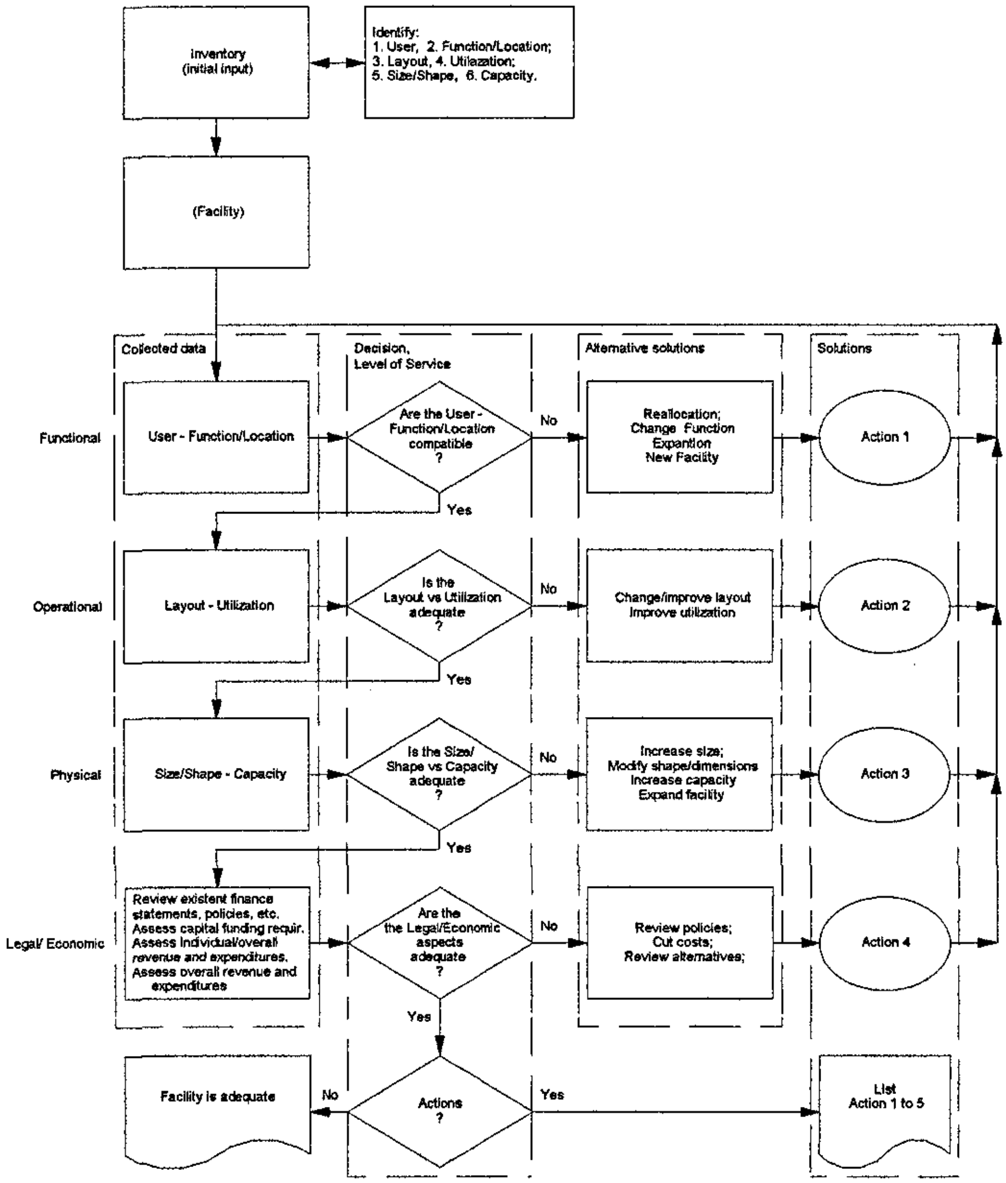


FIGURE 5.2: Space Management Algorithm

The only valid basis upon which rest a design for a facility or space is that of function. This is an obvious statement to make when the whole of the terminal is being planned to serve a number of functions. It has happened that certain areas have been given space left over and others have had not been considered at all.

Function means the conciliation of the actual use of an area and its proper use; i.e. the use that a space was designed for and the use that the airport has been making of it. An analysis of building function is to verify if a cloakroom for instance is used as such (its functional characteristic is work as a cloakroom). It is quite common at some airports to find that a space which was intended to be a commercial space, for example, is being used by an airline as an office, or a corridor has been transformed in a security check point (not designed for it); or even adding commercial areas indiscriminately to the detriment of operational activities. All these may not be directly acknowledged as a misuse of such spaces but the inventory investigates the causes and consequences of it.

A building's function is to serve and organise. Flows and patterns of use are a primary issue. It is necessary to ask if the facility is used with the needs of the user most in mind. The space should work within the specifications of the potential user. Within that context flexibility for variation should be allowed.

Operational

There are times when the expansion of an existing building or even a new facility may not be an acceptable solution to the terminal's space needs. The timing may be wrong, funding may not be available or the space deficiency may be too limited to warrant a full-scale terminal building effort. Still, a solution may be needed to meet the needs of a particular service or operation that is being crippled by space limitations. Changing the operational procedure may be the right solution.

The operational approach should be more narrow, more concentrated, and be more detailed than a broad strategy for which planning is concerned. This is likely to be for a shorter time period of action.

The space requirements in its operational sense are identified through the description of the *layout* and *utilisation* of each facility, by establishing the usual operational procedure in each space. This procedure is usually based on the preceding 'Functional objective'. A typical example of layout/utilisation is the formation of a queue at processing facilities like check-in. Identification of a long queue may be caused by misuse (few check-ins open while there are other ones available) or bad layout of check-in desks. In order to be able to evaluate such space, it is necessary to identify the realities that exist.

Physical

The quality of service may be dependent on internal organisation and efficiency - operational characteristics - , but this, in turn, is promoted by a good physical plan.

The physical characteristics of a space can be evaluated by its *size* - dimensions and shape - related to its *capacity* (see Chapter 6). Capacity may be complex as the size of a facility may not determine its ultimate capacity, which will depend on other factors. It may be a strong constraint. Each facility should be evaluated with regards to whether or not its size is satisfactory to meet the requirements of the existing level of activity. This is directly or at least indirectly related to passenger activity at the airport. Future demand may be not overlooked.

Legal and Economic

Even if the financial impact analysis is not a complex task, it might be the factor that would impede the execution of a new facility or the expansion of an existing one.

Although the legal aspects are easily identified it may be difficult to implement its requirements as is the case in some security procedures or even some health and governmental regulations. Each terminal facility should include:

1) An identification and evaluation of the legal constraints;
2) An estimation of total costs (considering inflation, financing costs, timing, etc.);
3) A cash flow over the expected period;
4) Maintenance & operating costs and expected new revenues;
5) Through Life Cycle Costing (if applicable) An analysis of the best alternative solutions.

The economic aspects may be considered as a distinct phase in the space evaluation process.

5.3 Sizing the Terminal

The major difficulty in the designing process is the consideration of medium and long term future inputs that are characterised by a high level of uncertainty. The lack of necessary information is a problem and hinders the process. The availability of data is usually poor. These problems are discussed in Chapter 2.

5.3.1 Rules of Thumb

The empiricism that has permeated the terminal design process and the absence of specific data has caused many rules of thumb to emerge. Several distinct level of service standards for different organisations in different countries and distinct space requirements have also emerged.. Rules of thumb are based on data from existent airports and should be only used as a rough estimate in the earlier stages of the design process. The values are in general applicable to certain regions or country with similar characteristics and may not be generalised. As such, some values when applying to an airport may give an accurate result while others may be far from the realty. Some examples of rules of thumb are given below:

- Imbalance between peak hour enplaned or deplaned passengers may be assumed to represent approximately 60 to 70 percent of the total peak hour passengers.
- Peak month passengers may be approximated as 10 % of the annual passengers, considering that the minimum peak is 8.33 % of the annual passengers.
- Number of aircraft movements in the average day of the peak month may be estimated as 1.05 times the average daily activity for the year.
- Terminal building [FAA, 1988]: 14 m^2 of gross terminal building area per design peak hour passenger, or 0.007 to 0.011 m^2 per annual enplanement at airports with over 250,000 annual enplanements can similarly be applied for domestic terminals. For international operations the estimated value should be 24 m^2 per peak hour passenger.
- Area for Concessions [Hart, 1985]: 10 to 15 % of gross terminal area for airports up to 1.5 million enplanements and 10 % of gross terminal area for airports with more than 3 million enplanements.
- Commercial areas: 1,000 m^2 per million passengers in addition to that 20% to 30% for all the backup space.
- Terminal building 10,000 m^2 per 1 million passengers per annum
- Baggage Claim: 1 baggage claim device per 1 million passenger per annum, or 0.13 m of conveyor belt per arriving peak hour passenger.
- For airport master planning purposes, the ceiling for daily gate utilisation is generally 9 to 10 departures per gate.
- Telescopic bridge/ gate: 1 passenger loading bridge per 400,000 passenger per annum.

- Airline Operations & Support areas can be approximated using 46 m^2 per total Gate EQA (calculated according [FAA, 1976]), including Cabin Service or Commissary, Ramp Service Personnel, Aircraft Line Maintenance, Office Area, Flight Operations Facilities, Flight Crew and Flight Attendant Facilities, Secure Area Storage, Volatile Storage.

- Departure Lounge can be estimated using 95 m^2 per total Gate EQA (calculated according [FAA, 1976]).

- If Peak Hour enplanements are not forecast, it can be estimated by using 70 times total Gate EQA.

- Public Corridor -. The capacity ranging from 52 to 82 person per meter width per minute. This is based on a width occupancy per person of 0.76 m and a depth separation per person ranging from 1,2 to 1,83 m, and a walk rate of person being 74 m per minute on average.

- Security -. Capacity for a single unite or station is in the range of 500 to 600 passenger per hour. The area required for this processing is in the range of 12 to 28 m^2 per station.

- Inbound Baggage and Claim - Space requirements - influenced by: Number of each aircraft type arriving during peak hour; Terminating passengers (as percent of total deplaning); Checked bags per passenger; Level of service goal. . (550 m^2 per narrow body aircraft and 740 m^2 per wide-body aircraft, including break down and claim area).

- Food and Beverage Service - snack bars, coffee shops, restaurants, bar-lounges. Space required is 10.5 to 12.0 m^2 per coffee/restaurant seat, including support space. Snack bars is 15 to 25% of shop/restaurant overall space requirement. Bar-lounges is 25 to 35% or coffee shop/restaurant overall space requirement.

- Cost of Airport Infrastructure - [IATA, 1995], for every billion dollars spent on new aircraft, half a billion dollars is required for supporting infrastructure.

Table 5.1: Other Concessions and Services [FAA, 1988a]

	Minimum Space Allowance (m^2)	Area per Million Annual Enplanement (m^2)	Area per Terminal (m^2)	Obs
News and Tobacco	14	55 to 65	-	-
Gift and Apparel Shop	-	55 to 65	-	-
Drug Store	65	55 to 65	-	-
Barber and Shoe Shine	14	one chair	-	10.0 to 11.0 m^2 per chair
Rental Auto Counters	-	32 to 37	-	-
Displays	-	8 to 9	-	-
Insurance	-	14 to 16	-	-
Public Lockers	-	6.5 to 7.5	-	-
Public Telephones	-	9 to 10	-	-
Post Offices	-	-	16.5	for each terminal with 2.75 million annual enplanement
Vending Machines	4.6	14	-	-
Public Toilets	-	125	140 to 167	per 500 peak hour passenger
Medical Aid Facilities	-	-	20 to 60	-
Nursery	-	-	4.5 to 5.6	The number of such facilities may range from two up, depending upon terminal size and configuration
Building Structure	-	-	-	5% of the total gross area
Building Mechanical Systems (HVAC)	-	-	-	12 to 15% of the gross total space
Circulation	-	-	-	circulation 15 to 30% of the total gross area;
International Facilities (Customs, Immigration, Agriculture and Public Health Services)	-	-	615	per each 100 passenger per hour arriving. (includes Supporting Facilities).
Airport Management Offices Airport Police /Security Offices	-	-	-	space requirements is proportional to staffing

The above figures are approximated values based on data collected from group of airports with similar characteristics in a specific time period.

5.3.2 Equivalent Aircraft (EQA)

The FAA (1988a) approach for planning is based on the peak hour of the average day to the peak month for the airport in study. The peak hour aircraft movements are also developed to derive an Equivalent Aircraft (EQA) as a single number reflecting the seating capacities and quantity of aircraft. The FAA sizing method is almost based on the EQA. IATA (1995), on the other hand, also suggests that facility planning must be based upon hourly flows. To arrive at an hourly demand a typical busy day is considered as the second busiest day in an average week during the peak month which is determined from historical data.

Grouping the aircraft according to their variation in capacity and size, predominantly the wing span is a common procedure for sizing terminals. The grouping adopted is given in Table 5.2. For other classifications see Chapter 6. The EQA are usually determined as a direct linear transformation of the number of passengers per aircraft.

Table 5.2: EQA - Equivalent Aircraft - Grouping

Group	Aircraft Type	Seating Capacity	Average Capacity	EQA
A	CV580 / DC9-10 / BAC111 / YS11-B / M404 / F27-B	40-80	60	0.6
B	B737 / B727-100 / DC9-30 / CV880 / F100	90-110	100	1.0
C	DC8-50&62 / B727-200 / B737-300&400 / B707/ MD80	120-160	140	1.4
D	DC8-61 / B757	170-210	190	1.9
E	DC10 / L1011 / A300 / B767 / MD11	220-280	250	2.5
F	B747 / B777 / A330	300-420	360	3.6
G	High Capacity Widebody	420-500	460	4.6

Source: Adapted from[Ashford, 1992; FAA, 1988a]

The EQA is the summation of the number of aircraft of each group times the factor given in Table 5.2 as following:

$$EQA = \sum_{n=A}^{G} M_n f_n$$

where,

M_n = number of aircraft in each group n.
f_n = EQA factor

The forecast may produce the foreseen aircraft mix for a specific scenario that allows the designer to determine the EQA. This information may not be available. However, in theory, it is important to know, for example, how many aircraft of each category would not only compose the mix, but to consider the case of a mix that would give the maximum number of Equivalent Aircraft. The problem is to determine what would be the combination or number of combinations of aircraft, which would allow a certain number of passengers in the peak hour, giving concomitantly the maximum EQA to be processed

The mix of aircraft being considered must accommodate the number of passengers expected in the peak hour. At least one group should provide the number of aircraft to carry that number of passengers. As the EQA is the common denominator to size different facilities, the objective is to maximise the EQA. Considering only two groups of aircraft, making the problem easier to understand, the following equations can be written:

$$EQA = f_A M_A + f_B M_B \quad (1)$$

$$c_A M_A + c_B M_B = Pax \quad (2)$$

$$c_A M_A \qquad \leq P_1 \quad (3)$$

$$c_B M_B \leq P_2 \quad (4)$$

$$M_A, M_B \geq 0 \Rightarrow \forall M, M \in \mathrm{I} \quad (5)$$

where,

c_A = average capacity of aircraft of group A
c_B = average capacity of aircraft of group B
Pax = Total passenger in peak hour
P_1 = number of passengers using aircraft of group A
P_2 = number of passengers using aircraft of group B

This type of problem where the objective is to maximise the equation (1) subject to constraints given in equation (2) to (4) is a common linear programming problem -- originally developed to invent new flight patterns and to solve complex logistical problems for military operations in the 40s during WW II [Daellenbach, 1983; Sultan, 1993]. Since then, the subject of linear programming has been used in a number of areas from military defence to medical application, transportation engineering, facility location, sales force deployment and computer design. The number and types of applications are very large.

The equation (1) is called objective function. The restrictions (2)-(4) are called the main constraints and the restrictions (5) are called non-negativity constraints. In the example given and illustrated in Figure 5.3, it is assumed that the peak hour passengers '*Pax*' is 820, and the two groups of aircraft are given in Table 5.3 below:

Table 5.3: EQA, example of linear programming

Group	Aircraft Type	Seating Capacity	Average Capacity (c)	EQA
A		40-160	123	1.23
B		170-500	353	3.53

The number of passengers P_1 and P_2 are set to equal the total passengers *Pax*, meaning that the number of aircraft in each group is not restricted, and the objective function may have just one basic variable greater than zero. The total number of aircraft in the mix may pertain, in this case, to just one group. These restrictions are shown by lines with arrows indicating the limits, see Figure 5.3. At first glance, the solution looks trivial; that making the number of aircraft in one of the groups equal zero, will give the maximum EQA. This is not entirely true. Firstly because the outcomes should be integers and a null value in one member may give a decimal number as a result. Secondly, there is more than one solution: two near solutions (see squares) and four probable solutions with excess capacity or smaller load factors (circles). Theoretically, the maximum value is attained in more than just one single point in the graph, but in every point of the line EQA, or the set of all points where the objective function takes on a specific value. On the other hand, if other constraints but passengers are incorporated into the problem, for example, the minimum total aircraft wing span length or the minimum total apron area required being considered, then the solutions may be investigated. When the forecast exactly predicts the aircraft mix the solution is direct, but in making assumptions with different scenarios the above procedure may provide the required information.

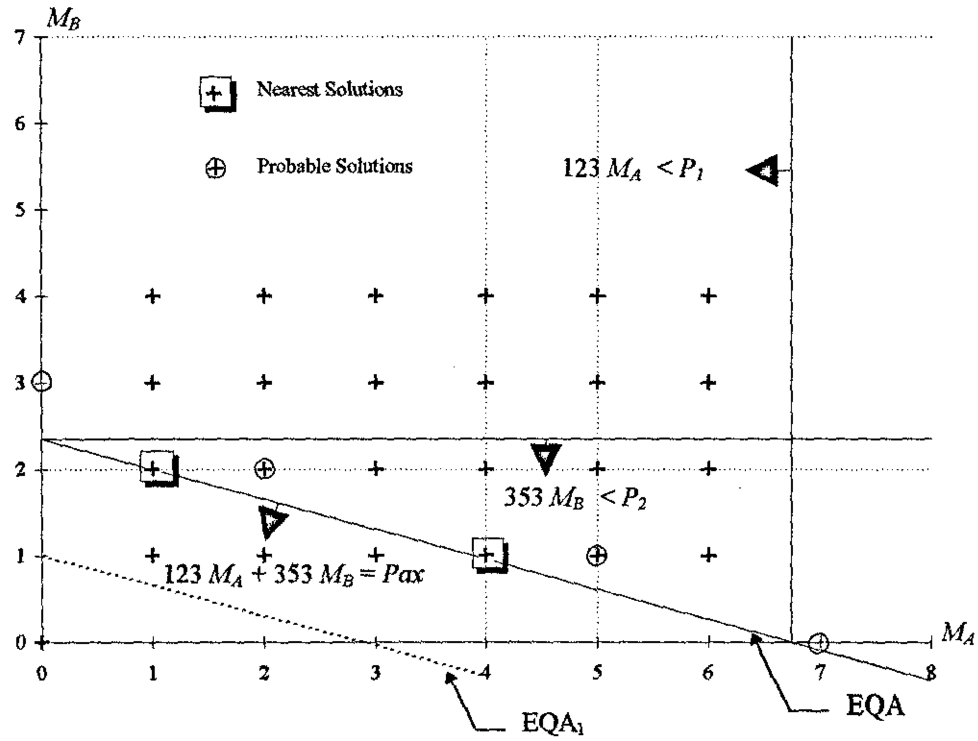


FIGURE 5.3: EQA Calculation based on Linear Programming.

The problem of solving a large number of linear equations with many variables is not difficult. There are several methods developed to solve the equations automatically. The Simplex method is one of them that can be looked over in any book of linear programming, see Sultan (1993) for example.

A set of peak hour varying from 500 to 10,000 passengers were adopted to represent the demand imposed on the terminals. The aircraft mix that generated these passengers was calculated using the above discussion, based on the fact that there is a tendency of aircraft size to shift as the traffic volume increases. Table 5.4 shows the results of EQA calculations. For the terminal size results see Table 5.9 at the end of this Chapter.

Table 5.4 EQA Calculation

	Aircraft Mix										
Peak Hour Passengers	**500**	**1,000**	**2,000**	**3,000**	**4,000**	**5,000**	**6,000**	**7,000**	**8,000**	**9,000**	**10,000**
70% Imbalance Arr/Dep	350	700	1,400	2,100	2,800	3,500	4,200	4,900	5,600	6,300	7,000
Category											
A	5	8	8	6	4						
B	2	5	10	11	11	15	11	10	8	8	5
C	1	1	4	8	11	11	11	11	9	9	9
D		1	1	4	5	7	9	10	9	9	9
E			1	2	2	3	5	7	8	8	10
F					2	2	3	5	7	8	11
G						1	2	2	4	6	6
EQA =	**6**	**13**	**25**	**38**	**50**	**63**	**75**	**88**	**100**	**113**	**125**

5.3.3 Departure/Arrival Curb and Waiting Areas.

Curb

A curb length should be provided to accommodate the variety of vehicles that use the terminal curb area at the peak hour. Although the calculation of the curb length requirement suggested by the formulae on FAA (1988a) and IATA (1995) methods seems to be very simple, the actual curb space usage, the loading and unloading of passengers by private and public vehicles can be very difficult to be controlled. Therefore the actual length required is more directly connected to the way that the curb is operated than on the total length provided. As the length of time that vehicles stop loading and unloading is the principal factor determining the curb length, strict policing to minimise dwell times may promote an efficient traffic flow. On the other hand, the arrangement of the building entrances, signs and internal layout of the terminal may also influence the overall performance of the curbside. It is preferable that the curb and terminal length are in balance. Where curb length exceeds terminal building length, further analysis of the factors generating the discrepancy should be carried out. In sizing the terminal it is logical to assume that the terminal length is equal the to curb length required. Therefore, collecting data on traffic characteristics, passenger modal preferences by vehicular type, percentages of passengers using the curb system, passenger/visitor and passenger/baggage ratios is important in the sizing procedure. The physical separation of arrival and departure curbs is also possible in two level terminals, however there may still be present some mixed use, i. e., departing passengers using arrival curb and vice versa, depending on the layout of the terminal, the car parking. Mandle (1982) related service levels and traffic volumes to curb length requirements. They adopted the following definitions for level of service:

- Level A - no traffic queues, no double parking.
- Level B - effective curb utilisation equal to 1.1 times actual curb frontage
- Level C - effective curb utilisation equal to 1.3 times actual curb frontage
- Level D - effective curb utilisation equal to 1.7 times actual curb frontage
- Level E - operational breakdowns, effective curb utilisation equal to 2.0 times actual curb frontage

The required deplaning curb length is around 20% greater than for enplaning. The values presented for service level A vary in a smooth curve, nearly linear, from 75 m of enplaning curb length for 500 peak-hour passenger departure to 610 m of enplaning curb length for 4,000 peak hour passenger departure.

It is easy to understand the dependency of curb length on vehicle dwell times by observing the IATA and FAA formulae. The other variables being constant, the curb length required is directly proportional to the sum of the dwell times of the vehicles using the curb system. Therefore, reducing the total dwell time by, for example, a factor of two, means that the curb length required will be halved.

The calculations of the arrival and departure curb length required for the terminals sized are shown at the end of this chapter.

Waiting Areas

Departure and Arrival Concourses; Departure Lounge: Gate Lounge, Common Lounge, Transit Lounge; CIP and VIP lounges are considered waiting areas. They are generally similar areas where the cumulative flow of passengers/people in a time period is determined by the required area or is defined by their capacity. The area required for a departure lounge, for instance, varying from 1.2 to 2.5 m^2 per person is a function of the number of passengers anticipated to be in the lounge "*n*" minutes prior to boarding to the aircraft. FAA (1988a) suggests that the provision of seating in a centralised waiting area (departure lounge) might be sized to seat between 15 and 25% of the design hour enplaning passenger and visitors if the gate areas (Hold Gates) have seating, otherwise, seating for 60 to 70 percent of design peak hour enplanements should be provided. Another suggestion is that for airports handling less than 100,000 enplanements annually the Departure and Arrival Concourses should be combined.

Paullin (1969) concluded that the size of a departure lounge depends on:

1. Size of airplane;
2. Number of available entry doors into the airplane;
3. Arrival pattern of passengers to the lounge; and,
4. The time allowed for boarding passengers.

In reality the boarding time is the main determinant in the required area, where for a 500 passengers airplane and a boarding time of about 35 min with one entry door would require a lounge area of approximately 150 m^2. If the boarding time for the same number of passengers was reduced to 10 min before departure, the lounge area would have to be about 650 m^2 and 4 entry doors would be required. See also Horonjeff (1968).

Although for Departure Lounges the FAA [ATA, 1977] suggests 1.0 to 1.5 m^2 per peak hour passenger, for Lobby-ticketing the graph indicates values around 0.5 to 0.8 m^2 per peak hour passenger. The IATA Airport Development Reference Manual, on the other hand recommends 1.9 to 2.7 m^2 for waiting/circulating areas and 1.0 to 1.4 m^2 for Hold Room areas. In the IATA formulae the concourse and departure lounge area required are directly proportional to the space required per person and to the average waiting time.

There are other areas that may be incorporated within these waiting areas such as toilets, commercial areas, decentralised security, gate check-in, etc. Certainly shopping and catering facilities will be appropriate in all waiting areas. Duty-free shopping should also be included in the airside concourse. With respect to departure lounge layouts, many variations are possible depending on the forms of terminal and whether centralisation or decentralisation is pursued. However, the main concern that should be analysed is departure lounges with and without holding gates. Terminals with a centralised departure lounge and gate holding areas have some operational advantages in terms of gate assignment and speed the process of boarding, but may have a large amount of space under utilised most of the time. Terminal 1 at Heathrow Airport is an example. Terminal 4 on the other hand, has a centralised airside concourse where departure lounge and commercial areas are integrated.

For more details of departure lounges characteristics see IATA (1995). The sizing of these facilities was made by using IATA and FAA methods and the results are shown at the end of this chapter.

5.3.4 Check-in

The check-in is a crucial element of the passenger terminal. It should be a main concern in sizing the building. It is the first point of passenger interaction in the terminal, and the first impression may govern the passenger perception of the level of service. It is also the time when the passengers have their baggage with them. Furthermore, there is always a little bit of anxiety about the flight to be taken. There is nothing worse than coming to a check-in and finding that your flight is going in three quarters of an hour but you can see that the check-in is going to take you at least half an hour. It is really not the right place to have a sub-standard service.

The check-in concept largely influences the passenger terminal layout. The configuration chosen may determine the width and also the depth of the building. Check-in can be distinguished by location and by shape (configuration). By location, there are three main check-in layout concepts [IATA, 1995]:

(1) *Centralised check-in*: where the passengers are processed in a common central area, usually the departure concourse.

(2) *Gate check-in*: where passengers proceed with their baggage directly to the check-in counters located at individual gate lounges.

(3) *Split check-in*: It is an intermediate configuration between the centralised and gate check-in, where the passengers and baggage may be processed in two or more locations within the terminal complex. It is actually a decentralised check-in.

By shape, it may also be divided into three main categories, although several variants exist.

(1) *Linear or frontal type*: where the counters are usually arrange in a linear layout. This configuration is the most frequently used.

(2) *Flow-through or pass-through type*: where the counters are also arranged in a linear layout but spaced so as to allow passengers pass between the counters.

(3) *Island type*: This type usually combines some characteristics of the linear and pass-through types.

The location of the check-in counters in relation to the building entrance, departure gate and aircraft position is a decisive factor for the overall concept of the passenger flow. The check-in operational procedures should also be considered, which may interfere with the efficiency of the system as a whole. In this sense the check-in can also be divided into three groups: Common check-in, Dedicated check-in and Split check-in.

- The *Common check-in* system is whereby passengers and baggage of any flight can be processed at any check-in counter. In terms, this system is only possible with the advent of automation and computers. The airport is usually provided with a Common User Terminal Equipment (CUTE), developed by SITA (Société Internationale Télécommunication Aéronautic), which is a software system that allows airport and airline to be connected with their own computer systems from any computer at the check-in desks. In its latest version CUTE O/S - Open System, the software system allows airports and airlines to use any communications networks and hardware on site. In other words the system consists of standardised workstations at airports and check-in gates that allow different airlines and handling agents access their own check-in systems to perform passenger procedures [Pilling, 1993].

This procedure has the advantage of reducing passenger waiting time; reducing personnel requirements; save airport space; increase efficiency; and, allow more flexibility to users -- the passenger can select the counter where fewer people are waiting to be processed. Conversely, it may require a more complicated baggage sorting system as the baggage of various flights may be processed to the same conveyor.

- The *Dedicated check-in* is where the passenger and baggage of a specific flight are processed at a specific group of counters. Where the terminal concept is decentralised the passenger might be checked-in at the Gate check-in.

  This procedure may generate long queues and poorer utilisation of resources, for instance, there may be a queue at the counter allocated to flight 'A', while the check-in allocated to flight 'B' is idle. A great number of counters may be necessary.

- In addition to these, a combination of forms as in the system of *Split check-in* may take place, whereby, for instance, the passenger having baggage are processed in the terminal, while passenger having only hand baggage are processed at check-ins at the Gate.

  Another form common in certain airports is the curb-side check-in, whereby passengers and baggage are checked-in at their arrival at the curb-side. The airlines are also investing in a self service check-in and ticketing for passenger with only hand baggage, highly automated and based on ATB (Automated Ticketing and Boarding Pass) machines. This system, which may give the most substantial gain in economic terms, would offer a better quality of service to the passengers. It can help reduce queues and make the check-in processing time faster.

There are many challenges to all those who are involved in airports in terms of efficiency, increase or decrease in productivity, cost cutting and rationalisation that are incorporated in a check-in evaluation. This starts in the design process and continues throughout the operations of the airport. The usual way to address the problem is through queuing analysis. The check-in facility is a typical queuing process, where passengers arrive, then wait in a line if the counters are busy, eventually are served, and finally depart from the desks. There must be enough desks to process all the passengers in time to catch their flight. However, the rate in which passengers arrive at the terminal and staff utilisation are particularly important to understand the mechanism by which queuing is formed or queuing times may be reduced. In simple terms, the airlines must increase the number of check-in desks opened in order to reduce queuing times. This is equivalent to increase the idle time of their staff, decreasing productivity and efficiency, and increasing costs. All these problems can be analysed by queuing theory.

Queuing systems consist normally of a few controllable aspects: the arrival pattern of the passengers, the service rate or service times, the number of desks, the capacity of the facility in terms of maximum queue length, and the order in which customers are served. By capacity it is meant the maximum number of passengers permitted within the boundary of the facility, both those in queue and those being served, which depend on nature of service, passenger arrival flow characteristics, and the level of services that is to be provided.

The queuing system may assume basically one of the three types depicted in Figure 5.4. Also of interest is the terminology for specifying queue's characteristics, called Kendall's Notation, which is I/S/N/C/Q, where I indicates the rate of arrival or input process; S denotes the service rate or service time distribution; N is the number of available servers; C the system's capacity; and Q designates the queue discipline.

Queue Characteristic	Symbol	Meaning
Arrival pattern, or Service time	D	Deterministic or uniform distributed
	M	Exponentially distributed
	E_k	Erlang-type-k (k=1, 2, ...) distributed
	G	Any other distribution
Queue discipline	FIFO	First In, First Out
	LIFO	Last In, First Out
	SIRO	Service In Random Order
	PRI	Priority ordering
	GD	Any other specialised ordering

The most basic waiting line model is M/M/1 which assumes that the interarrival times have a negative exponential distribution with parameter λ; service times exponentially distributed, with parameter μ, single channel; unlimited queuing size and service on a FIFO basis. The constant λ represents the average customer arrival rate, and the μ represents the average service rate.

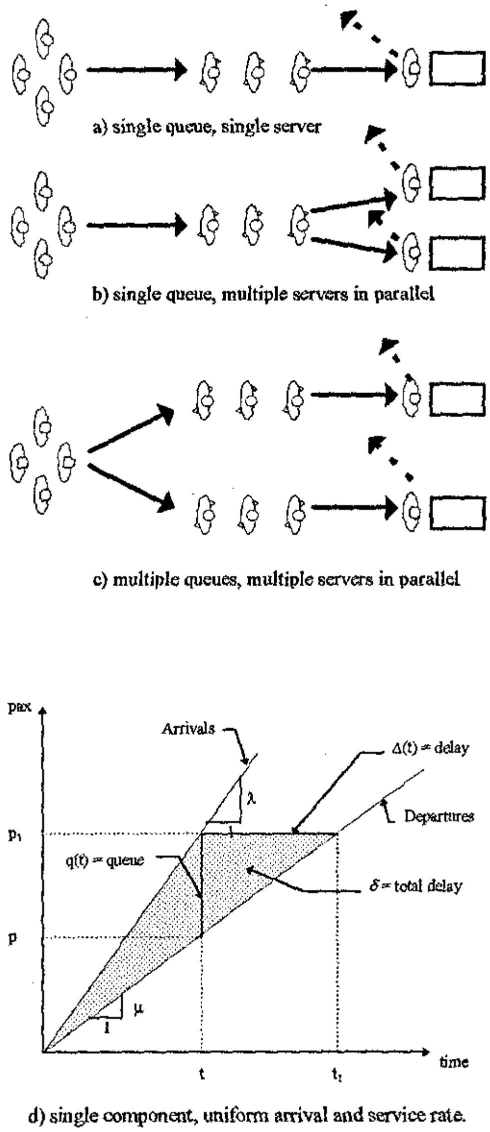


FIGURE 5.4: Basic types of queuing.

For example, Figure 5.4 shows a graphic characteristic of a deterministic queuing process, where a single component is modelled with uniform arrival rate at λ passengers per unit-time; and uniform service rate at μ passengers per unit-time. The queue length and delay time at a time t are indicated by $q(t)$ and $\Delta(t)$ respectively, and p is the cumulative number of passengers. The shaded area δ between arrivals and departures curves is the total delay time which can be calculated by:

$$\delta = \int_0^t \lambda\, t dt + \int_0^{t_1} p_1 t dt - \int_0^{t_1} \mu\, t dt$$

Solving this equation and rearranging the variables, the total waiting time is

$$\delta = \frac{p^2}{2}\left(\frac{1}{\mu} - \frac{1}{\lambda}\right)$$

Consequently, the average waiting time per passenger is

$$\delta = \frac{p}{2}\left(\frac{1}{\mu} - \frac{1}{\lambda}\right)$$

Although this illustrated system can be applied to a real problem, see Wirasinghe and Perera (1992), the queuing systems have a somewhat more complex structure, where the distributions involved are rarely uniform, more than one flight occurs simultaneously, and several desks with different service rates are present. System models type M/D/n or M/M/n are more likely to represent the actual problem. Queuing theory approach has also been used to analyse check-in and the other processing facilities of an airport terminal -- ticketing, customs, immigration, and security.

The main objective of this procedures when sizing the check-in facility is to determine the number of desks required to process the expected number of passengers at a certain level of service. In this respect one of the airline check-in allocation procedures that may increase the number of desks required is usually forgotten. The airlines distinguish passengers of international flights by First, Executive and Economic classes, which require separate groups of check-in desks. These classes correspond to a certain number of passengers that vary from airline to airline and from aircraft to aircraft. Analysing the aircraft fleet of 23 major airlines, the average value for their aircraft seating arrangements are around 7% for First Class, 17% for Executive Class, and 76% for Economic Classes. However, the number of passenger for each class may vary significantly from a minimum of 12 to a maximum of 56 seats for First Class, from 8 to 157 seats for Executive Class, and 116 to 479 seats for Economic Class, dependent upon the aircraft type. The calculation of the number of check-ins in airports with predominance of international flights should take in account these divisions.

The area occupied by a check-in desk (including scale and conveyor belt) may vary from around 7 to 15 square meters. Figure 5.5 shows size and dimensions for the three main check-in arrangements.

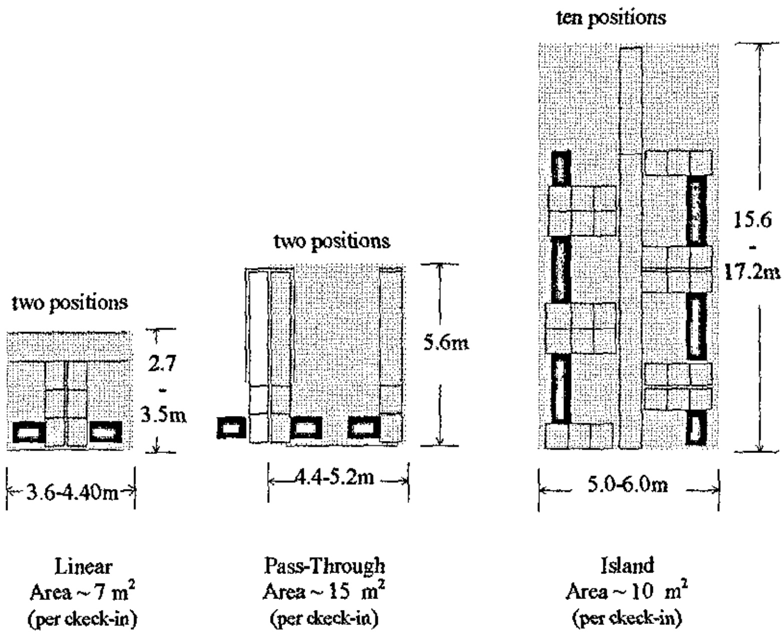


FIGURE 5.5: Check-in desks - size & dimensions.
(Adapted from [IATA, 1995])

The areas given in Figure 5.5 do not account for queuing in front of the desks. IATA gives the following equation which allow an approximation for queuing area:

$$A = s\frac{20}{60}\left(3\frac{(a+b)}{2} - (a+b)\right) \qquad (+10\%)$$

where,

s = area per passenger (queue length x lateral space).
50% of peak hour passengers arrive within the first 20 minutes.
a = peak hour passengers
b = transfer passengers not served airside.

5.3.5 International Facilities

Departure and Arrival Passport Control

This facility is required at airports with international traffic and provides for the inspection and examination of all persons to determine their compliance with the legislation of border controls (such as Immigration and Nationality Act). Space requirements for this service include general offices, automated equipment room, supervisor's office, interviewing room, detention room, lab equipment rooms, primary inspection booths, secondary inspection counters, conference/training room, locker and toilet, storage, and others on a case-by-case basis.

The layout of this facility varies from airport to airport and the total area does not seem to have a pattern at all. The arrangement is normally adapted according to the building enclosure. The total area required is the sum of counters area, queuing area, offices, equipment room, and others such as detention room, interview rooms, toilets, storage, employee lockers and rest room, etc.. These requirements will vary depending upon expected volume of traffic and also upon the local authority policy. For instance, government policy may determine inspection for different types of passport holders and therefore separate channels will be necessary, which may imply in more counters, staff and consequently more space. Although difficult to agree with in a standard to size this facility, the total area required, according to the FAA (1988a), including offices should be around 70 m^2 per booth. However, Blow (1991) suggests a value of 25 m^2 per desk. These values are far from a rule of thumb because as the situation changes (simplification or elimination of procedures), the nature of the space and facilities required by the governmental control agencies can be significantly altered.

Although the total area can assume any form or even be scattered in the building, the desk layout are very similar. An example of typical immigration desk layout is shown in Figure 5.6.

A queue is likely to be formed. Assuming that a percentage of the peak hour number of passengers would arrive within the first 15 minutes, the following IATA equation gives the total queuing area required:

$$A = s\frac{15}{60}\left[4\frac{(d+b)}{2} - (d+b)\right] \qquad (+10\%)$$

where,

s = queuing area per passenger (queue length x lateral space) (m^2)

d = peak hour number of terminating passengers

b = transfer number of passengers processed airside.

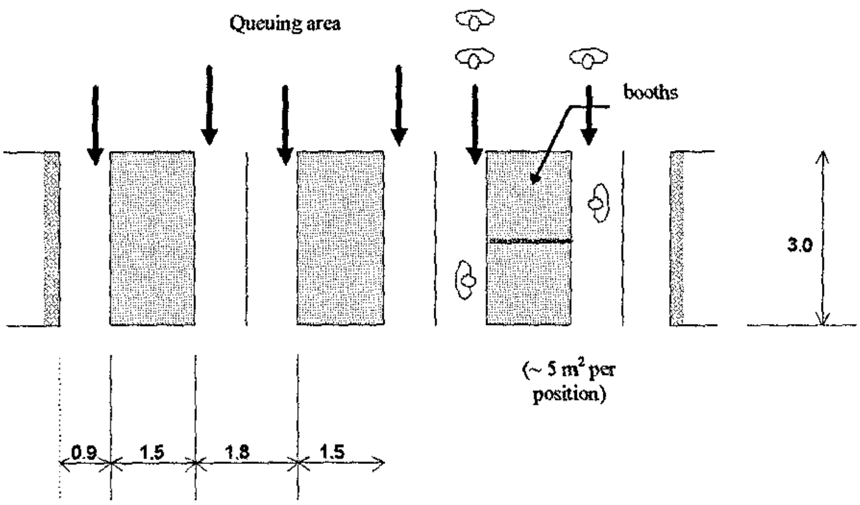
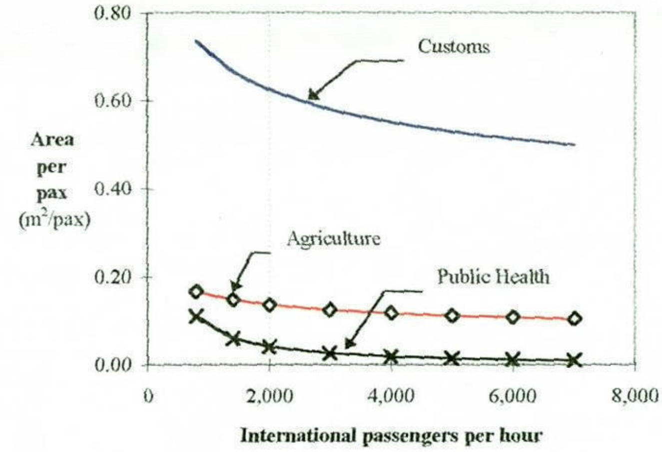


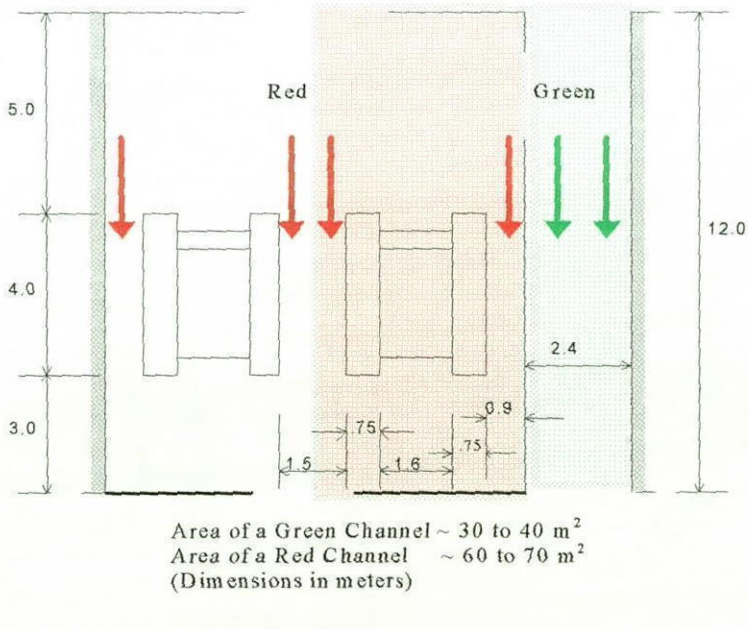
FIGURE 5.6: Example of Immigration Desks. (Dimensions in m)

Customs

This facility is required at airports with international traffic to inspect and control aircraft, passengers, baggage and cargo on items (goods) which are prohibited or subject to taxation. The number of positions required for the inspection of terminating passengers' baggage may vary in accordance with the local government requirements and the type of traffic handled. Some flights may be thoroughly inspected, but for the majority of them some form of sampling or selective inspection is usually practised. This sampling concept is known as the *red* and *green* channel system, whereby passengers with articles to *declare* proceed through a channel indicated by a *red* sign and passengers with *nothing to declare* proceed through a channel indicated by a *green* sign. Customs authorities normally make a random check of passengers proceeding through the green channel. This procedure is a form of reduction in the degree of Customs inspection, whereby only selected passengers and baggage may be inspected. It maintains the enforcement results of the system and reduces the necessary resources in terms of staff and total area requirements.



a) Customs, Agriculture and Public Health - Area required per peak hour passenger. (Adapted from [FAA, 1988a])



b) Customs - Example of layout.
[Source: IATA ,1995]

FIGURE 5.7: Customs - Layout and Area requirements.

The approximate total area required according to FAA (1988a) is indicated in Fig 5.7 a) where two thirds of the area is used by offices and supporting areas, such as storage, employee locker & toilets, computer room, conference/training, cashier booths, vault, storage, etc. Blow (1991) suggests a value of 0.5 m^2 per passenger for this facility. These are average values for early planning phases. The final space requirements depend on flight and passenger characteristics and local government policies, which will require analysis on a case-by-case basis. An example of a layout for a dual channel with an attempt to define the area required is illustrated in Fig. 5.7 b).

Health Control

The purpose is to enforce regulations to prevent the introduction, transmission or spread of transmissible diseases from foreign countries into the country of entry. This facility exist in only a few countries. It is usually the first control point of a passenger arriving, therefore, a inspection counter is required. The total area requirement may include one or more inspection counters, isolation area, toilets and a office area. The specific definition of requirements is on a case by case basis, determined by the local Public Health Service Agency. As a general guideline, the IATA (1995) suggests a calculation based on the number of inspection positions required based on the time to clear the largest aircraft operating at the airport and on the average service time per passenger. This requires a layout similar to the immigration booths.

Agriculture

Not all governments require this facility. Agricultural Control provides an inspection service for passengers and aircraft arriving from foreign countries with the purpose of protecting the environment by preventing the introduction of injurious plant and animal pests and diseases into the country of entry. Space requirements vary and may include special laboratories, special accommodation for animals, special equipment facilities for garbage cooking or sterilising apparatus, incinerator, supervisor's office, conference/training room, locker and toilets, storage, break/lunch room, etc. Additional space must be analysed on a case-by-case basis. An area approximation is shown in Fig. 5.7 a).

5.3.6 Security Control

The main aim is the general control of the movement of unauthorised persons and commodities into or out of a country. The security check is the individual search of the passengers and their hand baggage to prevent weapons and explosives from being carried on board the aircraft either directly by the passenger or in his/her baggage or indirectly being transferred from arriving, transit or transfer passengers. A complete separation of arrival and departure routes is required to minimise the problem.

As a result of the different passenger pattern flows, the security control can be centralised or decentralised. Centralised security controls are preferable once the requirements in terms of man power, equipment and facilities are significantly reduced compared with a decentralised system.

Security check facilities can be located in corridors, departure lounges, departure concourse, or even curbside areas. Nevertheless, they are usually points of interface between a public non-sterile area and a non-public sterile area. The average capacity of one x-ray unit with magnetometer, where passengers are searched by a walk through magnetometer and hand baggage searched by a x-ray scanner, is around 500 to 600 people per hour [Blow, 1991], depending on traffic characteristics.

The attention of the designers and planners should drawn, however, to the fact that any sort of equipment (x-rays, magnetometers, conveyor belts, computers, etc.) system required by an airport facility needs, no matter its degree of reliability, regular maintenance. The equipment availability depends upon traffic volumes, distribution of the flights per month, days of the week, and hours of the day. A back-up system should be provided to avoid the risk of stopping the operation in the event of the main system becoming inoperative. This usually consists of an additional set of equipment or the alternative of a manual passenger and hand baggage search.

A typical layout of a walk-through magnetometer and x-ray scanner including manual search booth for further search if necessary is shown in Figure 5.8:

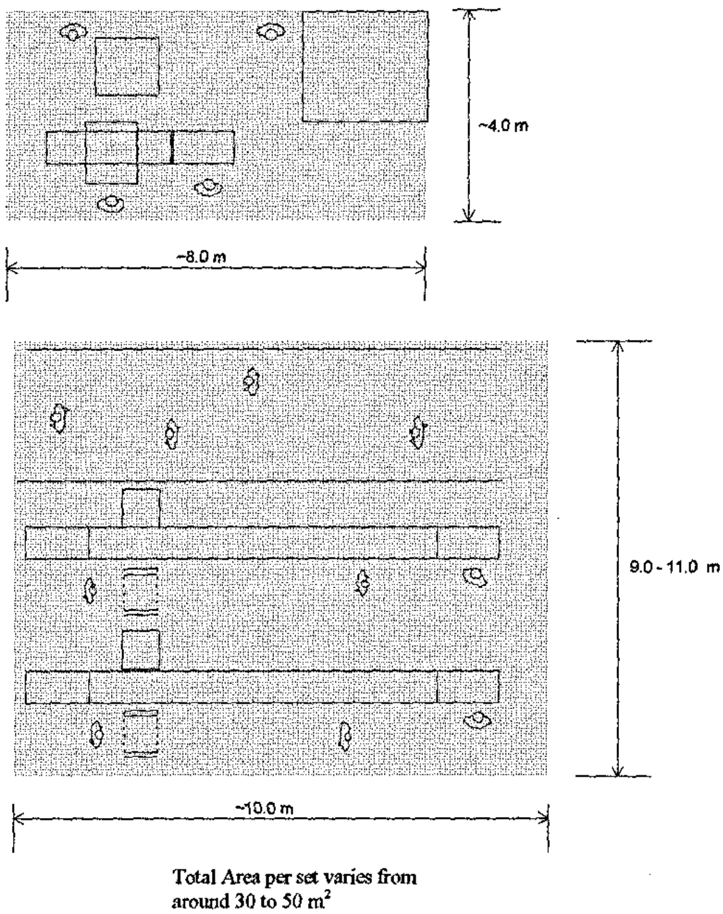


FIGURE 5.8: Example of Total Area requirement for Security Control.
(Source: [IATA, 1995; Hart, 1985])

5.3.7 Baggage System

The baggage handling system in airports is processed in two distinct ways: for departing passengers, the objective is to free the passengers of heavy baggage at the earliest opportunity, then sort and convey the baggage to the appropriate aircraft; for the arriving passengers the system must provide for unloading the baggage from aircraft and convey to a baggage reclaim area for presentation to and convenient identification and retrieval by the passengers.

Here, as it is with other airport systems, availability of the equipment, such as conveyor belts, cannot be overlooked. A form of back-up system must be provided. The system must be modular and independent as possible to allow flexibility for operation and maintainability, mainly in case of failure of any part of the system. Baggage Make-up Area or Baggage Claim Area with smaller circulating belts may be advantageous for its simplicity and it may add modularity to the system.

Departing Baggage

The Baggage Make-up Area is the area where the baggage is conveyed after the passengers have been checked-in in the terminal. In this area, also called the sorting area, the baggage is sorted and loaded into containers or carts for subsequent delivery and loading to the appropriate aircraft. The Baggage Make-up Area should be located as close as possible to the check-in counters to facilitate the conveyance of baggage between locations. The size of this area is basically dependent on the schedule forecasts of aircraft and passenger movements, including the division of types and baggage.

The Baggage Handling System can be divided in three main categories:

- *Manual*, in which the effort is sorting the baggage is done manually. Hart (1985) goes further suggesting that this category is almost physically static with inert shelves, sliding boards or combinations with roller sections.
- *Semi-Automatic*, in which the baggage is directed to flight loading positions by staff action.
- *Fully Automatic*, in which the baggage is sorted by automatic scanning by a laser reader of a special destination tag attached on the baggage at check-in time.

Within these categories there are some common types of outbound baggage equipment (for more detail see Blow (1991), Ashford (1992) and FAA (1988a):

- Belt conveyor - with capacity of 26 to 50 bags per minute;
- Inclined Belts with vertical lift devices - capacity of 18 to 45 bags per minute
- Re-circulating devices and Elongated oval configurations. This circular devices facilitate sorting bags into carts or containers for a greater number of flights and larger aircraft by allowing a "dynamic storage" of bags until they can be sorted into carts or containers.
- Semi-automated sorting - the equipment moves bag onto a lateral slide or conveyor designated for separated departures
- Tilt-tray sorters - operates with coding and sorting features as well as lateral conveyors accumulating baggage for each departing flight. Zurich Airport has a tilt tray mechanism.
- Destination coded vehicle systems - or a fully automatic sorting system with laser bar code reading or with OCR (Optical Character Reading) system. As

computer technology advances, new possibilities of baggage conveyance will be available in the near future.

With the present systems, the baggage and passenger flows are mutually linked and the disruption of one would hinder the other. There would be a great improvement in the system if eventually these processes could be independent.

Arriving Baggage

In this case the baggage is unloaded from the aircraft and delivered to the passengers in the baggage claim area in the terminal. There are two main areas required for this process: *break-down area*, in which baggage is off-loaded from carts and containers onto the baggage claim device, located usually close to the apron area; and, the *baggage claim area*, in which baggage is retrieved by the passengers.

There are several types of claim devices. The most common are:

- Linear (Shelf). That is merely a shelf on which baggage is off-loaded for passenger identification and retrieval;
- Simple Conveyor Belt. In which the conveyor belt arrangement is linear. The baggage is conveyed to a accumulation point for passengers retrieval.
- Flat Bed (Circular - directed feed - racetracks). It is the claim device preferred by the airline community [IATA, 1995], and is applicable when the break-down area is adjacent and parallel to the claiming area and or the same floor level.
- Slopping Bed (Circular/ oval - remote feed). It is applicable where the break-down area can not be located immediately adjacent to the claiming area and on the same floor level.

Layout and size

The layout and size of these facilities are the most variable (see Appendix B). The solutions at different airports are not necessarily the same, even adopting similar system design criteria. To any given baggage handling problem there is always more than one solution from both operational and economic considerations. For outbound baggage system the arrangement is dependent mainly on:

- Aircraft type and schedule (time, capacities and load factors, destinations, number of flights = sortation, etc.);
- Centralisation or decentralisation of the system;
- Carts and containers characteristics (type, size, numbers, method of staging -- parallel/perpendicular --, etc.);

- Baggage characteristics (number of bags to be loaded per unit of time, size & shape, oversized/ odd-shape, special handling).
- Passenger traffic distribution (originating versus transfer, international versus domestic, etc.);
- Check-in arrangement and check-in operational procedure (centralised versus decentralised, common use versus dedicated use, etc.);
- Number of airlines.

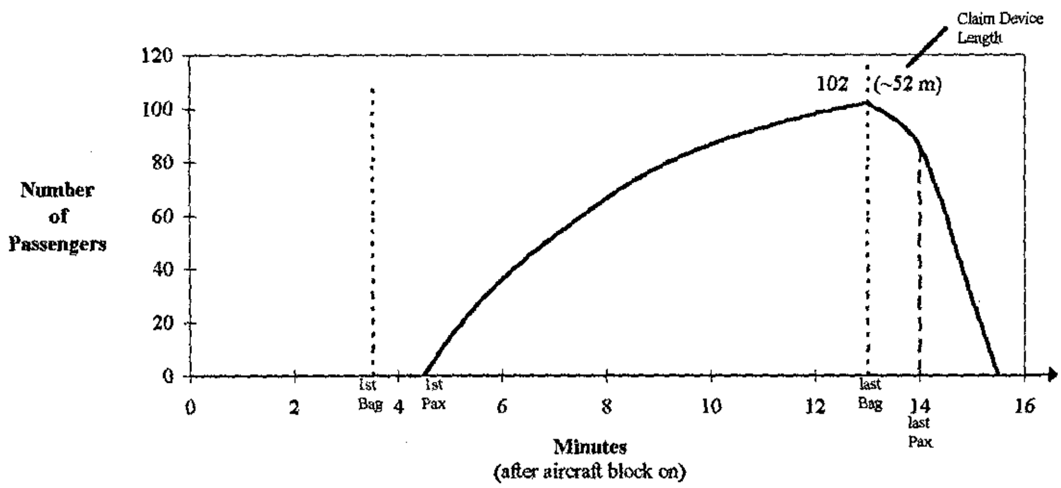
For inbound baggage the arrangement may depend on:

- Aircraft type and schedule;
- Passenger traffic distribution (terminating versus transfer, international versus domestic, percentage not claiming baggage, etc.);
- Baggage volumes (baggage/passenger ratios, delivery standards, etc.);
- Terminal geometry (passenger flow);
- Type of on-loading system (direct or indirect feed);
- Type of system (capacity - bags per minute).

The development of these design factors must be determined prior to undertaking the conceptual design of the baggage system but there are other secondary factors that may also be considered, such as column spacing, minimum clear heights, vehicular access relative to the apron, bypass lane, mechanical ventilation of enclose areas, and minimum device width.

Although the calculation of the outbound baggage room and baggage claim area can be done by sophisticated methods based on simulation analysis, the start up point is to determine the length of conveyor belts necessary for each baggage system. Examples of how to size these facilities is given by Hart (1985). The process is quite simple. For outbound baggage the necessary conveyor length is determined by the total number of carts and containers required to assist the aircraft in the peak hour. With the carts and containers dimensions and method of staging the total length is then calculated. For the baggage claim area the process is developed based on the conveyor capacity. Firstly the number of simultaneously passengers at the baggage hall in the peak hour should be determined. Then, determine the average number of bags per passenger and the bag length on the conveyor. The total length required is calculated by multiplying the number of passengers by the number of bags per passenger and by the length per bag. This process is very simplistic. However, when the times involved in the process, for the first and last passenger to arrive at a claim area and for the first and last baggage to be delivered on a claim device, are accounted for the solution can become very complex. Figure 5.9 presents a example of number of passengers accumulated on a claim device for a single aircraft B747, assuming the values and conditions indicated on the notes in the figure.

It should be noted that for one aircraft the process still seems simple, but with superposition of times and curves for several aircraft the calculation can be quite difficulty. Baggage delivery standards for the first and last bag to be delivered on a claim device after aircraft arrival, the distance and time that the passengers take to arrive at the baggage claim area, the bag/passenger ratio, and so on, are all factors that may alter significantly those values in Figure 5.9.



Notes: Aircraft B747 - Load Factor 0.75,
Walking distance ~ 250 m at speed = 75 m/min,
Passenger flow = 30 pax/min,
Manual loading and unloading ~ 30 Bags/min ,
20% of retrieval
Accumulation = 30 pax/min - 20%,
With 2/3 of the passengers close to the device,
Width of passenger claiming ~ 0.76 m per passenger.
Other times (container handling, conveyance, etc.) included.

FIGURE 5.9: Example of Length calculation based on the number of accumulated passengers on a Baggage Claim Device.

Based on the computation of arrival peaks occurring in 15 to 20 minutes periods, Hart (1985) gives tabular information that may help in the first stage of design, see Table 5.5. Figure 5.10 shows the net space necessary for the Baggage Claim Area for a range of Peak Hour Passengers. The results are based upon values from the tables above and assuming an average load factor of 80 %, baggage ratio equal 1.3 per passenger, and 65 % of the total terminating passengers claiming their baggage.

Table 5.5: Dimensions of Baggage Claim Devices by Aircraft Seat Capacity [a]

Aircraft Seat Capacity	Direct Feed: Exposure to Public	Direct Feed: Off-loading	Direct Feed: Total	Remote Feed: Sloped Pallet [b]	Remote Feed: Off-Loading 1 or 2 Feeds	Remote Feed: Carousel or Flat-bed [c]
420	62.5	27.4	90	76	12	82
370	53.3	24.4	78	64	12	72
270	39.6	21.3	61	46	9	52
200	30.5	15.2	46	37	12	40
170	24.4	12.2	37	27	12	30.5
140	21.3	10.7	32	23	9	24
100	15.2	7.6	23	18	9	20

[a] Assumptions: 85% load factor. 75 to 35% termination. 60% of termination active claim. Baggage ratio 1.3. Baggage off-loading at 12.5 bags per minute per handler. Visitor ratio 0.99.

[b] Effective width for baggage presentation 1.5 m.

[c] Effective width for baggage presentation 0.7 to 1 m.

(Source: Adapted from [Hart, 1985])

Table 5.6: Area per Passenger Claiming per Linear metre of Device

	Area (net) (m^2): Transited (any shape)	Sloped Pallet Oval, width 1.5 m	Flat-bed Oval, width 0.7 to 1.0 m	Carousel Circle
Device	0.914	1.524	1.280	1.402
Active Claim	0.914	1.326	1.676	2.042
Passenger Access	1.524	1.524	1.524	1.524
Visitor Circulation				
33 % visitors	0.823	0.671	0.610	0.427
66 % visitors	1.646	1.372	1.097	0.853
99 % visitors	2.438	2.042	1.829	1.280

(Source: Adapted from [Hart, 1985])

Table 5.7: Linear Metre of Claim Device per Passenger Claiming

Claim Device	Dimensions of device per passenger claiming (m)
Direct Feed	0.305
Remote Feed	
Sloped pallet	0.366
Flat bed (oval)	0.305
Carousel (circle)	0.396

(Source: Adapted from [Hart, 1985])

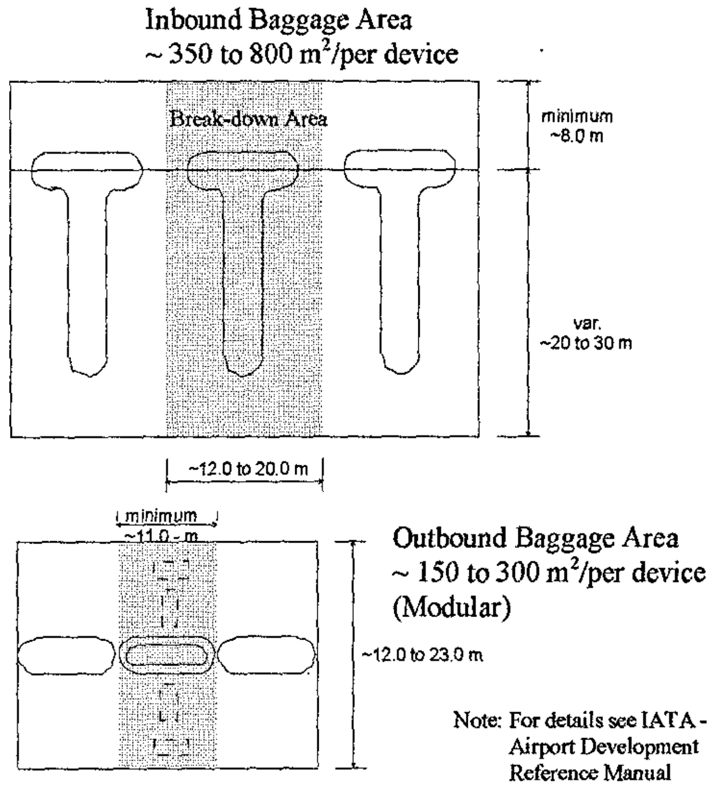


FIGURE 5.10: Example of layout of Departure and Arrival Baggage System.
(Source: Adapted from [IATA, 1995])

5.3.8 Structure

Any structure consists of a combination of various structural elements where art, common sense, sentiment and aptitude are present. Structure should comply with conditions and limitations of economy. But the aesthetic aspects of construction cannot be neglected or omitted altogether. And, material and construction methods are part of the problem.

To clearly identify the exact range that constitutes an optimum solution for a specific structure system is quite impossible. There are several concepts competing with each other which may all be efficient, and the solution may be based on other considerations rather than on structural efficiency. Spacing between columns is one concern. As the span increases, a rigid structure (subject to buckling and bending) may gain weight very rapidly, so that it must be replaced at a certain point by structures with characteristics of tension systems [Schueller, 1983].

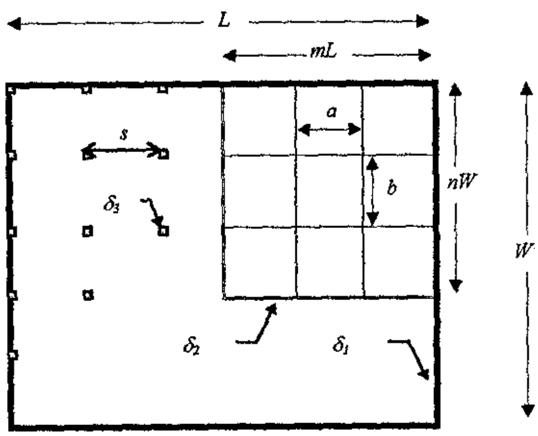
Buildings located in seismic zones for example should have a totally different approach. Open floor space is another concern that may influence the structural system that should involve space free of columns and load bearing walls. That structural pattern will at some extent determine the modularity and layout of the building. Multi-level buildings add questions of vertical access and structural concerns to the building itself and to its foundations.

Other factors are also relevant such as floor load, floor-to-ceiling height, roofs, and mechanical and electrical systems.

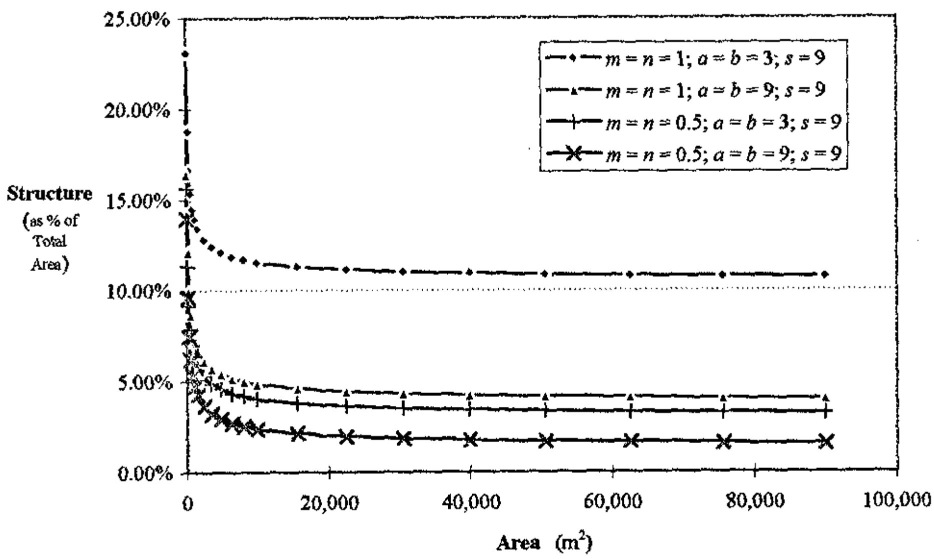
Although the plan area correspondent to structure (walls and columns) is rarely accounted for in the preliminary stages of the sizing process, its value may be representative. Some authors [FAA, 1988a; Ashford, 1992] assume that the total area for structure may represent 5% of the total area of the airport terminal. Measuring the total area of structure (through blue prints of the plan view of the terminals) for six airports: Birmingham, Dublin, East Midlands, Leads Bradford, and Sao Paulo, the values were found to be between 7% and 10% of the total area.

To illustrate the relationship between structure area and total area, consider a building with dimensions L and W, which has a grid of external and internal walls with average thickness δ_1 and δ_2 respectively as depicted in Figure 5.11a.

Assuming that the number and length of the internal walls are given as a function of the external dimensions and of the size a and b of the partitions, with $0 \leq m, n \leq 1$. The columns are assumed to have section area δ_3 and spacing between columns equal s. The total area of the building A_T and the total area of walls A_w (columns included) on the floor plan area are:



a) Schematic representation of walls and columns in a floor plan.



a) Area of structure in relation to total area.

FIGURE 5.11: Building walls and area of structure as percentage of total area.

$$A_T = LW$$

$$A_W = 2(L+W)\delta_1 + mnLW\left(\frac{1}{a}+\frac{1}{b}\right)\delta_2 + \left(\frac{LW}{s^2}+\frac{L+W}{s}+1\right)\delta_3$$

The percentage of structure in relation to the total area is,

$$Structure = \left[2\left(\frac{1}{L}+\frac{1}{W}\right)\delta_1 + mn\left(\frac{1}{a}+\frac{1}{b}\right)\delta_2 + \left(\frac{1}{s^2}+\frac{1}{sW}+\frac{1}{sL}+\frac{1}{LW}\right)\delta_3\right]100 \quad (\%)$$

Figure 5.11b shows the values for the structure considering a square building with variation on the spacing between partitions and columns as indicated. As expected, it is the extension of the internal partitions that mostly contributes for the increases in structure area, i. e. the percentage of the floor plan area that has partitions, which is represented by the coefficients m and n.

It seems to be reasonable to adopt 5% of the total area as a preliminary value for the structure as suggested by FAA (1988a), without incurring in substantial error.

5.3.9 Circulation

Based upon considerations on circulation outlined in Chapter 6, the following assumptions were made to define the main circulation for the established range of peak hour passengers:

- That 50% of the arriving or departing passengers pass through a corridor section within 20 min.
- The average walking speed is approximately 74 m/min.
- The average width of one passenger with baggage is 0.80 m [Tutt and Adler, 1990].
- Depth separation between two people walking equal 1.8 m. Thus, ~ 74/1.8 people per minute pass through a corridor 0.80 m wide.
- A boundary layer of 0.60 m is added at each side of the corridor for compensating the edge effect.

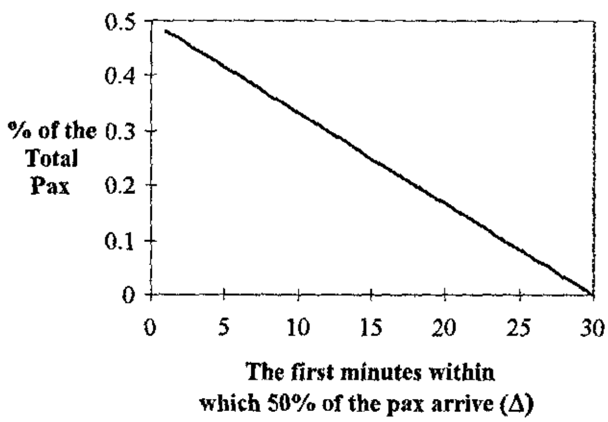
Therefore, the corridor width is calculated by:

$$W = \frac{S}{V} Pax\left(0.5 - \frac{\Delta}{60}\right) + 2b$$

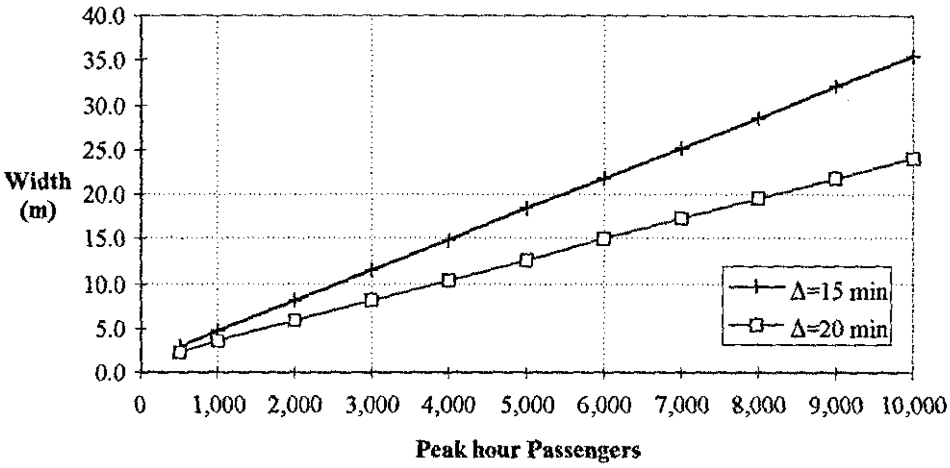
where,

W = corridor width (m)
S = area occupied by a person walking at speed V (m2)
V = average walking speed (m/min)
Pax = Peak Hour Passenger
Δ = the first minutes within which 50% of the passengers arrive
b = boundary layer (m)

Figure 5.12 gives the results of corridor width considering Δ = 15 min and Δ = 20 min, and also shows the relation between the peak hour passenger and the assumption that there will be a concentration of passengers in a short period of time.



a) Δ distribution



b) Corridor width

FIGURE 5.12: Calculation of corridor width.

5.3.10 Airline Space

In considering airline facilities there are many questions which need to be asked: What areas are necessary for airline operations? Why do the airlines need areas of dimensions 'x' or 'y'? Where do these areas have to be located? How and when do they have to be provided? Will the areas that the airline is asking for be given to them? How many employees does an airline need? What is the relationship between an airline and its necessities (of area, employees, materials)? Is it related to the number of flights, aircraft, passengers? or is there actually no consistent correlation? How much back-office area is necessary for supporting check-in services, or for office area for managerial personnel and clerks, or for the storage of urgently needed items for providing service to aircraft cabin (catering) or, for aircraft line maintenance (supplies, tools, storage, personnel)?.

These questions involve a number of variables related to airport characteristics, passenger traffic characteristics, airline station and service characteristics to which there is no objective and concrete answer. Airline space requirements vary widely at individual airports and depend upon a number of factors including the size and role of the airline's operation at the airport. Also the amount of space desired/occupied by an airline is dependent upon the charge/rent for that space. Although this is largely a matter between the individual airline and the respective airport authority, the airline's activity is the same. Airlines pursue their principal business of selling transportation services, dealing with passengers, aircraft and airports. Therefore, in spite of the differences that may exist between airlines, the similarities within the system suggest some relationship between the factor generating demand and airline space, as far as other terminal building spaces are related to passengers and aircraft.

Hardly any information is available related to this issue that can be used at the initial planning level to establish either the specific area need (administrative offices, crew area, etc.) or the total Airline Operational Area within the Terminal Building of an airport.

The Airline Activity.

Handling activities of an airport are very varied and each one of them requires skilled and trained staff to carry out the tasks. At least a sufficient amount of area must be provided to accommodate the staff. The activities developed may vary in intensity from a small airport to a large one. A small airport, usually has only small aircraft to handle, a low frequency of operation and a comparatively small number of passengers and cargo to handle. The wide variety of tasks can be done by a flexible handling staff. The small airport has different problems from those faced by larger busy airports. A distinction also has to be made between different stations. Although an airport itself may be very large, an airline may be handling or supervising (through the handling agreement) the handling of only one or two flights a week while the based airline will be involved in all activities. These activities can be divided into three categories: (1) Ground Handling, (2) Technical Services, and (3) Flight Operations. The two main airline spaces in a terminal which perform these tasks are Airline Ticket Counter/Office, and Airline Operations Area.

The Airline Ticket Counter / Office.

The Airline Ticket Counter/Office-ATO is defined as the area at the airport where the airline and passenger make final ticket transactions and check in baggage for a flight. It includes the airline check-in counter, airline ticket agent service area, outbound baggage-handling device, and support office area for the airline ticket agents. The demand forecast and establishment of the arrival rate of passengers at the check-in counters is viewed as the key for planning this area.

The type and number of airline counters positions, which are determined by each airline according to its staffing criteria and company standards for processing passengers and baggage, are influenced mainly by: design hour enplanements (derived from projections of peak hour/average day of peak month enplanements plus other considerations), contact ratio (shows the relationship between the number of passengers who contact counter agents and the total number of enplanements or originating passengers), passenger arrival distribution patterns (the rate as which enplaning passengers arrive at lobby counters for processing), average process time for each type of counter activity, and service goals of an individual airline or airport authority (expressed as the percentage of passenger contacts who will wait for service 'x' minutes or less).

The airline office support area is defined as the area that usually includes space for accounting and safekeeping of receipts, agent supervision, communications, information display equipment, and personnel areas for rest, personal grooming, and training. Some terms used to identify these functions are: Checkout room, Ticket audit, Agent Lounge, Supervisor office, Manager office, Storage (office and counter supplies). The approach to airline space is divided in small stations and larger stations. At small stations, usually single-level terminals, all company administrative and operational functions are usually gathered. At large stations typical arrangements, in which some terminal functions are decentralised (outbound baggage rooms are located on the level below the airline counters) requiring a multi-level terminal. Some airlines' functions may be developed in remote buildings. The airline space needed is dependent upon the airline's own staffing criteria and its standards for processing passenger and baggage for each airport. The procedure of evaluating such amount of space is usually obtained by collecting and analysing data from questionnaires.

Airline Operations Area.

Airline Operations area is defined as the area occupied by airline personnel for performing the functions related to handling the aircraft while it is on the ground in preparation for departure. It is usually located near the apron. This area is composed of the area required for flight crew and flight attendants (lounge; storage space; area for flight planning, weather, and flight information; restrooms; stewardess grooming area) ground-service personnel, aircraft line maintenance personnel and storage. It is suggested that the area requirements have to be determined from an analysis based upon the type and character of service to be provided at the airport and the manning necessary to support the service. The following facilities and services, according to IATA (1995) are indicated as requiring allocation of airline space in the passenger terminal, although some of them may be placed in a separated building:

- Airline Station Administration, including station management, accounts, secretarial staff crew routing, payroll, etc.,
- airline operational control, area for meteorological data and flight plans, message centre, etc.,
- operational trim (weight and balance computation),
- co-ordination of functional flow activity,
- baggage handling area,
- handling, storing and processing of cargo and mail, and associated offices (where a separate cargo building is provided, accommodation should be made available in the passenger building for handling top-up and transfer cargo on passenger aircraft),
- air-crew rest and meal facilities (depending upon airline requirements),
- staff meal facilities,
- staff toilet facilities, including showers and changing/ locker rooms where necessary, adjacent to the working areas,
- aircraft loading, apron servicing, and cabin cleaning personnel (including marshalling personnel where aircraft marshalling is an airline commitment),
- bonded aircraft bar and commissary storage,
- air-crew catering and associated facilities,
- storage and servicing of aircraft containers, apron service vehicles and equipment,
- line maintenance, supplies, tools, storage, and personnel area, etc.

Storage areas and administrative areas can be combined. Depending upon the schedules of flight operations, flight crew and attendant facilities may not be required or can be combined with other facilities for other personnel. Similarly, flight operations can be combined with other facilities for administrative personnel. The least relatively flexible space in terms of area is cabin service. Even this facility may use an inconsequential amount of area because the characteristics of the operation may be that very few aircraft will require cabin service. At very active airports, the opposite may be true, and the facility may consume a significant area.

Detailed inputs and more extensive planning participation are required from the airlines, specially for exclusive-use space. If one airline is absent in this process the planning system seems to be disrupted and sizing the airline spaces then should only be developed on an estimate of traffic volume.

Space required

A Rule of Thumb for estimating this area for master planning purposes is given at the beginning of this chapter, and includes all of the operations areas previously described, including cabin service facilities that may require the greatest amount of area in terms of storage requirements.

FAA - Planning and Design of Airport Terminal Facilities at Non-hub Locations (1980) recommends that the tenant airline should furnish a tabulation of the spaces and space requirements for their individual needs in the airport terminal, and suggests that airline office space should be provided behind the ticket counters having access to the ticket counter and baggage make-up area. A crew lounge may also be included. Limited maintenance space and storage for aircraft supplies is usually required and can be located near the aircraft parking apron or, if not, in part of the space behind the ticket counter. IATA (1989) states that the airline participation in planning and design of airport terminals is of capital importance, whether it is for entirely new facilities or for modification to existing ones. Airports and Construction Services Directorate -Transports Canada (1986) recommended that the amount of space required for the airlines operation facilities should be determined on a site basis following negotiations with those carriers involved.

The general overview is that the active participation of the airport authority, airlines and other tenants, and a consultant(s) engaged by the parties is essential for the effective planning and design of a terminal building. Where rules-of-thumb are provided for the purpose of making order of magnitude estimates of passenger terminal activity and space requirements, they are not satisfactory for the design and detailed analysis or evaluation of a particular airport.

The present thought for designing airline space is that this is largely a matter between the individual airline and the respective airport authority (designer) and accordingly the space requirements are still dependent upon a number of factors, including the size and role of the airline's operation at that airport.

There are also many other interference related to the provision of space and its working conditions: thermal, aural, spatial, visual, social and including lighting, heating and ventilation. A relevant point is that office work largely consist of the movement and processing of information. The processing of information either computerised or manual involves collecting of information, processing, storage, retrieval and output. Moreover, as technology changes, its impact on the airline methodology of processing information will require further evaluation of existing office spaces in airports to respond to new procedures (e.g. CUTE II - Common Use Terminal II enables using of shared facilities) and new ways of processing passengers. The likelihood of change has become so evident that flexibility in airport design has been viewed as a fundamental measure in airport performance, and the use of modularity has become convenient for design/construction at least as much as for adaptability in operation and for expansion. It is interesting to note that the process of designing is fundamentally based upon human interactions. The designer must select the appropriate measurements to the user for sitting, standing, or moving about. If space is important for passenger flow, to design an adequate airline office certainly will improve human performance (job productivity). The right way of designing an office would be to obtain a detailed analysis of all the actions that the staff would have to carry out and the equipment that would be involved. This is very difficult in an airline operation environment for several reasons including the variations in the operational characteristics of terminals and the overall variability of the level and nature of the traffic.

On the other hand airline offices are not different from any other office space for there are people (manager, secretary, etc.) furniture (desks, chairs), equipment (computers, copiers) and the space required will depend upon such considerations as:

(1) The policy of the airline/airport authority;

(2) The status of the airline within its organisational structure (type of station, based airline, etc.);

(3) The type of space in which the work is to be done (e.g. administrative, line maintenance, storage, etc.);

(4) The status of the individual (e.g. first class, executive or economy);

(5) The furniture and equipment to be accommodated;

(6) The needs of the individual or his work for quiet or privacy;

(7) The space available at the airport;

(8) Rent price policy established by the airport authority;

(9) Cost.

Apart from these constraints, the determination of space and the appropriate dimension of airline office functions has received negligible attention. One impression resulting from visits to airline offices in several airports and from analysing the layout of others has been that the basis for designing seems to be quite arbitrary. Although a particular airport configuration may imposes limitations upon a designer's freedom to shape airline offices, there is little indicators of the space needed. For example, not all space within an office is effective functional space, for there are in addition the 'extra' spaces of lavatories, special furniture or equipment, meeting rooms, bulk storage and cleaners/catering space. Salmon (1979) suggested that further space of the order of 15% must be added on as an allowance for access to the immediate working area. He also observed that in practice a maximum working space carefully calculated will be expanded by at least 25% once that office space becomes operational. Langdon (1966) after surveys in more than 2,500 office rooms showed that furniture occupies between 25 and 30 percent of the floor space.

The range of areas required for various levels of staff tends to fall between 5.5 and 13 m^2, giving an average of 9.5 m^2 per person. For more senior staff and executives the following minimum areas per head are given as a guide to the size of their private offices.

- Senior Clerk, secretary 9 m^2
- Manager or professional 14 m^2
- Director, Senior Management 20 m^2

Nemecek (1973) investigated 15 Swiss large space offices finding that the floor area per person was (including area for furniture) 7.3 to 14.4 m^2. Langdon (1964) investigated 2,734 small and medium size offices in London and found that the average area per work place was 11.4 m^2 for men and 9.3 m^2 for women. The same author found that the majority of the people were satisfied with office areas of 12 to 16 m^2 per person. He recommended an average area of 11 to 14 m^2 for all offices. According to the function the areas were: Firm 'X' Directors 32 m^2; Top Executives 27 m^2; Senior Executives 19 m^2; Two senior secretaries sharing 19 m^2; One senior secretary 13 m^2; Technical staff PA's Supervisors 9 m^2; Secretaries, Clerks, Machine operators, Typists 6 to 6.5 m^2;

Firm 'Y' Directors 23 m^2; Senior executives 19 m^2, Managers 12 m^2; Assistant Managers 8 m^2; Secretaries 5.5 m^2; Clerks 4.6 m^2. Boje (1971) suggested 8 square metres, plus reserve, for each work position (Average area per workplace, m^2, Total 17 m^2 -Effective 12 m^2 - Office 9.6 m^2). Bailey (1990) suggested that approximate estimates of the floor area required may be based on 9.3 to 11.6 m^2 per person, with this forming approximately 80 percent of the gross floor area. Panero (1979) observed that only a few large firms had an established policy for determining their office standards. Where such standards had been fixed the minimum area was of the order of 5.5 square meters per person. Neufert (1988) recommends that the space required (including office accessories and their operating areas) may vary from 4.3 m^2 per simple worker to 25 m^2 (or more) per manager. The Dartnell Corporation (1964) asked 278 participating office executives to estimate the area allowed each person working in the office, including furniture and came up with the following tabulation:

m^2 per person	Number of Companies
0.6 - 1.0	12
1.9 - 2.8	38
3.3 - 4.2	50
4.3 - 4.6	06
4.7 - 5.6	22
6.0 - 7.0	12
7.5 - 8.5	16

Other estimates were from 9.3 to 46.0 m^2 per employee. However they concluded that the methods of arriving at estimates varied from the actual space needed for each clerical worker in his or her immediate area, to the average area, i.e. the entire office area divided by the number of employees. Walley (1982) discussed principles of office layout and expressed that clerks will need 13 to 19 m^2 and managers between 25 to 60 m^2.

Analysing the existing office spaces throughout the airport layouts 360 office spaces were sized giving an average of 16.00 m^2 per office. This included the overall space of each office and is not intended to represent the amount of space used by individuals. The offices computed varied from 6.00 to 25.00 m^2.

The question remains whether or not a standard for airline office space should be established. If space standards for office buildings are difficult to set, for airline office will be more difficult considering that in the process of designing airport terminals the main focus is not the airline space. In some airport terminals, designed and constructed to cope with future demand, the real problems of capacity and congestion, expressed by lack of space only will appear after various years of operation. This problem is true for passengers and airline space.

An ideal space to be provided to an airline that has only a station manager is about 16 m^2. If there is a secretary at least 9 m^2 should be added.

Space in the terminal becomes more valuable as traffic continues to grow and an overall shortage of office space is also likely to occur. Therefore, it is important to consider from the earliest stage all individual areas of an airport terminal including office space.

An airline requires space necessary to perform its tasks. In essence these tasks are almost identical for smaller or larger airports, only the intensity or quantity of work to be done may differ as a function of aircraft type and size, traffic volume, and as much as the handling services are performed by handling companies or by another airline (through a joint venture agreement). This implies some relationship between the work done and the space needed to perform that work. For terminals, the overall space requirements are normally related to peak passenger flows and individual facilities are usually sized in terms of anticipated passenger loading from forecast aircraft in the peak.

Analysing the data of airlines' manpower and their traffic volume, from some European Airports, it was found that there is a relationship between the total number of employees and the volume of average passengers/week transported by each airline. There is also a relationship between the number of employees of each airline and aircraft movements.

Any airline should have as much space as it considers necessary for the proper conduct of its business at an airport. In practice, this will almost certainly be mingled with factors that may impose constraints from both the airline itself or the airports availability to allocate space.

The accommodation requirements of an airline depend on many factors concerned with the size of its operation, the number of functions it would expect to conduct itself and whether or not it does its own handling, and most important the airport policy. The majority of the airports (or governments) dictate the ground handling policy allowing an airline to be fully or partially self handled/or handled by other airlines. To some extent the airport will also be involved in evaluating and providing space for airlines. Very soon an airport will find, in a number of cases, that the facilities allocated to airlines will be smaller than required. Also an airport will be faced with new entrant airlines and will have to provide them temporary facilities. From experience, it can be said that those airlines occupying temporary facilities have had them made permanent. Therefore a revised policy has to be pursued by the airport in respect of airline space requirements, to avoid being taken by surprise. As the traffic grows, the same concern given to passenger space should be given to airline space.

In this respect, the phenomenon of traffic peak does, in fact, constitute for most airlines a manpower problem, which mostly influences the need of space. At airports the customer service standards drive the need for more staff. There is concern amongst the airlines about the number of people per square metre. Determination of the staff requirements is to be undertaken first. The airline need for space can be pointed out as dictated by the following factors:

a. Forecast of expected passengers,
b. Type of aircraft,
c. Number of operations per week,
d. Number of staff,
e. Special need/offer of lounge (for example VIP lounge),
f. Type of handling (own handling versus handling company).

Almost the same parameters are used as criteria for the recruitment of more employees, i.e., the needs of personnel are dependent on flight plan, specific load factor, the distribution of arriving passengers, waiting lines and waiting times (Standard level of service) and time needed for carrying out specific functions. To sum up briefly, most airlines based their staff requirements upon a set of standards to be achieved in dealing with passengers and aircraft.

There are also concerns about cost and availability of space considering the policy adopted by some airports, where the airline space is not viewed as a matter of basic requirement. The price for this space is very high.

The preferable location of the airline office depends upon the terminal configuration. It should permit a planned expansion with the emphasis on economy and flexibility in the terminal layout. An evaluation to optimise the use of terminal space and establish which airline functions could be relocated and which functions are highly essential to remain in the main terminal building should be part of the design process.

Suggesting Sizing Method

Temporal measures, especially processing time and delay, might be of fundamental importance when analysing airline space requirements as it can be linked to the staffing process. The level of service related to processing time and delay will determine indirectly the number of airline personnel. Typically an airline will define a standard time for processing a passenger and consequently some level of delay or queue length, that is the maximum acceptable, would be expected. An airline using a single ticket counter decides that maximum passenger processing time (including waiting time in queue) should be 10 minutes. A second counter (one more worker) must be assigned when delays exceed that. The main problem is that each airline, and each facility has unique operating characteristics and demands placed on it. Ashford (1984) found that there is no agreed standard number of personnel per flight for a particular type of aircraft. After observations of a number of US and European airports with close to 100 flights being examined he found that the number of personnel necessary for loading/unloading a B-747/DC10 aircraft type varied from a minimum of 4 to a maximum of 14 people, and for a B-707 a minimum of 3 and a maximum of 8. These differences were dependent upon local circumstances, local labour agreements and differences between companies. A key factor to bear in mind is that many of the physical demands are related to the peak hour traffic rather than the annual totals.

A strong correlation exist between the airline requirements and its traffic volumes in terms of staffing and space with respect to passengers and aircraft. Although there may be variation between one airline and other, there is a certain minimum requirements for each aircraft with which the airline operates at a specific airport. Table 5.8 shows these requirements separated by aircraft groups, which is commented upon in Chapter 6. The objective is to determine from the labour requirement the amount of space necessary for each aircraft type.

Table 5.8: Labour requirement per aircraft group

Aircraft Group	Turnaround time (min)	Supervision	Receptionist	Ramp Operators	Carts and Dollies	Airline Back Office Area (m^2)	Airline Operational Area (m^2)
A	20/30	1	1/3	4/6	2/3	12/35	36/55
B	25/35	1	2/4	6/8	3/6	25/60	55/70
C	30/45	2	3/5	8/11	6/9	60/85	70/100
D	35/50	2	4/6	11/13	8/10	70/95	100/120
E	45/60	2	5/7	13/17	10/12	85/105	120/155
F	55/75	2	6/8	17/22	12/15	95/120	155/200
G	60/80	3	7/10	22/26	14/18	110/140	200/235

(Adapted from [Martinelli, 1988] and Aircraft Airport Manuals) See also [Tutti and Adler, 1990]

The resources of labour and equipment in Table 5.8 vary from airline to airline with implications upon the turnaround time. For instance, within certain limits it is possible to reduce the necessary resources by increasing the turnaround time. However, the contrary may not be achievable. Efficient utilisation of labour and equipment as the number of aircraft increases or the optimisation of shift hours may also contribute for the variation on such resources.

5.3.11 Commercial Activities

The ability of any airport to generate revenue is an essential ingredient in the evaluation of the planning for expanded; remodelled airport facilities. The creation, improving and developing of commercial activities at airports not only to ensure the best service to passengers and visitors but essentially looking at the financial revenues from these activities has been the focus of attention at many airports in recent years. Revenues from these activities are, in fact, the principal means by which many large airports are still profitable.

Profitability is a goal which should generally be expected by those who are managing airports. However, the fact that airports perform an indispensable public service and should therefore be subsidised, which is the case in most parts of the world where airports are owned by national governments and as such, are considered instruments of national policy without regard to their economic soundness, should be reappraised.

Ashford (1992a) states that total revenues generated at airports are frequently divided into two principal categories: *operating revenues*, associated with the running and operations of the airport, e.g., landing fees, fuel charges, concession fee, space rentals; and *non-operating revenues*, not directly associated with the running of the airport which could be considered to continue even if the airport were closed down, e.g., interest earned on investments and securities, sales of services, training and consultancy, selling or leasing properties owned by the airport operation.

Operating revenues are further sub divided into five categories:

1. Landing Area Revenues: Landing fees, Passenger tax, Parking Ramp fees.
2. Terminal Area Concessions; includes the revenue from all non-airline sources within the terminal.
3. Airline Leased Areas; leases from non-airline operations including warehousing, freight forwarders, manufactures, farming.
4. Other Leased Areas
5. Other Operating Revenue, e.g., equipment rental, the resale of utilities.

Hasan (1986) says that Canadian airports classify the operation revenues into four categories: (1) Airside Revenues, (2) Terminal Revenues, (3) Groundside Revenues, (4) Others.

ICAO (1993) describes concessions and rentals as non-aeronautical activities in a wide range of different shops and services, office and other premises occupied by airlines and governmental agencies, as well as free zones. Revenues from these non-aeronautical activities consist of fees for the nights to operate businesses at the airport, rental of leased land and premises, and some commercial concessions most frequently formed at international airports are:

- Aviation fuel suppliers
- Food and Beverage concessions (restaurants, bars, cafeterias, vending machines, etc.)
- Various shops
- Banks / foreign exchange
- Airline catering services
- Taxi services
- Car rentals
- Car parking
- Airport advertising
- Airport / city commercial transport services (buses, limousines, etc.)
- Duty-free shops: liquor and tobacco, perfume and toiletries, watches, cameras and optical
- equipment, radios and recording equipment
- Petrol / automobile services stations
- Hairdressing / barber-shops
- Hotels / Motels
- Freight consolidators / forwarders or agents
- Souvenir shops

The method of classifying these revenues may vary and may be not relevant, but the important issue to address is that the revenues generated by aeronautical activities (landing areas revenue or airside revenues) are rigid. The capability to improve these revenue areas lies with the airlines rather than with the airport operator. The airport owners and managers have little control over the demand. Doganis (1992a) states that is the airline not the airports who decide where and how the demand for air travel will be met.

Alternatively, airports sustain many different types of commercial activities - non aeronautical types - which generate incomes that have been gaining importance in the economics of airports. For instance, looking at commercial activities of BAA airports, in 1986, some 35% of BAA p/c's income was from concessions and a further 12% from rents and services. Together they formed a proportion of total income that has grown consistently from 42% in 1980/81 to 50% in 1986 and to 57% in 1990. Some 59% of Heathrow's income in 1990 is from commercial activities. The average revenue split among European airports in 1989 was 44% for non-aeronautical activities (commercial) and 56% for aeronautical (traffic). Revenues from non-aeronautical commercial activities are approaching 50% of the total income earned by Aer Rianta, the Irish airports management company. [ICAO, 1993a)

San Francisco International Airport's proposed operating budget in fiscal year 1994/95 projects 20% of total revenues to be collected from airline landing fees and terminal rentals, 53% from concessions tenants and, 20% from other sources. (San Francisco International Airport, 1994)

Doganis (1993), in developing a commercial activities for an airport, outline two alternative strategies:

a) The *traditional airport model* with few commercial activities and aimed oriented to facilitating and speeding up passenger handling and throughput; giving emphasis to meet the basic and essential needs of passengers, airlines, and other direct airport customers or users. It is a strategy usually adopted by government owned airports. It is typically adopted in some countries where airport are considered public utilities due to the community dependence on the airport for its basic economy and communication and more strictly where the level of operation is low, the subsidy is countenanced, and the airport is totally dependent on government funding.

b) *Commercial oriented* policy, where the aim is to maximise commercial revenues mainly from non aeronautical activities. This is called *commercial airport model*. In recent years, motivated by changes in government policy - tendency to privatisation - pressure to be more financially self sufficient, impossibility to further increases in aeronautical charges and other emphasis on generating more commercial revenues, many airports have adopted this strategy.

Apart from the dependence on sales potential of concessionaires to generate revenue there are four factors which influence the levels of non aeronautical development:

1- *The space provision* - for the commercial airport certainly will require greater amount of space both within and outside the airport terminal to meet present and future needs of the different market segments and commercial activities. The right amount of space is fundamental to balance the nature and range of facilities and services that might be provided in order to increase revenue from all commercial sources.

2- *Adequate terminal space management* - the lay out and location of commercial spaces are vital for generating sales. The other variables being constant, i.e. the factors related to concessionaires skills and experience and their ability to sell remaining equal, location may be the difference of concessionaires increase their total sales.

3- *Financial resources* - investment in new buildings or facilities to improve the allocation of space available may be needed and lack of such resources may contribute to low levels of commercial activities.

4- *Organisational aspects* - for airport managers it is much easier to generate commercial revenues than trying to increase aeronautical revenues, which is heavily dependent on traffic levels. The airport ability to influence the latter is very limited. However, to develop commercial activities the airport administration must be able to exercise control over the granting of concessions or rentals and should have direct responsibility for the management of these activities and the resulting revenues.

In this context lack of flexibility in the organisational structure given the importance to commercial activities, causes low levels of commercial development for an airport.

The most difficult aspect for the development of commercial activities is the definition of the amount and location of the space required.

Commercial Space: Amount and Location

The commercial activities occupying airport buildings space are many and varied.

It is a common practice to plan these facilities on a marketing analysis, studies, surveys and judgement based on past experience. Total area requirement is usually based upon commercial objectives establish at the beginning of the planning process and it is generally function of the volume and type of traffic to be handled, passengers, visitors and staff; the expected rate of utilisation turnover customer per passenger, average purchase per passenger; customer per seat or other correlation; and the commercial policy adopted by the airport. Figure 5.13 depicts some of these factors. One problem is that there is little documentation on space requirements and sizing methodology for most of commercial facilities. Additionally, it is very difficult to develop a comprehensive approach method for this subject once data is considered confidential or instrument of internal marketing strategies and therefore cannot be disclosed. Studies are usually undertaken, in a case by case basis.

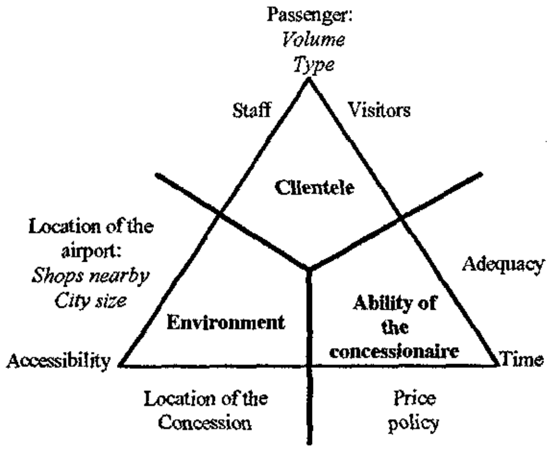


FIGURE 5.13: Commercial Factors.

Although there is a lack of resource documentation on space requirements and sizing methodologies compared with other functions within the terminal there is some general guidance to airport planners on non aeronautical commercial activities space requirements for consideration in airport master planning studies. The Airport Economics Manual which was published by ICAO, in 1991, contains guidance to airport managers, including a chapter on the development and management of non aeronautical activities. The ICAA Manual on Commercial Activities [ICAA 1982], aims to give information and guidance as the means of creating, improving and developing commercial operations at airports.

The FAA (1988a), - also gives figures for space requirements, categorising the terminal facilities as following: Food and Beverage services and Other concessionaire services:

Food and Beverage services include snack bars, coffee shops, restaurants, and bar lounges. The sizing of food these services involves applying "use factors" (average daily transactions divided by average daily enplanements) which for planning purposes are suggested as following.

(1) 40 to 60% at terminal airport with a high percentage of long haul flights.

(2) 20 to 40% at transfers airports and through airports, and

(3) 15 to 25% at terminal airports with a low percentage of long haul flight.

The ranges of area requirements for various "use factors" depend on the annual passenger enplanements (millions).

Other concessionaire services are provided as appropriate for the size and activity of the airport. See details in FAA (1988a) pp 92,93 and also Table 5.4 (Rules of Thumb).

The total amount of space available for commercial purposes within the terminal clearly affects the potential revenue that an airport can generate. According to FAA (1988a) this amount of space occupied by commercial activities is roughly in the range of 17% of the gross terminal area.

Hart (1985) compared ten major airports in USA where the percentage of the gross terminal area of commercial space covered a range of 7% to 40%. For early planning purposes he suggests 10 to 15% of gross terminal area for airports under 1.5 million enplanements and 10% for airports with greater number of enplanements. He also assert that calculations of concession space is a matter of specific experience.

BAA suggests 1,200 to 1,300 m^2 per million passengers that should be distributed roughly between the principle areas, departures landside, departures airside, arrivals airside, arrivals landside. For instance these divisions might be something like: 35% of the commercial space would be departure landside, 55% would be departure airside, and then probably the rest - 10% - would be arrivals landside.

Houcine (1991) suggested some formulae to size commercial facilities that he divided into three commercial activities as following:

1. Restaurants and Bars;
2. Commerce in Public Areas; and
3. Commerce in Restricted Areas.

All areas were distinguished by different traffic volumes.

1. Restaurants and Bars

For airport with traffic volumes smaller than 1 million passenger per annum the area is given by:

$$S = \frac{r\ Pax}{10{,}000}$$

where,

S = area required in m^2 (excluded area for kitchen and storage).

Pax = Total Annual Passengers,

$r = a.b$ = area required in m^2 per 10,000 passengers (m^2/10,000 pax),

a = turnover per passengers (in money spent per passenger - \$/pax),

b = ratio between area and turnover (m^2/\$).

The 'r' values that is fundamental for sizing the facilities are given bellow considering three hypothesis of utilisation:

	r	
Hypothesis	**Restaurant (m²/10,000 pax)**	**Bar (m²/10,000 pax)**
Low	4	2
Medium	6	3
High	8	4

Calibrated for French Airports

For airports with traffic volumes equal or greater of 1 million passenger per annum the area is given by:

$$S = \frac{Pax \times F \times Q}{365 \times R}$$

where,

S = area required in m^2 (excluded area for kitchen and storage).

Pax = Total Annual Passengers,

F = frequency ratio (%),

R = customer per seat per day.(customer/seat),

Q = area per seat (m^2/seat).

The frequency ratio varies between 3 to 6% for restaurants and 20 to 40% for bars. This factor is dependent on the number of greeters and visitors per passenger and on the distance for the airport from the city business centre. The parameter R has the same external influence and varies between 1 to 3 for restaurants and 15 to 35 for bars. The parameter Q is suggested to be function of a level of service specified as:

Level of Service	Q (m^2/pax)
Excellent	3.0
Good	2.0
Acceptable	1.5

2. Commerce in Public Areas

The area required is given by:

$$S = \frac{r\, Pax}{10{,}000}$$

where,

S = area required in m^2 (excluded area for kitchen and storage).

Pax = Total Annual Passengers,

$r = a.b$ = area required in m^2 per 10,000 passengers (m^2/10,000 pax),

a = turnover per passengers (in money spent per passenger) ($/pax),

b = ratio between area and turnover (m^2/$).

The differences remain in the '*r*' value for different traffic volumes as shown below:

Traffic Volumes (Million of passengers per annum)	r (m^2/10,000 pax)
< 1.0	0.8
1.0 to 6.0	0.8 - 1.0
≥ 6.0	1.0

3. Commerce in Restricted Areas

For restricted areas the same formula as for public areas is used with again the difference on the '*r*' parameter that assume the following values:

Traffic Volumes (Million passengers per annum)	r (m^2/10,000 pax)
< 0.2	7.0
0.2 to 2.0	7.0 - 4.0
≥ 2.0	4.0

4. Supporting Areas (including kitchen and storage).

   Additional supporting area is considered as 50% of the total commercial space calculated so far, i. e., 50% of the sum of restaurants, bars and commerce in public and restricted areas.

Houcine (1991) final conclusion is a rule of thumb for French airports which assume that the commercial space is around 6 to 10% of the total terminal gross area.

Ideally the evaluation of commercial activities should be preceded by a market research that would derive the correct amount of space to be provided in each case. Unfortunately the forecast of ratios and correlations such as average purchase per passenger, consumption of other groups, turnover for types of activities, might be very difficult, taking into account that from one airport to another even in the same country considerable differences may exist.

After having established the amount of spaces for the shops, restaurants, bars and other commercial activities, the second problem is the distribution of the areas within the terminal. In addition to this, the problem of stocks and transport in respect to the considerable quantity of goods, in volume and weight, which are needed to supply such commercial activities, should be considered.

The following describes their location and distribution:

- Location of a commercial activity should be in a prime traffic flow area.
- The majority of the commercial space have to be located at departure level/side.
- The majority of the landside commercial space should be placed after check-in.
- Ideally the customer does not have to change level to get to commercial facilities, avoiding mainly the main retailing spaces to be at a different level. However, catering - landside catering facilities - bars and restaurants - could go on a different level, at a mezzanine for example.
- It is ideal to get the commercial facilities down to the gates.

- *The location should be such that present the customers with all the major retail* opportunities, the location should really be concentrated on the main circulation areas and facilities.
- The basic principle is to try to maximise the penetration, so that make every customer to walk to every possible, every shop that is provided.
- The tendency in terms of general design principle is to provide clear open spaces, where even if the people cannot be route through shops, they are allowed to see where they are going and where the shops are. Provide clear views of whether it is commercial facilities or gate facilities, so they can see where they want to go, having the comfort and the assurance that they are not going missing the flight, and more important they are not lost.

Case Study on Commercial Location at Sao Paulo International Airport.

Sao Paulo International Airport is a quite new airport. With two terminals in 'Y' shape, pier concept, it was designed as a modular concept to include four terminals, each capable of handling 7.5 million passenger a year. The first terminal was inaugurated in January of 1985 and the second terminal in August 1992. The actual throughput was around 9 million passengers in 1995. It is a *two level concept terminal with departures on the second level and arrivals on the first level.* There is also a mezzanine level for mostly commercial activities and public services.

The commercial activities are scattered among the three levels with 45% of the total commercial area on the departures, 38% on the mezzanine and 17% on the arrivals level. There is around 30% of commercial space in the restricted area and the rest 70% in the public area. There are approximately 90 concessions and services, including six free shops. Nevertheless the Free Shops located in the restrict area, particularly in the arrivals, cater only for international passengers, they yield more than 75 % of the total commercial revenue. These Free Shops are located on the main route of the passengers, however not all the other spaces have the same possibility. Location of commercial spaces and how it relates to the other spaces in the terminal does not just happen by chance, and it is not something that should be only based on common sense. The relationship among spaces may account for the interpretation of different layouts. One problem may be how to express this relation.

The initial study was an attempt to associate the building configuration morphologies with the pragmatic basic concepts using the theory of Space Syntax.

Space Syntax is a method developed by Hiller (1984), that allows the representation, quantification, and interpretation of spatial configuration in buildings and settlements. This seems to be an attempted rational approach to evaluate a commercial layout disposition.

Although the passenger flow is subject to a sequence of strongly programmed events, it has been increasingly weakened by introducing commercial facilities placed along the passengers main circulation areas. How these commercial spaces relate to the whole spatial order of the terminal can be represented by the relationship of the axial lines of the movement and sight which are formed by the configurations of spaces in the terminal. This is known as axial mapping in space syntax terms [Hillier, 1984]. It is a description of the terminal in terms of continuous areas of circulation space showing their interrelation with other labelled spaces in terms of permeability, i.e., in the way the spaces are linked. In this respect the theory of space syntax establishes two set of measures of these spatial relations which may be used. One is the degree to which a space is *integrated* or segregated with respect to the rest of the spaces in the building, and the other measure is the degree to which a space *controls* the spatial relations of its neighbours [Penn, 1983].

The central concept of space syntax is *integration* which is associated with the concept of depth. Depth is a topological distance 'd' which is the minimum number of lines that must be crossed to get from one line to the other, plus 1. Integration is expressed by the measure of relative asymmetry given mathematically by:

$$A = \frac{2(\overline{D} - 1)}{L - 2}$$

where,

$\overline{D}$ = Mean depth

L = Number of lines

(see [Teklenburg et al, 1993])

The integration value of space expresses the relative depth of that space from all other in the axial lines plan.

A preliminary analysis of several airports showed a strong integration marked by the routes of the programmed activities, coinciding with the predominant knowledge which the designer exercises in the degree of choice whether and where to place commercial activities in the terminal.

The axial map for Sao Paulo Airport with a measure for integration was drawn using Axman program [Sheep, 1991] and included all three floors that is shown in Figure 5.14. The curved lines represent the connection between floors. The graph theoretically correlates movement in terms of people per hour with integration, being the colouring from red to blue. Red means many people, highly integrated and blue few people or highly segregated.

Data of all commercial activities were collected from Sao Paulo International Airport allowing an evaluation of the whole building complex. An attempt to correlate integration with revenue from commercial activities was made, based on the principle that more people would attract more business and increased revenue.

Figure 5.15 illustrates the airport revenue generated by all commercial activities separated by floor. The airport revenue is presented by its monthly total and by its value per square metre. It can be seen that the airport authority has no commercial policy whatsoever whether in relation to renting charges from the spaces or in relation to the total revenue accrued from each shop.

On the other hand, Figure 5.16 shows that there is a very strong correlation between the measure of integration and the airport revenue per square metre of each commercial area. It means that two practical conclusions can be drawn from this result:

a) a strict policy could be adopted by the airport in terms of efficiency to the commercial activities distributed in the terminals with a ensuing coherent renting policy; and

b) the commercial spaces could be positioned in relation to the most integrated circulation areas.

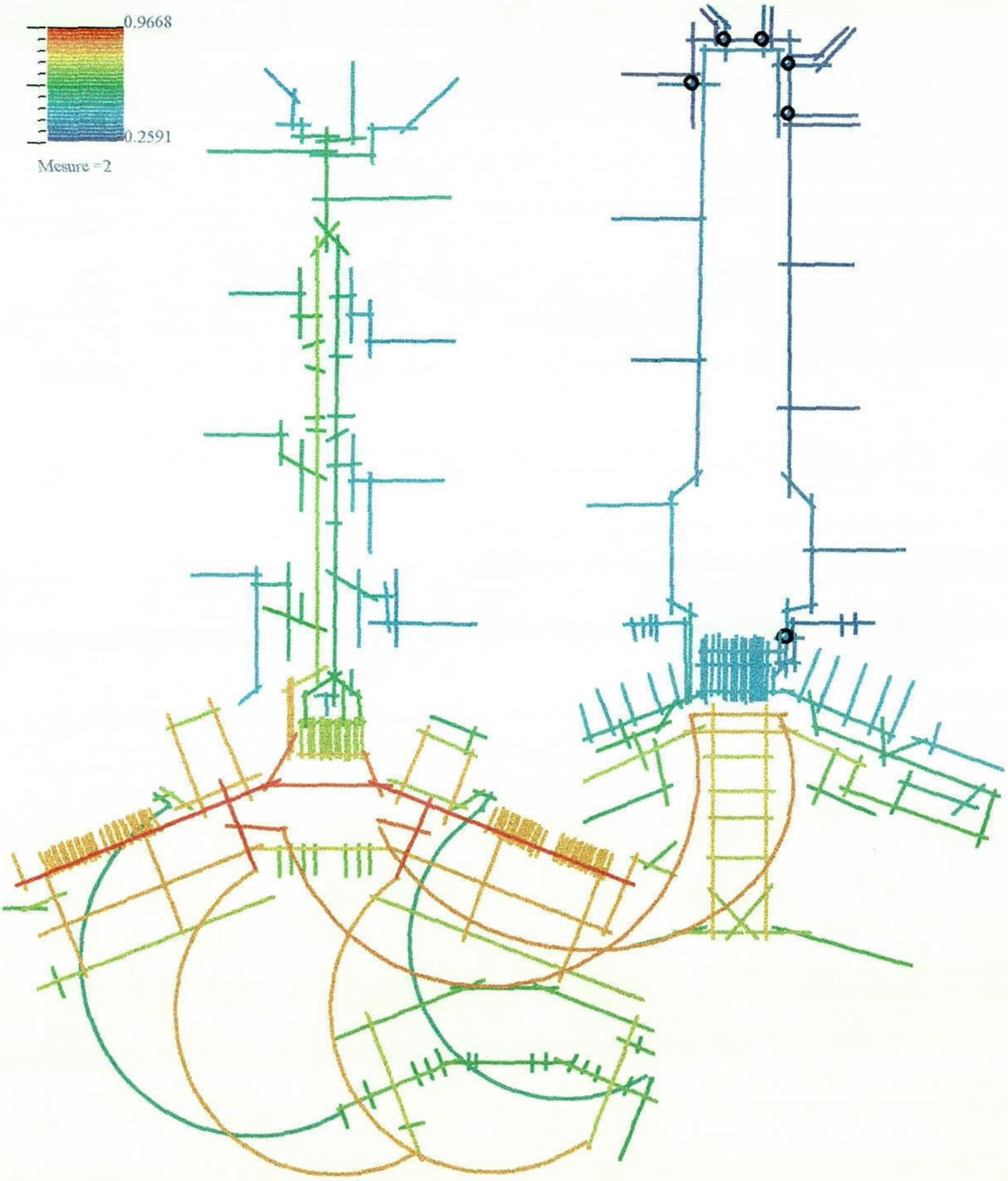
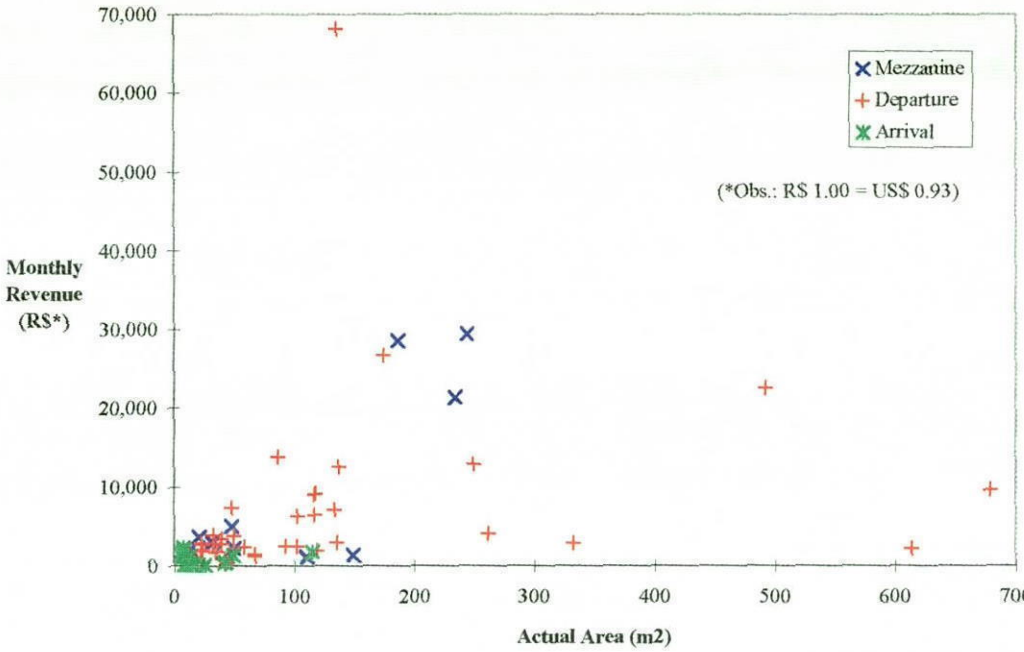


FIGURE 5.14: Axial Line Map - Measure of Integration
Sao Paulo International Airport - All floors: Departure, Arrival & Mezzanine



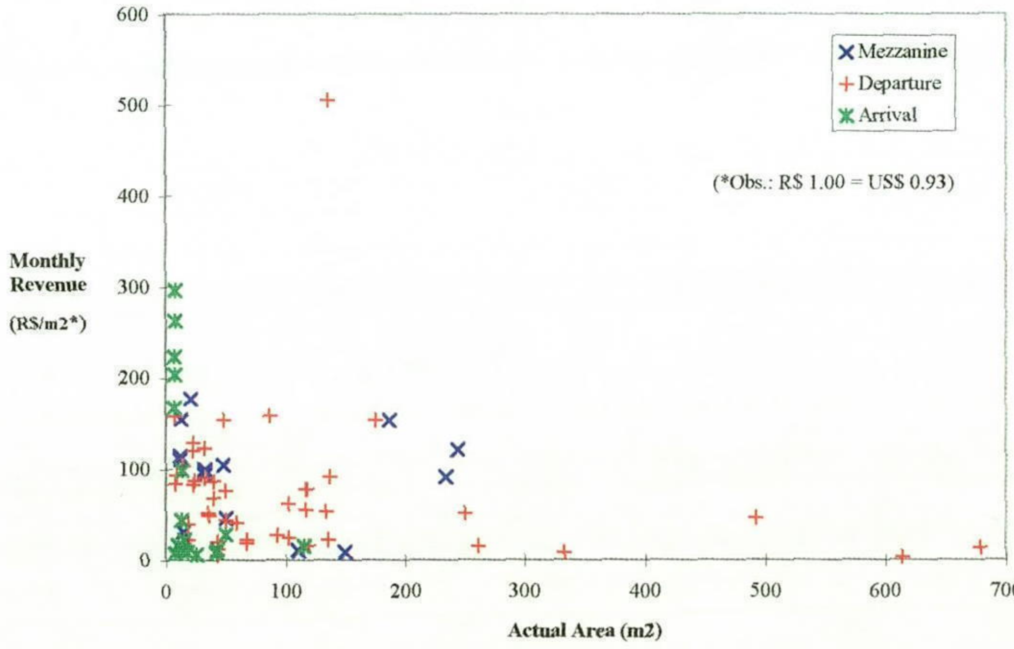


FIGURE 5.15: Commercial Revenue by area size for Sao Paulo International Airport
(Source: Sao Paulo Int. Airport)

Although the results seem promising, the aims of the analysis were to explore the possibility of a methodological approach that might be used to define commercial location and how far syntactic representations could help in the relation between spaces and commercial activities.

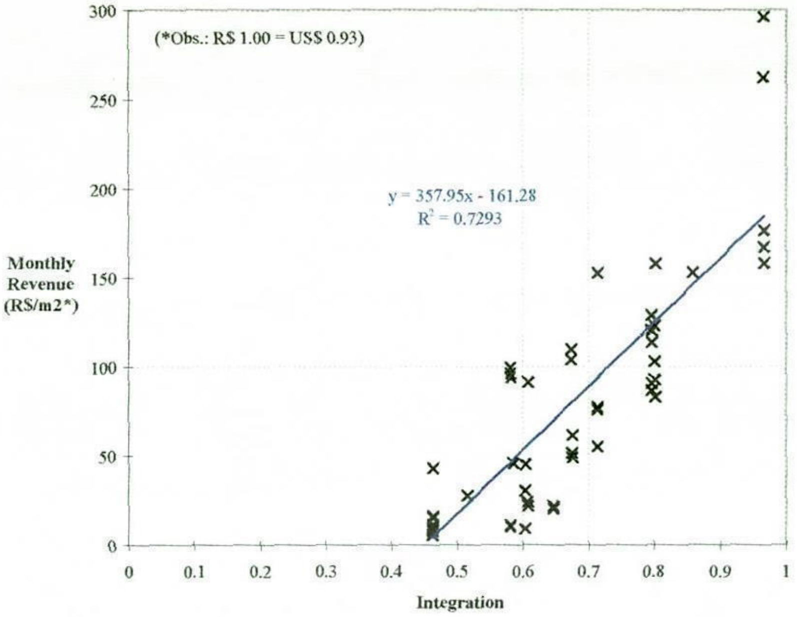


FIGURE 5.16: Relationship between Integration and Revenue per square metre for the commercial spaces Sao Paulo International Airport

The high coefficient of correlation in Figure 5.16 suggests that commercial activities should be located along the most integrated lines. This suggests also that the Space Syntax theory may help the designer in the allocation of commercial spaces within the terminal. However, these conclusions should be carefully analysed. The problems that may be raised are twofold. Firstly, it is important to realise that the Space Syntax approach is not the case of establishing a regression and the correspondent correlation between two variables. Even so, a high correlation coefficient between two variables does not necessarily indicate a causal relationship. There may be a third variable which is causing the simultaneous change in the first two variables. In order to establish a causal relationship it is necessary to have a more accurate and careful analysis of data collected from the airport. It is necessary to analyse the other factors involved in the commercial business such as, product, passenger volumes - originating and transfers, domestic and international; mix of short haul and long haul flights; city size and regional influences; mix of resident and non resident users; proximity and quality of off-airport amenities; exposure, distribution, and accessibility of amenities; merchandising ability of concessionaires; adequacy of facilities; on-time performance of airlines; price policy; profit margins; and operating costs; but it was not possible to obtain all of them at once for this analysis. Secondly there was no observational methodology undertaken to enable confirmation of the theoretical approach. Within these restrictions the issues raised will require a further and different kind of research.

5.4 Terminal Sizing Calculation

There is a considerable difficulty in trying to size a terminal from scratch using only one of the existing methods, such as the IATA program. The program's objective is to define and evaluate capacity rather than for generating the space required. To obtain a proper terminal total area a number of other assumptions have to be made. The FAA method on the other hand, although more comprehensive than the former, is driven by its concern to size US domestic terminals, and constrained to a very laborious and time consuming method and needs many graphs and nomograms.

Apart from the problem of space generation of each method there is a further problem related to the particular dimensions of each facility. Nevertheless both methods give some advice for some of the facilities in terms of dimensions. However, no matter which sizing methodology is used one or other element is always missing. Therefore a combination of methods IATA and FAA, see Chapter 3, was used to generate the results shown in Table 5.9. The terminals were adopted and sized in function of their hourly capacity varying from 500 to 10,000 peak hour passengers.

TABLE 5.9: Terminal Sizing Calculation Results

Facilities	Peak Hour Passengers										
	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
70% Load Factor	350	700	1,400	2,100	2,800	3,500	4,200	4,900	5,600	6,300	7,000
IATA program											
Dep. Curb	47	88	170	251	332	412	492	571	651	730	810
Number of Check-in	12	22	40	58	76	94	112	130	148	166	184
Check-in	84	154	280	406	532	658	784	910	1,036	1,162	1,288
Airline Back-Office	102	210	395	611	800	998	1,199	1,401	1,588	1,789	1,983
Outbound Baggage	350	678	1,175	1,752	2,260	2,769	3,401	4,012	4,622	5,029	5,842
Dep. Concourse	1,390	2,276	4,398	6,494	8,577	10,652	12,721	14,785	16,846	18,903	20,959
Dep. Passport Control	116	196	319	479	638	798	957	1,117	1,276	1,436	1,595
Number of Positions	2	3	4	6	8	10	12	14	16	18	20
Security	32	64	96	128	160	224	256	288	320	352	384
Number of Positions	1	2	3	4	5	7	8	9	10	11	12
Dep. Lounge	636	1,214	2,346	3,464	4,575	5,681	6,785	7,885	8,985	10,082	11,178
Semi-Total Departure	2,710	4,791	9,009	13,334	17,542	21,779	26,103	30,397	34,673	38,752	43,229
Pub. Health	100	100	100	100	100	100	100	100	100	100	100
Arr. Passport Control	153	306	579	852	1,125	1,398	1,671	1,944	2,218	2,491	2,764
Number of Positions	2	4	7	10	13	16	19	22	25	28	31
Baggage Claim	2,308	3,462	4,616	5,770	6,347	6,924	8,078	9,232	9,232	9,809	10,386
Number of Devices	4	6	8	10	11	12	14	16	16	17	18
Agriculture	64	111	191	263	329	392	453	511	567	622	676
Customs	88	175	350	525	700	875	1,050	1,225	1,400	1,575	1,750
Number of Positions	1	1	2	2	3	4	4	5	5	6	7
Arrival Concourse	955	1,821	3,518	5,196	6,862	8,522	10,177	11,829	13,477	15,123	16,767
Semi total Arrival	3,668	5,975	9,354	12,706	15,463	18,212	21,529	24,841	26,994	29,720	32,443
Semi Total	6,378	10,766	18,363	26,039	33,005	39,991	47,632	55,239	61,667	68,472	75,672
Airline Operations Area	300	615	1,300	1,813	2,337	2,906	3,541	4,198	4,721	5,238	5,872
Commercial	1,444	3,541	6,976	9,992	12,223	14,316	16,117	19,291	21,262	23,335	25,418
Circulation											
HVAC											
Structure (8%)	510	861	1,469	2,083	2,640	3,199	3,811	4,419	4,933	5,478	6,054
Arr. Curb	59	114	219	324	428	531	635	737	840	943	1040
Total	8,632	15,783	28,108	39,927	50,206	60,412	71,101	83,147	92,583	102,524	113,015
Apron											
70% Imbalance Arr./Dep.	350	700	1400	2100	2800	3500	4200	4900	5600	6300	7000

TABLE 5.9: Terminal Sizing Calculation Results

Facilities	Peak Hour Passengers										
	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Peak Hour Passenger	*500*	*1,000*	*2,000*	*3,000*	*4,000*	*5,000*	*6,000*	*7,000*	*8,000*	*9,000*	*10,000*
Aircraft Mix											
A	5	8	8	6	4						
B	2	5	10	11	11	15	11	10	8	8	5
C	1	1	4	8	11	11	11	11	9	9	9
D		1	1	4	5	7	9	10	9	9	9
E			1	2	2	3	5	7	8	8	10
F					2	2	3	5	7	8	11
G						1	2	2	4	6	6
EQA=	6	13	25	38	50	63	75	88	100	113	125
Avrg Seat	80	87	103	123	143	160	183	195	222	234	250
Facility											
Dep. Curb (m)	47	88	170	251	332	412	492	571	651	730	810
(*) LoS A (m)	*57*	*113*	*227*	*340*	*453*	*566*	*680*	*793*	*906*	*1,019*	*1,133*
LoS C (m)	44	88	176	264	353	441	529	617	705	793	881
LoS E (m)	28	56	111	167	223	279	334	390	446	501	557
Check-in	76	139	252	365	479	605	706	832	945	1,058	1,172
Structure (8%)	6	11	20	29	38	48	56	67	76	85	94
Circulation (10%)	8	14	25	37	48	60	71	83	95	106	117
Check-in area (m2)	89	164	297	431	565	714	833	981	1,115	1,249	1,383
Queuing (m2)	88	175	350	525	700	875	1,050	1,225	1,400	1,575	1,750
HVAC (15%)	11.34	20.79	37.8	54.81	71.82	90.72	105.84	124.74	141.75	158.76	175.77
Total Area	188	359	685	1,011	1,337	1,679	1,988	2,331	2,657	2,983	3,308
Number of Check-in	12	22	40	58	76	96	112	132	150	168	186
Grouped	2x6	2x11	2x20	2x29	4x19	4x24	4x28	4x33	6x25	6x28	6x31
Width (m)	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Check-in Length (m)	25	47	85	123	161	204	238	280	319	357	395
Queuing Length (m)	4	4	5	5	5	5	5	5	5	5	5
Airline Back-Office	102	210	395	611	800	998	1,199	1,401	1,588	1,789	1,983
Structure (8%)	8	17	32	49	64	80	96	112	127	143	159
Circulation (15%)	15	31	59	92	120	150	180	210	238	268	297
HVAC (15%)	10.24	20.96	39.52	61.12	80	99.76	119.92	140.08	158.8	178.88	198.32
Total Area	136	279	526	813	1,064	1,327	1,595	1,863	2,112	2,379	2,638
Length (m)	25	47	85	123	161	204	238	280	319	357	395
Width (m)	6	6	7	7	7	7	7	7	7	7	7
Outbound Baggage	350	678	1,175	1,752	2,260	2,769	3,401	4,012	4,622	5,029	5,842
Structure (8%)	28	54	94	140	181	222	272	321	370	402	467
Circulation (10%)	52.5	101.7	176.25	262.8	339	415.35	510.15	601.8	693.3	754.35	876.3
HVAC (15%)	35	67.8	117.5	175.2	226	276.9	340.1	401.2	462.2	502.9	584.2
Total Area	466	902	1,563	2,330	3,006	3,683	4,523	5,336	6,147	6,689	7,770
Width (m)	23	23	23	23	23	23	23	23	23	23	23
Length (m)	22	40	70	104	136	164	200	236	276	300	348
Number of Carousels	2	2	2	2	4	4	4	4	6	6	6
Dep. Concourse	1,390	2,276	4,398	6,494	8,577	10,652	12,721	14,785	16,846	18,903	20,959
Structure (5%)	70	114	220	325	429	533	636	739	842	945	1,048
Circulation (15%)	209	341	660	974	1,287	1,598	1,908	2,218	2,527	2,835	3,144
HVAC (10%)	139	228	440	649	858	1,065	1,272	1,479	1,685	1,890	2,096
Toilets (m^2)	56	112	224	336	448	560	672	784	896	1008	1120
Total Area	1,863	2,959	5,717	8,442	11,150	13,848	16,537	19,221	21,900	24,574	28,367
Length(bas. ck-in length) (m)	25	47	85	123	161	204	238	280	319	357	395
Probable width	55	49	52	53	53	52	53	53	53	53	53
Length(bas curb length) (m)	47	88	170	251	332	412	492	571	651	730	810
Probable width	40	34	34	34	34	34	34	34	34	34	35
Dep. Passport Control (50% Int.)	116	196	319	479	638	798	957	1,117	1,276	1,436	1,595
Positions Req. (50% intl.)	2	3	4	6	8	10	12	14	16	18	20
Length (m)	5	6	8	12	16	20	24	28	32	36	40
Position Area (6m^2 each = 4(6.6x3))	12	18	24	36	48	60	72	84	96	108	120
Positions area (m2)	50	100	175	250	325	425	500	575	650	725	800
Queuing	44	88	175	263	350	438	525	613	700	788	875
Offices	77	130	213	319	425	532	638	744	851	957	1,063

TABLE 5.9: Terminal Sizing Calculation Results

Facilities	Peak Hour Passengers										
	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Structure (8%)	10	18	31	46	60	77	91	106	120	135	149
Circulation (10%)	17	32	56	83	110	139	166	193	220	247	274
HVAC (15%)	19	35	58	85	113	144	171	198	225	252	280
Total Area	179	321	557	832	1,106	1,389	1,663	1,937	2,212	2,486	2,761
Length (m)	5	6	8	12	16	20	24	28	32	36	40
Queue Length (m)	10	13	21	21	21	21	22	22	22	22	22
Security	32	64	96	128	160	224	256	288	320	352	384
Number of X ray	1	2	3	4	5	7	8	9	10	11	12
Number of Magnetometers	1	1	2	2	3	3	4	4	5	5	6
Individual Units Area (m^2)	32	32	32	32	32	32	32	32	32	32	32
Length for group of two (length = 9.8m)	10	20	29	39	49	69	78	88	98	108	118
Total Area	32	64	96	128	160	224	256	288	320	352	384
IATA Area (for a single set 32 m^2 ~ 8x4)	32	64	96	128	160	224	256	288	320	352	384
Frontage (IATA)	4	8	12	16	20	28	32	36	40	44	48
Length (m)	8	8	8	8	8	8	8	8	8	8	8
Dep. Lounge	636	1,214	2,346	3,464	4,575	5,681	6,785	7,885	8,985	10,082	11,178
Structure (8%)	51	97	188	277	366	454	543	631	719	807	894
HVAC (10%)	63.6	121.4	234.6	346.4	457.5	568.1	678.5	788.5	898.5	1008.2	1117.8
Toilets (m^2)	80	160	320	480	640	800	960	1120	1280	1440	1600
Area so far	830	1,593	3,088	4,568	6,039	7,504	8,966	10,424	11,882	13,337	14,790
Circulation ()	489	1,239	3,082	5,622	8,329	11,585	15,101	19,516	23,236	28,189	34,451
Total Area	1,320	2,831	6,170	10,189	14,367	19,089	24,067	29,940	35,118	41,525	49,241
Width (m)	3.0	3.0	3.5	3.8	4.2	4.5	4.8	4.9	5.3	5.5	5.4
Pier width	6.0	6.0	7.0	7.5	8.4	9.0	9.6	9.9	10.6	10.9	10.9
Linear Length (m)	276	528	882	1,211	1,438	1,670	1,868	2,114	2,238	2,445	2,718
Pier Length (m)	138	264	441	605	719	835	934	1,057	1,119	1,223	1,359
Number of Lounge Gates	8	15	24	31	35	39	41	45	45	48	50
Gross Avrg area/gate(m^2)	165	189	257	329	410	489	587	665	780	865	985
Net Avrg area/gate (m^2)	104	106	129	147	173	192	219	232	264	278	296
Net Semi-Total Dep.	2,702	4,776	8,981	13,293	17,489	21,726	26,025	30,319	34,582	38,649	43,113
Semi-Total Departure	3,694	6,476	12,232	18,123	23,861	29,653	35,529	41,400	47,230	52,799	60,017
% of total	36.74%	35.60%	36.20%	36.34%	36.44%	36.49%	36.52%	36.55%	36.57%	36.61%	39.21%
Pub. Health	100	100	100	100	100	100	100	100	100	100	100
Structure (8%)	8	8	8	8	8	8	8	8	8	8	8
Circulation (15%)	15	15	15	15	15	15	15	15	15	15	15
HVAC (10%)	10	10	10	10	10	10	10	10	10	10	10
Total Area	133	133	133	133	133	133	133	133	133	133	133
Number of positions	2	2	2	2	2	2	2	2	2	2	2
Area position = (15 m^2)4.8x3	15	15	15	15	15	15	15	15	15	15	15
Offices (m^2)	118	118	118	118	118	118	118	118	118	118	118
Arr. Passport Control	153	306	579	852	1,125	1,398	1,671	1,944	2,218	2,491	2,764
Positions Required (50% Intl.)	2	4	7	10	13	16	19	22	25	28	31
Length (m)	4	7	13	18	24	29	34	40	45	51	56
Position Area (5m^2 each = 4(6.6x3))	12	24	42	60	78	96	114	132	150	168	186
Positions area (m^2)	50	100	175	250	325	400	475	550	625	700	775
Queuing	44	88	175	263	350	438	525	613	700	788	875
Offices	22	44	77	110	143	176	209	242	275	308	341
Structure (8%)	6	12	20	29	37	46	55	63	72	81	89
Circulation (10%)	12	23	43	62	82	101	121	140	160	180	199
HVAC (15%)	11	22	38	54	70	86	103	119	135	151	167
Toilets											
Total Area	106	212	395	578	760	943	1,126	1,309	1,492	1,675	1,858
Length (m) (Frontage)	4	7	13	18	24	29	34	40	45	51	56
Queue Length (m)	12	12	14	14	15	15	15	15	15	15	16
Baggage Claim	2,308	3,462	4,616	5,770	6,347	6,924	8,078	9,232	9,232	9,809	10,386
Number of claim units	4	6	8	10	11	12	14	16	16	17	18
Area using Avrg Size for NB-WB (577m^2)	2,308	3,462	5,193	6,347	6,924	8,078	9,809	10,386	10,386	10,963	11,540

TABLE 5.9: Terminal Sizing Calculation Results

Facilities	Peak Hour Passengers										
	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Area Excluding Bag Claim units	288	548	1,056	1,558	2,056	2,552	3,046	3,540	4,032	4,524	5,015
Break-down area (143 m^2 =16x8.9)	572	858	1,144	1,430	1,573	1,716	2,002	2,288	2,288	2,431	2,574
Claim area (with b claim units-434.5 m^2~16x27)	1,740	2,610	3,480	4,350	4,785	5,220	6,090	6,960	6,960	7,395	7,830
Structure (5%)	115	173	231	289	317	346	404	462	462	490	519
Circulation (10%)	231	346	462	577	635	692	808	923	923	981	1,039
Toilets											
Total Area (m^2)	2,658	3,987	5,316	6,646	7,310	7,975	9,304	10,633	10,633	11,297	11,962
Gross Area per unit	664.55	664.55	664.55	664.55	664.55	664.55	664.55	664.55	664.55	664.55	664.55
Net area per unit NB & WB(~16x36)	577	577	577	577	577	577	577	577	577	577	577
Agriculture	64	111	191	263	329	392	453	511	567	622	676
Structure (5%)	3	6	10	13	16	20	23	26	28	31	34
Circulation (10%)	6	11	19	26	33	39	45	51	57	62	68
Total Area (m^2)	74	127	220	302	379	451	521	588	653	716	778
Dimensions (square)	9	11	15	17	19	21	23	24	26	27	28
Dimensions (rect.- width)	7	9	12	14	15	17	18	19	20	21	22
(rect.-length)	11	14	19	22	25	27	29	31	32	34	35
Customs (50% Intl.)	88	175	350	525	700	875	1,050	1,225	1,400	1,575	1,750
Red channel	1	1	2	2	3	4	4	5	5	6	7
Green channel	1	1	2	2	3	4	4	5	5	6	6
Area Red Channel (m^2)	60	60	120	120	180	240	240	300	300	360	420
Area Green Channel (m^2)	30	30	60	60	90	120	120	150	150	180	180
Offices	58	117	233	350	467	583	700	817	933	1,050	1,167
Structure (8%)	7	14	28	42	56	70	84	98	112	126	140
Circulation (10%)	9	18	35	53	70	88	105	123	140	158	175
HVAC (15%)	13	26	53	79	105	131	158	184	210	236	263
Total Area	177	264	529	703	968	1,232	1,407	1,671	1,845	2,110	2,344
Frontage (m)	7	7	15	15	22	30	30	37	37	44	49
Length (m)	12	12	12	12	12	12	12	12	12	12	12
Arrival Concourse	955	1,821	3,518	5,196	6,862	8,522	10,177	11,829	13,477	15,123	16,767
Structure (8%)	76	146	281	416	549	682	814	946	1,078	1,210	1,341
Circulation (10%)	96	182	352	520	686	852	1,018	1,183	1,348	1,512	1,677
HVAC (15%)	143	273	528	779	1,029	1,278	1,527	1,774	2,022	2,268	2,515
Toilets											
Total Area (m^2)	1,270	2,422	4,679	6,911	9,126	11,334	13,535	15,733	17,924	20,114	22,300
Length(bas curb length) (m)	59	114	219	324	428	531	635	737	840	943	1,040
Probable width (m)	16	16	16	16	16	16	16	16	16	16	16
Net Semi total Arrival	3,668	5,975	9,354	12,706	15,463	18,212	21,529	24,841	26,994	29,720	32,443
Semi total Arrival	4,418	7,146	11,272	15,272	18,676	22,068	26,025	30,066	32,680	36,044	39,375
Net Semi Total	6,369	10,750	18,335	25,999	32,952	39,937	47,554	55,160	61,576	68,369	75,556
Semi Total	8,113	13,622	23,504	33,395	42,537	51,721	61,555	71,466	79,910	88,844	99,392
Airline Operations Area	300	615	1,300	1,813	2,337	2,906	3,541	4,198	4,721	5,238	5,872
Structure (8%)	24	49.2	104	145.04	186.96	232.48	283.28	335.84	377.68	419.04	469.76
Circulation (15%)	45	92	195	272	351	436	531	630	708	786	881
HVAC (15%)	45	92	195	272	351	436	531	630	708	786	881
Total Area	414	849	1,794	2,502	3,225	4,010	4,887	5,793	6,515	7,228	8,103
Dimension (square)	20	29	42	50	57	63	70	76	81	85	90
Rect. (length)	26	37	54	64	72	81	89	97	103	108	115
(width)	16	23	33	39	45	50	55	60	63	67	71
Commercial	1,444	3,541	6,976	9,992	12,223	14,316	16,117	19,291	21,262	23,335	25,418
Food and Beverage	561	1,362	2,401	3,063	3,615	4,218	4,737	7,045	7,762	8,535	9,318
Other Concessions	588	1,453	3,050	4,619	5,739	6,732	7,586	8,164	8,900	9,700	10,400
Other rental areas	294	726	1,525	2,310	2,869	3,366	3,793	4,082	4,600	5,100	5,700
Structure (5%)	72	177	349	500	611	716	806	965	1,063	1,167	1,271
Circulation (10%)	144	354	698	999	1,222	1,432	1,612	1,929	2,126	2,334	2,542
HVAC (15%)	217	531	1,046	1,499	1,833	2,147	2,418	2,894	3,189	3,500	3,813
Total Area	1,877	4,603	9,068	12,989	15,890	18,611	20,952	25,079	27,640	30,336	33,043

TABLE 5.9: Terminal Sizing Calculation Results

Facilities	**Peak Hour Passengers**										
	500	**1,000**	**2,000**	**3,000**	**4,000**	**5,000**	**6,000**	**7,000**	**8,000**	**9,000**	**10,000**
Total area so far (net)	8,114	14,906	26,611	37,804	47,512	57,160	67,212	78,650	87,559	96,942	106,845
(m^2/pax)	23	21	19	18	17	16	16	16	16	15	15
Circulation (15% of total area)	1,217	2,236	3,992	5,671	7,127	8,574	10,082	11,797	13,134	14,541	16,027
HVAC	1,217	2,236	3,992	5,671	7,127	8,574	10,082	11,797	13,134	14,541	16,027
Structure (8%)	649	1,193	2,129	3,024	3,801	4,573	5,377	6,292	7,005	7,755	8,548
Arr. Curb	59	114	219	324	428	531	635	737	840	943	1040
(*) LoS (m)	68	136	272	408	543	679	815	951	1,087	1,223	1,359
LoS C (m)	54	108	215	323	431	538	646	754	861	969	1,077
LoS E (m)	33	67	134	201	267	334	401	468	535	602	669
Total (1) (Includ. Circ Struc, etc.)	10,404	19,074	34,366	48,887	61,652	74,342	87,393	102,338	114,066	126,408	140,538
Total (2)	11,197	20,571	36,723	52,169	65,567	78,880	92,752	108,536	120,831	133,780	147,447
m^2 per pax	32	29	26	25	23	23	22	22	22	21	21
Apron											
Area (m^2)	10,240	20,451	36,984	54,964	70,431	86,198	102,390	119,502	134,184	150,175	166,440
Actual Frontage (m)	276	528	882	1,211	1,438	1,670	1,868	2,114	2,238	2,445	2,718
Linear	79	150	289	427	563	712	834	969	1,104	1,239	1,373
Pier	273	344	483	621	757	906	1,028	1,163	1,298	1,433	1,567
Remote Pier	479	575	742	937	1,109	1,288	1,474	1,661	1,835	2,018	2,201
Satellite	366	398	442	476	505	533	554	575	594	613	630
Satellite with open space (RI=50)	680	712	756	791	819	847	868	889	909	927	944
Transporter	30	68	129	198	258	319	388	448	517	578	646
DL width based on actual frontage	3.0	3.0	3.5	3.8	4.2	4.5	4.8	4.9	5.3	5.5	5.4
Intl. Facilities Departure											
Net (m^2)	116	196	319	479	638	798	957	1,117	1,276	1,436	1,595
Gross (m^2)	179	321	557	832	1,106	1,389	1,663	1,937	2,212	2,486	2,761
Intl. Facilities Arrival											
Net (m^2)	340	581	1,029	1,477	1,925	2,373	2,821	3,269	3,718	4,166	4,614
Gross (m^2)	416	609	1,056	1,414	1,861	2,308	2,666	3,113	3,470	3,918	4,335
Intl. Total (50%)											
Net (m^2)	456	776	1,348	1,956	2,563	3,171	3,778	4,386	4,994	5,601	6,209
Gross (m^2)	595	930	1,614	2,245	2,967	3,697	4,329	5,050	5,682	6,404	7,096
50% Intl. Pax											
% over the total area											
Departure Net	4.28%	4.09%	3.55%	3.60%	3.65%	3.67%	3.68%	3.68%	3.69%	3.71%	3.70%
Departure Gross	4.85%	4.95%	4.55%	4.59%	4.63%	4.68%	4.68%	4.68%	4.68%	4.71%	4.60%
Arrival Net	9.28%	9.72%	11.00%	11.62%	12.45%	13.03%	13.10%	13.16%	13.77%	14.02%	14.22%
Arrival Gross	9.42%	8.52%	9.37%	9.26%	9.97%	10.46%	10.24%	10.35%	10.62%	10.87%	11.01%
Total Net	7.16%	7.22%	7.35%	7.52%	7.78%	7.94%	7.95%	7.95%	8.11%	8.19%	8.22%
Total Gross	7.34%	6.83%	6.87%	6.72%	6.98%	7.15%	7.03%	7.07%	7.11%	7.21%	7.14%
Intl. Facilities Departure											
Net (m^2)	232	391	638	957	1,276	1,595	1,914	2,233	2,552	2,871	3,190
Gross (m^2)	359	641	1,114	1,663	2,212	2,777	3,326	3,875	4,424	4,973	5,521
Intl. Facilities Arrival											
Net (m^2)	681	1,162	2,058	2,954	3,850	4,746	5,643	6,539	7,435	8,331	9,227
Gross (m^2)	832	1,218	2,113	2,828	3,722	4,617	5,331	6,226	6,941	7,835	8,670
Intl. Total (100%)											
Net (m^2)	912	1,553	2,696	3,911	5,126	6,341	7,557	8,772	9,987	11,202	12,417
Gross (m^2)	1,191	1,860	3,227	4,491	5,934	7,394	8,658	10,101	11,364	12,808	14,191
100% Intl. Passengers											
Departure Net	8.22%	7.87%	6.86%	6.95%	7.04%	7.08%	7.09%	7.10%	7.12%	7.16%	7.14%
Departure Gross	9.25%	9.43%	8.71%	8.77%	8.86%	8.95%	8.94%	8.94%	8.95%	8.99%	8.80%
Arrival Net	16.99%	17.72%	19.82%	20.83%	22.14%	23.06%	23.17%	23.26%	24.21%	24.59%	24.90%
Arrival Gross	17.21%	15.71%	17.14%	16.95%	18.12%	18.94%	18.58%	18.77%	19.20%	19.61%	19.84%
Total Net	13.37%	13.47%	13.70%	13.99%	14.43%	14.71%	14.72%	14.73%	15.00%	15.14%	15.19%
Total Gross	13.67%	12.78%	12.85%	12.60%	13.04%	13.34%	13.14%	13.20%	13.28%	13.45%	13.33%

TABLE 5.9: Terminal Sizing Calculation Results

Facilities	Peak Hour Passengers										
	500	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Corridor width (min. 2.00m) 15 min./50% pax	2.9	4.6	8.1	11.5	14.9	18.4	21.8	25.2	28.7	32.1	35.5
Corridor width (min. 2.00m) 20 min./50% pax	2.3	3.5	5.8	8.1	10.4	12.7	15.0	17.3	19.6	21.9	24.2

(*) See TRB (1987)

Based on the table above and using Auto CAD software program 144 drawings were generated according to the four basic terminal concepts: linear, pier, remote pier and satellite (see Appendix D). All the resulting areas and dimensions were recorded to allow the concept evaluation based on passenger distribution to be developed in the following chapters.

5.5 Summary

The challenge for a manager is find a solution for a problem. Whatever the situation is, there is no operational solution that can justify an inadequate design. Though most of the problems faced in the operation life of an airport are commonly solved by a combination of redesign and change in operational procedures, i.e., by transforming and expanding the existent facilities, an extra cost is incurred on such solutions. Therefore a well established and systematic design principles must be followed in order to avoid such problems.

This chapter states that space is viewed as the main constituent generated in the process of sizing. The beginning of the chapter is dedicated to on emphasise on the steps for evaluating space considering the conditions and circumstances of existing and new terminals. There are five factors that are discussed which are considered to be of paramount importance in evaluating and defining spaces: *flexibility, compactness, accessibility, extensibility and economics.* There is also a concern that space should be analysed and take into account its functional, operational, physical and legal/economic aspect of the terminal.

Finally each main terminal facility is considered in the context of terminal sizing and all the calculation results were presented at the end.

Other areas such as administration for the Airport authority may not be considered as essential since they can be placed outside the terminal and should be analysed on a case by case basis.

6. CHAPTER VI - What variables?

6.1 Introduction

The purpose of this chapter is to discuss the parameters and attributes that should be considered in the development and evaluation of terminal concepts. It discusses those elements included in the designing process that most influence the concept evaluation. Some of the elements have a causal effect on the concept choice when viewed as variables in relation to the life span of the project, but may have few or no influence when related to a point in time. For example, the total area required for a terminal of five million passengers a year, theoretically would not vary for different terminal concepts. This is clearly demonstrated in the current design standard process where the calculations of the required space are carried out regardless the shape of the building. This does not discount the fact that some new technology or new simulation programmes may allow the inclusion of shape in the process or even that in the planners' mind, in some way, it would have been accounted for. If one assumes that the physical resources requirements for a given volume of traffic will be constant, what would be the parameters that really make a difference.

6.2 Redefining Main Variables

The main factors that influence terminal concept design discussed in Chapter 4 are now reorganised and explained. They can be arranged in three main interrelated groups: Physical, Operational and Economic factors. Each group involves the variables that have a direct relationship to its intrinsic characteristics, i.e., the physical variables are those that have direct relation to size, shape, geometry, distance and relative location of spaces. The operational variables involve the utilisation of the physical arrangements. And, the economics variables correlate cost and finance matters with factors of the other two groups. There still is a group related to legal aspects as seen in Chapter V, however its influence can be consigned to specific situations.

The relationship between these three groups is depicted in Figure 6.1, which represents the fundamental key for the layout design. The physical attributes determine the space arrangements based on expected operational standards (level of service). The economic factors then confine the trade-off between the need to provide spaces to the operational level that is envisaged. It follows that spaces should be arranged according to physical factors that satisfy the operational procedures. The space layout -- physical attributes -- is seen as coping with the consequences of the operational procedures.

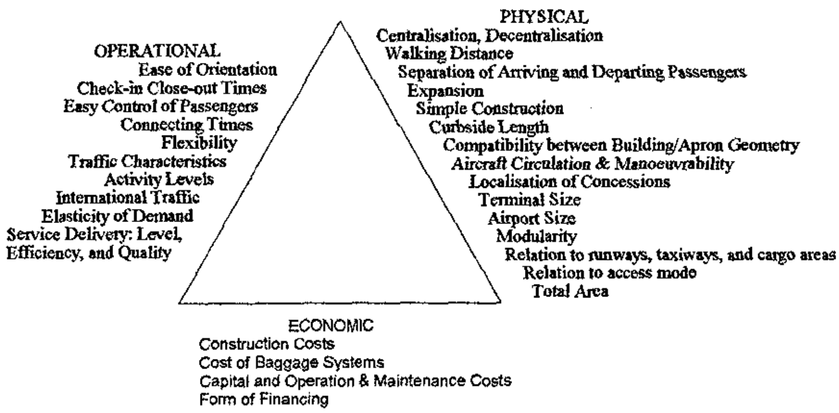


FIGURE 6.1: Relationship between Main Variables

It becomes necessary to ask what would be the effects of the configuration on design and space layout. The notion of some kind of configuration structure with functional implication is usually present. Configurational aspects have significant effects on Terminal performance, and they should have. Geometrical arrangements are determinants of functional efficiency and economical constructions. Generally, it would be accepted that shapes are conceived to achieve such requirements. Consideration has to be given to satisfying of requirements or use or purpose by the best physical implementation and not precluding satisfactory visual effects. These translate into the three principles of design: a) Function -- use or purpose: b) Structure -- physical implementation of function: and c) Aesthetics -- the sense of beauty and appearance.

Configuration in this sense may be related to two main functions: processing and circulating. This is illustrated in Figure 6.2. It is interesting to note that processing and circulation may influence each other, but the other two relations are asymmetric. Configuration may influence the location of processing facilities, but the location of facilities cannot influence configuration. Likewise configuration may influence circulation, but circulation cannot influence configuration.

Processing activities can influence the circulation of people within the terminal, but it cannot influence the fixed configurational parameters which describes its spatial location. Similarly, the concept may affect the amount and type of circulation required inside the terminal, but cannot be determined by it.

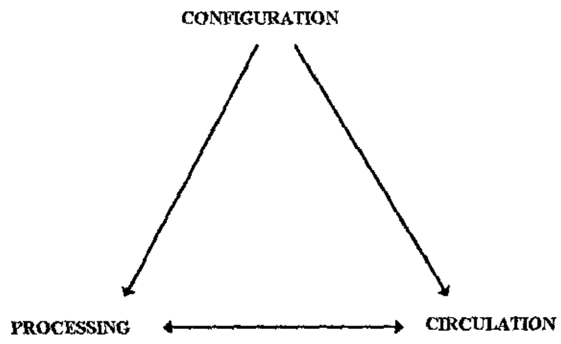


FIGURE 6.2: Relationship between Configuration, Processing and Circulation

The search to distinguish the causal effect of two variables which are both correlated with a third and which are also correlated to each other is always difficult.

Concepts, more comprehensively configurations, can be correlated to the main variables and the main parameters that define space. A summary of this tripartite relationship is illustrated in Fig 6.3, (compare with Fig. 2.14, Fig. 6.1 and 6.2) where space, level of service, attributes and descriptors, functions, and configuration are all interrelated.

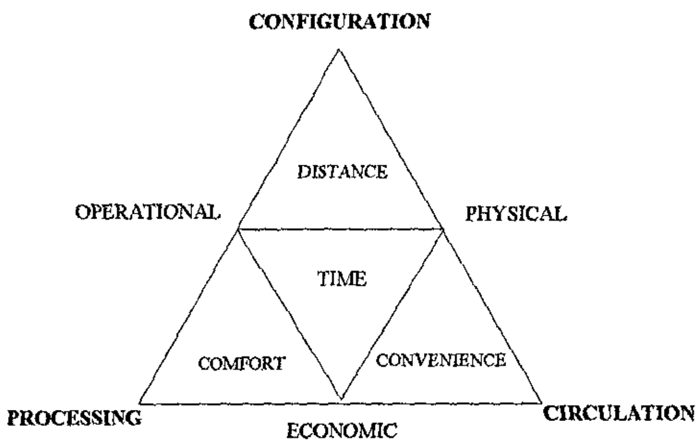


FIGURE 6.3: Configuration, Level of Service, Space, Functions and Factors in the Process of Design

The most important element of layout is space. Space is the outcome of form and shape -- the result of the arrangement generated by form and shape is the rationale of terminal concepts. The symbiotic relationship of form and space in a building is represented by its internal spaces. Those spaces such as check-in, ticket counters, departure lounges, etc. have specific and similar functions that should be grouped into single, linear or clustered forms. Other spaces, such as departure concourse and arrival concourse are flexible and can be defined by other spaces or groups of spaces that surround them. The spatial organisation of form & space can be viewed as:

- Space within a space
- Interlocking spaces
- Adjacent spaces
- Spaces linked by a common space

Therefore, a terminal concept is a large enveloping layer or skin, with a pre-determined form and shape, containing within its volume a group of smaller spaces performing different functions. These internal spaces (facilities) may be formed by interlocking or adjacent space and spaces or group of spaces that are separated by distance and linked or related to each other by intermediate spaces (corridors/circulation).

The properties of form as well as their spatial relationship will ultimately determine or identify the concept they define and the intrinsic qualities of the terminal. Ching (1979) describes these properties as: shape, size, position and orientation as physical properties and colour, texture and visual inertia as aesthetic properties. The former will be discussed later. The aesthetic properties are characterised by *proportion* and *composition*. According to Reekie (1976) proportion refers to the ratio between related distances, lengths or sizes of mass and area. Composition is the conscious arrangement of parts or elements to produce a functionally and visually satisfying whole.

Proportion		**Composition**	
simple	complex	clear and uncluttered	chaotic
consistent	irrational	well arranged	fragmented
rhythmic	random	grouped	dispersed
orderly	disorganised	focused	diffused
unified	uncoordinated	concentrated	scattered
homogeneous	muddled	interesting	commonplace
integrated	confused		
comprehensible	incoherent		

6.3 Shape, Size & Dimensions

Shape refers to the edge contour of a plane. The primary shapes are the circle, the triangle and the square. They can be extended to generate other forms. As we have seen in Chapter 4 there are four basic concepts (forms) of terminals: linear, pier, satellite and transporter.

As the spatial arrangements can be organised in many different ways, economic theories usually attach a cost-shape factor for evaluation of the alternatives available. The plan shape has an important effect upon the cost of the building. For instance [Ashworth, 1988] presents two mathematical equations to evaluate building alternatives:

a) Plan Shape Index $= \dfrac{g+\sqrt{(g^2-16r)}}{g-\sqrt{(g^2-16r)}}$

where,

g = average perimeter -- sum of perimeters of each floor divided by number of floors, and
r = average plan area -- gross floor area divided by number of floors.

b) Optimum envelope area $= N\sqrt{N} \Rightarrow \dfrac{x\sqrt{f}}{2S}$

where,

N = Optimum number of storeys
x = roof unit cost divided by wall unit cost
f = total floor area (m^2), and
S = Storey height (m)

The former index aims to measure the plan shape efficiency of a building and the latter the selection of the appropriate number of storeys for a building based upon roof and wall costs. It is certain that the overall cost of the project will be affected by its plan shape. This is the result of the relationship known as wall to floor ratio or perimeter to floor area ratio:

WFR = Perimeter length/Floor Area

It means that the area being constant, the more complex the shape, the higher will be the overall cost of the structure. This is attributed to the effect on foundations, walls, and roofing costs, mainly due to the increase in the number of corners involved. Ashworth (1988) added that a square plan shaped structure will in the majority of cases provide the most economic solution. This would not always be a practicable solution, because of its deficiency in natural lighting. Moreover, the perimeter cost of a building can be in the order of twenty to thirty per cent of its total cost [Seeley, 1978]. As a general rule the simpler the shape of the building the lower will be its unit cost.

Other indices of shape related purely on geometry represented by measurement of ratios containing values of area, perimeters and axes, which were used for measuring the shape of geographic areas, are shown in Table 6.1.

Braaksma (1976, 1979), has established two indices related directly and indirectly to shape, respectively compactness and decentralisation.

He defined Compactness as the ratio between the perimeter of a circle of area equal to the area of the terminal by the actual perimeter of the terminal, or

$$C = \left(\frac{2\sqrt{\pi \cdot A_p}}{P_p} \right) 100\%$$

where,

C = Compactness Index
A_p = area of plan view of terminal, and
P_p = perimeter of plan view of terminal

Decentralisation as:

$$D = \frac{F}{G \times T} \times 100\%$$

where,

D = Decentralisation Index
F = number of separate processing facilities or areas (Excluding gates position)
G = number of gates positions or operating standards
T = number of types or categories of processing facilities or areas.

From an economical point of view, size is an important factor in terms of cost efficiency, because unit costs are in inverse proportion to changes in size. The quality of specifications being equivalent, the smaller buildings will have higher unit costs than larger ones. In other words, increases in the size of a building usually produces reductions in unit cost. Size and dimensions are also correlated to the wall/floor ratio. To illustrate this the following example is shown in Figure 6.4, assuming that a similar method of construction is to be used in buildings A, B, and C.

TABLE 6.1: Shape Indices

Index	Formula	Author
Elongation Ratio	$\frac{a}{b}$ $\frac{2\sqrt{\frac{A}{\pi}}}{b}$ (*)	Werrity, (1969) Shwmm, (1956)
Form Ratio	$\frac{A}{a^2}$ $\frac{4A}{\pi \cdot b^2}$ (*)	Horton, (1932) Haggett (1965)
Circularity Ratio	$(4A)p^2$ or $\frac{4\pi \cdot A}{p^2}$ (*)	Miller, (1953)
Compactness Ratio	$\frac{2\sqrt{\pi \cdot A}}{p}$ $\frac{A}{A'}$ $1.273\frac{A}{a^2}$	Richardson, (1961) Cole, (1964) Gibbs, (1961)
Ellipticity Index	$\frac{4A}{\pi \cdot ab}$ (*)	Stoddart, (1965)
Radial Shape Index	$\sum\left(t_i - \frac{1}{n}\right)$ (*) $\sum_{d=1}^{n}\left[\left(\frac{100t_i}{\sum_{i=1}^{n} t_i}\right) - \left(\frac{100}{n}\right)\right]$ or $\frac{A}{\left(2\pi \int_A t^2 dA\right)^{1/2}}$ (*)	Boyce and Clark, (1964) Blair and Bliss, (1967)
Standard Shape Index	$\frac{A \cap A_s}{A \cup A_s}$	Lee and Sallee, (1970)
Shape Efficiency	$\frac{\sum_{i=1}^{n} P_i \cdot d_{ik}^2}{\sum_{i=1}^{n} P_i \cdot d_{ij}^2}$	Massam and Burghardt, (1968) Massam and Goodchild, (1971)

A = Area
A' = Area of Smallest circle to enclose figure
A_s = Area of the Standard Shape
a = Diameter of minor axes
b = Diameter of major axes
p = Perimeter
n = Number of vertices
t_i = Normalised radial axes from centroid to vertices
t = Radial axes from centroid to small area dA
P_i = Population
d_{ij} and d_{ik} = distances travelled by the population P_i
i = townships within an area
j = actual administration centre locations
k = optimally located administrative centre position

(*) *All ratios attain the value 1 for a circle*

This Table has been adapted from Haggett (1969, 1977) where full references are to be found.

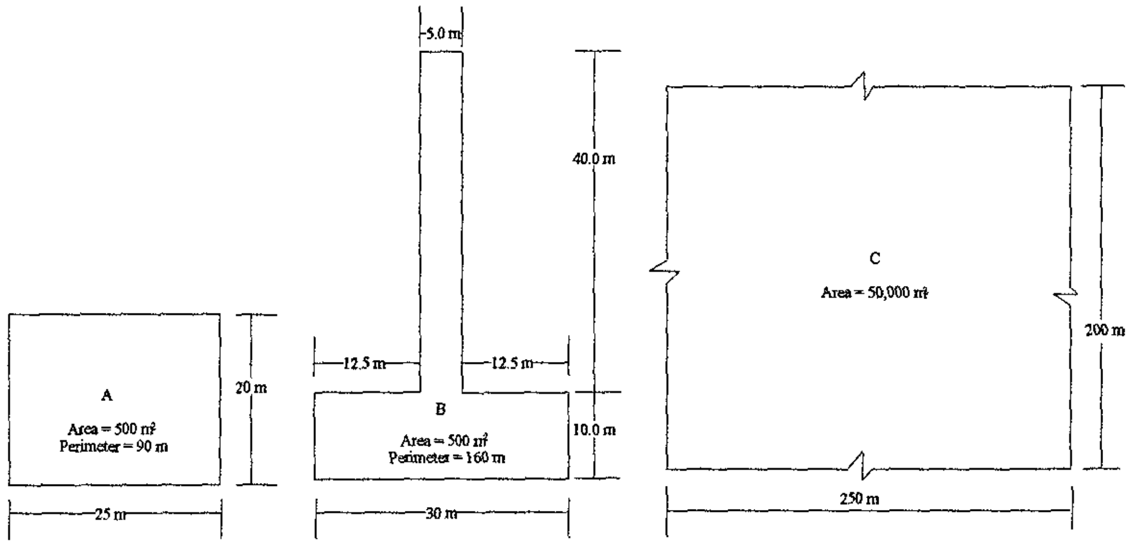


FIGURE 6.4: Example of influence of size and dimensions in construction cost.

Material	Building A Cost (£)	Building B Cost (£)	Building C Cost (£)
Ground Slab at £22/m^2	11,000	11,000	1,100,000
Foundation at £92/m	8,280	14,720	82,800
Enclosing Walls at £55/m^2	19,800	35,200	198,800
Total	39,080	60,920	1,380,800
Unit Cost (£ per m^2 of floor area)	78	122	28

This is a hypothetical situation, but illustrates the relationship between shape and size & dimensions. The building B would be about 55% more expensive than building A in terms of construction costs per unit. It is evident that this percentage vary in proportion to the relative unit prices of each component. If only the enclosing wall were considered, the difference would be building B being 77% more expensive than A. This is assuming of course that the unit costs of the elements will not change with the variation in shape and size. Comparing building A and C with the same assumption shows that size may influence significantly the unit cost.

It should be remembered, for instance, that every corner added to the outside wall may cost as much as 0.5 m of extra wall, which will increase the total cost of the building. It may be considered as well, that many buildings have outside walls constructed with materials which add to the cost of the building or to its operation and maintenance in years to come, even with the most simple shape, mainly because of its component materials such as much glass. A current example is the facade of the new Kansai Airport.

The size and dimensions of the individual airport facilities may also influence the layout and consequently impose restriction on shape. In this respect a number of airports were surveyed and the overall size of the main facilities are indicated in Appendix B.

6.4 Single Level or Multi-Level Terminals

The different arrangements and separation of levels are dependent on many factors such as scale of operation, need for passenger segregation and degree of centralisation, site characteristics, and whether the boarding will be via telescoping loading bridges. Although in industrial and residential buildings the number of floors may play a more important role in terms of construction costs where the number of floors may be high, the airport passenger terminals in general the number of floors is not large, typically two or three.

In terms of number of levels or building height, that would be applied to airport terminals, Ashworth (1988) indicated that cost components of a building can be divided into four categories:

- Cost components that fall as the number of storeys increase (e.g. roofs, foundations);
- Cost components that rise as the number of storeys increase (e.g. lifts, escalators, installations);
- Cost components which are unaffected by height (e.g. floor finishes, internal doors); and
- Cost components which fall initially and then rise as the number of storeys increase (e.g. exterior enclosure).

The number of levels of airport terminals can be grouped in five main arrangements as follows:

1) *Single- level road / Single-level terminal.* Arrival and departure passengers are processed side-by-side at same level. The boarding to aircraft is by means of stairs. Passengers usually walk to aircraft parked along the terminal. These are suitable for smaller volumes airports, where the cost to provide loading bridges is not justified.
2) *Single-level road / Double-level terminal.* This design is also known as one-and-one-half level terminal, where arrival and departure procedures take place side-by-side at same level. The departure lounges are placed on a higher level, allowing passengers boarding via telescopic loading bridges.
3) *Double-level road / Double-level terminal.* The lower level is usually for arrival and the upper level for departure. This arrangement allow vertical separation of arrival and departure processing in the terminal.
4) *Single-level roads / Double-level terminal.* This is a variation of *3)* with horizontal separation of arrival and departure access roads.
5) *Double-level road / Three-level terminal.* This design allows vertical segregation by placing departing passengers routes at high level with downwards circulation to the aircraft.

Table 6.2 shows a list of main terminal facilities indicating its relative position with respect to other facilities and possible level location and arrival or departure areas. The information contained in the table was collected from the drawing plans of a number of selected airports.

For the variation of concepts (shapes) and sections (number of levels), Parsons [FAA, 1973] indicated over sixty possible combinations of cross section, including location of baggage claim, ticketing and other passenger-processing functions.

TABLE 6.2: Single Level or Multi-level Terminal

Facility: Adjacency	**Single Level**		**Multi-Level**		
	Dep. Side	Arr. Side	1	2	3
1. **Kerbside**: Departure Concourse, Car Parking, Kerbside Check-in, Commercial areas, Outbound Baggage System.	x			x	
2. **Departure Concourse**: Check-in & Ticket Counter Services/Passport Control & Security, Kerbside, Commercial Activities, AIS & MET briefing, Information - (Admin. Wardens).	x		x	x	
3. **Check-in** (*): Departure Concourse, Passport & Security Control, Airline Offices, Outbound Baggage System,	x			x	
4. **Passport Control & Security** (Dep.): (**) Departure Lounge, Check-in/Departure Concourse, Commercial Spaces, Tax free Shops.	x			x	x
5. **Departure Lounge**: Apron (Aircraft), Passport Control, Security, Commercial Spaces, Ticket-lift Counters, Other Spaces.	x			x	x
6. **Outbound Baggage** (*): (Sortation area): Apron - Check-in, Airline Operational Space, Inbound-Transfer Baggage (Break-down area).	x	x	x		
7. **Corridor**: Public Health/ Immigration, Apron (Aircraft)	x	x	x	x	
8. **Public Health Control**: Immigration, Corridor (Circulation), Departure Lounge, Offices.		x	x	x	
9. **Immigration** (Arr. Passport Control): Baggage Claim, Public Health , Circulation (Corridor), Departure Lounge, Customs, Offices		x	x		
10. **Baggage Claim** (*): Customs, Immigration, Arrival Concourse, Free Shops, Inbound Baggage (Break-down), Outbound Baggage (Sortation area), Apron.		x	x		
11. **Customs**: Arrival Concourse, Baggage Claim, Offices, Immigration, others.		x	x		
12. **Arrival Concourse**: Kerbside (Arrival), Customs, Commercial Spaces, Baggage Claim		x	x		
13. **Kerbside** (Arrival): Car Park, Arrival Concourse, Commercial Spaces		x	x		
14. **Commercial Spaces**: Offices, Departure Concourse, Departure Lounge, Arrival Concourse, Passport Control, ...	x	x	x	x	x
15. **Offices**:.../..., Check-in, Immigration, Customs, Commercial Spaces, Others.	x	x	x	x	x
16. **Other Spaces** (VIP/CIP Lounges, Toilets, HVAC, Business Centre, Plant rooms, etc.): varied	x	x	x	x	x

(*) It should usually be divided in groups or modules for maintenance reasons and for separation between International and Domestic Traffic

(**)Separated Security for Int./Dom. traffic

Note: For Multi-Level terminal the second floor is usually for departure and the first floor for arrival passengers..

The number of level road is usually determined by traffic volumes. FAA (1988a) recommends that for a traffic level of over 500,000 enplaned passenger per year, structures of more than one storey should be investigated. The number of terminal levels will largely be determined by the aircraft mix. Apron level boarding is a logical solution for smaller aircraft with low number of passengers and usually with self contained stairs. For wide-body aircraft a second-level will certainly be required.

6.5 *Centralised or Decentralised*

Centralisation or decentralisation is a complex issue rather than a controversial matter as suggested by Hart (1985). Although the passenger building's main function is interchange between transport modes, the terminal is an agglomerate of separated grouped functions: commercial, operational, administrative, passengers and baggage processing. The key to achieve the objectives of any terminal concept is simplicity and convenience. Intuitively, complex passenger flow routes are a consequence of complex plans and buildings shapes. This is somewhat related to centralisation or decentralisation of functions. Separation of functions is the main factor in achieving simplicity. For example, if other facilities such as administration offices and commercial are incorporated with passenger facilities, not only may the flow be distorted but the possibility of expansion, flexibility and efficiency may be compromised. It has been a concern in some airports, which are becoming commercially oriented, that the expansion of commercial activities into some 'operational areas' would hinder the main function of the terminal. Conversely, to locate those facilities where there will be no public is a nonsense. Figure 6.5 illustrate the most simple and convenient terminal scheme.

Centralisation may not be convenient for passengers since, with centralised functions, the distances between facilities may increase. On the other hand centralisation has the advantage of economy of management. There are different degrees of centralisation in an airport terminal depending upon the number of functions that are centralised or decentralised. The decentralisation can be achieved by dividing the operation according to passenger characteristics, for example, adopting unit terminals for international/domestic split, long-haul/short-haul flights, of which Heathrow Airport is a distinct example; or by adopting airline unit terminals, as in United States; or by breaking down internal functions, such as security checks or using curb-side or gate check-in, even separating governmental activities (Customs, Immigration).

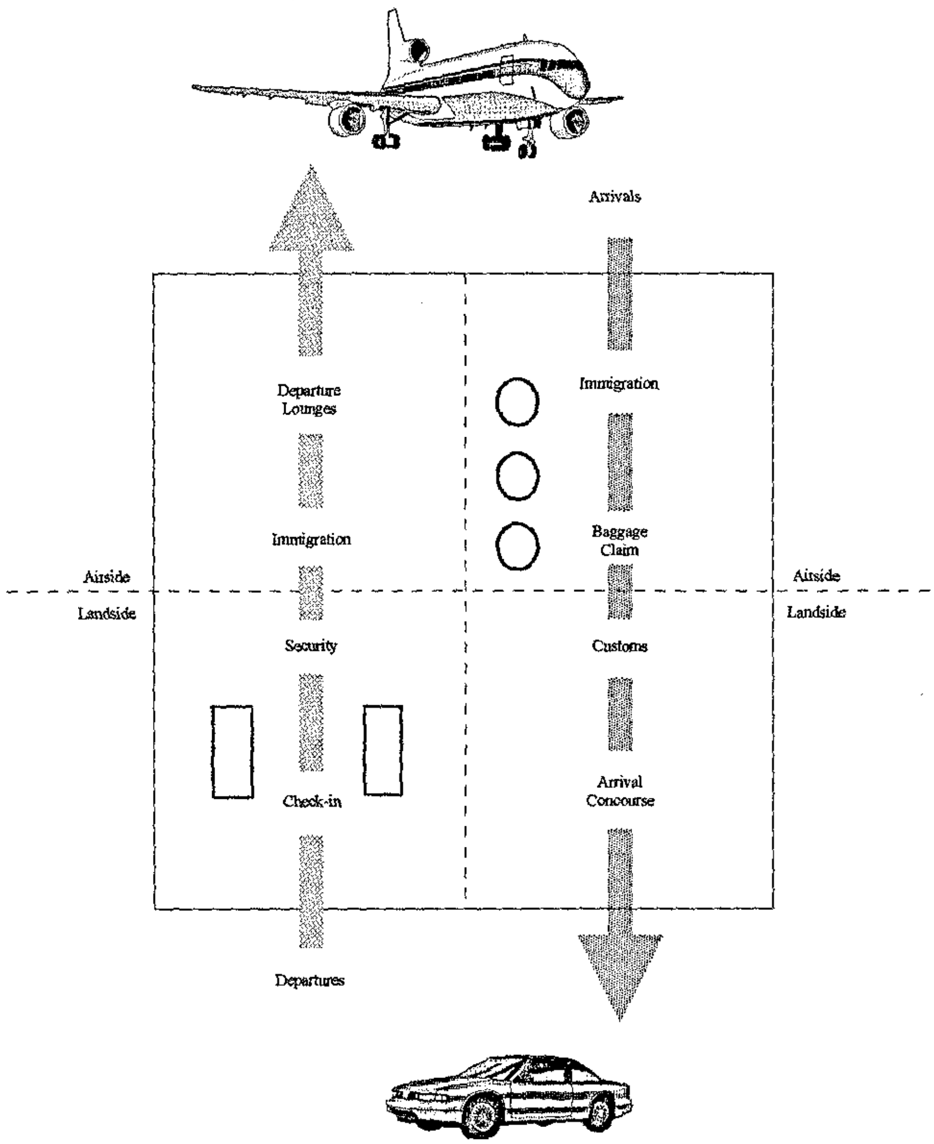


FIGURE 6.5: Plan scheme of a simple airport terminal

6.6 Circulation

Circulation space is another of the main elements. In traditional office and industrial buildings circulation is considered non-usable space, and in terms of layouts the planning efficiency factors are measured as a function of the usable and non-usable ratio, in terminal planning, circulation spaces fulfil one of the main function of the terminal: *change of transport mode*. The ratio of circulation space to the overall space cannot be ignored. This does not discount the fact that an economic layout for any building will have as one of its main aims the reduction of the amount of circulation space to an acceptable minimum neither that the designer has not to attempt to make the best possible use of space within each alternative design, aiming for a profitable arrangement. It is interesting that some circulation spaces, such as in entrance halls, stairways and lift wells, passages, etc., are even regarded as 'dead space'.

The basic shape of a building will determine the efficiency of its internal circulation spaces. The result is that this will certainly affect the time required by a person to travel from one part of the building to another. Therefore the flow of people and the internal layout will also affect the quality of the building. In this sense circulation is the connection in time through a sequence of spaces, which encompass:

(1) access to the terminal;

(2) the building entrance;

(3) the configuration of the path;

(4) path-space relationship (edges, nodes, termination of the path), passing by spaces, passing through spaces, terminating in spaces; and,

(5) form of the circulation space (corridors, balconies, galleries, stairs, rooms, etc.).

The ratio of circulation space will depend upon the shape and size -- *concept* -- of the terminal. This may typically represent 25 to 30% of the connector (see definition in [FAA, 1988a]) total area of a linear terminal with around one million passengers a year to 50 to 70% of the total connector area in the same concept but with twenty to thirty million passengers a year. Typical circulation ratios for blocks of flats with four flats on each floor and access from a common hall are indicated by Seeley (1978) and shown bellow:

Plan Arrangement	Circulation Ratio
Rectangular block with common landing access	20%
Cruciform block with common landing access	30%
Slab block with internal corridor access	22%
Slab block with external balcony access	32%

Space shape and size are important elements for the layout process but the relative locations of the facilities is rather more important. Tregenza (1976) shows that the problem consists in minimising:

$$C = \sum_{i=2}^{m} \sum_{j=1}^{i-1} t_{ij} \cdot d_{ij}$$

where,

C is a measure of circulation cost;
The facilities or rooms are labelled 1 to m;
t_{ij} is the traffic flow between two facilities; and
d_{ij} is the travel distance.

The objective is to find an arrangement in which the summation of the product of the rate of movement between each pair i, j of facilities (rooms) and the distance between them is as small as possible. The difficulty of this strategy is the number of possible combinations. For m facilities there would be $m!$ possible arrangements. Moreover, there are two main conditions that reduce the applicability of similar methods. Firstly, the lack of reliable data or the difficulty of collecting such information. And, second the minimum circulation cost may not be the best solution when other criteria are considered.

In planning the circulation spaces to minimise the impedance to movement, three aspects should be considered:

- ⇨ Separation of different traffic flows (e.g. trolleys and pedestrian flows);
- ⇨ Separation of waiting areas (e.g. queuing area and circulation); and
- ⇨ Provision of information

The main circulation space in terminals is related to the main pedestrian routes, usually defined by corridors. In this case the analysis is usually based on predicted traffic intensities that follow those routes. The calculation of such spaces is not an easy task, since the necessary data is not always at hand.

The capacity of a corridor in a passenger building is usually calculated as a function of the walking speed and the area occupied by each person as he/she walks -- measured by the lateral distance and headway distance between persons in the direction of flow:

Flow rate (pax/min) = mean speed (m/min) x mean density (pax/m^2) x width of route (m).

For this same purpose ICAO (1987) suggests the following equation

$$Cc = \frac{WS}{WO \times HD}$$

where,

Cc = Corridor capacity (number of persons per minute, per one metre width);
WS = Walking speed (normally 75 m per minute);
WO = Width occupancy (0.6 ~ 0.8m per person); and
HD = Headway distance between persons (1 ~ 2 m).

The only shortcoming with these equations based upon average walking speeds is that this measure may not represent reality, since walking speeds vary significantly with the population and with the physical surroundings. Age and sex differences, groups, trip purpose, baggage, gradient, differing flow directions, and density are factors associated with differences in mean walking speed.

Seneviratne (1989) instead of assuming that capacity of a corridor is only a function of walking speed and passenger density, establishes a relationship considering construction and user costs as main factors as given by the equations:

$$Cu = \beta\left[t(v) - T\right]q$$

where,

Cu = Total user cost;
β = Value of travel time per unit time per pedestrian;
t = Mean travel time at a given pedestrian flow;
v = Flow in persons per unit time per unit of effective width;
T = Mean travel time under free flow (unrestricted) conditions; and
q = Demand (number of pedestrians on the corridor) in pedestrians/unit time.

and,

$$C = y_o w + \lambda_o$$

where,

C = Total construction and maintenance costs per unit area and unit time;
y_o = Marginal cost;
w = Width of the corridor; and
λ_o = Discounted fixed cost.

The sum of these two equations is then rearranged, giving the optimum value for the corridor width as:

$$w = \left[\frac{b\beta}{y_o}\right]^{1/2} q$$

where, b is a constant.

Considering that the pedestrian flow q is a random variable with mean and variance μ and σ^2 respectively, instead of a constant flow, Seneviratne shows that the optimal width can be given by:

$$\left[\left(\frac{2d\beta}{ny_1}\right)\left(1+F^2\right)\mu^2\right]^{1/(n+2)}$$

where,

d = Constant;
n = Constant < 1; and
F = Coefficient of variation of flow.

For vertical circulation using escalators, in the absence of detailed data, Tregenza (1976) suggests an assumption for traffic calculations of 60 person/min per escalator regardless of dimensions. He also concludes that it might be reasonable to assume that the capacity of passenger conveyors or moving ramps are the same as that of similar escalators; and also that the capacity of an escalator is approximately that of a corridor with the same overall width. Figure 6.6 summarises the results of the study carried out by Fruin (1973) in respect to pedestrian movement on stairs.

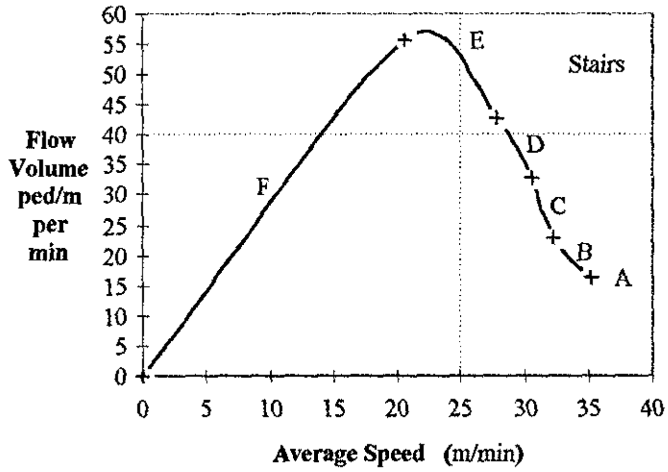
For corridors that are less than 1.2 m wide, the maximum capacity is not proportional to the width and the equations relating passenger speed and densities may not be applicable. The width becomes too narrow for two people walking abreast with ease, or faster-moving pedestrians are unable to pass the slower. It is recommended that corridor widths have to be adjusted for edge effects. The appropriate adjustment should be about 0.45m for each side (wall) and 0.6 m for counter flow, if it exists.

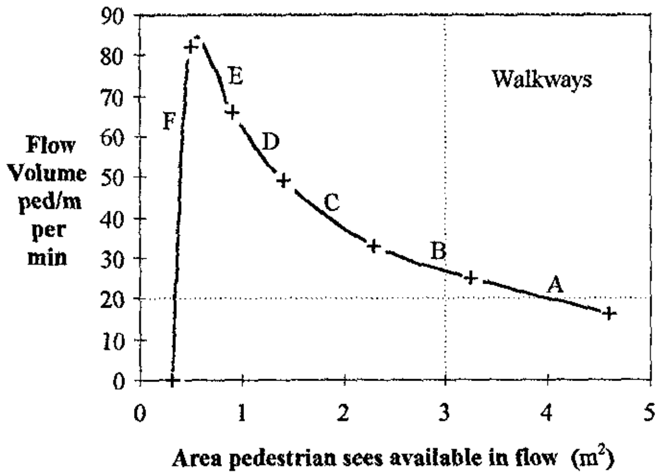
Another aspect of capacity of a corridor is the permissible flow of passengers in it. Fruin (1973) one of the first to study pedestrian movement scientifically, adopted an approach of level of service for a different combinations of flow and congestion, which is illustrated in Figure 6.6. Based on the same approach, de Neufville (1982) suggests that the width of corridor should be:

$$\textit{Total Effective Width Required} = \textit{Outbound Width} + \textit{Inbound Width} + \textit{Edge Allowances}.$$

And the *width* required for flow in any single direction is the peak flow per minute over the critical period divided by the appropriate flow of pedestrian per unit of width, provided that a minimum of 0.75m is guarantied for comfortable movement.

The concept of level of service in pedestrian movement was also analysed by Seneviratne (1985). The difference in his study is that it was based on the premise that speed varies with flow. He was concerned on determining the criteria other than density, speed and flow that pedestrians may perceived as important qualities of a facility. His report suggested that the main objective of pedestrians was to minimise walking distance and the quality or level of service was defined in actual relation to peoples behaviour and perceptions.





LEVEL OF SERVICE	DESCRIPTION
A	Free circulation.
B	One directional flow, free circulation. For reverse and cross flows, minor conflicts.
C	Slightly restricted circulation speed due to difficulty in passing other. For reverse and cross flows, some difficulties.
D	Restricted circulation for most pedestrians. For reverse and cross flows, significant difficulties.
E	Restricted circulation for all pedestrians. Intermittent stoppages. For reverse flows, serious difficulties.
F	Complete breakdown in traffic flow. Many stoppages. Not recommended.

FIGURE 6.6: Pedestrian flows through stairs and walkways at different level of services
(Adapted from [Fruin, 1973])

6.7 Walking Distance

Walking distances seems to be the paramount characteristic in transportation planning, particularly for airport terminals, see Prokosch (1970), Seneviratne (1985), Robusté (1991), North, (1993), Seneviratne, (1994). It is the most important factor of the level of service provided to passengers according to Babic (1984), Wirasinghe (1987) and Bandara (1992).

The reasonable walking distance or the distance considered within the limits of comfort and convenience for passengers is a distance of about 300 to 400 m from the centre of the airside of the passenger building to the farthest aircraft parking position. In fact ICAO (1987) and IATA (1995) recommend 300 m as a maximum desirable walking distance, and similar consideration is agreed amongst the designers and experts in airport planning and design. The passengers' travel time involved in the process throughout the terminal should also be considered. A travel distance of 600 m is considered to be the maximum practical walking distance. For greater distances, the consideration of time is more important than the effort required to walk. If the distance to be travelled is less than 600 m then the inverse is true. Either way, IATA recommends that a form of mechanical assistance should be provided if the walk distance between the point of check-in and the point at which the passenger boards his/her aircraft exceeds 300 m. IATA describes two forms of People-moving system: Horizontal Passenger Conveyors and Passenger Rapid Transit Systems (PRT).

The introduction of a mechanical system appears to be a solution to minimise the problem of travel time for distances greater than 600 m and the effort of walking when this becomes excessively uncomfortable for distances greater than 300 m. Although giving rise to discussion and some controversy, people movers and walkways have become more and more popular in airport terminals. The change, for example, of many airports for Hub and Spoke operations have moved airport planners to re-think the terminal design, including people movers as a must. According to Yates (1992) the old linear concept is now coming to be seen as offering the best potential for the development of that kind of operation, but using people mover. The new Kansai International Airport is a case in point with its mile-long concourse.

Prokosh (1970) classified these mechanical systems in four broad categories:

- *Continuous* - non- intermittent mechanical devices under control of a switch, e.g. moving sidewalk, escalator;
- *Automatically Controlled* - mechanical system under control of an automatic device, e.g. Seattle-Tacoma Shuttle;

- *Passenger-Controlled* - any mechanical device or system which is under the control of the passenger on demand, e.g. elevator;
- *Driver- Controlled* - device under the control of a driver, e.g. bus, mobile lounge.

Other authors Leder (1991) Young (1995) mention four primary pedestrian movement alternative system available to airports:

- → *Courtesy Carts*
- → *Buses*
- → *Automated People Movers*
- → *Moving Walkways*

Among these the two main common mechanical systems applied to airports are passenger conveyor (travelators, moving walkways) and People Movers Systems (PMS). Moving walkway is a pedestrian carrying device on which passengers may stand or walk.. Although the first proposal for an elevated moving pavement was put forward by an American Engineer in 1874, it was not until 1893 that the first moving platform which carried passengers was constructed for the World's Columbian Fair in Chicago [North, 1993]. From the 1950s they have become more common place, and can be found in many of the majors airports around the world, rail stations and parking garages.

People mover systems have been described as 'public transit systems specifically designed to carry large numbers of people over short distances at frequent regular intervals'. People Mover Systems have been the answer to the problem of distances at many airports. They are listed in Table 6.3. PMS and walkway devices have their inherent advantages and disadvantages that can be found elsewhere Prokosch (1970), Fruin (1973), Puckett (1974), Fabian (1981), Muotoh (1982), Fabian (1983), Wirasinghe (1987), Sproule (1991), Yates (1992), North (1993), Young 1995). The main characteristics and cost of different public transportation system is summarised in Table 6.4. A similar comparison is made by Young (1995) with technologies restricted to airports, as shown in Table 6.5.

The walking distances, whether a mechanical system is required or not, are the resultant of terminal configuration and the number of alternative routes imposed by the layout of the facilities. The ideal configuration is one that should give the minimum walking distance, provided that the layout is kept as simple as possible. Thus, if we assume a simple rectangular terminal with required area 'A' to accommodate its functions, the problem would be find the dimensions 'a' and 'b' that would convey the minimum total walking distance to walk through the building.

Table 6.3: Airports with People Mover Systems (Adapted from: [North, 1993])

Airport	Type of System	Date of installation
Tampa	AEG Westinghouse C100	1971, 1981 and 1989
Dallas	LTV/Vought	1973
Seattle	AEG Westinghouse	1973
Atlanta	AEG Westinghouse C100	1980 (Sep.)
Birmingham	Maglev	1980
Miami	AEG Westinghouse	1980 (Apr.)
Houston	Wedway TGI	1981 (Jul.)
Orlando	AEG Westinghouse C100	1981 (Oct.)
Gatwick	AEG Westinghouse C100	1983 and 1988
Las Vegas	AEG Westinghouse	1985
Singapore	AEG Westinghouse C100	1989
Chicago	VAL 286	1991
Orly	VAL 286	1991
Stansted	AEG Westinghouse C100	1991
Frankfurt	AEG Westinghouse C100	1992
Narita	Otis Shuttle	1992
Cincinatti	Otis Shuttle	1993
Kansai	NTS	1994
Pittsburgh	AEG Westinghouse	1994
Denver	AEG Westinghouse	1995
Tampa	TGI UM	Under construction
Honolulu	AEG Westinghouse C100	Under construction
Newark	Von Roll Type 3	Under construction

Table 6.4: Comparison between transport systems

System	Capital cost twin lanes/guideway: £x10^6/Km	Commercial speed: Km/h	Capacity per vehicle/train	Capacity range (max.): 1000 pph/direction	Total Operating cost per km per annum: £x10^6	Total operating cost per km (8% over 30 yrs): £x10^6	Total cost over 30 year life: £x10^6	Cost per pass/km: pence *
Taxis								
General Traffic	0.10-0.14	20	6-8	0.7-1.1	0.6-0.9	6.8-10.1	6.9-10.2	9.5-10.1
Dedicated lanes	0.26-0.30	25	6-8	2.7-4.3	2.1-3.3	23.6-37.2	23.9-37.5	8.9-9.0
Minibuses								
General traffic	0.26-0.36	15	9-16	1.5-2.2	0.5-0.8	5.6-9.0	5.9-9.4	4.0-4.4
Dedicated lanes	0.44-0.54	20	9-16	5.4-9.0	2.0-3.2	22.5-36.0	22.9-39.4	4.3-4.5
Standard buses								
General traffic	0.60-0.80	15	50-90	7.2-9.6	0.7-1.0	7.9-11.3	8.5-12.1	1.2-1.3
Bus lanes	0.80-1.00	20	50-90	14.4-19.2	1.4-1.9	15.8-21.4	16.6-22.4	1.2-1.2
Trolley buses								
General traffic	1.2-2.0	15	75-90	5.4-8.1	0.9-1.2	10.2-13.5	11.4-15.5	1.9-2.3
Bus lanes	1.3-2.1	20	75-90	11-16	1.5-2.4	17.0-27.0	18.3-29.1	1.8-1.9
Guided buses								
Mechanically guided	1.7-3.9	15-25	50-90	19-29	1.8-3.2	20.3-36.0	22-40	1.2-1.4
Travelators								
Uniform speed (elevated)	12-20	1.8-3.2	N/A	10-32	0.1-0.13	1.13-1.46	13-21	0.7-1.3
high speed	Not known	3-12	N/A	16-65	Not known	Not known	Not known	Not known
People movers (elevated)	12-25	15-25	20-500	2-30	0.1-0.7	1.1-7.9	13-33	0.7-13.3
Light rapid transit								
street running	10-20	15-25	125-500	9-25	0.5-1.3	5.6-14.6	16-35	1.0-2.8
Light rail (segregated)	5-10	30-40	125-500	9-25	0.4-1.0	4.5-11.3	10-21	0.7-1.7
Metro (Underground)	30-65	30-40	600-1200	35-70	1.0-2.0	11.3-22.5	40-90	0.8-1.9

* Operating at 50% capacity for 18 hours/day, 363 days per year, over 30 years. (Source: [North, 1993])

Table 6.5: Characteristic of mechanical systems for airports

Mode	Typical Operating Speed	Headway	Capacity
Courtesy Cart	4.8-8 km/h	variable	5 pax/cart 150-200 pax/h
Bus	16-56 km/h	5-15 min	15-60 pax/bus 500-1,500 pax/h/direction
Automated People Mover	12-80 km/h	1-5 min	1,000-14,000 pax/h/direction
Moving Walkway	30 m/min	none	max.: 7,800 pax/h typical: 5,000 pax/h

Adapted from [Young, 1995]

If the passenger circulation occurs along the main orthogonal axes parallel to the sides of the rectangle, see Figure 6.7; the probable average distance walked will be proportional to the sides a and b. To find out the dimensions that give the minimum walking distance consider,

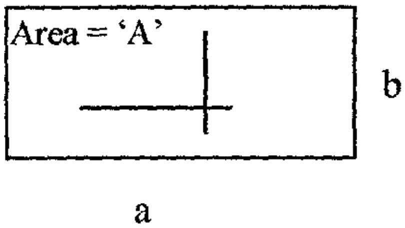


FIGURE 6.7: Minimum walking distance.

$$A = ab \Rightarrow a = \frac{A}{b}$$

$$D \sim a + b \Rightarrow D \sim \frac{A}{b} + b$$

Setting the derivative of the last equation equal to 0 the minimum values can be found,

$$-\frac{A}{b^2} + 1 = 0 \Rightarrow b = A^{\frac{1}{2}} \Rightarrow a = \frac{A}{\sqrt{A}} = b$$

The conclusion is that the square is the particular rectangular building configuration shape that would give the minimum total walking distance. The square is logically, the polygonal shape that also gives the minimum perimeter. According to Seeley (1978) the circle is the geometric figure that gives the minimum perimeter, but may be 20 to 30% more expensive in terms of construction cost. This is also coherent with the distance between two points that is taken as the sum of two orthogonal segments, i.e. the smallest hypotenuse of a triangle of area 'A' will occur when the right sides (Cathetus) are equal as depicted in Fig. 6.8.

Seneviratne & Martel (1991) suggested a performance index (PI_w) to evaluate walking distance defined as a function of the coefficient of variation (CV_w) of walking distance, given by:

$$PI_w = \frac{1}{1 + CV_w}$$

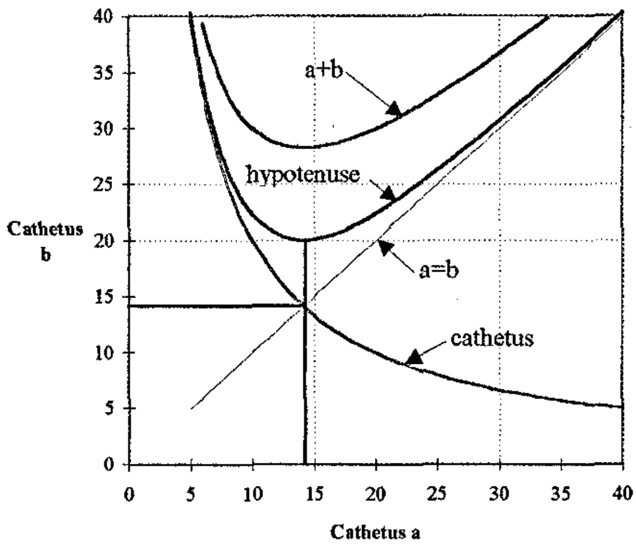


FIGURE 6.8: Minimum orthogonal distance between two points.

They also defined the following level of service in relation to PI_w :

LOS	PI_w
A	≥ 1.0
B	0.8-0.9
C	0.6-0.7
D	0.4-0.5
E	0.2-0.3
F	≥ 0.1

It is also valid to add that according to the results of a personal interview survey of departing passengers, Seneviratne and Martel (1994) found that for the three main functions of the passenger terminal -- *circulation, waiting areas and processing points* --, the passengers perception of the most important variables influencing these three elements were:

- for *Circulation*, Information (according to 53% of respondents);
- for *Waiting Areas*, Seat Availability (according to 44% of respondents); and
- for *Processing* Elements, Waiting Time (according to 60% of respondents).

The case in point is that for circulation, 38% of the respondents felt that walking distance was the most important variable. The other two variables considered, Availability of Space and Level Changes accounted only for 6% and 3% respectively.

Finally, it is worth stressing the paramount importance of the *walking distance* parameter as it underlies, directly or indirectly, ceteris paribus, the passenger travel time, the level of service provided, the simplicity or complexity of the passengers routes, the size of the terminal, the form and shape -- or terminal concept --, and the cost involved in the terminal construction and operation.

6.8 Aircraft

The aircraft fleet is undoubtedly one of the most important actors in the airport design process. For the airlines, aircraft represent their basic resource.

If for the design of internal facilities of an airport terminal the concern is with passengers, for the choice of a Terminal Concept the aircraft will certainly be the determinant factor. It can well be the most constraining element in airport compatibility. The following diagram depicted in Figure 6.9 may illustrate this.

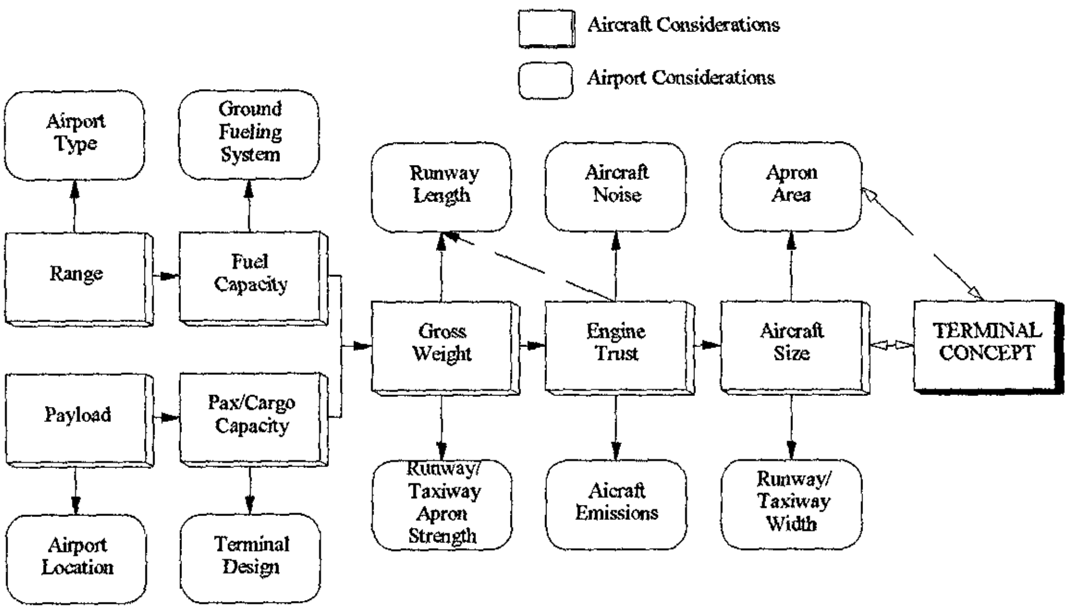


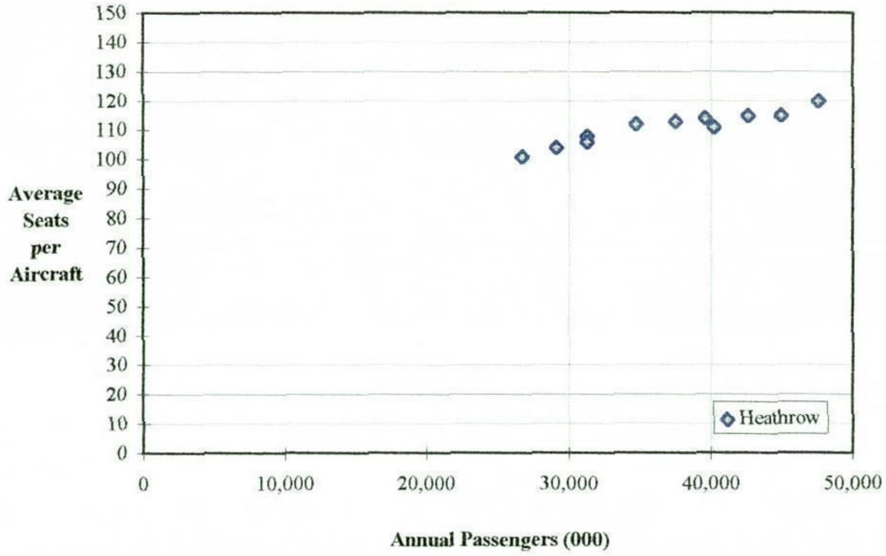
FIGURE 6.9: Aircraft Airport Relationship
(Adapted from M.Sc. Airport Management Lecture notes)

In addition to providing estimated parameters such as peak hour passenger statistics for sizing terminal facilities, the means for calculating aircraft mix, average seats per aircraft, average load factors, and gate utilisation are paramount for the design process. The forecast passenger aircraft movements are usually developed taking into account these factors, i.e., the projected passenger demand, the forecast fleet mix, the average number of seats per aircraft and the load factor. Considering the composition of the fleet mix serving the airport, factors such as stage lengths, schedule frequency, environmental restrictions, fuel costs, specific airline fleet decisions, and increasingly, airfield capacity may determine the equipment to be used in the future.

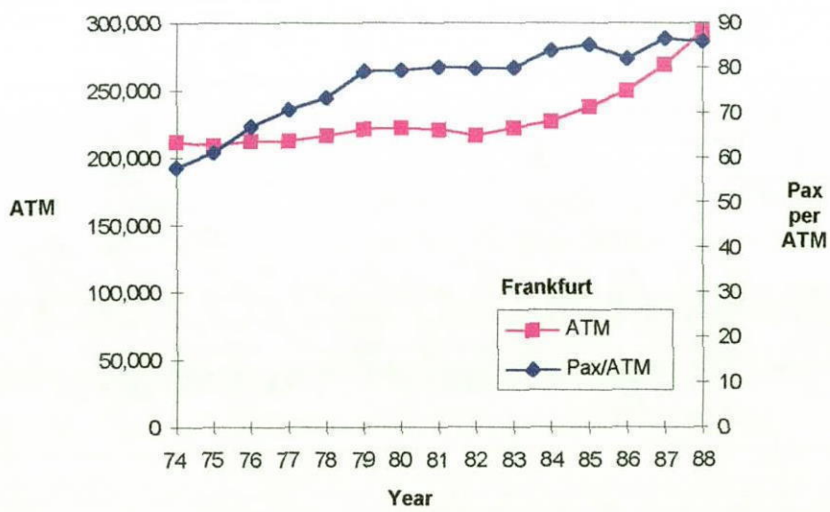
Some general assumptions can be made, whereby the existing fleet mix in certain airports may be updated to reflect future conditions:

- Continued environmental concerns and noise regulations, and probable increased fuel costs will accelerate the replacement of Stage II aircraft with Stage III aircraft [Beyer, 1988].
- Increasing concerns about safety may also accelerate the retirement of older Stage II aircraft.
- The continued consolidation of the airline industry may lead to less competition at some airports resulting in fewer operations during peak periods. Demand during these periods could be met by fewer airlines using larger aircraft.
- Problems related to airspace and airfield capacity constraints will also demand an average increase in aircraft size -- probable a NLA - New Larger Aircraft.
- It seems to be a natural tendency to increase the capacity of the aircraft as the passenger volumes increase, though this is not universally true. Some examples are plotted in Figures 6.10, 6.11 and 6.12.

Passengers are obviously important in the design process, but of equal importance are aircraft, which are the generators of passenger flows. Aircraft vary enormously in individual characteristics such as performance, weight, size, seating capacity, range, and type of engine. To enable homogenisation of use, i.e., to enable a common use of a particular stand by different aircraft types, the categorisation of present and future aircraft serving at the airport into groups, according to their similar characteristics is a very common practice. Apart from categorisation, other aspects are relevant to design, such as aircraft load factor, turnaround time, number of aircraft gates, equivalent gates, and equivalent aircraft.

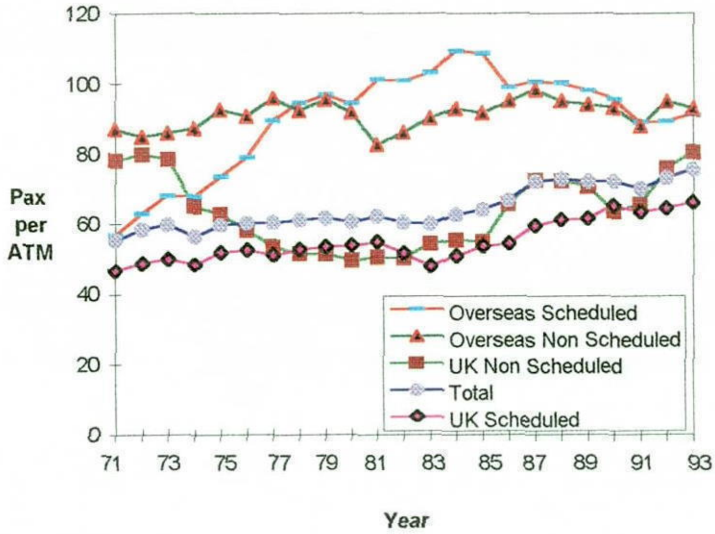


a) Heathrow Airport Movement -- from 1983 to 1993 (Source CAA, 1994)

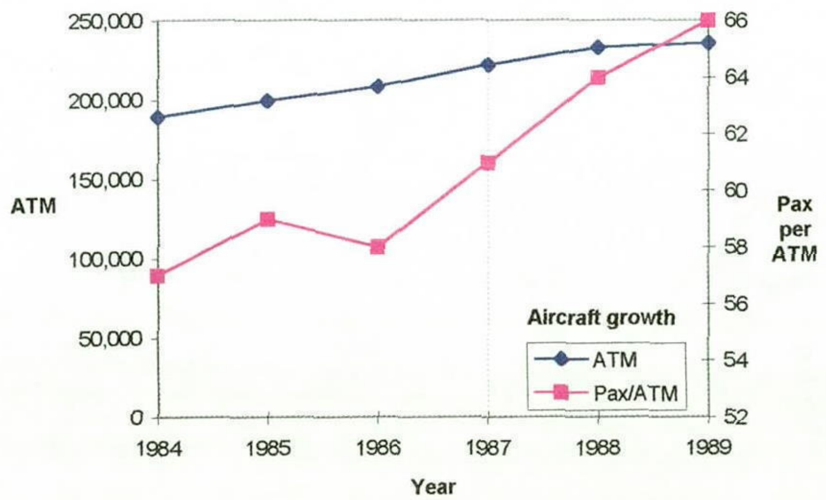


b) Aircraft/Passenger relationship at Frankfurt Airport

FIGURE 6.10: Relationship between Aircraft and Passengers

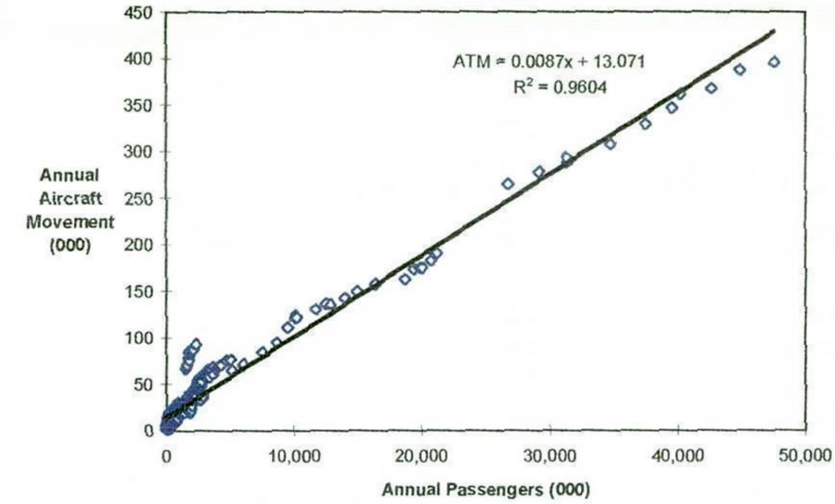


a) Average Number of Passengers per Air Traffic Movement of UK Airports, from 1971 to 1993 (Source: Adapted from CAA Statistics)

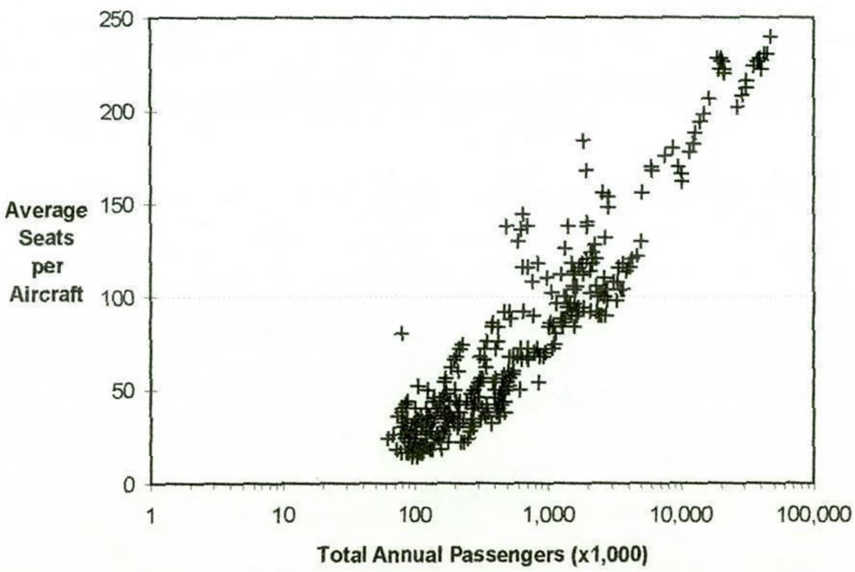


b) Average number of Passengers per ATM - Schiphol Int. Airport. from 1984 to 1989. (Source: Data from Schiphol Airport)

FIGURE 6.11: Example of Aircraft and Passenger Relationship.



a) Aircraft movements versus Total Annual Passengers of main UK Airports



b) All UK airports -- from 1983 to 1993

FIGURE 6.12: Correlation between Aircraft and Passengers of UK Airports from 1983 to 1993.
(Source: Adapted from CAA Statistics)

6.8.1 Aircraft Categorisation

There are several aircraft categories for specific purposes. For sizing terminals the common procedure is to group aircraft according to their similar characteristics in seating capacity and size -- predominantly the wing span.

The types are varied, see Figure 6.13 and 6.14. The aircraft operated by the airlines are capable of service lives in excess of 20 years, and old aircraft are still operated. Nevertheless, the number of basic types of aircraft operated by the airlines tends to be reduced as a factor of better operational efficiency. In the same way, to be attractive to the customer, the average age of the fleet should be reduced as well. The airline has to adapt its fleet to satisfy its customers. This may range from the refurbishment or modification of the aircraft interiors to acquisition of new aircraft, and even the need for bigger and faster ones. It is a compromise between service, profit and cost mixed with demand and capacity. This raises the issue of the need of a NLA -- New Larger Aircraft -- claimed by some major airlines. The view is that the use of larger aircraft may be the solution for the increasing airport and airway congestion foreseen by forecasters, given that the demand for air travel will more than double by the year 2011. Therefore, in sizing new airports or planning extension of the existent ones some consideration should be given for an NLA.

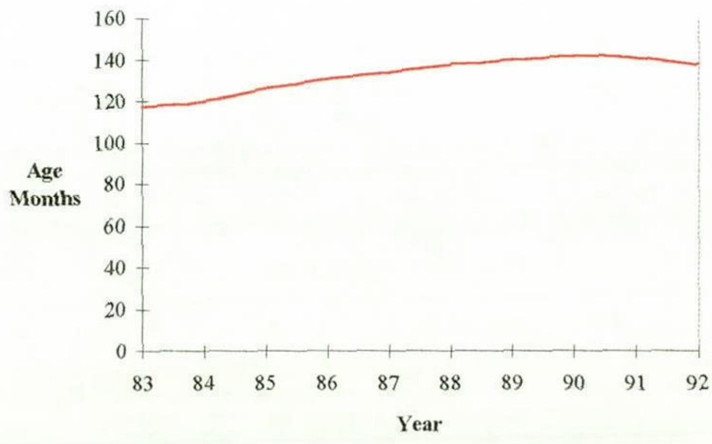


FIGURE 6.13: Fleet Average Age - Industry wide
(Source: Boeing, 1992)

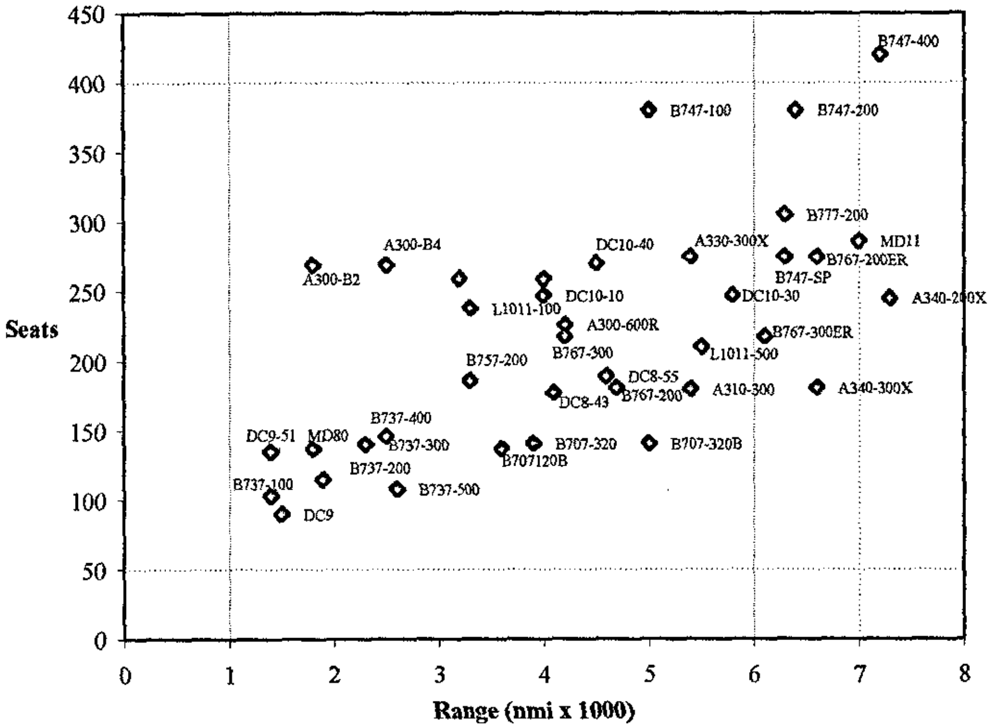


FIGURE 6.14: Aircraft Type related by Range and Number of Seats.
(Source: Airport Design Manuals)

The great impact of NLAs on existing and new airports will be on the need for space. As terminals are usually designed to cope with peak hour maximum loads, check-in areas, departure lounges and baggage claim areas, amongst others, will be over stretched to accommodate such aircraft. The ICAO (1983, 1990) at beginning of 80s have recognised the need to consider NLA in giving an indication of future aircraft design parameters (see Table 6.6) and guidance on the design of runways, taxiways and aprons for such aircraft.

Table 6.6: NLA Aircraft characteristics - ICAO

Aircraft Characteristics	Dimensions
Wing span	up to 84 m
Outer Main Gear Wheel Span	up to 20 m
Overall Length	up to 84 m
Tail Height	up to 23 m
Maximum Gross Weight	up to 567,000 Kg

The inherent problems that NLA's may bring to the development of an airport system are discussed in detail elsewhere Wilson (1989), Wolffran (1989), Caves (1993), Jenkinson (1993), Airport Support (1994), and David (1995).

Although NLA's have been discussed for quite a while, the standards set down by organisations in terms of aircraft categorisation do not include NLA's yet. For instance, ICAO (1990) adopts a system of reference codes for the establishment of those standards, composed of a code number (*1-4*) -- referencing the runway length, and a code letter (*A* to *E*) -- with respect to aircraft wing span and outer main gear wheel span, see Table 6.7, which comprises aircraft with wing spans up to 65 m.

The aircraft categorisation is usually established according to one or more of its characteristics: physical size, wing span, fuselage length, weight, range, speed, thrust, and capacity.

For example, in the Airport Planning Manual [ICAO, 1987] four aircraft groups are suggested which are shown in Table 6.8.

For the purpose of exit taxiway design, aircraft are grouped [ICAO, 1983] on the basis of their speed at sea level as indicated in Table 6.9.

The FAA (1990) uses an airport reference code with two components relating airport design to aircraft. The first component, depicted by a letter *A* to *E*, is the *aircraft approach category* and relates to aircraft approach speed (*Operational Characteristic*). The second component, depicted by a Roman numeral *I* to *VI*, is the *airplane design group*, characterised by the aircraft wing span (*Physical Characteristic*), see Table 6.10.

Table 6.7: ICAO Aerodrome Reference Codes [ICAO, 1990]

Code Number	Aeroplane Reference Field Length	Code Letter	Wing Span	Outer Main Gear Wheel Span
1	Less than 800 m	A	Up to but not included 15 m	Up to but not included 4.5 m
2	800 m up to but not included 1,200 m	B	15m up to but not included 24 m	4.5 m up to but not included 6 m
3	1,200 m up to but not included 1,800 m	C	24 m up to but not included 36 m	6 m up to but not included 9 m
4	1,800 m and over	D	36 m up to but not included 52 m	9 m up to but not included 14 m
4	1,800 m and over	E	52 m up to but not included 65 m	9 m up to but not included 14 m

Table 6.8: IATA Aircraft Categorisation

Group	Aircraft
S	F28, B737
M	B707-320, A300, L1011, DC10
L	B747-SP, B747
LL	B747-II (future aircraft)

Source: [IATA, 1995]

Table 6.9: ICAO Categorisation for exit taxiway design purposes

Group	Threshold Speed km/h
A	< 169
B	169 to 222
C	223 to 259
D	260 to 306

Group			
A	B	C	D
Convair 240	Convair 600	B707	B747
DC3	Fokker F27	B727	DC8
DC7	Viscount 800	DC8	DC10
		Trident	IL62M
			L1011
			TU154

Source: [ICAO, 1983]

For sizing the terminal the FAA (1988a) group the aircraft according to their seating capacity as shown in Table 6.11.

Table 6.10: FAA Aircraft Categorisation

Category	Approach Speed * (Knots)	Group	Wing Span (m)
A	< 91	I	< 15
B	91 to 121	II	15 to 24 not including
C	121 to 141	III	24 to 36 not including
D	141 to 166	IV	36 to 52 not including
E	> 166	V	52 to 65 not including
		VI	65 to 80 not including

* Based on 1.3 times their stall speed in their landing configuration at their maximum certificated landing weight

Source: [FAA, 1990]

Table 6.11: FAA - Categorisation by seating capacity

Seating Capacity	Aircraft
1 to 60	CV500/DHC7/SD3-30 & 60/F27/F28
61 to 80	DC9-10/BAC-111
81 to 110	B737/DC9-30/BAE146-100 & 200
111 to 160	DC8/B707/B727-200/DC9-50
161 to 220	DC8-61/A300/B767/B757
221 to 280	B747SP/DC10/L1011
281 to 340	DC10/L1011 (high dens./stretch)
341 to 420	B747
421 to 500	B747 (high dens./stretch)

Source: [FAA, 1988a]

The separation of aircraft in flight deserves also concern due to wake vortex. For this the ICAO criteria of grouping aircraft are:

Heavy (H)	136,000 kg or greater
Medium (M)	less than 136,000 kg and more than 7,000 kg
Light (L)	7,000 kg or less

And, the UK [CAP 168] adopts four categories for the same purpose, which differ from the ICAO as following:

Heavy (H)	136,000 kg or greater
Medium (M)	less than 136,000 kg and more than 40,000 kg
Small (S)	40,000 kg or less and more than 17,000 kg
Light (L)	17,000 kg or less

The lengths and strengths of paved runways at major airports planned to accept the traffic forecasts are based on the requirements of the aircraft, therefore an alternative example of classification may take into consideration the runway and pavement requirements as illustrated in Table 6.12.

Table 6.12: Example of aircraft grouping according to Runway needs

Categories	Length at Sea Level (m)	Surface or Strength (LCN)*
1. General Aviation		
Light Single Engined	750	Grass
Light Twin Engined	900	Grass
Medium Twin Engined	1100	Tarmac or Grass
Jet Executive	1200-1800	20
2. STOL **	600	20-70
3. Small Twin Jet and Non-Jet	1700	40
4. Short-Medium Haul Jets	2450-2600	60-70
5. Long-Haul and Intercontinental jets	3200-3650	80-90

* LCN = Load Classification Number

** STOL Short Take-off and Landing

6.8.2 Load Factor

The ratio between the number of passengers in the aeroplane and the number of seats it contains is called *Load Factor* -- LF. As a seat is a perishable commodity, for the airline business LF is a vital economic information, which typically is close to 65 percent on long-haul operation of a modern wide-bodied aircraft.

The average LF n_p during a fixed period of time on a specific route is defined as [Teodorivic', 1988]:

$$n_p = \frac{\lambda}{nN}$$

where,

λ = average number of passenger during a fixed period of time on the route;

n = number of seats in the airplane; and,

N = flight frequency, i.e., the number of flights during the time period under observation

Figure 6.15 shows the significance of the average load factor n_p as a function of flight frequency. Conversely, as in peak hour evaluation, average load factors may be a misleading measure because of the time sensitive nature of air transport demand. It is necessary to recognise the extent to which air travel demand fluctuates widely above and below overall averages, be it daily, monthly or annually.

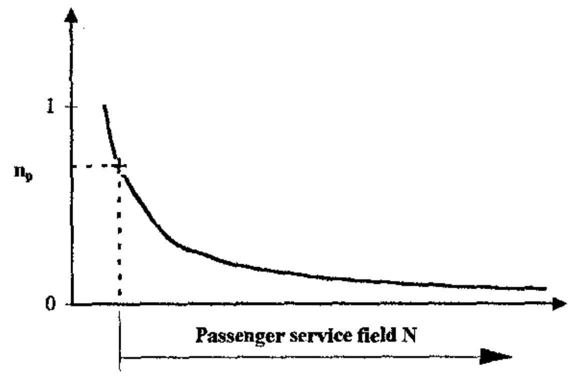


FIGURE 6.15: Passenger Load Factor as a function of flight frequency.
(Source: [Teodorivic', 1988])

6.8.3 Aircraft Turnaround

The turnaround time may be defined as the time on blocks which is required in order to off-load, to tank and to load the aircraft and to carry out the required maintenance activities. The minimum turnaround time results from the length of the critical path, which is the necessary sequence of procedures in which either a certain order is required or can only be commenced after a previous activity has been completed.

The usual activities that comprises an aircraft turnaround are:

- Passenger disembarkation
- Aircraft refuelling
- Catering
- Cabin Cleaning
- Unloading of cargo, mail and baggage
- Loading of cargo, mail and baggage
- Passenger embarkation
- Start up

The total turnaround time may vary according to circumstances and type of activity, nevertheless those times may depend mainly on:

1) Passenger disembarkation / embarkation time
   - type of disembarkation / embarkation, i.e. (steps, mobile lounges, loading bridges, buses)
   - average number of passengers

- transit passengers remain on board.

2) Refuelling the aircraft
   - form of refuelling (e.g. underground -- tank truck, number of pump trucks, number of tank trucks, total number of fuel hoses)
   - quantity of fuel (kg)

3) Catering
   - form of catering (e.g. with pax o/b, without pax o/b, outbound catering, outbound and return catering, with upper-deck catering, reloading of return catering -- from belly --, meal loading, drinks are reloaded -- from belly)
   - number of high loaders
   - volume of catering

4) Cabin Cleaning
   - form of cleaning (e.g. end of flight cleaning, shortened end of flight cleaning, transit cleaning, with or without pax o/b)
   - equipment (high lifters)
   - procedure (e.g., starting during or after pax disembarkation)
   - number of staff

5) Unload/Load of cargo, mail and baggage
   - type of cargo, mail and baggage -- Bulk Load or ULD
   - type of holds -- Bulk load - forward, rear, aft hold
ULD - forward, rear, main deck
   - equipment -- Bulk load - with or without conveyor belt
ULD - with transporter or
- without transporter (direct loading onto dolly)
   - number of loaders

6) Start up
   - with push-back
   - without push back
   - The average time for start up is usually:

B747	5 min
DC10	4 min
A300/310	4 min
DC8/B707	5 min
B727	2 min
B737	1 min

The disembarkation of passengers, cleaning, catering and embarkation of passengers are routines which are normally convenient to carry out in that order. The unloading and loading of aircraft, along with re-fuelling, catering and toilet drainage, are all routines which can be performed independently of one another. In some European countries, during extended winter periods for instance, the need for de-icing may be the determinant factor for turnaround times.

Table 6.13: Turnaround Time

Aircraft	Turnaround Time			
	Manufacturer Time (min)	Average Time (min) *	Average Time (min) **	Average Time (min) ***
FA4	10	43		
BA31	10	43		
E120	10	34		
SH6	10	34		
SD34	10	34		
F27	18.5	41		
F28	20	48		
B732	28	58	57	53
B733	28	58	58	51
B734	28		53	51
B727	30	66		56
B721	28		63	
B722	32		44	
B707	60		93	
B757	25	82		47
B767	30	175	68	54
A312	30	76		
A300	30	70	69	46
DC10	30	245	108	47
L1011	30	231	79	41
L1011-5	35	122		
B747	60	288	92	60
B747-F	60	265		
DC8	44		82	106
DC9	28	48		
DC9	25.5	65		

Sources: * [Caves, 1987]
** Rio de Janeiro International Airport
*** Sao Paulo International Airport

Groups	Average Time (min)
Narrow	59
Medium	72
L	104
LL	89

Table 6.14: Gate occupancy time, min.

Aircraft	**Turn round station**	**En route station**
A-300-600	30	20
B-737	28	22
B-747-200	60	30
B-757-100	30	20
B-767-200	30	20
B-777	45	25
DC-9-51	30	20
DC-10-10	30	20
MD-11	52	24
MD-87	25	14

Source: Aircraft Manufactures (Airport Planning Manuals).

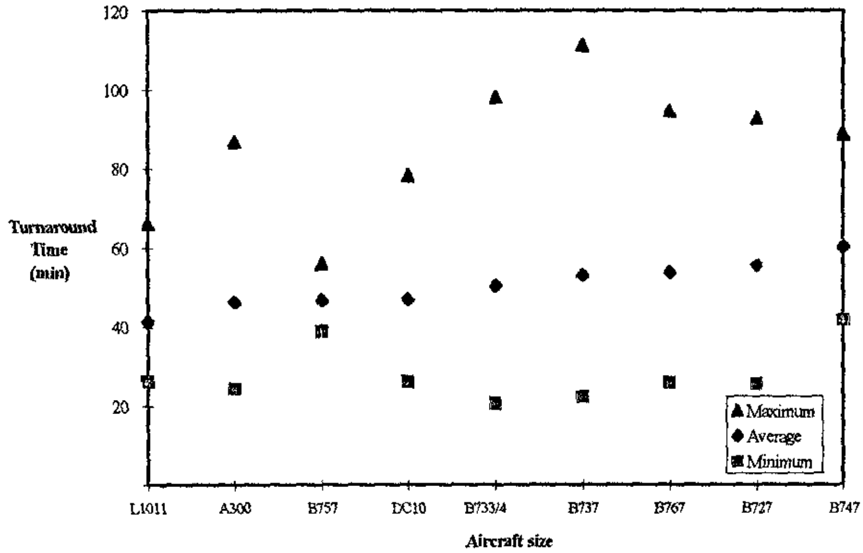


FIGURE 6.16: Turnaround Time - Sao Paulo International Airport (1990).

The average turnaround times specified by the manufactures compared with statistics of actual turnaround times are shown in Tables 6.13 and 6.14 and Figure 6.16.

It is suggested by Caves (1987) that reducing turnaround times would increase capacity in terms of passengers per hour. He concluded that "... the main factor controlling the turnaround time is the schedule within which the airlines feel that they can balance punctuality and aircraft utilisation, given the unpredictability of weather, winds, air traffic control servicing and mechanical reliability." Using a Pert diagram to analyse delays in airports (turnaround times) Yagar (1973) concluded that improvement in aircraft schedules, rather than of passengers, seems to be the solution to decreasing the delays in air travel and their associated costs, without loss of capacity.

Manufacturers and airlines feel that reducing aircraft turnaround times will improve aircraft utilisation. However, improved aircraft utilisation should be concomitant with either maintaining or increasing the load factors.

Table 6.13 shows that the turnaround times predicted by the manufacturers in their Airport Planning Manuals are far from being achieved, being in most of the cases half of the actual necessary time. Caves (1987, 1993) findings for some European and USA airports was that less than 10 per cent of the turnarounds were accomplished within the minimum times claimed by the manufacturers.

6.8.4 Gate Requirements

The required number of aircraft stands at a passenger terminal may be estimated by several methods. It usually depends on passenger aircraft movements by aircraft type and their gate occupancy time. The passenger aircraft movement during the peak hour by aircraft type may be estimated by two procedures [ICAO, 1987]:

1)

- Forecast annual passenger aircraft movement;
- Determine peak day ratio;
- Calculate peak day aircraft movement;
- Determine aircraft peak hour ratio;
- Forecast aircraft mix; and,
- Obtain peak hour passenger aircraft movement by aircraft type.

2)

- Forecast peak hour passenger volume;
- Determine peak hour average load factor;
- Forecast aircraft mix, and,
- Obtain peak hour passenger aircraft movement by aircraft type.

One of the first methods to calculate the number of gates was introduced by Horonjeff (1962, 1983). He suggested the following equation:

$$G = \frac{vt}{u}$$

where,

G = number of gates;
v = design hour volume of arrivals or departures (aircraft/h);
t = weighted average stand occupancy time (h); and,
u = utilisation factor, suggested to be 0.6 to 0.8 where gates are shared.

Piper (1974) suggested:

$$G = mqt$$

where,

G = number of gates;
m = design hour volume of arrivals or departures (aircraft/h);
q = proportion of arrivals; and,
t = weighted mean stand occupancy time (h).

Bandara and Wirasinghe (1988) attempted to recognise the stochastic nature of flight arrivals and defined the number of gates required as:

$$G = R(T + S)$$

where,

G = number of gates;
R = random variable that represents arrival rate;
T = random variable that represents occupancy time; and,
S = random variable that represents the time between departure from a gate and the next arrival.

Sir Frederick Snow [Ashford, 1992] suggested:

$$G = 1.1m$$

where,

G = number of gates;
m = design hour volume for arrivals and departures (aircraft/h).

Loughborough Method [Ashford, 1992]:

$$G = vt$$

where,

G = number of gates;
v = design hour volume for arrivals or departures (aircraft/h);
t = weighted mean stand occupancy time according route type:
0.9 h for domestic,
1.1 h for short-haul international,
3.8 h for long -haul international.

Hart -- Hourly Method [Hart, 1985]

$$G = \frac{m}{2r}$$

where,

G = number of gates;
m = total number of peak hour aircraft movements;
r = movement factor -- 0.9-1.1 for originating or terminating flights
1.2-1.4 for transfer
1.5-2.0 for through

Hart -- Daily Method [Hart, 1985]:

1) Compute current average daily departure/gate (=q')
   less than 5 is low; 10 considered the maximum
2) Estimate future average daily departure/gate (q)
3) Divide future daily departure (d) by future average daily departure per gate (q).

$$G = \frac{d}{q}$$

Hart -- Annual Method [Hart, 1985] (see later example for Nice Int. Airport):

1) Determine current annual utilisation per gate
   Annual enplanements per gate < 15,000 considered low, and
   > 150,000 considered high
2) Determine number of gates by estimating number of enplanements per gate
   Divide future enplanements by enplanements per gate

Hassounah and Steuart (1993) suggested that the total required number of gates can be obtained by aggregating the maximum values of exclusive use of gates by particular air carriers or by flights of certain sectors, as

$$G_k = E(N_k) + 1.645\sqrt{Var(N_k)}$$

where,

G_k = number of gates for flights of each carrier or sector k;

$E(N_k)$ = Mean of the random variable N which is the number of gates occupied by aircraft k;

$Var(N_k)$ = The variance of the random variable N.

For a common gate use strategy the value $E(N)$ for total number of gates should be used instead and the maximum value of G over time of day provides an estimate of the required number of aircraft gates.

de Neufville (1980) suggested the following equation:

$$G = A + 2\sqrt{A}$$

where,

G = number of gates;
A = Average number of aircraft expected at peak periods.

Russian researchers suggested (see [Mackenzie, 1974] where the references can be found):

$$G = 2\frac{I}{24}TK$$

where,

G = number of gates;
I = the number of flights per day;
T = average gate occupancy time; and,
K = a "coefficient of non-conformity" which varied from 2.4 - 4.6.

Stafford (1969) suggested the following formula to calculate the forecast of gates required by any group which will have future mutual use:

$$G_f = (G_p - 2)\frac{Pax_f}{Pax_p} + 2$$

where,

G_f = Future number of gates;
G_p = Present number of gates;
Pax_f = Future volume of passengers; and
Pax_p = Present volume of passengers.

For ICAO (1987) the required number of aircraft stands at a passenger terminal may be estimated by the following formula:

$$G = \sum\left(\frac{T_i}{60} N_i\right) + \alpha$$

where,

G = number of gates;
T_i = gate occupancy time in times of aircraft group i;
N_i = number of arriving aircraft group i during peak hour; and,
α = number of extra aircraft stands as spare.

The number of arriving aircraft can be assumed as 50% of the total movement or by applying a heavy direction factor particular to the airport in study, and usually of the order of 60 to 70% of the total peak hour movement.

FAA (1983) provides also a method to determine the number of gates based upon a series of graphs, which give the number of gates through the gate hourly capacity as:

$$G^* \times S \times N = \textit{Hourly Capacity}$$

where,

G^* is the Hourly Gate Capacity in operations per hour per gate, which is function of R, which is a function of the percentage between the widebody aircraft and the non widebody aircraft gate occupancy time (minutes). If operations do not include widebody aircraft, the Gate Mix is 100% and R=1.

S = Gate size factor, which is function of Gate Mix (percentage of non-widebody aircraft) and percentage of gates that accommodate widebody aircraft.

N = Number of gates.

A study for the development of the Nice International Airport [Aéroport Int. Nice, 1980], in 1980, established the following methodology to calculate the gate requirements:

Traffic Forecast

Year	Passengers	Aircraft Movement	Pax/Movement
1978 *	3,000,000	40,700	80
1985	4,570,000	48,100	95
1990	5,940,000	58,200	102
1995	7,560,000	68,700	110
2000	9,900,000	82,500	120

* (Existent)

The average number of passengers per aircraft was assumed to grow 2% per annum. The peak hour ratio factors, which is the relation between the number of movement in the peak 40th hour and the total number of movements, were adopted based on extrapolation of statistics from the Aéroports de Paris (Roissy and Orly):

Year	Factor (f_i)
1978	1/2,400
1985	1/2,500
1990	1/2,600
1995	1/2,700
2000	1/2,800

With the average number of passengers per gate in 1978 equal 3,000,000/16 = 187,500 pax/gate, and based on the assumptions above, the average number of gates required was calculated:

$$G = \frac{Pax_i}{P_{G_i}}$$

where,

G = Future number of gates;
Pax_f = Forecast annual passengers in year i; and
P_{G_i} = Productivity in terms of passengers per gate in year i.

and,

$$P_{G_i} = P_{G_{i-1}} \frac{P_{m_i}}{P_{m_{i-1}}} \times \frac{f_i}{f_{i-1}}$$

where,

$P_{G_{i-1}}$ = Productivity related to the previous known period;
$P_{m_{i-1}}$ = Passenger per movement in previous year;
P_{m_i} = Passenger per movement in year i;
f_i = Peak hour factor in year i; and,
f_{i-1} = Peak hour factor in previous year.

Thus, the number of passengers per gate can be calculated as:

$$P_{G_{1985}} = 187{,}500 \times \frac{95}{80} \times \frac{2{,}500}{2{,}400} = 232{,}000\, pax/gate$$

$$P_{G_{1990}} = 232{,}000 \times \frac{102}{95} \times \frac{2{,}600}{2{,}500} = 260{,}000\, pax/gate$$

$$P_{G_{1995}} = 260{,}000 \times \frac{110}{102} \times \frac{2{,}700}{2{,}600} = 290{,}000\, pax/gate$$

$$P_{G_{2000}} = 290{,}000 \times \frac{120}{110} \times \frac{2{,}800}{2{,}700} = 328{,}000\, pax/gate$$

Thus, the number of gates required would be:

Year		Gates
1985	4,570,000/232,000	20
1990	5,940,000/260,000	23
1995	7,560,000/290,000	27
2000	9,900,000/328,000	31

These gates were further divided into active gates and remote gates in a proportion of 4 to 1, i.e., 80% of the passengers were assumed to be served by loading bridges. That brings another important consideration in aircraft categorisation with respect to type of stands. The following division was made:

	1979 (%)	1985 (%)	1990 (%)	1995 (%)	2000 (%)
Class I (B747)	1	2	3	4	5
Class II (DC10)	23	25	31	38	42
Class III (B727)	76	73	66	58	53

The final gate requirements are given below:

Year	Total Gates	Gates Class I and II (9,000 m^2 each)	Gates Class III (4,700 m^2 each)
1985	20	9	11
1990	23	12	11
1995	27	17	10
2000	31	22	9

The FAA (1988a) uses the concept of EQA (see Chapter 5) -- Equivalent Aircraft technique to provide a common denominator for number of gates and aircraft seats. Three EQA factors are discussed:

a) Base Year Total Gate EQA;

b) Future Total Gate EQA; and,

c) EQA Arrivals.

Base Year Total EQA is obtained by multiplying the number in each category of aircraft seating capacity for each 'active' gate position by the appropriate EQA conversion factor.

Future Total Gate EQA is obtained by a similar procedure based on the allocation of gates proportional to the forecasted peak hour ADPM - Average Day / Peak Month Movements for each aircraft type.

EQA Arrivals are used primarily for sizing baggage claim facilities and are based on the assumption that 50 percent of the total gates are used for arriving aircraft in periods of peak 20 minutes.

The problem with these deterministic models is that they are based upon a single measure which attempts to represent a probabilistic distribution, which seems to be the case with the number of gates required. Although some stochastic models that include a probability distribution for the value of the variables incorporated in the model have been developed, there is no guarantee that such models would realistically represent the airport situation in 10 to 15 years. They do not appear to offer a particular advantage over deterministic models which could be as accurate as any other method.

6.8.5 Equivalent Aircraft (EQA) (see Chapter 5)

The EQA methodology is a useful procedure for normalising individual aircraft characteristics requirements to those of a typical equivalent aircraft enabling the planner to estimate the impact of future growth on various terminal components with a common denominator. The EQA methodology is based on aircraft movements as the greatest consumer of airport space and the primary generator of passenger flows. Aircraft size, seating capacities and load factors are differentiated characteristics for the appropriate category.

However, it is important to point out that as the traffic grows the average seats per aircraft movement tends to increase, meaning that the fleet mix tends to incorporate larger aircraft. Examples of this pattern can be observed in Figures 6.10, 6.11 and 6.12 above. Accordingly, looking at Figure 6.17 -- a statistic compilation by the author of about 170 airports --, shows that boarding loading factors also increase during peak periods, as indicated by the relationship between the passenger and aircraft curves. The fluctuation of passengers per ATM that is likely to occur at any airport is also exemplified in Figure 6.17.

In summary the EQA is a method of representing the aircraft quantity and seating capacities estimated in the forecast as a single number, e. g., if a typical narrow-body aircraft with 100 seats (B737) is used as the reference aircraft with an EQA of 1.0, a B747 with 400 seating capacity will have a EQA equal 4.0.

6.8.6 Apron

Apron is the space required for aircraft parking areas and aircraft circulation and taxiing to connect those areas with taxiways. The apron is the connection between the aircraft and the terminal, and also between aircraft and the airfield.

The size and dimensions of the apron depend on three main factors:

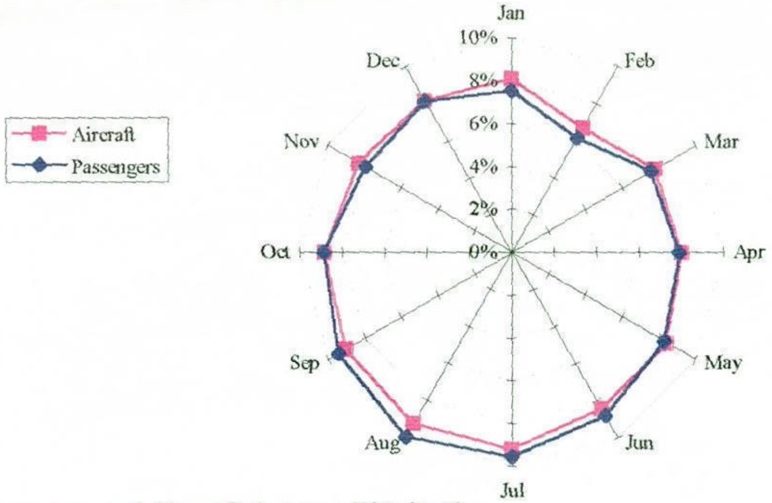
a) the mix and volume of aircraft expected to use the apron, i.e. the number of gates required;

b) parking criteria -- i.e., the method used by aircraft to enter and leave an aircraft stand;

c) the basic layout of the terminal apron, including aircraft ground activity, service roads and access to taxiways.

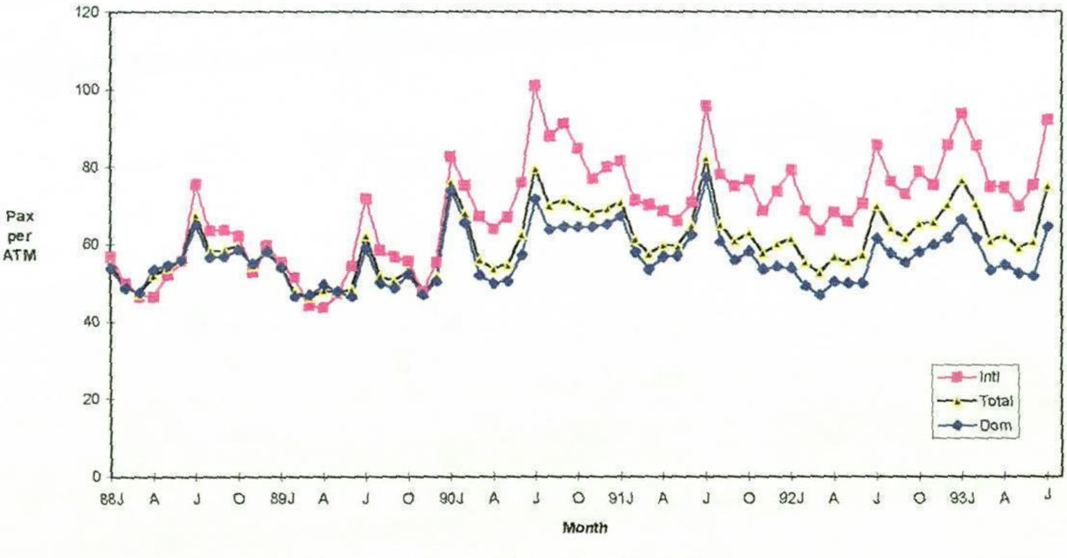
The first factor has already been discussed, involving load factor, turnaround times, aircraft categorisation and number of gates. There are several methods used by aircraft to enter and leave an aircraft stand which can be summarised in two groups as either self-manoeuvring or tractor-assisted. The most common procedure is the tractor assisted taxi-in, push-out method -- called nose-in parking, where the aircraft generally enters the stand area nose forward under its own power and stops in a nose-to-terminal position. The push-out operation requires the use of a tractor and tow bar and is carried out without the engines started. This procedure allows a much closer spacing of aircraft stands, reducing apron space. The third factor is intrinsically related to the conception of terminal shapes. It is more likely that the aircraft rather than the terminal itself is the principal generator of the Terminal Concept. The arrangement of aircraft will delineate the concept of terminal as it is being drawn. This reiterates the definition of terminal concept in Chapter 4. Furthermore, it relates to the spatial configuration of the whole airport, integrating the terminal, taxiways and runways.

In terms of individual aircraft and based on manufacturers turnaround times and actual average turnaround times, Figure 6.18 and 6.19 show apron space requirements and aircraft productivity by aircraft type. The theoretical productivity refers to the aircraft turnaround times specified by the manufactures in their Airport Planning Manuals, while the actual productivity is based on the actual aircraft turnaround times from Tables 6.13 and 6.14. It can be seen that as aircraft sizes increase the apron area required increases proportionally due mainly to increase in wing span, but productivity also increases, i.e., the number of passenger per hour increases. Theoretically the area of apron required per passenger also decreases (see Fig 6.19). When time productivity is taken into account the apron area is almost levelled off (excluded B707). In both sense the efficiency of the apron is improved by increasing aircraft capacity. It is also implied that reducing wingspan would obviously reduce the apron area and terminal frontage, consequently improving the apron-terminal spatial relationship. Figure 6.19 shows that the number of passengers per unit terminal frontage increases with increasing aircraft size.



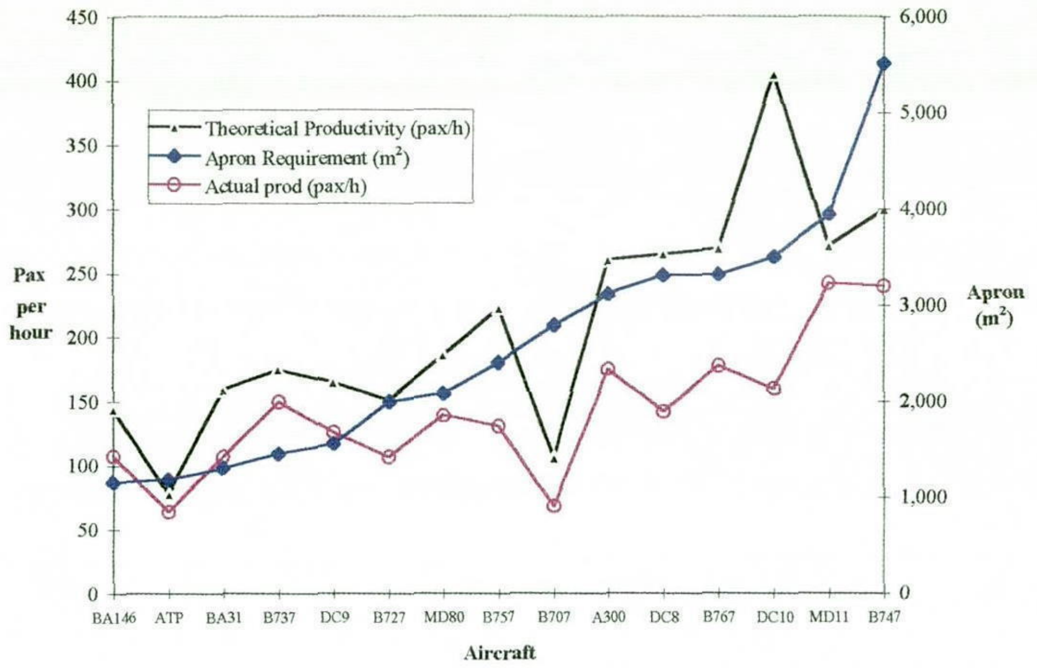
Passenger and Aircraft Average Distribution

% of Total - ICAO Statistics - 1991
(from 170 airports around the world)



Sao Paulo Airport – Pax per ATM From Jan 88 to Jul 93

FIGURE 6.17: Relationship between passenger and aircraft.



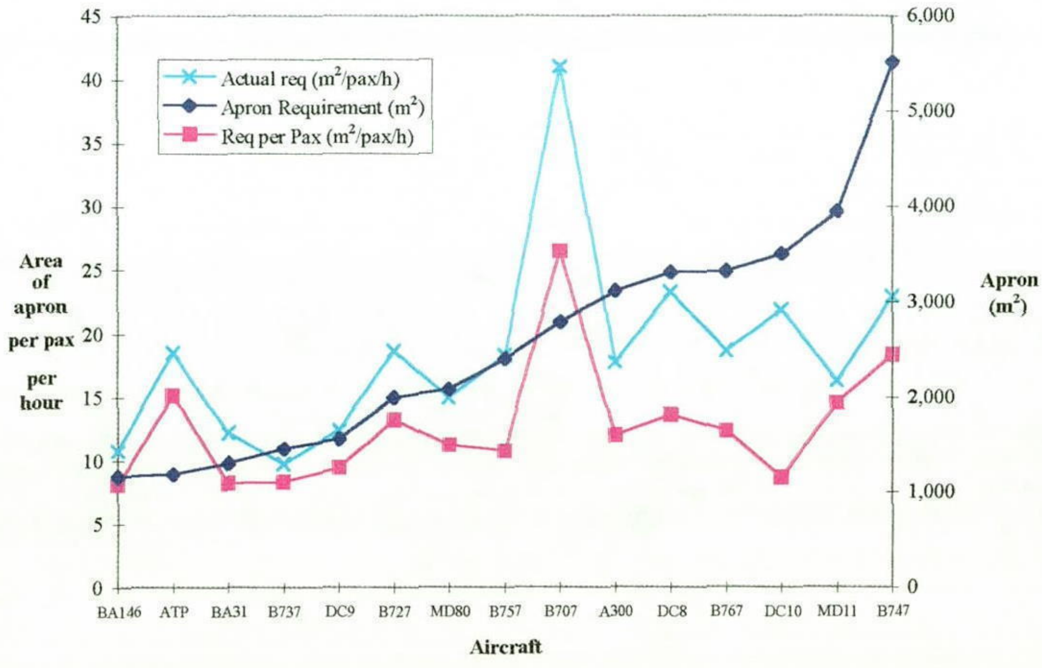
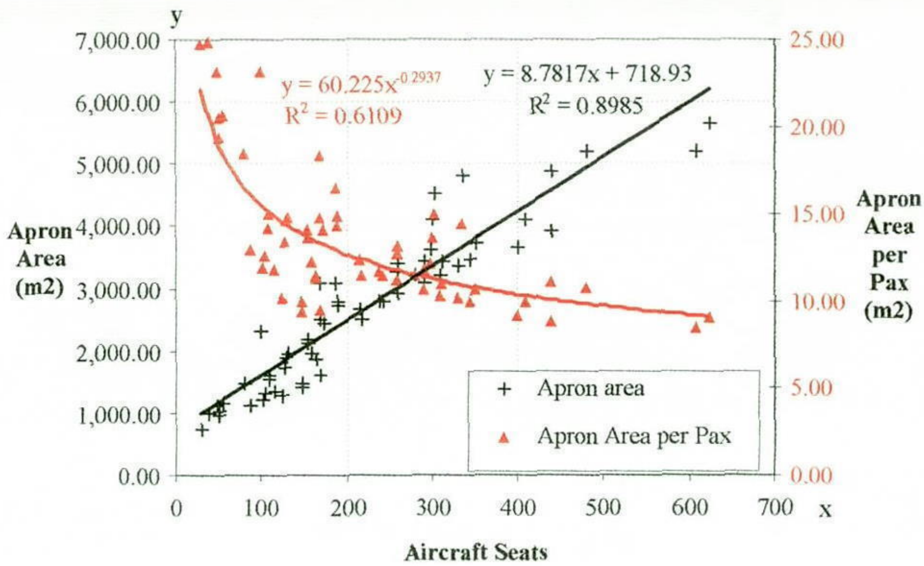


FIGURE 6.18: Aircraft productivity in relation to passenger and apron area.
(Data based on manufactures turnaround times and actual turnaround times from Table 6.13 and 6.14 – Apron area includes 7.5 m clearance between aircraft)



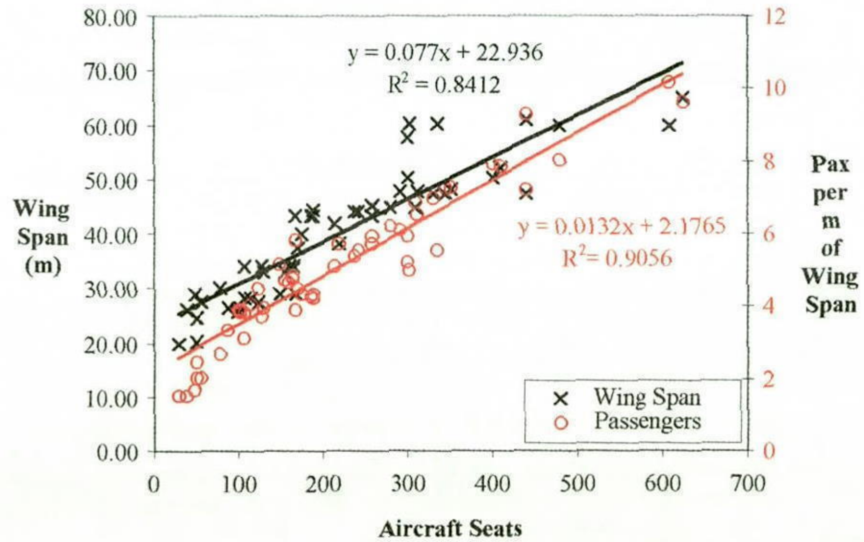


FIGURE 6.19: Aircraft characteristics in terms of apron geometry requirements

(Aircraft with maximum seating capacity - Source Manufacturers)

(Apron area with 7.5 m of clearance between aircraft)

(Load Factor = 100%)

6.9 Further considerations

There are several points which might influence some of the discussed factors (see also Chapter 2) that are crucial for the solution of the problems facing the designer of an airport terminal:

- Finding suitable methods for designing the airport system. The proper meshing of terminal scale and the scale imposed by the aircraft (mainly the future aircraft) presents with a great challenge to designers.

- A very real effort should be made to discover a coherent measure of Level of Service for the airport users, so the spaces which they utilise may become not only compatible with their needs but also may reinforce the positive elements of their social culture; and the cost of providing it does not turn out to be a wasteful measure.

- Flexibility. Solving the problems of man's need for space is complicated by the increasing incidence of economic changes in our society and fluctuations on foreseen traffic volumes. This can prove extraordinarily serious to the airport and flexibility may be the key to unfold the unexpected.

- Expandability. Not all facilities are necessarily designed for expansion nor are all constructed to remain fixed. There are many parts of an airport -- sometimes only a few facilities -- which have to be changed to cope with traffic fluctuations that were not accounted for. Phasing the construction and/or allowing for expansion can be fundamental when designing for 10 or 15 years hence.

- It has to be learned from past experiences that planning must be co-ordinated and courageously applied. It must be emphasised, however, that using the experience of past plans as a model is a matter of policy, not practice, for those plans can not, in any case, be copied to present and future designs. No plan is perfect, yet planning is necessary; and the key to success may rest on avoiding the mistakes of the past.

- To emphasise that an airport terminal is essentially a summation of space, inasmuch as the sense of space is a synthesis of many sensory impacts: visual, auditory, kinaesthetic, olfactory, and thermal. Hall (1969) stressed that "virtually everything that man is and does is associated with the experience of space". The establishment of Level of Service as a unique measure to satisfy the customer needs requires more than saying that comfort are achieved when one can realise that those relationships are function of a particular facet of activity under examination at a given moment.

- Time. The passenger experience of time is unavoidable. The time perceived by a passenger contrasting with the actual time that he/she spent in a terminal building may have strong implications in his/her perception of the level of service offered. Nearly all variables are associated with time. Therefore, to know and being able to control the involvement of time may improve the future design.

- New technology. New technology may create new factors and impose changes in the design procedures.

6.10 Summary

Terminal Concept is fundamentally a question of geometrical form definition, which depends upon factors directly related to the terminal-aircraft apron geometry, which is itself strongly associated to *passenger distribution.*

The main consideration is to try to isolate the variables that will most directly influence the Terminal Concept evaluation. They are the variables that, when modified, directly induce a change on the terminal geometry or vice-versa.. This chapter has discussed these main variables: *shape* and *size & dimensions*, *walking distances* and *circulation spaces*, *centralisation* and *decentralisation*, *number of levels*, and *aircraft-apron.*

There are so many factors involved in the concept evaluation process that it is difficult to choose the principal ones. It is even more difficult to understand the causal effects between them. However, the order may not always be important, since they are certainly interrelated. Nevertheless, The concept process begins with centralisation. Decentralisation is also an important factor, particularly with regard to the division of traffic and airline splits as this also affects check-in and security arrangements.

The next question may be related to number of levels. This is closely related to whether telescopic airbridges will be provided. This has not always a straightforward technical answer left to the designer. It is likely to be a compulsory element for airports with higher levels of traffic (see Fig. 4.8).

Shape and dimension (length and breadth) then becomes imperative. This has in itself a straight relation with walking distances, circulation spaces and aircraft-apron spatial arrangement. In other words, if the space requirements are calculated based upon traffic volumes giving a "X" area of necessity, different aircraft-apron arrangements will produce different shapes and dimensions. The results of such distinct conceptions may have two hypothesis:

1) that each arrangement can be, if possible, conceived with the same total area "X", therefore the distinction between them will <u>mostly</u> remain on the difference in walking distances, or

2) although the area "X" is common to all shapes at the beginning, when formulating different shapes the final area will certainly be different and the distinction between them will probably be characterised by difference in circulation spaces and walking distances.

A common denominator for the above can be interrelated with the way *passengers are distributed* within the terminal and on the apron (terminal/aircraft arrangement).

7. CHAPTER VII Framework for Evaluation

7.1 Introduction

The purpose of this chapter is to discuss search procedures which will be used in the development of a framework for the evaluation of terminal concepts. These procedures will lead to the evaluation procedure, and serve as an instrument to understand the development of Terminal Concept as defined in Chapter 4. The evaluation process should be designed to provide a structure that permits comparison between the different alternative concepts, necessarily incorporating the most important variables. The objective is to try to find a process or a framework that can interrelate the important variables, described in Chapter 6, to provide meaningful information about the outcome of the alternatives, their consequences and, most importantly to allow comparison between them.

An airport terminal is a system that enables the movement of passengers from one type of transport to another. Also, it is known that the walk distance or the distance that each passenger travels over to accomplish this connection is one of the most important factors. Time, geometry, shape and form are implicit variables and properties intrinsically related to this movement. As discussed in Chapter Six such variables have to be considered when evaluating Terminal Concepts. The establishment of a relationship that includes all the elements such as *geometry and distance (circulation spaces), configuration (centralised/decentralised, number of levels) and aircraft (apron configuration)* and *passengers' distribution* seems to be the appropriate combination for the evaluation of different Concepts.

Having decided provisionally on the variables to test, the next step is to devise a means of measurement. The major emphasis is placed on how passengers are distributed within the terminal system, since this implies correlation with the other elements. However, how can passenger distributions be measured? This section addresses the mathematical structure that will allow to determine the magnitude and pertinence of this distribution to compare different terminal forms. The implication of geometry and geometrical elements such as centre of gravity and centroid are explained in this mechanism as integrated parts of the mathematical procedure.

The distribution's measure proposed in this Chapter is analogous to the theory of moment of inertia [*Timoshenko, 1968; Ginsberg, 1977; Leithold, 1986; Ugural, 1991; Gere, 1992; Beer,* 1992] in mechanics and strength of materials. The "*potential moment of transport*" or simply *moment of transport* is defined as: The moment of transport of an element of a terminal about an axis is 'pd^2', where 'p' is the potential passengers (capacity), and 'd' (meters) is the perpendicular distance from the element to the axis. The passenger distribution can be measured with relation to aircraft, departure lounge, baggage claim, check-in, or any other facility. The moment of transport is referred as potential because it represents the ultimate capacity of the system in study and also because it is a static measure based on geometric relationship. It is a purely geometric relationship.

The procedures use the concept of the Moment of Transport to collapse the many design factors to a manageable representative factor.

7.2 Moment of Transport

Associated to the moment of inertia are physical properties such as centroid, centre of gravity and radius of transport, which may also be defined analogously. It is important to note that these properties change not only due to different terminal shapes but with the distribution of passengers when operational procedures are altered, including modifications in load factors, increase or decrease in transfer passengers, and distinct aircraft gate assignment.

7.2.1 Centroid, Centre of Gravity, First Moment of Transport

In a plane area, the centre of gravity is a physical property of a terminal. If the passengers' distribution is uniform throughout the terminal, this property exactly coincides with the associated geometric properties of the terminal plane, which is called centroid.

The equations for the centre of gravity of a terminal with respect to an orthogonal pair of axes are:

$$\bar{x} = \frac{1}{P}\int \lambda x dp \qquad \bar{y} = \frac{1}{P}\int \lambda y dp$$

where $P = \int \lambda dp$ is the capacity in terms of number of passengers composed of volumes of passengers from individual aircraft 'dp', where λ is the density or load factor. These equations can similarly be applied equally for the analysis of groups of passengers at check-ins, departure lounges and other elements of the terminal; one need only take care to select an appropriate volume element. As the component volume and the centre of gravity of each individual element (aircraft) are already known, the integrals may be replaced by finite sums. The load factor 'λ' will cancel in the equations above when it is constant throughout the terminal, and then the equations for the centre of gravity are equal to

$$\overline{x} = \frac{1}{P}\sum_{i=1}^{n} x_i dp_i \qquad \overline{y} = \frac{1}{P}\sum_{i=1}^{n} y_i dp_i$$

where now $P = \sum_{i=1}^{n} dp_i$

The centroid C, see Fig. 7.1, therefore, represents a point in the plane about which the passengers (capacity) are equally distributed. The elements $\sum_{i=1}^{n} x_i dp_i$ and $\sum_{i=1}^{n} y_i dp_i$ are called here *First Moment of Transport*, about the x and y axes.

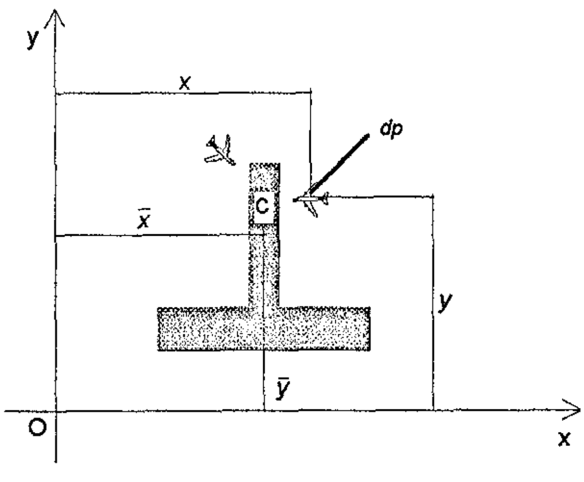


FIGURE 7.1: Terminal Area, Centroid

If the terminal, arranged with aircraft, possesses an axis of symmetry (or is symmetric about a point), the centroid must be located on the axis (or about that point) since the first moment of transport about an axis of symmetry (or a point of symmetry) equals zero.

7.2.2 Second Moment of Transport

A *moment of transport* conveys information regarding the distribution of the passengers of a terminal configuration about an axis. Clearly, if two terminals have the same potential number of passengers (capacity), then different configurations (shapes) will determine different moments of transport. The moments of transport of a terminal (see Fig. 7.1) with respect to the x or y axes, respectively, are defined by the summations:

$$T_x = \sum_{i=1}^{n} y_i^2 dp_i \qquad T_y = \sum_{i=1}^{n} x_i^2 dp_i$$

where x_i and y_i are the co-ordinates of the element dp_i. Because dp_i is multiplied by the square of the distance, the moment of transport is called *second moment of transport*. T_x and T_x are always positive quantities as the co-ordinates x_i and y_i are squared.

7.2.3 Radius of Transport

The *radius of transport* about an axis x or y is the distance from x or y at which all the passengers of the elements considered would have to be concentrated to effect the same moment of transport. It is defined as the square root of the moment of transport divided by the total passengers, thus

$$r_x = \sqrt{\frac{T_x}{P}} \qquad r_y = \sqrt{\frac{T_y}{P}}$$

where r_x and r_y denote the radii of transport with respect to the x and y axes, respectively.

7.2.4 Polar Moment of Transport

The *polar moment of transport* of a terminal with respect to point O, Fig. 7.2, can be defined as the summation:

$$T_o = \sum_{i=1}^{n} \alpha_i dp_i$$

Where α is the Euclidean distance between the point O and the element dp_i and it is given by:

$$\alpha^2 = x_i^2 + y_i^2$$

The polar moment of transport can be rewritten as,

$$T_o = \sum_{i=1}^{n} \alpha_i dp_i = \sum_{i=1}^{n} \left(x_i^2 + y_i^2\right) dp_i = \sum_{i=1}^{n} x_i^2 dp_i + \sum_{i=1}^{n} y_i^2 dp_i$$

or

$$T_o = T_x + T_y$$

The Euclidean Distance as an important measure for the Moment of Transport is discussed latter in this Chapter.

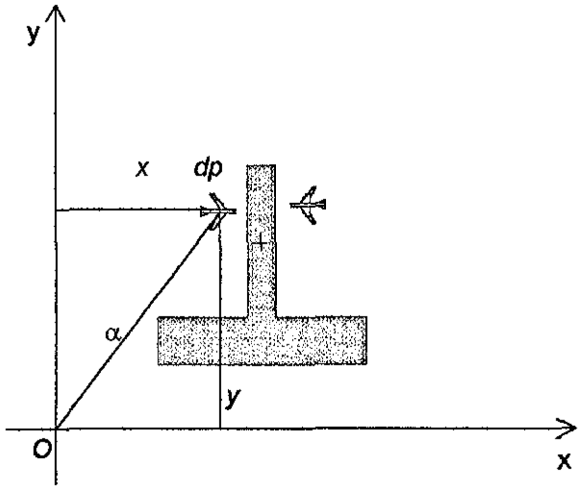


FIGURE 7.2: Polar Moment of Transport

That is, the *polar moment of transport* with respect to any point O is equal to the sum of the moments of transport with respect to two perpendicular axes x and y through the same point.

7.2.5 Parallel-Axis Theorem for Moment of Transport

The parallel-axis theorem relates the moment of transport with respect to an arbitrary x or y axis to the *moment of transport* around a parallel axis through the centroid, Fig. 7.3.

From the definition of moment of transport, the following equation for the moment of transport $T_{x'}$ with respect to x axis is obtained:

$$T_{x'} = \sum_{i=1}^{n}\left(y_i + d_{yi}\right)^2 dp_i = \sum_{i=1}^{n} y_i^2 dp_i + 2d_y \sum_{i=1}^{n} y_i dp_i + d_y^2 \sum_{i=1}^{n} dp_i$$

The first sum on the right side is equal to T_x, the third sum is equal to $d_y^2 P$, and the second sum vanishes because the x_c- *axis* passes through the centroid, hence, this equation reduces to

$$T_{x'} = T_x + Pd_y^2$$

where P is the total passengers and d_y is the distance between the axes.

In a similar way the *polar moment of transport* with respect to an arbitrary point p and the polar moment of transport of the same element with respect to its centroid c, can be determined by,

$$T_p = T_c + Pd^2$$

where T_p is the polar moment of transport with respect to point p, T_c is the polar moment of transport with respect to its centroid C, and d is the distance between p and C.

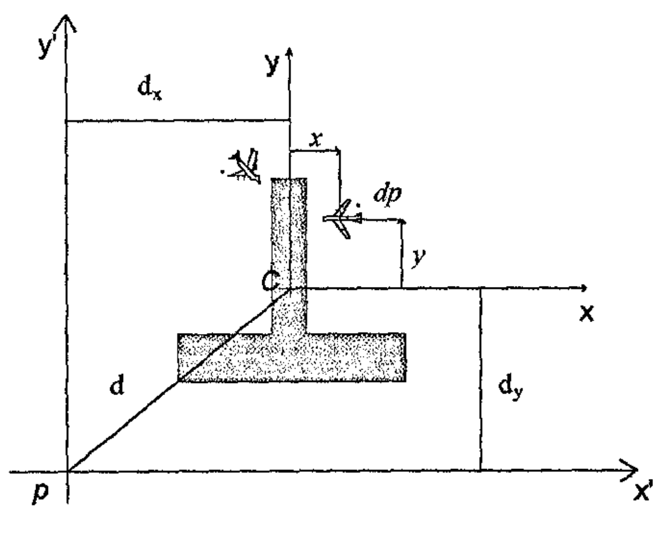


FIGURE 7.3: Parallel-axis Theorem

The consequence of the parallel-axis theorem is that $T_{x}, < T_{x'}$ *and* $T_{y}, < T_{y'}$ for all lines x' or y' parallel to x or y. To minimise the moment of transport one must simply pass the axis through the centroid of the terminal.

7.2.6 Product of Transport

The summation $T_{xy} = \sum_{i=1}^{n} x_i y_i dp_i$ in which each group of passengers dp is multiplied by the product of its co-ordinates is called *product of transport*. If the configuration has one axis of symmetry, the product of transport is equal to zero, Fig. 7.4.

Similarly, the parallel-axis theorem for product of transport is given by the equation:

$$T_{x'y'} = T_{xy} + Pd_x d_y$$

where d_x and d_y are shown in Figure 7.3.

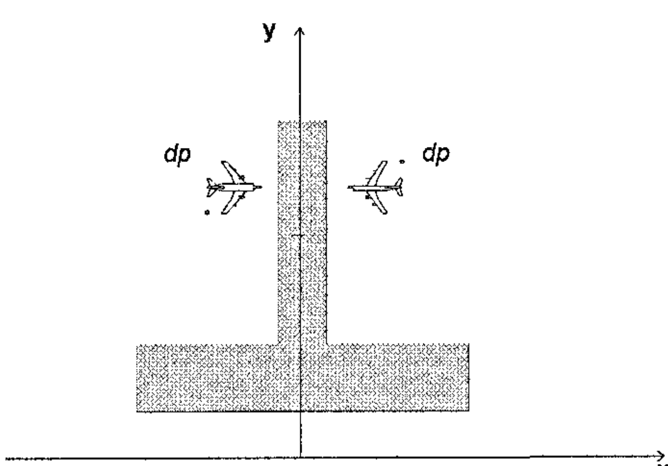


FIGURE 7.4: Product of Transport

7.2.7 Rotation of Axes and Principal Axes

As the moments of transport are dependent upon the location of the origin and the orientation of the reference axes, they vary as the axes rotate about the origin. The way in which they vary and their magnitude can be determined as following:

Consider the terminal shown in Fig. 7.5. The new co-ordinates x', y' of element dp can be expressed by projecting x and y upon the rotated axes

$$x' = x\cos\theta + y\sin\theta \quad \text{and} \quad y' = y\cos\theta - x\sin\theta$$

Assuming that the moment of transport and the product of transport are known with respect to the axes x and y, then the moment of transport with respect to x' axis is

$$
\begin{aligned}
T_{x'} &= \sum_{i=1}^{n} y_i{}'\,dp_i \\
&= \sum_{i=1}^{n} (y\cos\theta - x\sin\theta)^2\,dp_i \\
&= \cos^2\theta \sum_{i=1}^{n} y_i{}^2 dp_i + \sin^2\theta \sum_{i=1}^{n} x_i{}^2 dp_i - 2\sin\theta\cos\theta \sum_{i-1}^{n} x_i y_i dp_i
\end{aligned}
$$

which simplified by the double-angle trigonometric relations and using the equations for moments and product of transport gives

$$T_{x'} = \frac{T_x + T_y}{2} + \frac{T_x - T_y}{2}\cos 2\theta - T_{xy}\sin 2\theta$$

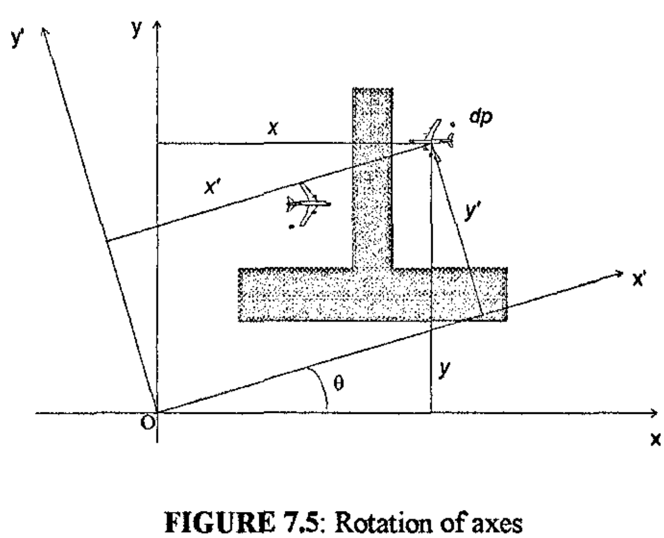


FIGURE 7.5: Rotation of axes

In a similar manner, we can obtain $T_{y'}$ by replacing θ by $\theta + 90°$ in the above equation; the result is

$$T_{y'} = \frac{T_x + T_y}{2} - \frac{T_x - T_y}{2}\cos 2\theta + T_{xy}\sin 2\theta$$

The new product of transport can also be obtained,

$$T_{x'y'} = \frac{T_x - T_y}{2}\sin\theta + T_{xy}\cos 2\theta$$

To find the values of the angle θ that make the moment of transport $T_{x'}$ a maximum or a minimum, the above equation is solved for θ, and gives

$$\tan 2\theta_p = -\frac{2T_{xy}}{T_x - T_y}$$

in which θ_p denotes the angle defining a principal axis. One conclusion examining the variation in the product of transport as θ varies is that the product of transport is zero for the principal axes.

The principal moments of transport can also be determined, assuming again that T_x, T_y and T_{xy} are known, then the larger moment T_1 is obtained by

$$T_1 = \frac{T_x + T_y}{2} + \sqrt{\left(\frac{T_x - T_y}{2}\right)^2 + T_{xy}^2}$$ and the smaller by $$T_2 = \frac{T_x + T_y}{2} - \sqrt{\left(\frac{T_x - T_y}{2}\right)^2 + T_{xy}^2}$$

It is important to observe that, taking the sum of $T_{x'}$ and $T_{y'}$,

$$T_{x'} + T_{y'} = T_x + T_y$$

This sum is the *polar moment of transport* of the terminal with respect to the origin and shows that the value remains constant as the axes are rotated about the origin.

7.3 Euclidean distance

A set of facilities or group of passengers ('elemental area') are represented in a two dimensional configuration with known Cartesian co-ordinates. Each facility (or aircraft in this case) may be replaced by integers{1, 2, 3}. Their locations can be algebraically located as ordered pairs $\{(x_{11}, x_{12}), (x_{21}, x_{22}), (x_{31}, x_{32})\}$, where the first subscript refers to the facility and the second refers to the co-ordinate. Then, the straight line between any pair of facilities (aircraft) is defined as Euclidean Distance $d_{(i,j)}$ given by:

$$d_{(i,j)} = \left[\left(x_{i1} - x_{j1} \right)^2 + \left(x_{i2} - x_{j2} \right)^2 \right]^{1/2} \quad \text{or}$$

shortly as

$$d_{(i,j)} = \left[\sum_{k=1}^{2} \left(x_{ik} - x_{jk} \right)^2 \right]^{1/2}$$

The Euclidean distance has some properties that may be outlined as [Gatrell, 1983]:

⇒ To each ordered pair (i,j) it must attach a non-negative real number which is the distance between i and j, $\Rightarrow d(i, j) \geq 0 \ \forall \ i, j$.

⇒ If $d(i, j) = 0$, then $i = j$ and indicates that the distance from any location to itself is zero.

⇒ Euclidean distance is the length of the shortest possible line joining the location of a pair of objects. There is only one such distance for any pair.

⇒ The distance measure has the property of symmetry: $d(i, j) = d(j, i)$.

⇒ The distance measure obeys the triangle inequality: $d(i, j) \leq d(i, k) + d(j, k)$

These properties are equivalent to those that a mathematician requires of a 'metric'. A set of points and a set of distances (a metric, by definition) that relates those points define a metric space. [Copson, 1988].

If the objects being characterised have more than two dimensions, which it is not the case, the Euclidean distance can be generalised for multidimensional spaces -- m dimensions, given by:

$$d_{(i,j)} = \left[\sum_{k=1}^{m} \left(x_{ik} - x_{jk} \right)^2 \right]^{1/2}$$

It is important to note that the Euclidean metric is not the only one available. Suppose that the exponents of the equation above are replaced by general exponents n and $1/n$ and, to ensure that the distance remains non-negative the difference between co-ordinates becomes absolute value, thus:

$$d_{n(i,j)} = \left[\sum_{k=1}^{n} \left| x_{ik} - x_{jk} \right|^{n} \right]^{1/n}$$

This expression defines the Minkowski n-metrics which is a family of metrics. The special case in which $n = 2$ is the Euclidean distance. For $n < 1$ the triangle inequality is violated and the relation is no longer a metric. The geometric interpretation of this function can be seen elsewhere [Gatrell, 1983]. The emphasis is that the Euclidean distance is the only Minkowski metric for which $d_{(i,j)}$ is unaltered by rotation of the axes. None of the other processes possess the property of rotational invariance.

A list of some other distance measures is given by the following equations [Everitt, 1980]:

City Block: $d_{i\,j} = \sum_{k=1}^{n} \left| x_{ik} - x_{jk} \right|$

Sup Norm: $d_{i\,j}^{(\infty)} = \sup_{k=1\ldots m} \left\{ \left| x_{ik} - x_{jk} \right| \right\}$

Minkowski: $d_{i\,j} = \left[\sum_{k=1}^{m} \left| x_{ik} - x_{jk} \right|^{n} \right]^{1/n}$

Mahalanobis: $d_{i\,j} = \left(x_i - x_j \right)' W^{-1} \left(x_i - x_j \right)$

where W is the variance - covariance matrix and x'_i and x'_j are the (1xn) vectors of scores for individuals i and j.

Apart from physical or geometrical distances, there are other characteristics or concepts of distance that are conceptual to discern and have few if any metric properties. At least four concepts of distances can be identified, see [Gatrell, 1983]:

- Time distance
- $ Economic distance
- Cognitive distance
- Social distance

To some extent time distance may not be separated from geometrical distance, but with the event of more sophisticated mechanical systems -- people movers -- being introduced in airports in recent years minimising the effect of walking distance, the time the passenger takes to move from one location to any other may be more significant to the process of evaluating the arrangements of spaces than the physical distance between them.

The economic distance may refer to the monetary cost incurred in providing the physical/mechanical means to overcome the distance and the proper extension of that of time distance, recognising the old adage that 'time is money'.

The implicit or explicit judgements about the separation of objects and how different passengers would experience moving from one location to another may be influenced by their distance cognition which may involve from the passengers' emotional involvement to the level of service offered.

The provision of space mainly related to level of service requires a discussion of social distance in terms of interaction and attribute concept of proximity, where the spacing adopted varies with the nature of the interaction -- intimate, personal, social or public -- and other mediating factors such as personality of the individual being approached and physical settings.

It is interesting that these concepts of distance have been gradually and formally incorporated in the process of terminal design with a methodological emphasis on level of service and also through simulation techniques. When translated into the empirical domain however, they were probably intuitively accounted for in the architects mind but not explicitly stated in the process of design.

Although conceptual in their definitions, they are in one way or another explanatory variables in their functional relationship with physical distance, where the tendency is to rely simply on measurements of Euclidean distance.

7.4 Application of Moment of Transport

The premise of Moment of Transport as defined in the foregoing paragraphs is an attempt to correlate the potential passenger distribution of a facility or groups of facilities and the geometry or shape given to the same facilities. The distribution can be equated along an arbitrary axis or in relation to a point. It is determined by calculating the moment that each element is producing in that axis or around the specified point in a certain terminal shape and comparing it with the results of another terminal having the same characteristics. The measurement of the distribution can be obtained through the moment (T_i) itself or through the radius (r_i) that is the distance from the axis at which the total passengers could be concentrated and still have the same moment of transport. When related to an axis the effect is only partial comprising the resultant of the elements that have a perpendicular distance to that axis. The moments are in fact defined with respect to axes lying in the plane surface where the elements are arranged. When related to a point, the moment of transport is defined with respect to an axis perpendicular to the plane of the arrangement at that point. It is important to note that the moment in relation to a point is equal to the sum of the moments of transport with respect to any two perpendicular axes x and y passing through that same point and lying in the plane surface, see Figure 7.6.

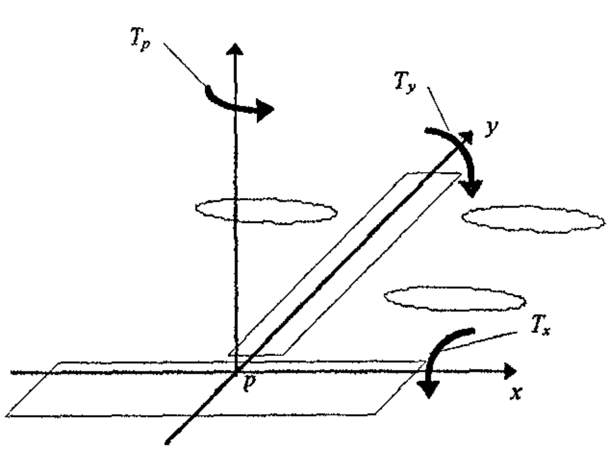


FIGURE 7.6: Moments of Transport: T_x, T_y with respect to axes x and y, and $T_p = T_x + T_y$ with respect to point p.

The dimensional unit of the moment is square metre times passengers (m^2 *pax*) and the dimensional unit of the correspondent radius is metre (m). The use of the latter for the analysis of terminal shape and passenger distribution seems to be an easier unit to comprehend than the dimensional unit of the former.

The passenger flow path within a terminal may reflect simply the underlying geometry rather than the direct route between two points. The routes are usually established with a marked grid-like street network characterised by numerous turns, and since the terminal is usually a rectangular shape the movement is likely to occur in a grid form. In general, the use of a Cartesian Axes will comprises the moments generated by the passengers distribution. Therefore the measure of the radius of transport with respect to a point in the plane surface of the terminal in study will determine the overall effect of the passenger distribution with respect to that point. Such a measure will be frequently used in the evaluation.

As the movement of passengers within the terminal is a dynamic process the problem remains of how to select the elements to establish the distributions. It is quite logical to suggest that the processing facilities are the main elements where the points for calculating the moments have to be placed. The single element -- the passenger --that is generating the moments is associated with the holding areas of the terminal. Also, the axes may be coincident with the main circulation spaces, yet the best option would be to place at least one of the axis in a segment that divides the terminal into two symmetric sections.

To illustrate how the moments are obtained, let the terminal shown in Figure 7.7 be considered. More specifically, observe that the distribution of passengers from the groups of check-ins (points p1, p2, p3 and p4) to the departure lounges (a, b, c, d, e, f, and g) can be arranged in a variety of ways. For example the check-in groups 1 and 2 can be assigned only for domestic passengers serving the departure lounges a, b, c and d and the group of check-ins 3 and 4 be assigned to international passengers serving the departure lounges e, f and g; or the distribution could be uniform -- all check-ins serving all departure lounges.

There are five steps to determine the moments:

1) Establish the passenger distribution. The distribution is a function of the potential capacity of the system, including load factors, sizes and shapes, within the capacity unit interval. In the example above the distribution is associated to the maximum capacity of the departure lounges.
2) Define the position of the axes x and y.

3) Determine the C.G. of the distribution or distributions considered using the first moment of transport

4) Determine the moments T_x and T_y with respect to the axes x and y that pass through the C.G..

5) Using the theorem of translation of axes, calculate the moment or radius of transport with respect to the points in study.

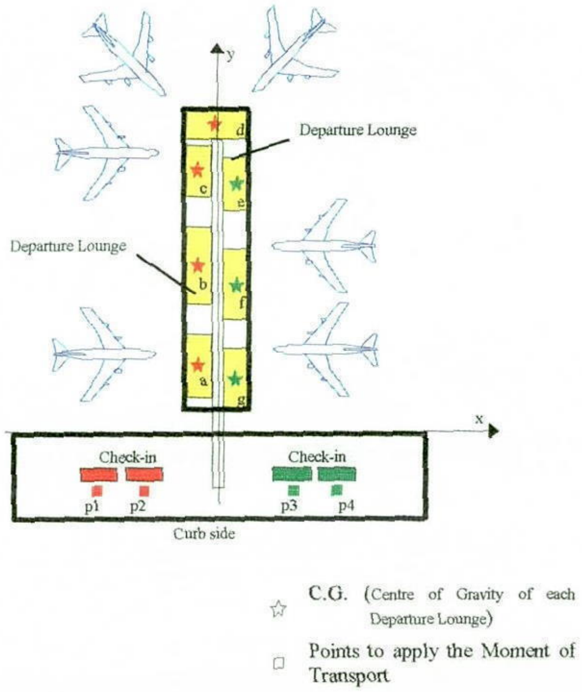


FIGURE 7.7: Moment of Transport relating the configuration of Check-in and Departure Lounge.

Another illustration is shown in Figure 7.8 where the distribution now is associated with the aircraft arrangement on the apron. An equivalent aircraft with average capacity of 140 passengers and dimensions of 40.8 m per 46.8 m, including a minimum clearance between the aircraft using the stand and adjacent building, aircraft on another stand and other objects, is adopted as the typical aircraft and positioned as shown by the dotted lines on the figure (arrangements 1-8).

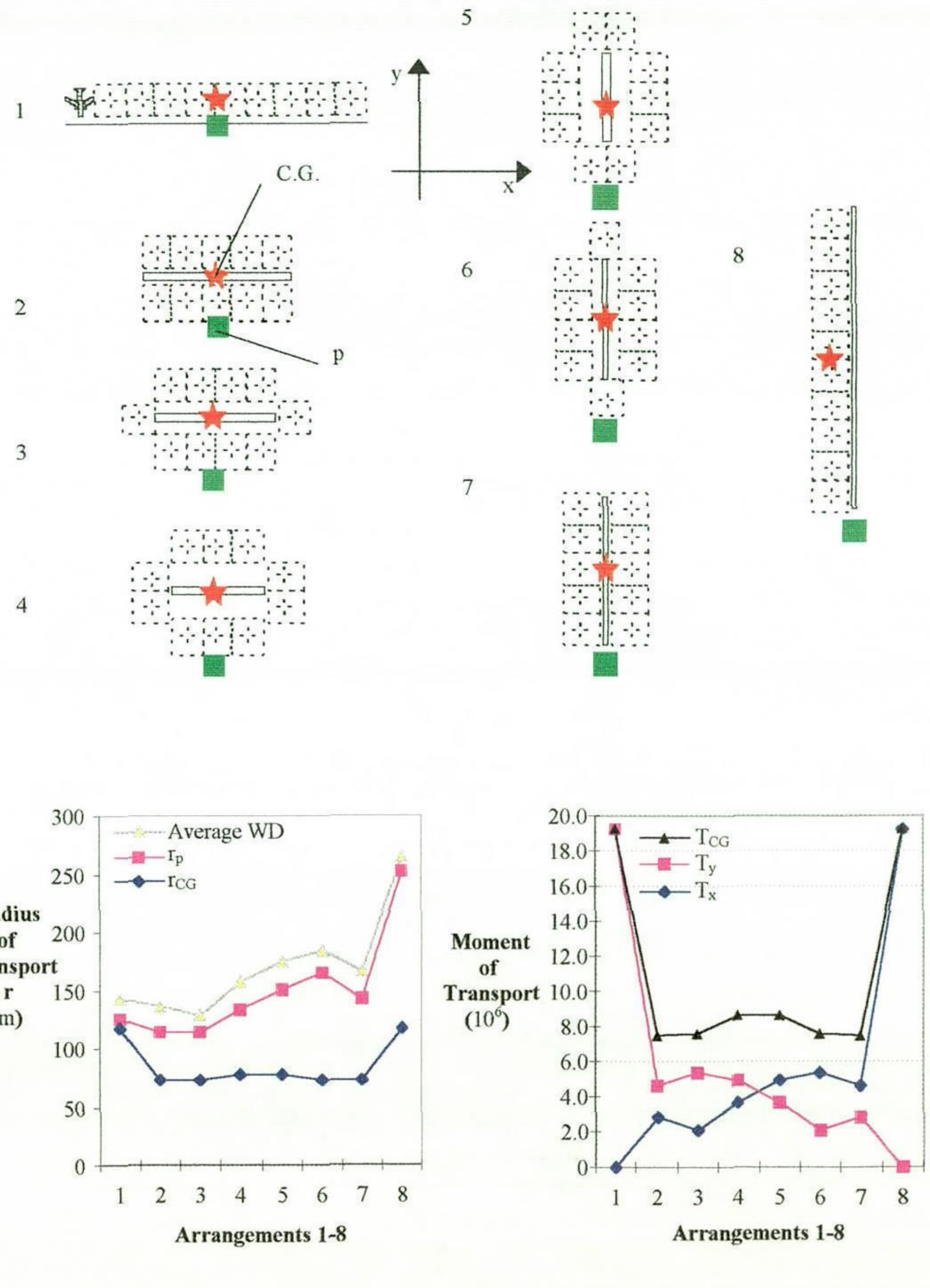


FIGURE 7.8: Example of Calculation of Moment of Transport with respect to the Centre of Gravity and point *p*, showing the correspondent radius of transport and average walking distance for 8 different aircraft arrangements.

The moments of transport with respect to the centre of gravity and with respect to the point p are calculated and the results are shown graphically in Figure 7.8.

The aircraft arrangement or layout starts from a linear configuration (number 1) parallel to the x axis going through a nearly circular shape (number 4), ending again in a linear form (arrangement 8) parallel to the y axis. From the fourth arrangement the figures are also rotated 90 degrees around the centre of gravity. It can be observed that the moment with respect to x axis passing through the centre of gravity of the arrangement varies from 0 in the first arrangement to its maximum value when the arrangement is linear and perpendicular to the axis. A symmetrical result occurs with the moment with respect to the y axis. The rotation of the figures make both moments symmetrical in relation to a particular arrangement in the middle between arrangements 4 and 5. This symmetry also makes the moment with respect to the C.G. symmetric. This moment ($T_{C.G.}$) decreases from its maximum value in the linear arrangement to a minimum in one particular arrangement in the middle point of the curve, (see graphic, right hand side of Fig 7.8). At this point, if the objective was to find the arrangement that would give the minimum moment with respect to the centre of gravity (or centroid), the answer would be an arrangement between 4 and 5.

However, suppose that a processing point "p" is added to the problem. For instance, let a point p be assumed as if all passengers should pass through to have access to the aircraft. Primarily, this point is significant in terms of passenger walking distance. Therefore the moments with respect to this new point are calculated. Although the values of the new moments are easily determined, based on the parallel-axis theorem, the radius of the moment of transport with respect to the point p are shown instead, see left hand side graphic in Fig. 7.8. The radius with respect to the C.G. are also depicted. The shape of the curve of the radius of transport with respect to the point p describes (approximately) a parabola, and the minimum moment falls between arrangements 2 and 3.

It is simple to infer from the configurations, and the result of the moments with respect to a point p that the minimum moment is a function of: 1) the concentration of closeness of the elements (passengers or distribution) around the centre of gravity (centroid); 2) the closeness between the point p and centre of gravity. These are obvious deductions once, by definition, the moment varies linearly with the increase of passengers and with the square of their distance from the point considered.

Another observation in respect to the radius of transport however is that it closely represents the passenger walking distance. The average walking distance for each one of the arrangements with respect to point p are calculated and are also shown in Fig. 7.8, which can be compared with the radius of transport. In fact the average walking distance is an arithmetic mean and the radius of transport is approximately a geometric mean. This is a significant result, considering that the walking distance is a predominant variable in the design of a terminal (see Chapter 6).

At this point one may argue for simply using the average walking distance instead. The mathematical framework for the moment of transport established in this chapter is a positive answer to this suggestion. The translation of average distance cannot be treated in the same way as the radius and moment of transport. Moreover, the moment of transport is clearly related to a particular geometric form, and is associated with a distribution passenger potential. Using walking distances it would be difficult to deal with.

7.5 Moment of Transport, Terminal Shape, and Traffic Volume

The foregoing paragraphs show the variation of the moment of transport in a number of arbitrary arrangements with a fixed volume of traffic, i. e. in the example given only the geometry of the passenger distribution varies, yet the average aircraft size and the total number of aircraft, which represents the traffic volume, remains constant.

To understand how the moment of transport or more specifically the radius of transport works -- which is the measure chosen to evaluate the different terminal concepts; keeping in mind that $r = \left(Moment/Passengers\right)^{1/2}$ --, it is adequate to vary form and traffic volume. Let the basic terminal concepts be investigated, namely:

Linear (L); Pier (P), Satellite (S); Remote Pier (RP) and Cross (C).

This should be explained. As explained in Chapter 4, the conventional basic terminal concepts are linear, pier, satellite and transporter. However, the transporter concept, having some advantages that should not be neglected, is doomed to disappear from the table of the designers. It is therefore excluded from the analysis.

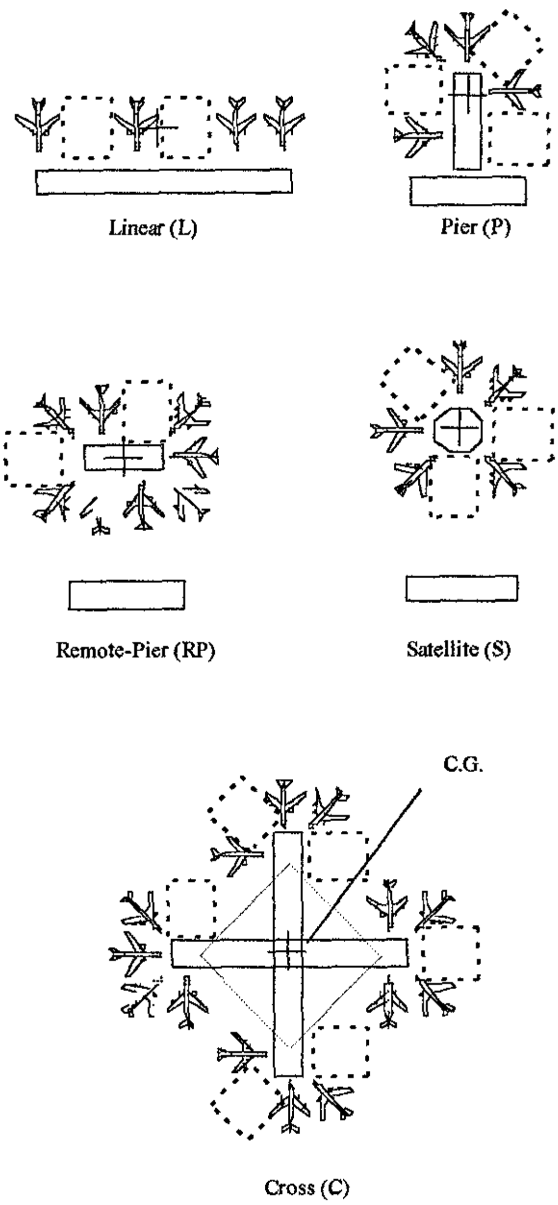


FIGURE 7.9: Moment of Transport applied to the C.G. of basic Terminal Concepts

The remote positions served by buses -- which must not be confused with the transporter concept --, should be incorporated in any design project for the reasons already stated in Chapter 4. It actually means that as a fundamental principle any concept adopted should have remote stands as a buffer. For the analysis of the moments a new form considered as a 'basic concept' is included, namely the Remote Pier. A 'cross configuration' is also included to demonstrate how the moments are influenced by geometric variation. Figure 7.9 shows these 'basic concepts'.

The example is based on the terminal sizing explained in Chapter 5. The equivalent aircraft applicable are indicated in Table 7.1 and used to calculate the moments and radius of transport with respect to the centre of gravity (centroid) of each one of the basic terminal concepts. The moments were determined with the arrangements varying from 1, 2, 3 ... to 50 aircraft of each type at a time and for each concept. A computer program (see Appendix C) was created for this repetitive calculation and the results are summarised in Figure 7.10, from which, a number of pertinent effects in the relationship between moment, traffic volume and form can be drawn.

Table 7.1: Average Aircraft Size and Capacity

Peak Hour Pax	**500**	**1,000**	**2,000**	**3,000**	**4,000**	**5,000**	**6,000**	**7,000**	**8,000**	**9,000**	**10,000**
Average Pax Seat	80	87	103	123	143	160	183	195	222	234	250
Average Width (*)	34.5	35.2	36.7	39.1	41.1	42.9	45.7	47.1	49.9	51.2	53.0
Average Length (*)	36.7	38.1	40.9	44.2	47.1	49.6	52.4	54.1	57.1	58.3	60.4

* includes a minimum clearance between the aircraft using the stand and adjacent building, aircraft on another stand (taxi-lane) and other objects

- The results intentionally show the relationship between the *radius of transport* and the 'potential' total passengers.

- For the sake of clarity not all the results are displayed, only the values correlated to three equivalent aircraft type: Small (S) with 80 passengers; Medium (M) with 160 passengers; and Large (L) with 250 passengers; i.e. the two extremities and the middle value, the other curves that fall between them were omitted.

- Although the arrangements could theoretically vary from 1 to 50 aircraft, examining Fig. 7.9, it is evident, for reason of coherence, that the linear concept is the only one that can practically start with a minimum of one aircraft. The minimum number of aircraft to form a Pier concept should be 5 aircraft; for the Satellite 6 aircraft, for the Pier 8 aircraft; and for the Cross concept 20 aircraft. The number of aircraft to be added in each concept is also different. The Linear is increased by 1 aircraft each turn; the Pier by 2 aircraft; the Satellite by 1; the Remote Pier by 2; and, the Cross by 8 (or 4, maintaining the same point of centre of gravity).

- Therefore, the minimum limits in terms of passengers for Figure 7.10 would be:

Configuration		**Passengers**	
	S	M	L
Linear	80	160	250
Pier	400	800	1,250
Satellite	480	960	1,500
Remote Pier	640	1,280	2,000
Cross	1,600	3,200	5,000

- The average aircraft characteristics are the result of a certain aircraft mix for a specific traffic volume, therefore the generalisation for a greater or smaller volume or number of aircraft is done with the objective of understanding the proposed relationship between passenger, aircraft, terminal shape and moment.

- Although passengers are part of the formulation of moment, it is clear from Fig. 7.10 that as the number of passengers increase the moment of transport increases proportionally. This is shown by the interesting finding that the ratio between the number of passengers and the radius of transport is nearly constant for all the concepts except *for the Cross concept.*

- Inasmuch as the walking distance is the only variable associated with the radius of transport, the greater the ratio *pax/r* value the smaller would be the radius of transport and consequently the shorter the total walking distance.

- It is quite evident from the graph that as the average aircraft size increases the radius of transport decreases, i.e. it is noticeable that larger aircraft serving the airport may imply shorter walking distances for the passengers.

- A greater ratio *pax/r* indicates shorter walking distances. However, the radius refers to the centre of gravity and therefore, may be practically used to evaluate transit and transfer passengers. Dependent upon aircraft mix and traffic volume, some concepts generate shorter total walking distances than others.

- Based on the curvature of the points (decreasing for low volume) in the graph, the Linear and Satellite concepts may function better for low volume of passengers than Pier and Remote Pier concepts (curvature increases).

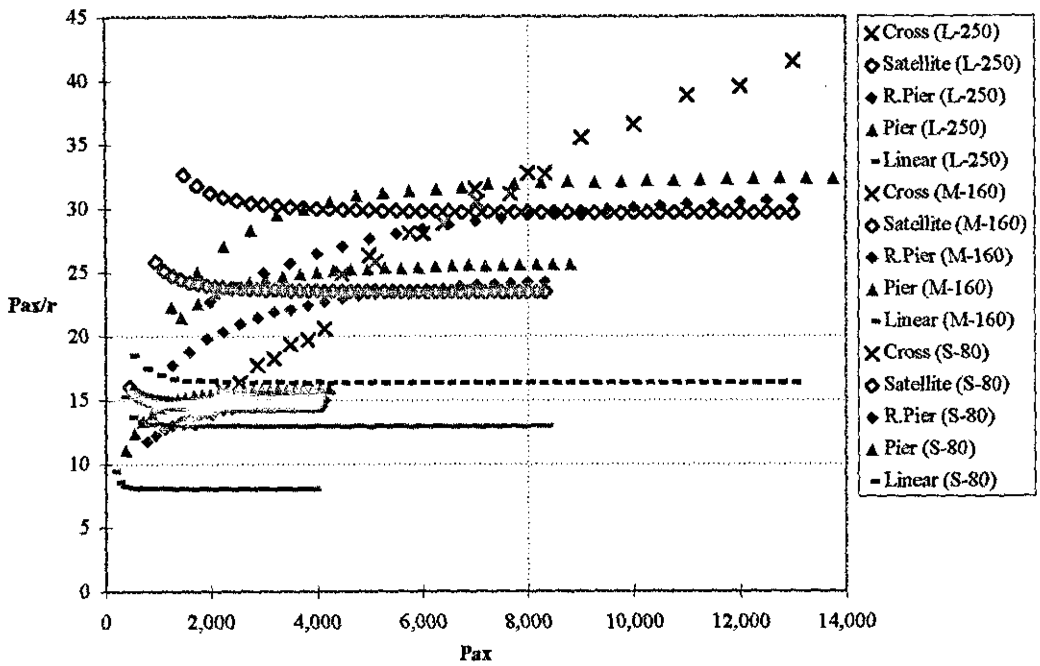


FIGURE 7.10: Relationship between Polar Moment of Transport through its radius (*r*) and Passengers for different Concepts and Average Aircraft Sizes

Note that the radius of the circle necessary to accommodate the aircraft on a Satellite concept is exactly equal to the correspondent radius of transport.

This is a conceptual approach to understanding the conduct of the radius of transport in the context of terminal configurations, however only the geometry, passengers distribution and walking distances are correlated. It is easy to grasp the simplicity in using this framework for comparing terminal concepts.

7.6 Moment of Transport Case Study

Undoubtedly a poor or a conceptually wrong design may be the cause for the failure of an airport terminal project, but the way that the terminal is operated can actually make all the difference between a 'good' and a 'bad' design.

When an airport is built, in case of an occurrence of any 'deficiency' in its operation, one of the difficulties remains in defining whether the problem is generated by a conceptual error in the design or that something might be wrong in the way that the terminal is being operated. It seems to be easier to find and correct an operational problem than to conjecture about the possibility that the terminal concept would have been incorrectly selected. Yet more difficult would be to speculate on the different concepts that might be the solution for the problem. Even if this was the case, a change in operational procedure would presumably have the same correction effect.

The answer whether the problem might be originated by the choice of a wrong concept would probably stay in the sphere of supposition and theory.

The case study of a terminal concept even for an existing terminal is still a theoretical analysis. Therefore the evaluation of terminal concept related to Moment of Transport is also developed in an hypothetical situation, in the sense that most of the parameters are assumed, yet it ressembles the real world. Based on the facility sizing methods explained in Chapter 5 and using one module of the DSS Expert System described in Chapter 3, and also using a CAD program, one hundred and forty two terminals -- 33 for each of the basic concepts, Linear, Pier, Remote Pier and Satellite, including multi-terminals --, were designed for the case study on Terminal Concepts, see an example in Appendix D. In doing that a number of assumptions were made which are described in Chapter 5. The Moments of Transport for each design were calculated and the results are discussed in this section.

Firstly, it is assumed that the passenger flow path is centralised through a single point as indicated by the square (red) dots in Figure 7.11. As the main terminals adopted in each case (different volume of passengers throughput) are the same for all concepts and the chosen points can be considered common points for all cases, the comparison between concepts by the Moment applied in such points is made possible.

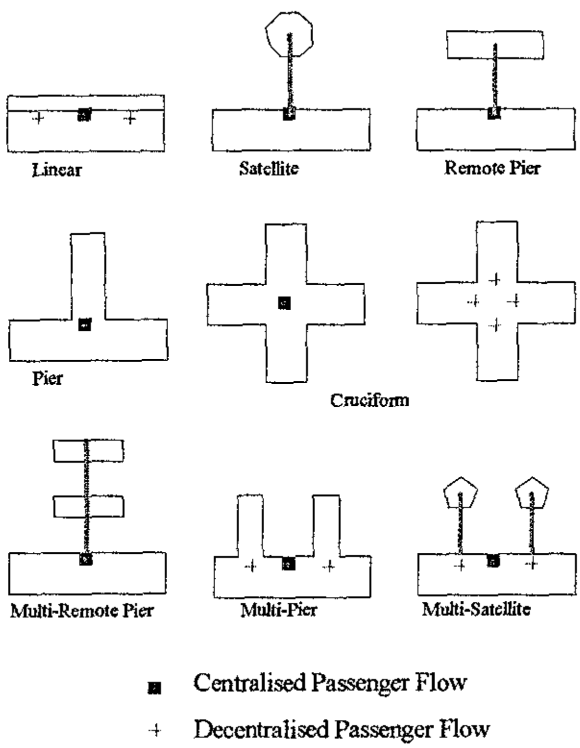


FIGURE 7.11: Points for application of Polar Moment of Transport.

Multi-Terminal Configuration with decentralised passenger path flows falls in the similar case of a single terminal. In such cases the decentralised points are also used for evaluation of transfer passengers if it is assumed that they exist.

Although the aircraft mix used to size the terminals takes into account different types of aircraft -- divided in groups A to G, the moments were calculated based on Table 7.1 using an average aircraft, in fact an equivalent aircraft for each volume of traffic. This is also an assumption that makes a comparison possible, since the gate assignment of different aircraft sizes and capacities into distinct terminal configurations would induce an inappropriate comparison, if a gate assignment optimisation was not carried out first. The pertinence of an homogeneous distribution advocates the main objective of the Terminal Concept evaluation that is not the optimisation of a particular terminal or concept through aircraft allocation, but mainly allows for coherent comparison. In a real case where the fleet mix is available it would be possible to firstly optimise each configuration before undertaking any comparison. The Moment of Transport framework can be used for this purpose.

The assumption of two levels for the terminals has a significant impact on the definition of where to place points to apply the moments, as it consequently affects the volume of traffic, the passenger flows, the passengers (aircraft) distribution, and the overall geometry. The assumption of only one level terminal would lead to a completely distinct set of analysis. Nevertheless consideration should be given that a single level terminal is generally recommended for very low volume airports.

7.6.1 Radius of Transport

Having established that the radius of transport represents the average passenger walking distance and also keeping in mind that the radius is the distance where all passengers are concentrated to produce the same moment of transport, a careful examination of the distinct components may derive a guide to allow comparison between different basic terminal concepts. The relationship between Peak Hour Passengers and the radius of transport (r) with respect to the centre of gravity ($C.G.$). and the Centralised point (p) for the different configurations are shown in Figures 7.12 and 7.13.

The radius with respect to the c.g. reflects the passengers distribution for transfer purposes, considering an homogeneous transfer rate between aircraft. The lower the moment (radius of transport) the more concentrated would the passengers be and the lesser effort would be necessary to transfer passengers between aircraft provided that the geometric centre of gravity of the departure lounges (or transfer lounges) is coincident with the c.g. or the aircraft distribution.

For a single terminal '*1T*' the Pier '*P*', Remote Pier '*RP*', and Satellite '*S*' concepts have similar moments of transport with respect to their distribution c.g., while the moment for the Linear '*L*' is far greater, see Figure 7.12 (*1T*). It means that the *L* concept with a single terminal would be suitable for transfer only when its traffic volume is up to 3,500 peak hour passengers. Above this the walking distances would become extremely inconvenient.

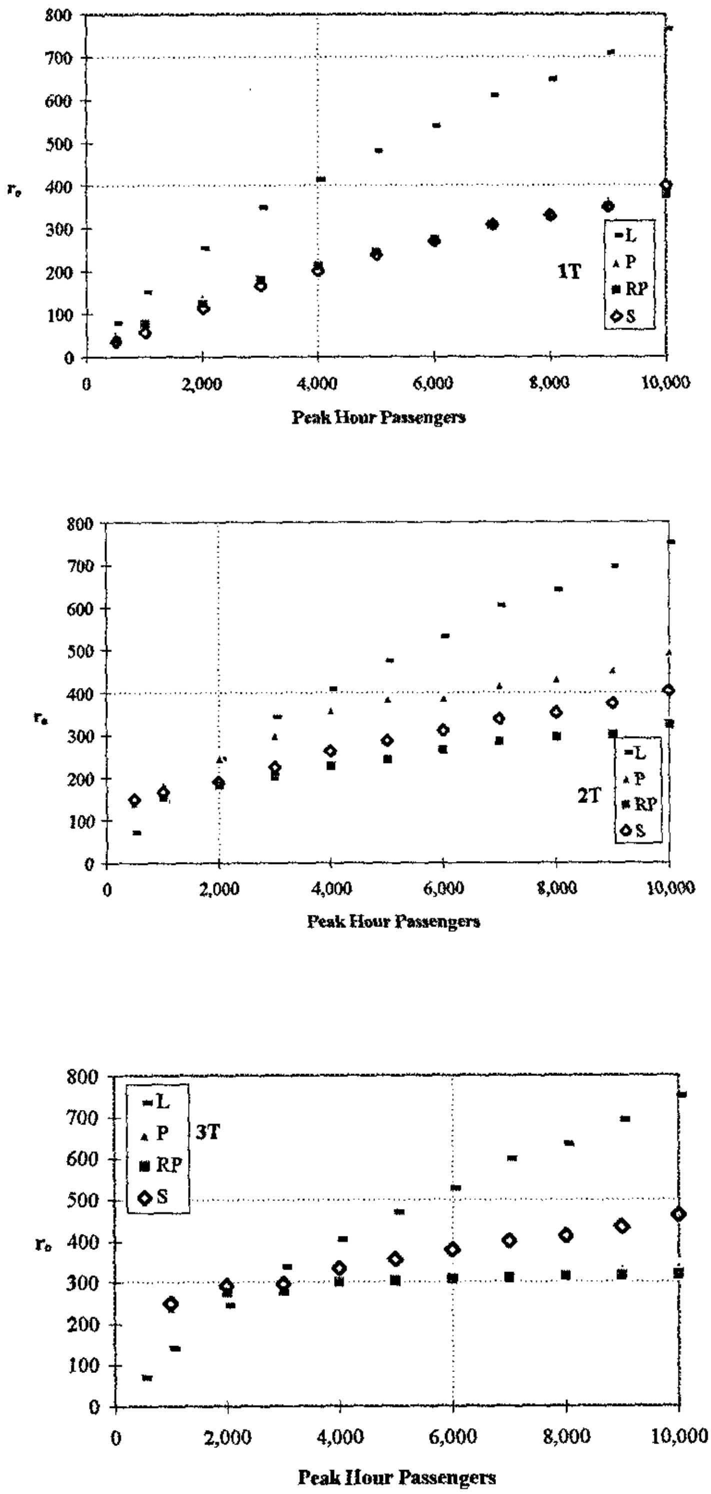


FIGURE 7.12: Radius of Moment Polar of Transport in relation to the C.G. for single and multi-terminals (e.g. with respect to the set of terminals).

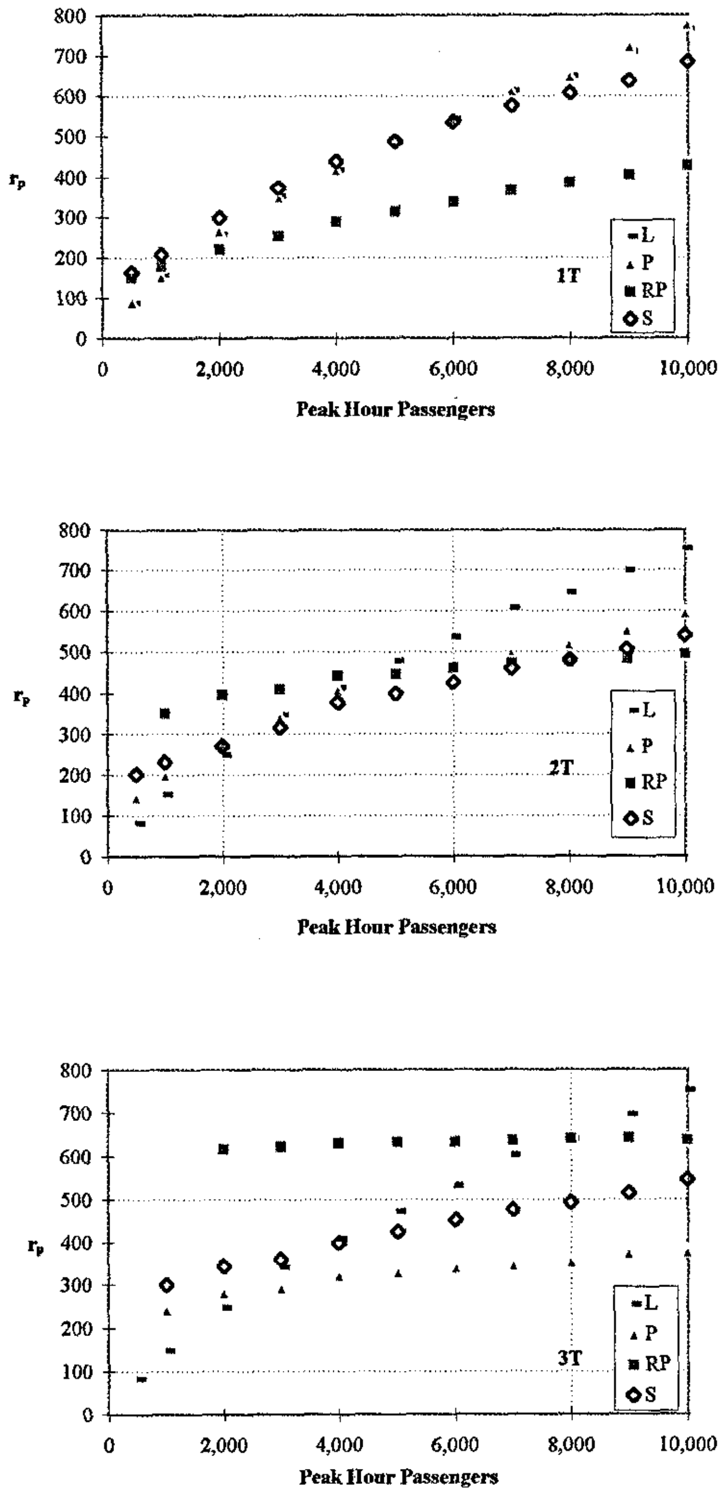


FIGURE 7.13: Radius of Polar Moment of Transport in relation to the common point p for single and multi-terminals.

As the number of terminals increases to two and three the moments shift to higher values increasing accordingly the average walking distances with respect to the c.g.. For *3T* it can be seen that the *L* shape becomes more attractive than the other concepts for transfers up to 3,000 peak hour passengers. It should be observed that the calculated moments for the multi-terminal shape refer to the c.g. of the combined configuration, i.e. the c.g. of the terminals together. The moments of the independent terminals will be considered later in the discussion of decentralisation.

The radius of transport with respect to the points '*p*' are similar to those with respect to the c.g., with the difference that the values are further shift to higher values. For peak hour up to 5,000 passengers the differences between the concepts in terms of average walking distances with respect to the point '*p*' can be very high, reaching ratios greater than 2, i.e. the passenger concentration of a L shape can be as much as 2.5 times higher than a RP shape, see Figure 7.13. The Linear concept still gives the shortest average walking distances for peak hour up to 1,500 passengers.

It has been demonstrated that the radius of transport indicates the degree of passenger concentration with respect to the axis or point being analysed. However, what occurs with the other variables when the geometry changes has to be considered. Furthermore, the relationship between the moment and the variables and the way that these variables may influence or are influenced by changes in form and dimensions cannot be ignored.

7.6.2 Circulation Space and Maximum Walking Distances.

One total area is usually calculated for each volume and composition of traffic independently of the type of terminal being considered. It is supposed that the area will not change with the variation of form. However ingenious the architect would be, some differences are likely to be incorporated in the design. In virtue of the variation in dimensions and shape, which makes the walking distances vary the area associated to the main circulation spaces is the first to be affected, causing a variation in the terminal gross area. Figure 7.14 shows that the circulation spaces increase potentially with the increase of the radius of transport and similarly with the peak hour passengers growth. For the Pier, Remote Pier and Satellite concepts it shows that increasing the number of terminals causes the circulation space requirement to decrease significantly. For the Linear concept the values remain almost constants.

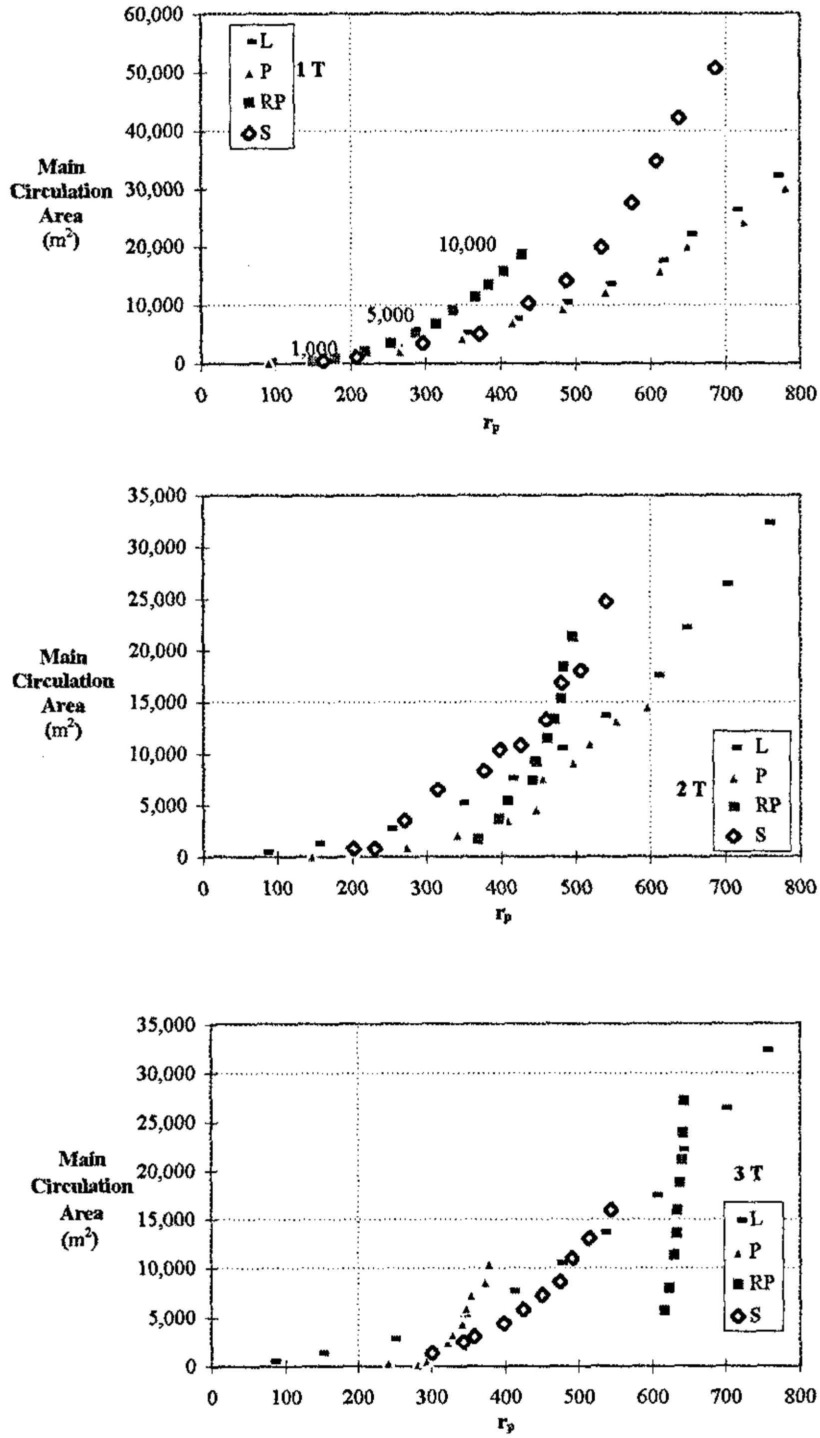


FIGURE 7.14: Main Circulation Space versus Moment of Transport applied at point *p*.
(for area calculation see Chapter 5)

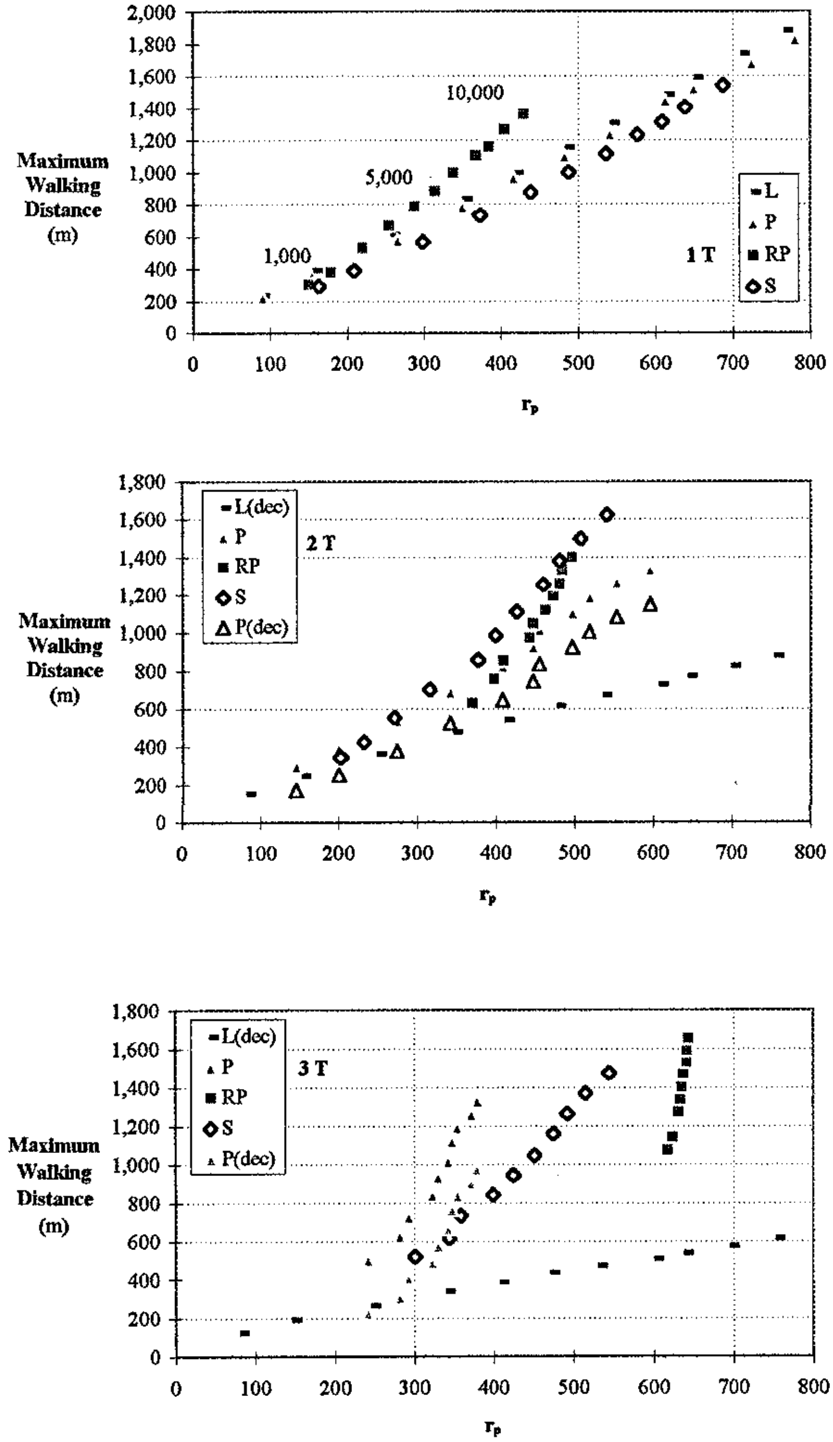


FIGURE 7.15: Maximum Walking Distance versus Moment of Transport applied at point *p*.

The circulation space for the Pier (*3T*) is the smallest considering all options of single and multi-terminals. However the smallest radius belongs to the single Terminal Remote Pier for peak hour passengers between 2,500 and 6,000, but the difference between the former and the latter is very small, around 10% to 15%. On the other hand the *RP* (*2T*) and *S* (*1T*) are the concepts with the greater circulation area requirement.

The maximum walking distances for each situation is shown in Figure 7.15. For the Multi-Linear concept the distances shown are for decentralised flows, otherwise they would be as equal as shown for the single terminal. It is clear that above 4,000 peak hour passengers the Multi-Pier (*2* and *3 T*) concept shows shorter distances than the other configurations. The most important is that the maximum walking distances vary proportionally to the radius of transport which was obviously expected.

7.6.3 Apron and Taxilane Areas

The apron area is just the area on the apron designated for parking of aircraft. Taxilanes are the areas which provide access to aircraft stands. The stands are for taxi-in push-out operation. As the taxilanes are designed around and adjacent to the aircraft stands the variation of area of both are nearly identical. Increasing the passenger volumes and the number of terminal units the areas also increase. Figure 7.16 and 7.17 show the relationship between these areas and the radius of transport with respect to point *p*. Comparing all configurations the Linear has the lowest area for both aircraft stands and taxilane; observing that for the Linear configuration there is only one taxilane. The range of variation between the configurations decreases with the increase of the volume of peak hour passenger. In other words it means that one should be more careful to choose a configuration with lower volumes of passengers than for higher volumes, if the apron/taxilane areas outweigh the other factors involved in the process of choice.

7.6.4 Total Land Area, Shape and Effective Land Use

The total area of land where the terminal/apron system is built also vary with the variation of shape. Considering an area as the outcome of a convex polygonal involving the terminal system, Figures 7.18 and 7.19 show the variation in area related to the radius of transport and the ratio between the effective area occupied by the terminal and the total area required. It is important to remember that the main terminals are equal for all the basic concepts and that their lengths varies in proportion to the curbside length required for each volume of peak hour passenger as calculated in Chapter 5. The total area includes terminal, apron aircraft stands and taxilane areas.

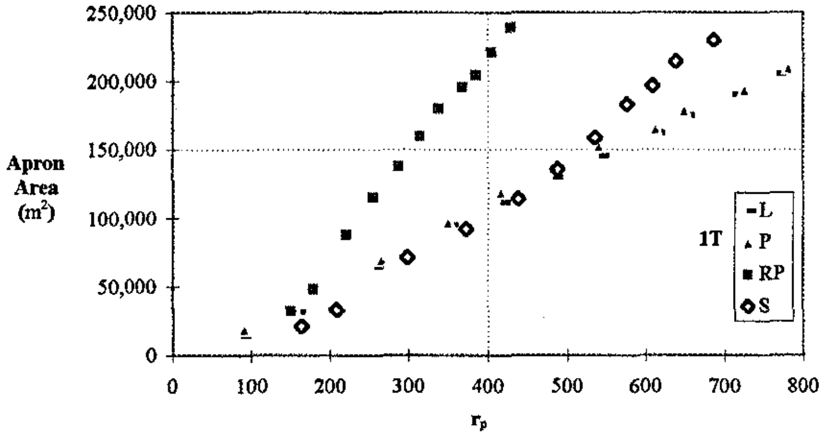
The first point to realise about the total land area is that, in the same way as the other factors, there is a linear relationship with the radius of transport. When calculated the coefficient of correlation is found to be greater than 0.9 for all concepts.

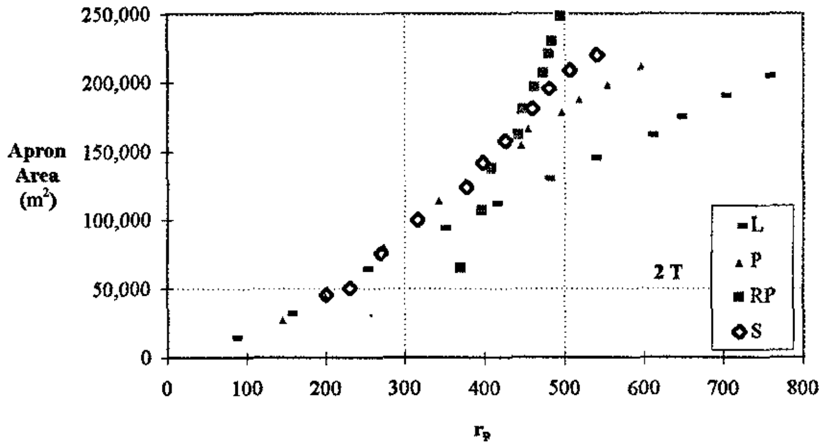
In the case of a single terminal, the Linear and Remote Pier shapes require smaller area than the Pier and Satellite. When two and three terminals are considered the Pier is the concept together with the Linear that require lesser space than the Remote Pier and Satellite, see Fig 7.18.

In terms of their effective occupation of the land required and considering that their effective area (terminal, apron, taxilane) are similar, the ratio between the latter and the former drops proportionally with the increased land requirement, which is a function of the variation in their dimensions and shape.

The poorest concept in terms of land use is the satellite configuration. Figure 7.19 shows the relationship between the total terminal/apron area and the total land area required for each concept. The Linear configuration increases slightly its effective use with the increasing in passenger volumes. It is also the shape that requires the smallest total land area. On the other hand, the satellite shape effective use generally decreases with the increasing in passenger volume. It means that greater amount of area with no use is required, such as the triangular area formed between two satellites. The Pier configuration contrasts with the Remote Pier. The Pier, for a single terminal is very inefficient requiring a great amount of land area as the passenger volume increases, based on quite exclusively its dimension which grows mostly in one direction - towards the apron. As the number of terminals increase to 2 and 3, the area required decreases and the land use becomes more effective. Conversely the Remote Pier is more effective for a single terminal than for multiple units.

Figure 7.19 also shows that some concepts make better use of the site for certain volume of passengers. For example the Pier configuration has higher land utilisation for volumes between 4,000 and 7,000 peak hour passenger.





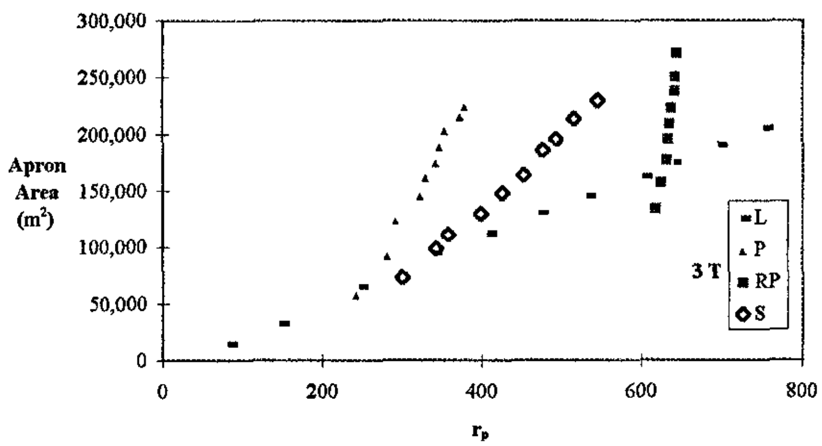


FIGURE 7.16: Apron Area versus Moment of Transport applied at point *p*.

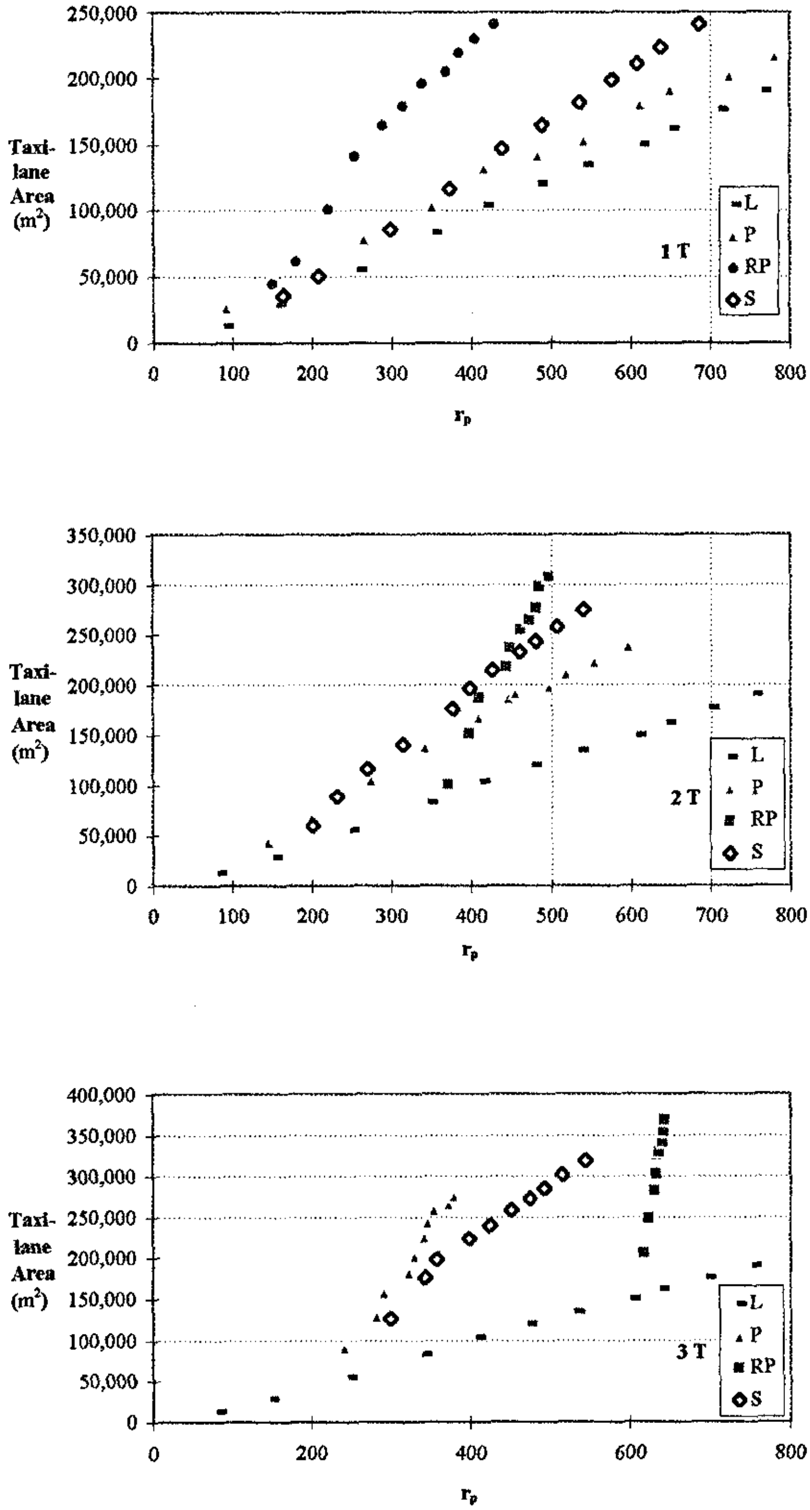
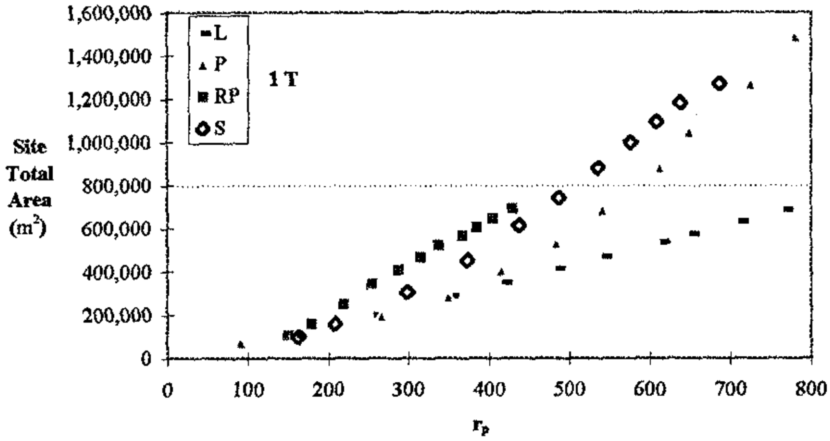
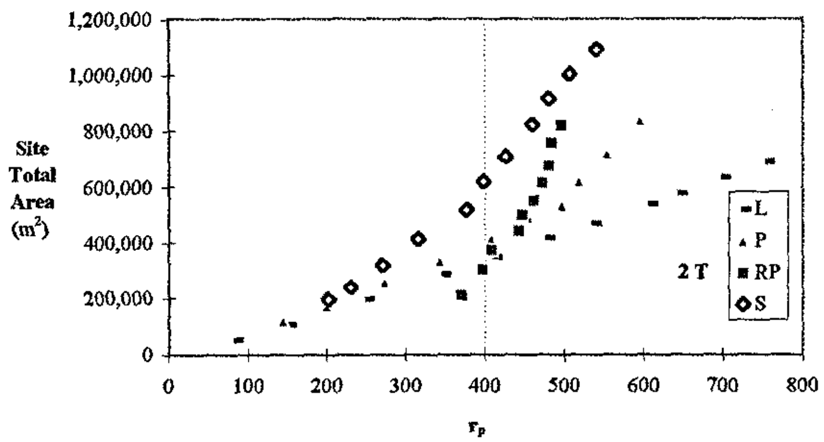


FIGURE 7.17: Taxilane Area versus Moment of Transport applied at point *p*.





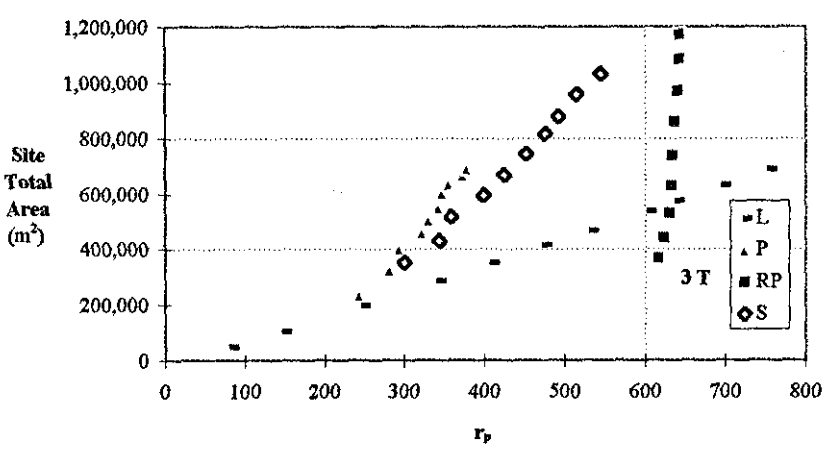
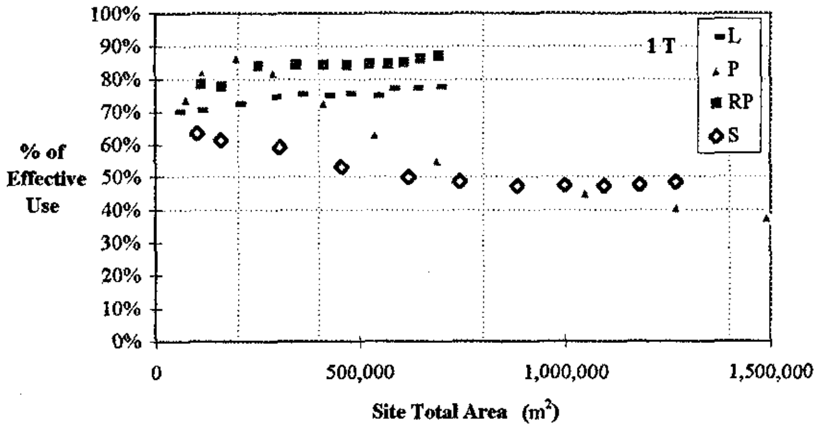
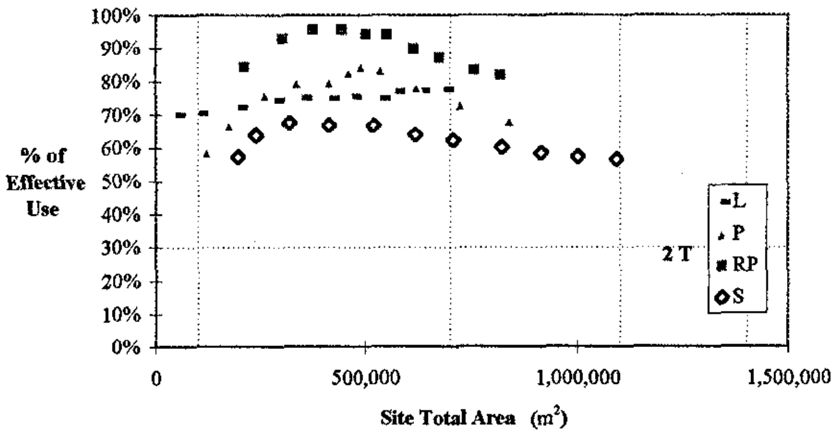


FIGURE 7.18: Total Area of the Terminal Site versus Moment of Transport applied at point *p*.





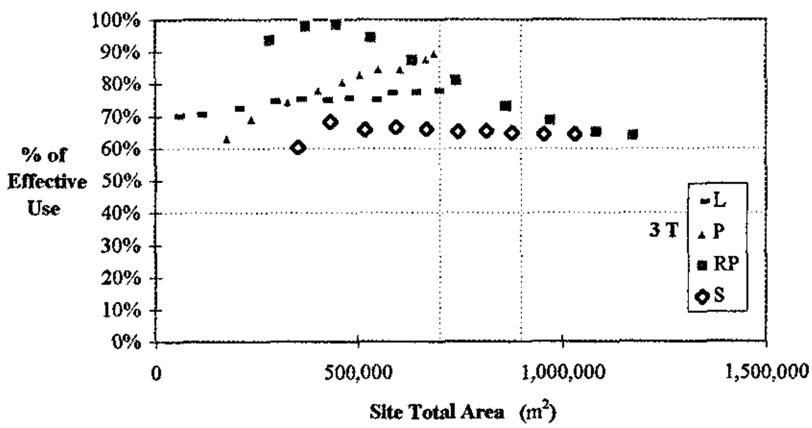


FIGURE 7.19: Percentage of the Terminal Site Total Area effectively used.

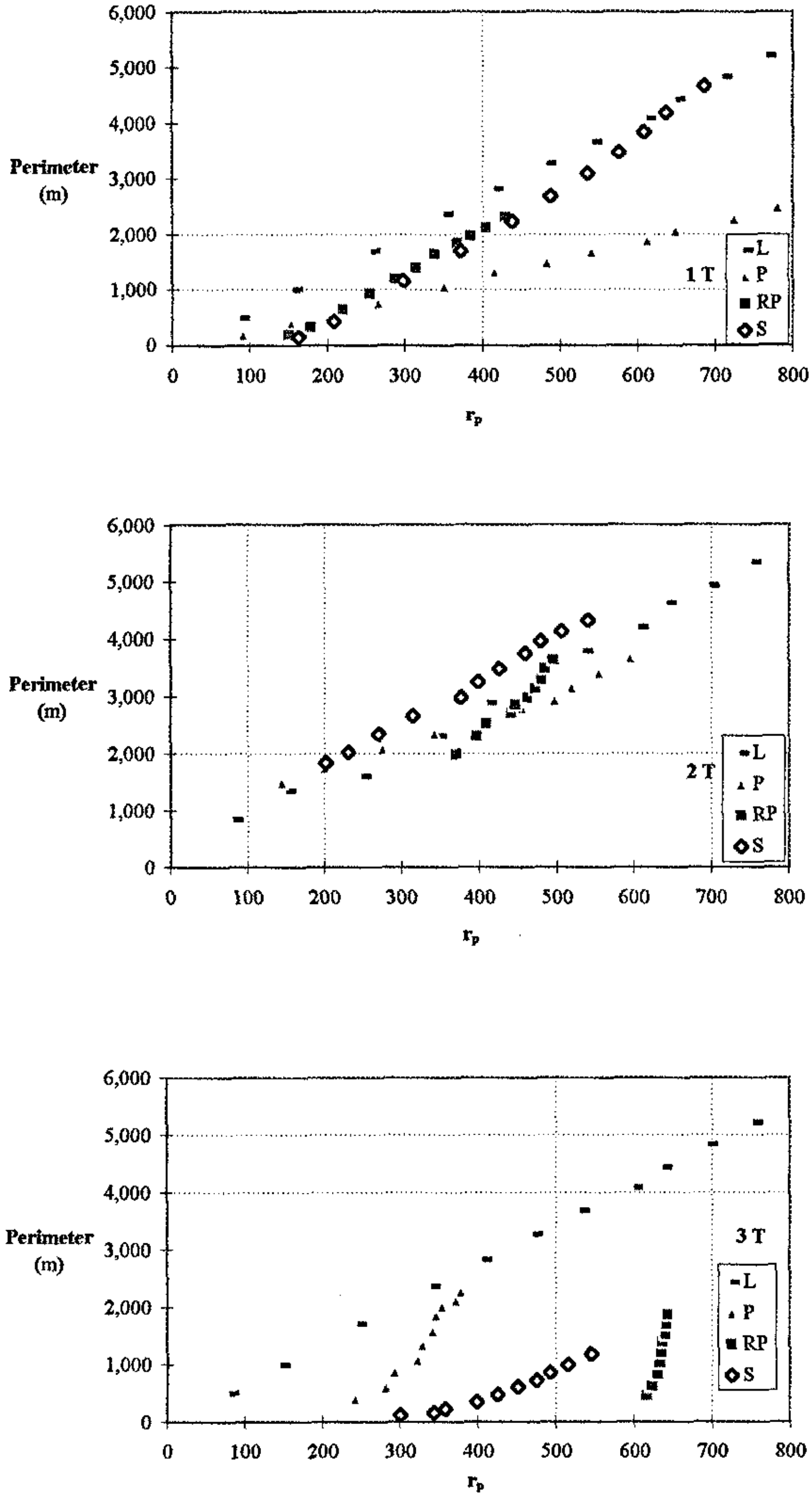


FIGURE 7.20: Perimeter (of the Connector) versus Moment of Transport applied at point *p*.

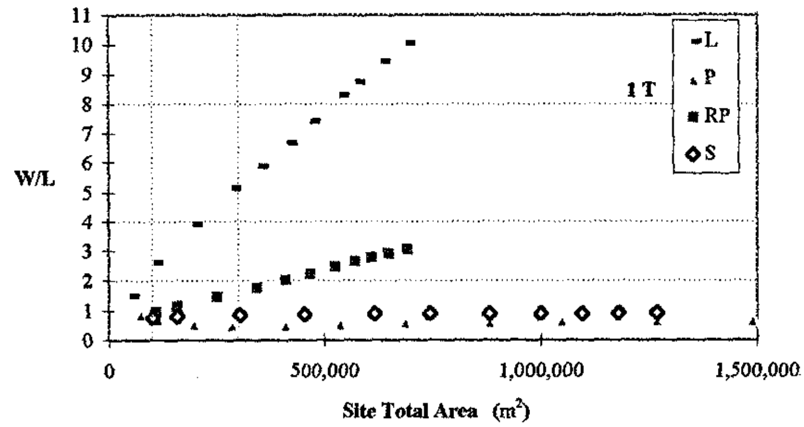
7.6.5 Perimeter and Ratio between Breadth and Length of the Land Required

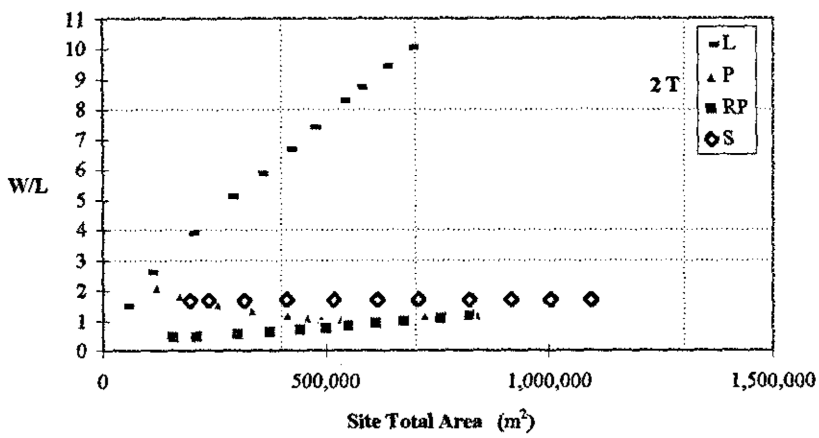
The perimeter is the boundary of the Terminal built area (Connector) and represents the need of external walls and foundations, see Chapter 6. Figure 7.20 shows the perimeter required by each basic concept related to the radius of transport. The Linear is the configuration with the longest perimeter requirement. Contrary to what one may think increasing the number of terminals (dividing the single terminal in smaller units) decreases the perimeter requirement, see the Pier and satellite configurations in Fig 7.20 (2T and 3T).

Another characteristic of the basic concepts is related to their dimensions Breadth (*W*) and Length (*L*). The latter is the measurement taken from the curbside to the furthest taxilane edge, and the former is the greatest distance taken parallel to the curbside. It can be the length of the main terminal (Pier) or the distance from the edges of the taxilanes around the apron (RP) or the distance between the edges of the apron (Linear). In other words, '*W*' and '*L*' are the largest dimensions of the land within which the terminal system is going to be fitted. Figure 7.21 depicts these relationships. If the ratio is greater than 3 for instance, it would become very difficult to insert in other terminal than a Linear concept. On the other hand, if the ratio is smaller than 1, the probable configuration would be a Pier or a Satellite (considering a single terminal).

With more than one terminal the relationship changes slightly. With two terminal units a ratio greater than 2 indicates that a Linear concept will probably be required. A ratio between 1 and 2 indicates a Pier or Satellite, and a ratio smaller than 1 indicates a Pier or Remote Pier configuration. With three terminals, a ratio greater than 3 would indicate a Pier or Satellite shape and a ratio smaller than 1 is likely to require a Remote Pier concept.

The correlation with passenger volume is also characteristic. The ratio for the Linear shape increases significantly with the increase in passenger volume, while the ratio of a Remote Pier increases only slightly and the degree with which it increases diminishes as the number of terminals increases. However, the ratio of a Pier shape decreases with the increasing of passenger volume. The ratio of a Satellite shape is nearly levelled off as the volume of passengers increases.





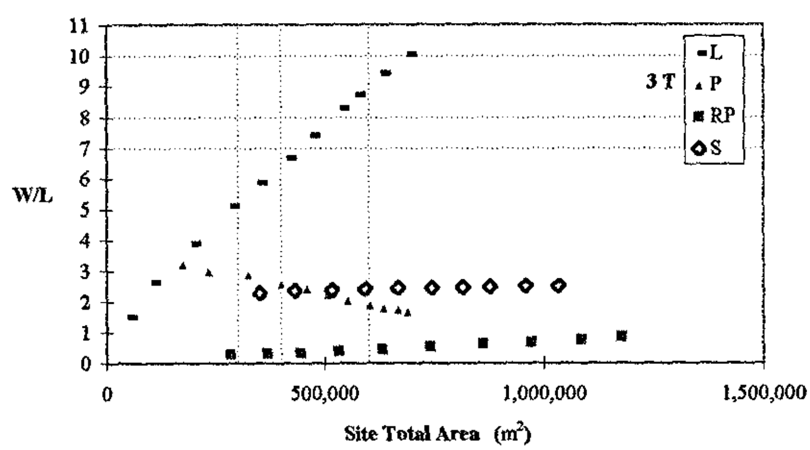


FIGURE 7.21: Ratio between Breadth (W) and Length (L) of the Terminal Site versus the Terminal Site Total Area.

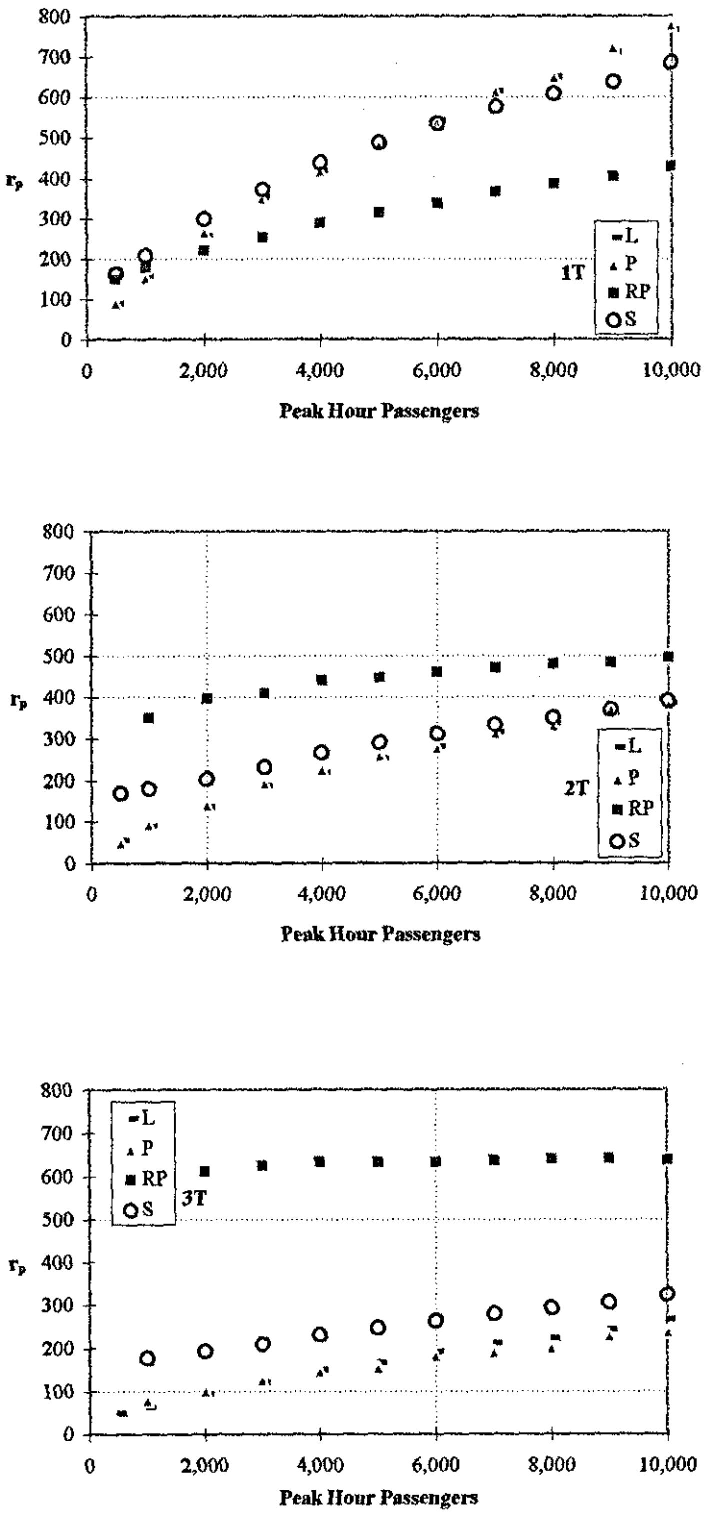


FIGURE 7.22: Radius of Polar Moment of Transport with respect to the decentralised point p for multi-terminals, see Fig 7.11. (Single terminal included for comparison).

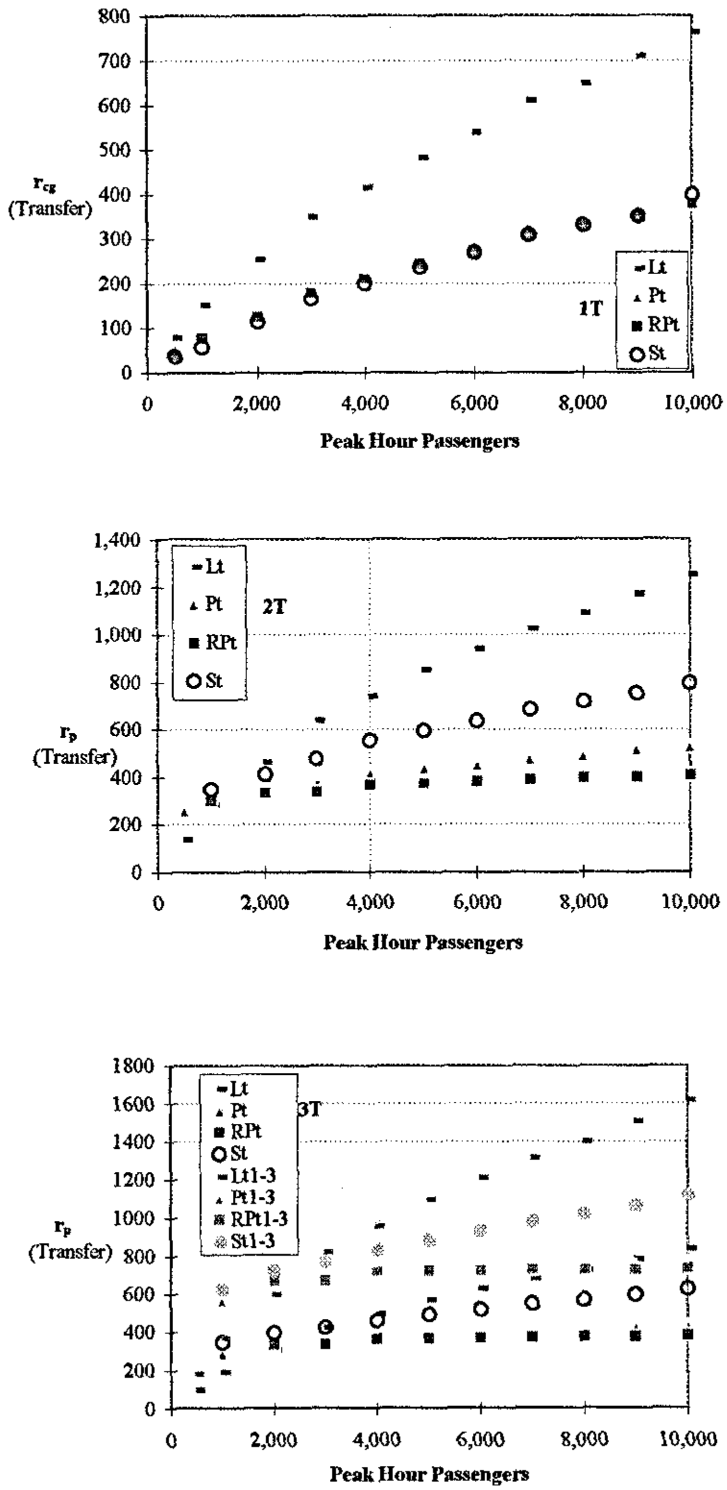


FIGURE 7.23: Radius of Polar Moment of Transport with respect to the decentralised point *p*; considering transfer passengers for a single terminal (*1T*), between two terminals (*2T, 3T*) and between two terminals apart (*3T*).

7.6.6 Decentralisation and Transfer Passengers

An analysis of the form of basic terminals and their passenger distribution was undertaken in the preceding paragraphs based on centralisation of the passenger flows through a specific singular point. While this is coherent with a single terminal concept, for two or more terminals, where decentralisation is already implied, maintaining centralisation seems to disregard logical principles. Therefore an evaluation of the passengers and aircraft distribution based on decentralised points appears to be more appropriate. Figure 7.11 already exemplifies these decentralised points. It is obvious that the total aircraft and passenger volumes are divided, creating smaller buildings, reducing distances and simplifying passenger flows. It brings the advantages and disadvantages of decentralisation as already discussed in Chapter 6.

The appropriateness of decentralisation in this case, as the traffic is split, is that the moments of transport with respect to the decentralised points decrease. It means that the walking distances, though the passenger volume may increase (the dimensions increase), start to become compatible within certain established limits. Figure 7.22 and 7.23 depict the radius of transport with respect to these decentralised points. It can be seen that the radii drop to values around 300 m which is compatible with what is preconceived as a reasonable walking distance. Nevertheless, the calculations do not represent the overall passenger walking distance. The distance walked in the main terminal building is not accounted for, once they are assumed to be equal for all concepts.

The exception occurs with the Remote Pier configuration that retains the same centralised point. A two parallel access to the Remote Piers would change this situation, however it is not being considered as one more alternative. In fact, many other alternatives would be possible, such as the cruciform terminal included before or any other shape even a combination of shapes could be a potential solution.

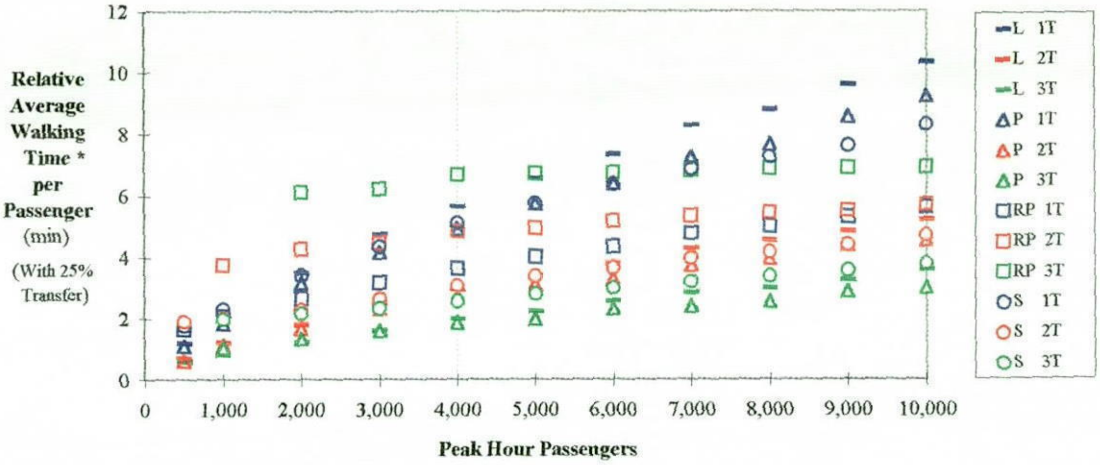
For a single terminal and for volumes up to 1,500 peak hour passengers the Linear and Pier shapes have lower moments. Above this value it is the Remote Pier that has smaller moments. As the volume of passengers increase the problem with a single terminal is the dimensions and distances become far greater for comfort. Therefore the split or decentralisation of the passengers seems to be the solution. Figure 7.22 also illustrates that for two and three terminals the Pier and Linear (dec.) give the lower radii of transport with respect to point *p* (decentralised). On the other hand, in the case of the Satellite and Remote Pier the lower moments occur with respect to the c.g. of the individual terminals.

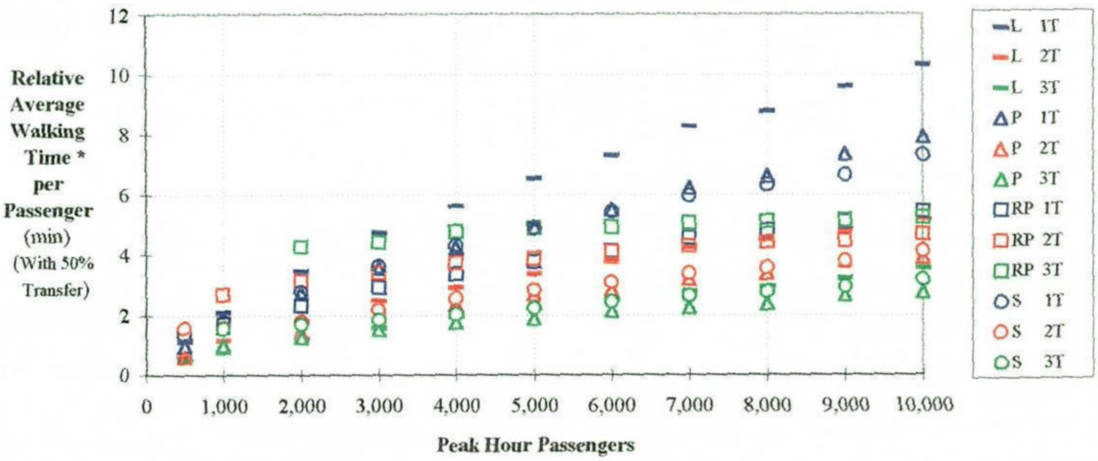
The alternative of splitting the passengers and decentralising the flows through individual units (multi-terminals) seems to solve one problem of enplaning and deplaning passengers. However, if a new variable is included in the process -- *Transfer Passengers* --, it would create a different problem instead of solving the first. Again, to illustrate the distribution of transfer passengers, the moments of transport were calculated and shown in Figure 7.23 through their radii of transport. It is evident that the advantages of shortening distances obtained from dividing the single terminal will probably be lost if the number of transfer passengers between terminals starts to increase.

To account for or to evaluate the influence of transfer passengers to the basic concepts, the total walking distances that all passengers undertake at the peak hour can be calculated, these being obtained by multiplying the radii of transport by the total volume of passengers. Assuming that the transfer passengers vary according to rates of 25%, 50% and 75% of the total peak hour passengers, Figures 7.24 show the results for comparison of the basic concepts. As the number of transfer passengers increase the total walking distance generally decreases for a single terminal and increases for the multi-terminals. The worst situation would occur in the case of more than two terminal units if the transfer was made between non adjacent units. Considering a single terminal and passenger volume above 3,000 peak hour passengers, as the number of transfers increases the appropriate configuration tend to be the Remote Pier.

For high volume of transfers and supposing that the passenger flows would be confined within each terminal unit, the best solution would certainly be toward decentralisation, i. e. splitting the traffic in two, three or more units.

With 25% of transfer passengers the best configuration becomes the Pier *(3T)*. As the percentage of transfer passengers increase the Satellite with the Pier become more advantageous. However, if the transfer of passengers occur between terminal units, as the volume of transfers increase the Remote Pier becomes more attractive, indicating a tendency towards a single terminal as the optimum configuration, see Fig. 7.24 and 7.25.





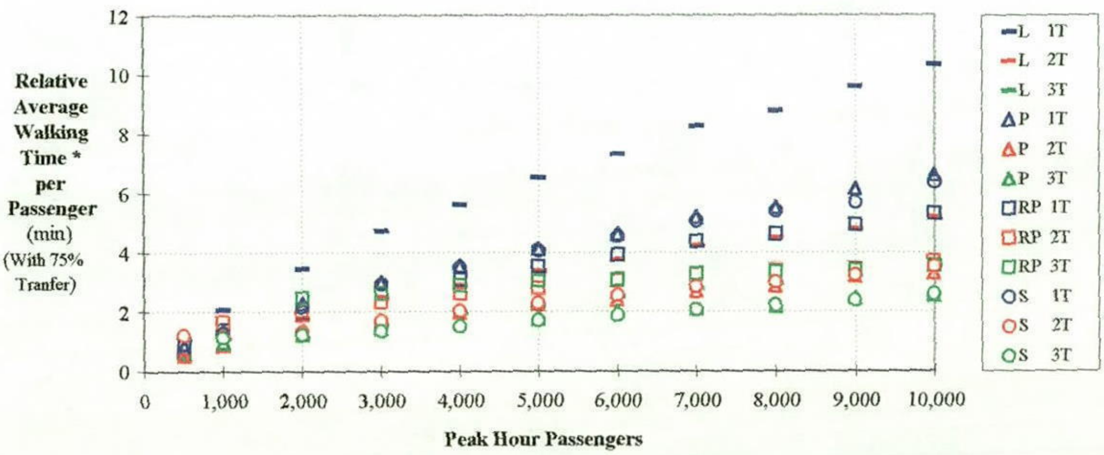
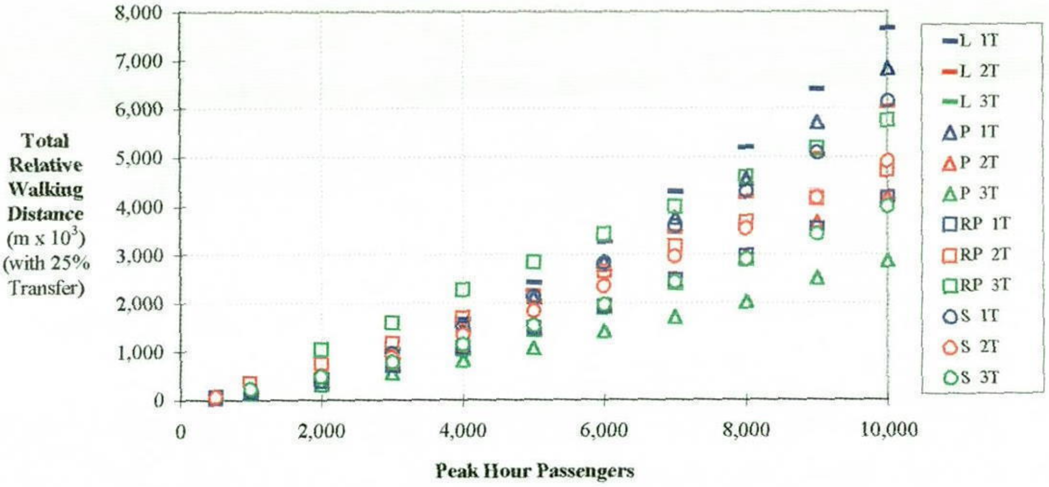
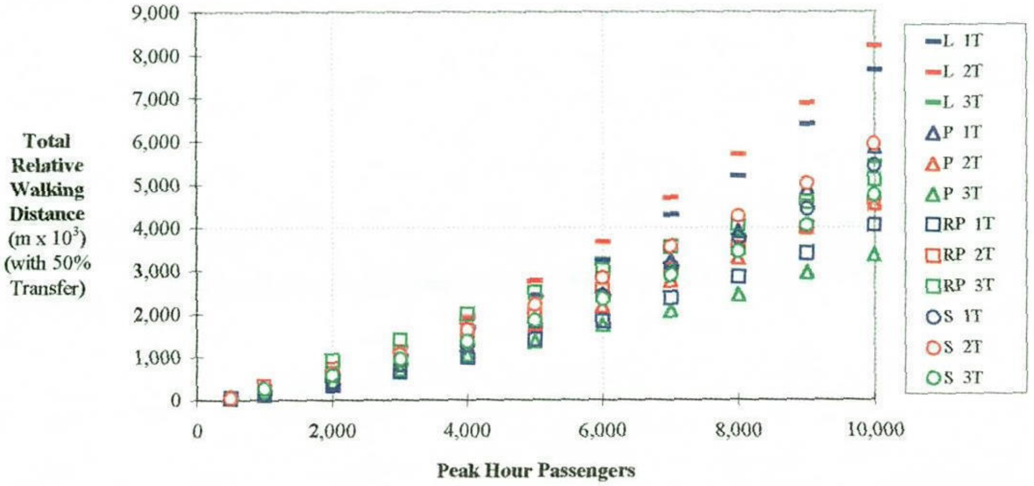


FIGURE 7.24: Relative average walking time computing enplaning, deplaning and transfer passengers. Assuming that the transfers occur within the boundaries of each terminal unit. * (Based on average walking speed = 74 m/min)





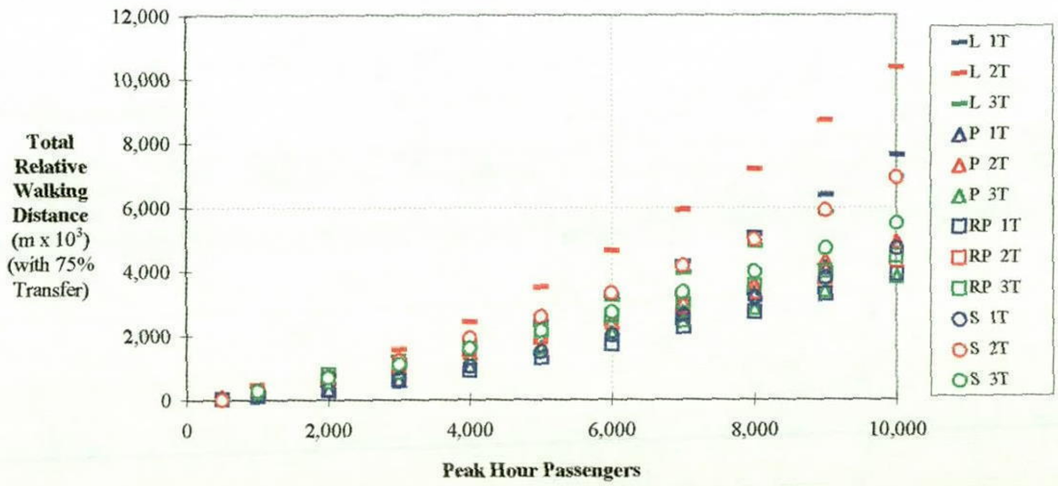


FIGURE 7.25: Total Relative Walking Distance for enplaning, deplaning and transfer passengers, assuming that the transferring may occur between terminal units.

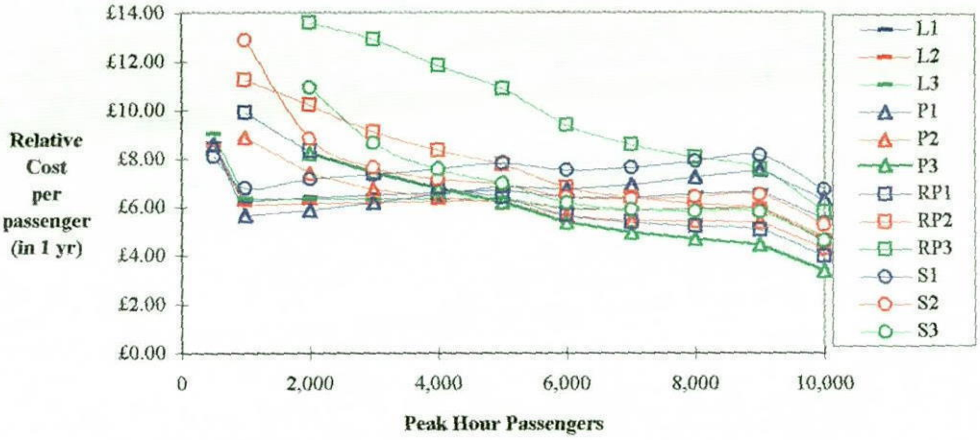
7.6.7 Construction and Operational Costs

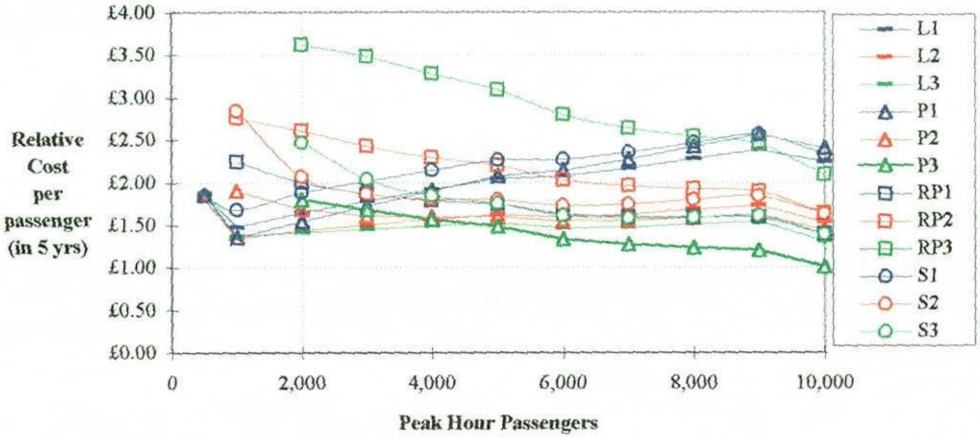
In the triangle that defines the variables affecting the terminal concept choice in Chapter 6, the economic aspects are one link (side) of the problem that should not be overlooked.

It is implied in the design process that the total area required for the terminal, ceteris paribus, is dependent upon the volume of passengers handled at the airport, independent of the configuration that may then be adopted. While this is not entirely true, as discussed and explained in Chapter 6 the actual variables or elements may change to generate different terminal concepts. The total terminal area may change in function of circulation space and consequent shape variation (dimensions) of the terminal. The total perimeter of the building also changes. The total area of apron (aircraft stands) and taxilane (access to the stands) may also change. And, the total land area required may also change. These are the main elements that may impose differences in the Construction Cost. The Operational Cost is assumed as the cost associated to the effort to move passengers through the terminal from their point of arrival to boarding the aircraft. And this relies quite exclusively upon two intrinsic variables, time and walking distances.

Assuming average costs for the construction elements above, terminal building, apron system (including taxilanes), external walls and assuming also a cost per passenger per minute expended to walk throughout the terminal, the total relative cost per passenger per year was calculated and is shown in Figure 7.26. The Operational Costs were calculated based on the radii of transport. This stresses the importance of passenger distribution in the context of terminal concept, therefore the appropriateness of evaluating these distributions through the proposed method of Moment of Transport.

The construction costs are fixed values applied once, while the operational costs will incur in the course of the life time of the airport. Figure 7.26 shows the incidence costs mainly the operational effort to move passengers through the terminal which is illustrated using 1, 5 and 10 years operation. As the volume of passengers increase it becomes clear that decentralisation may be fundamental to a good design. However, it should be noticed that transfer passengers is not considered in the calculation presented in Fig 7.26.





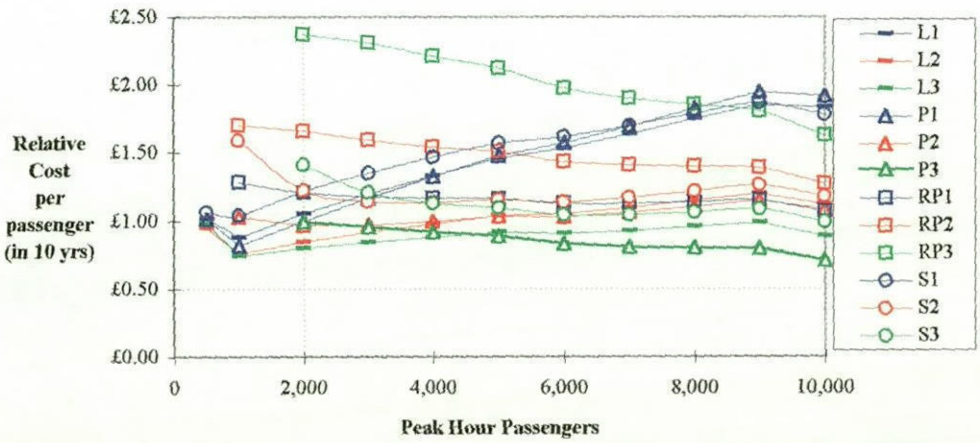


FIGURE 7.26: Economic analysis based on Construction Cost (CC) and Operational Cost (OP).

7.7 Summary

In this Chapter a simple idea based on Moment of Inertia in Mechanics, here called *Moment of Transport* is proposed as an approach for evaluation of *Terminal Concepts*.

The moment of transport establishes the passenger distribution wherever they are considered. It can be used to analyse the distribution of aircraft stands. It can also be used to evaluate the distribution of departure lounges and check-in counters, or any other combination between processing and holding facilities. It is in principle a static measure that gives the potential 'capacity' of the system being analysed. Moments can be generated with respect to axes or with respect to points. When the moments are calculated with respect to a point the resultant *Radius of Transport* represents the passenger average walking distance in relation to that point.

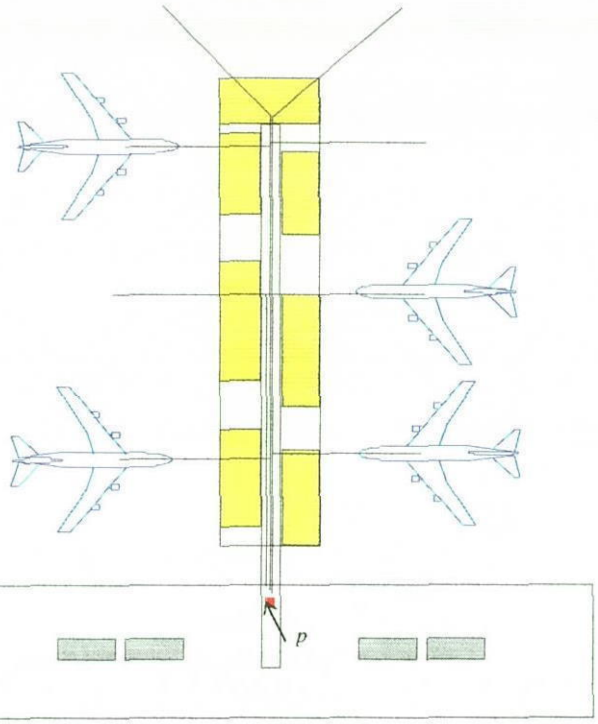
The Radius of Transport, as with the Moment of Transport, is a measure of the distribution of the passengers from the axes or points in question. The radius with respect to a point p can be expressed by

$$r_p^2 = r_x^2 + r_y^2$$

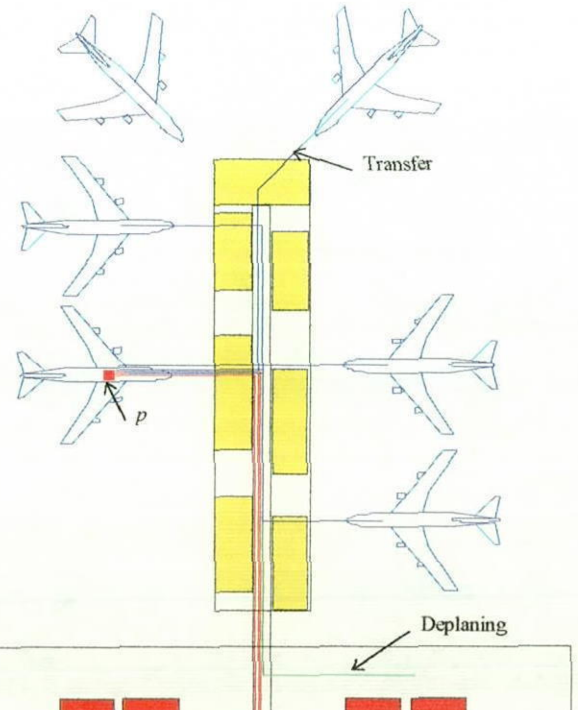
which means that the radius of transport about a polar axis equals the sum of the squares of the radii of transport about the two corresponding rectangular axes. The parallel axis theorems also hold for radii of transport being

$$r_p^2 = r_{cg}^2 + d^2$$

where $r_{c.g.}$ is the radius of transport about a centroidal axis parallel to the axis about which r_p applies and d is the distance between the axes. The quantity r_i^2 is the mean of the squares of the distances. The moment of transport is not equal the sum of the number of passengers times the square of the distance of the $C.G.$ to an axis, since the square of the mean is less than the mean of the squares.



a)



b)

FIGURE 7.27: Points for application of Moment of Transport with the distances that may apply.

Figure 7.27 a) illustrates the representation of passenger flow with respect to a centralised point '*p*' used in this Chapter. Part b) suggest a different representation that can also be used. The summation of the individual moments with respect to each aircraft gives the effect of the total passenger distribution.

It has been also established that the Moment of Transport varies with the variation of the aircraft mix. Increasing the aircraft average size makes the moment decreases.

A careful observation through the figures in this Chapter shows that the range of variation of moment of transport becomes substantially important as the volume of passengers increases. Therefore it is quite obvious that for volumes above 2,000 peak hour passengers the Moment of Transport may become a fundamental factor for the evaluation of terminal concept, i. e., the concept choice can be exclusively decided based upon the Moment of Transport generated by the distinct passenger distribution. If not so decisive, the Moment of Transport should at least be weight more than the other factors.

The main findings are dicussed in the next Chapter.

8. CHAPTER VIII Some Final Remarks

8.1 Introduction

This Chapter outlines the main findings on the methodology for the comparative analysis of airport terminal forms, commonly known as Terminal Concepts.

The number of variables or factors involved in the designing process is enormous, although not all of them have direct influence in the process of terminal type selection. The choice of a terminal form, all other factors being equal, is not only correlated to physical characteristics of the terminal and aircraft, such as shape, dimensions and sizes; but also dependent on the characteristics described in Chapter 6.

The traffic characteristics and volumes may pre-determine the type of terminal to be adopted. However, it is more likely that the specific characteristics of each case, which is very difficult to establish in terms of general rules, will determine the appropriate form of the terminal. Therefore a consistent procedure to allow comparison between not only basic concepts, but distinct and more innovative forms or combination of terminal forms is suggested in Chapter 7.

In order to understand why a categorisation of basic terminal types could help the designer on the process of terminal selection, suffice to say that the basic concepts are a generalised tendency to make building and aircraft compatible with form, which may serve as a starting point to conceptualise the proper shape that a terminal should have to satisfy the passengers needs under similar circumstances.

8.2 Implications of Passenger Distribution

The main variable or factor already mentioned, that really influences or is influenced by the variation of terminal/aircraft form is the passenger potential distribution. From where the passenger is coming, how he/she is going to be served and, and where he/she finishes his/her journey within the terminal is determined directly by the flow path and indirectly by the shape given to the terminal. Changing the shape of the terminal or aircraft layout will change the potential passenger distribution. Pertinent to such distribution there are physical and geometrical properties, such as centre of gravity, distances, sizes & dimensions, and centroid -- directly connected to passenger distribution, that describe some of the factors that may be considered in terminal concept comparative analysis.

Compactness, short distances, and simplicity are some of the already mentioned qualities required, which are associated with the layout -- passenger distribution -- of the terminal.

A simple relation called here Moment of Transport and given by $T = \int d^2 \; dp$ establishes a measure for the potential passenger distribution with respect to a rectangular pair of axes or with respect to a polar distribution (point). The smaller this measure the more compact is the terminal, the more concentrated the passengers, and the smaller the walking distances. Moment of Transport is the measure of passenger distribution and characteristic of form; therefore a terminal concept may be selected by comparison with other known forms through comparing the moments generated by their passenger distribution. It is most likely that the most concentrated form is the right concept.

As with every activity within the terminal, passenger distribution is dependent upon time and consequently the generated moment of transport incorporates it. The potential moment of transport can therefore be associated with any volume of passenger within a unit of time: hour, day, month, year, etc.

The distribution being homogeneous, the concentration of passengers, i.e., the radius of transport, is independent of the volume of passengers handled. The dependence is exclusively based upon the terminal shape.

Dividing the traffic and decentralising the flows make the effort to move passengers (operational cost) decrease, on the other hand the construction costs increase. However, the benefit is felt by the passengers who have their comfort increased. All these characteristics are associated with, and their variation can be correlated to Moment of Transport.

There are several perspectives for evaluating terminal forms using Moment of Transport. In addition to this, moment of transport, for instance, can help in optimising aircraft stand assignment, or evaluating the terminal efficiency and productivity.

For example, suppose that the potential moment T_p (Hourly capacity of the terminal) is known. If the actual moment T_{pa} is calculated, the productivity of the terminal could be determined by:

$$\tau = \frac{T_p}{T_{pa}} \quad \text{with } 0 \leq \tau \leq 1$$

It is unlikely that τ value would be greater than 1, assuming that the passenger distribution is optimised (ideal aircraft, check-in, and departure lounge assignment) and provided that the passenger volumes are less than the maximum capacity. On the other hand, the terminal efficiency can be measured by:

$$\varphi = \frac{r_{pa}}{r_p}$$

where r_{pa} and r_p are the radii of transport correspondent to T_{pa} and T_p, respectively. Actually, an analysis of both equations above will define the proper efficiency or productivity of the terminal.

A further use for moment may be on cargo terminals. A similar analysis may help to determine the ideal layout for processing and storage facilities.

The particular characteristic in this moment approach is its flexibility to allow the comparison of different combination of elements, shapes and arrangements.

In certain configurations involving unsymmetrical sections the use of Product of Transport permits an axis of symmetry to be found and the maximum moments to be calculated.

It seems quite obvious that a terminal system, where the centroid of the passenger distribution is coincident with the geometric centre of gravity of the terminal or more precisely the centre of gravity of the processing facilities is likely to have the right arrangement.

8.3 Basic Terminal Concepts.

The differentiation between the basic terminal concepts apart from their forms is usually made pointing out some of the advantages and disadvantages of each concept. These particular advantages and disadvantages (see Chapter 4) however, can not all be cross compared, making the selection process very difficult when looking only at these factors. In particular this difficulty, although questionable, is that not all attributes (advantages and disadvantages) can be quantified.

Before summarising the basic concepts, it is necessary to recapitulate some of the attributes that may generally pre-influence the initial selection of form: site characteristics, rate of growth, number of terminal levels, decentralisation, and transfer passengers.

The available site dimensions either constrained by runway and taxiway layout or by lack of land may initially impose a configuration type for the terminal; or at least it can be a serious constraint in certain situations. As seen in Chapter 7, Figures 18 and 19, the shape of the site may be a constraint for the terminal. For example, a strip of land destined for a terminal, with ratio between length and width greater than 3, is likely to accommodate only a linear building shape.

The rate of passenger growth associated with traffic volume may be a restriction to the configuration definition. Figure 8.1 shows a curve that indicates the percentage at which the volume of traffic would double according to time. For example, with a growth rate around 26% a year, the traffic volume is expected to double every three years. Actually, the average growth rate in the air transportation has been kept between 5 to 10% a year. With such rates the traffic volume is expected to double at around 10 years time. If in this case a terminal is designed and fully implemented for the foreseen capacity of 10 to 15 years hence, it would be operating under capacity most of the time. This shows the importance of phasing the construction along the airport life span.

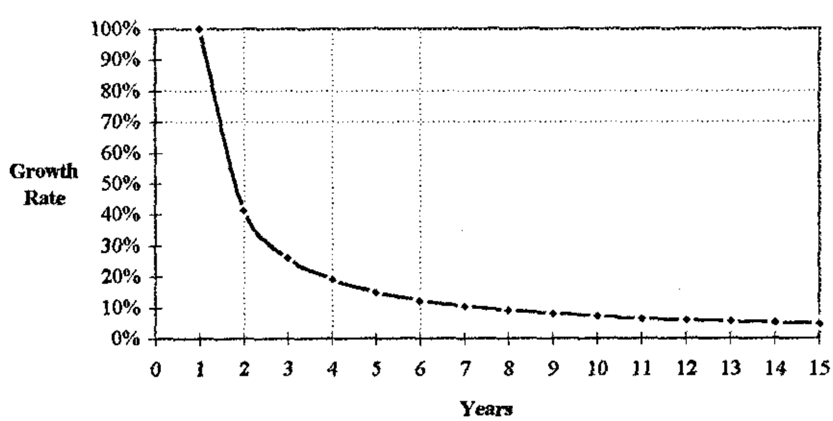


FIGURE 8.1: Rate of growth at with the volume of traffic double

Another important consideration related to rate of growth is flexibility and modularity associated with the staging of the project construction. Providing capacity for 15 years hence for example can be very costly to the airport if the final capacity is provided on day 1 of its operation. Figure 8.2 shows that, with 10% average growth rate a year, a terminal building may use only 25%

of its capacity in the first year, and may not use half of its capacity until half of its life span is gone. Figure 8.3 also shows that five years seems to be a reasonable modularity for staging the construction, which gives an ideal utilisation of the building, moreover when considering that the anticipated traffic may fail to materialise, see also Figure 8.4.

It is unlikely that high volume airports would adopt single level terminals; however the decision on number of terminal levels will certainly influence the configuration procedure. The decision on the number of levels is closely related to the decision to use passenger loading bridges. The latter may seem difficult to justify from an economic point of view, because loading bridges, in theory, are not absolutely indispensable and cannot therefore be 'economically profitable'. Yet airport and airlines are free to make an economic choice. The justification is mostly grounded on the quality of service provided to the airport's users and on the financing capacity of the organisation that will pay for the installation.

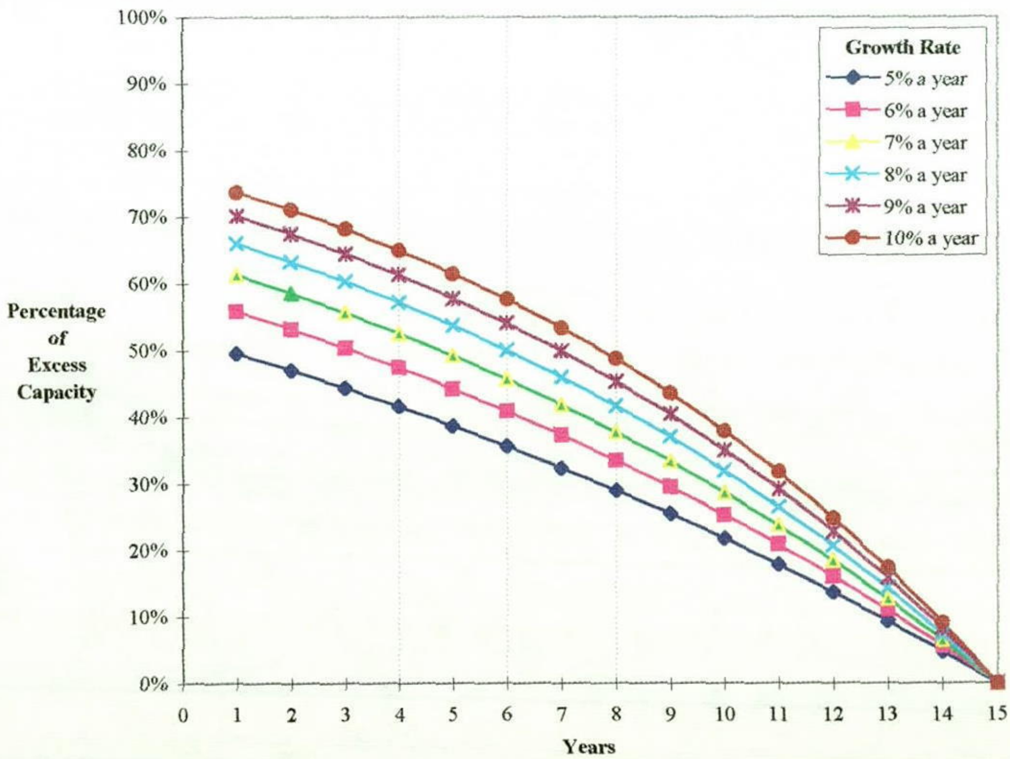


FIGURE 8.2: Percentage of excess capacity for a building constructed with expected traffic in 15 years hence.

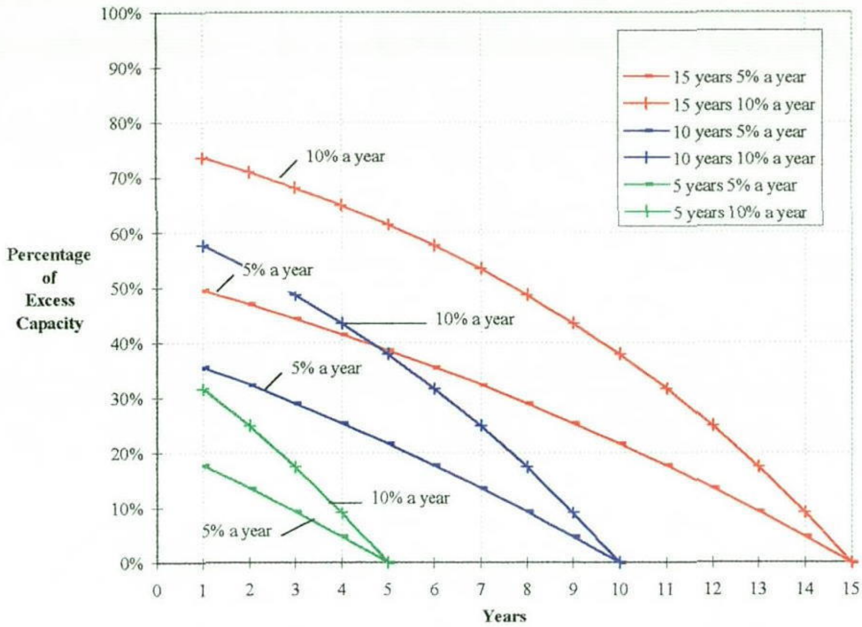


FIGURE 8.3: Percentage of Excess Capacity for 5 to 10% Growth Rate, in 5, 10, and 15 years hence.

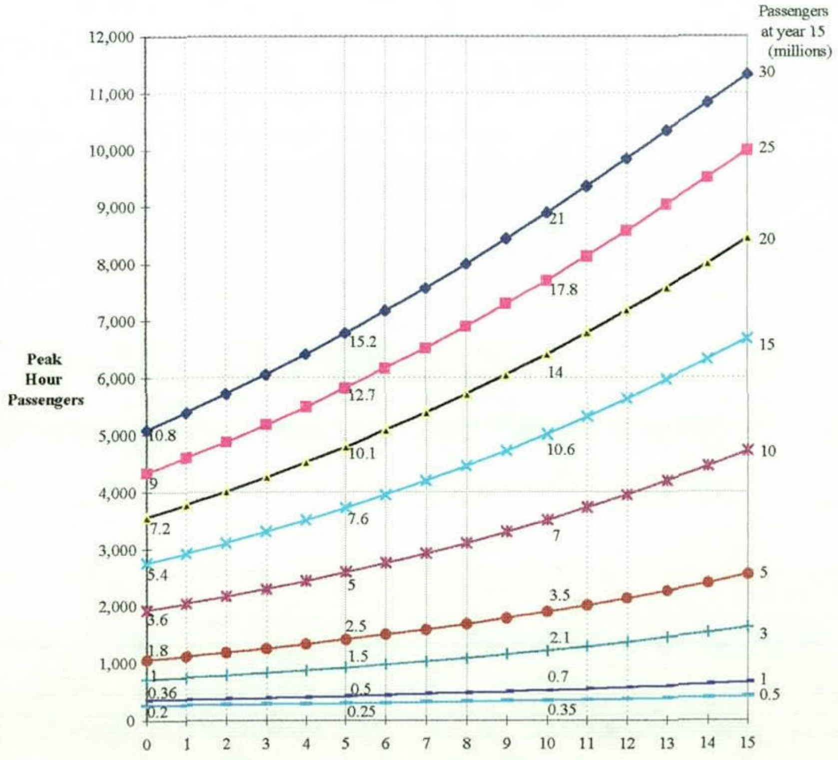


FIGURE 8.4: Variation in Peak Hour Passengers during 15 years of an airport project life span, considering an average growth rate of 7% a year for several passenger traffic volumes.

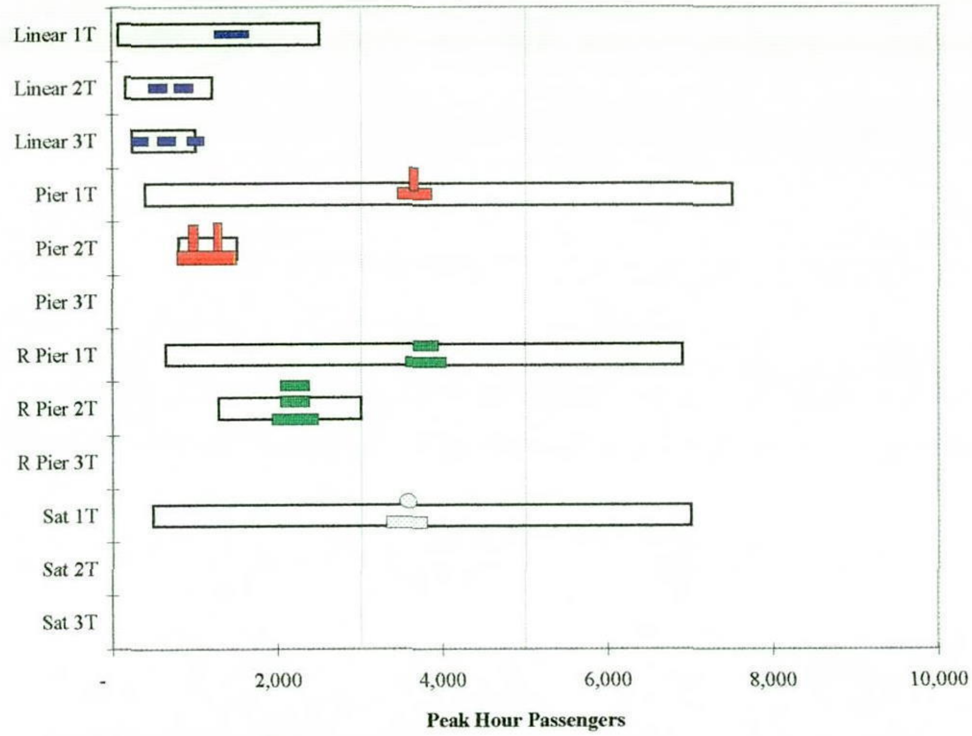
The division of traffic is another factor that is important in the definition of the configuration of a terminal. The possibility of splitting the traffic into multi-terminals or unit terminals may prove very efficient in terms of diminishing walking distances and simplifying passenger flows, though it may bring some of the disadvantages of decentralisation. The separation of International and Domestic traffic is included in this discussion. Some airports segregate the Domestic traffic to individual buildings, but it is not uncomon to accomodate both traffic into a single terminal where a flexible solution is the 'swing' gate, which can be either International or Domestic; e.g. Sao Paulo Intl. Airport, Euro-Hub in Birmingham.

The last but by no means least important factor to be taken into account is transfer passengers. A terminal with high percentage of transfer passengers, a hub airport for instance, has to rethink its concept. Other configuration rather than the basic forms considered here may be the right solution, a cruciform terminal for example of which the moment of transport with respect to its C.G. is very low as seen in Chapter 7, may be the right solution. Nevertheless, the operation procedures may play a prevalent role in this respect. The midfield passenger buildings exemplified by the New Denver International Airport, the cross ('X') shape of the Pittsburgh Airport, the new Hong Kong/ Chek Lap Kok may represent a new concept for designing airport terminals with high percentage of transfers.

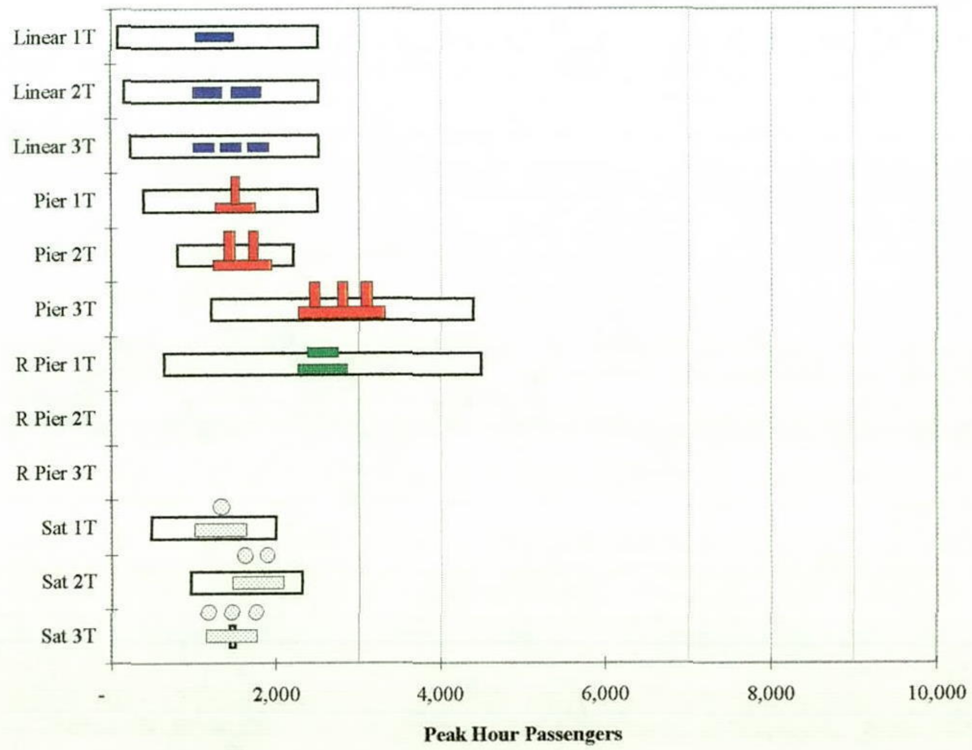
These are primary decisions that will affect the final concept choice. The three so called 'value features' in airport design proposed by Blow (1994) are in agreement with these characteristics:

- value features of size (growth rate);
- value features of layout (compactness, centralisation/decentralisation, number of levels);
- value features of flexibility (modularity, number of levels).

Having reviewed in general terms some of the factors that must be taken into account when considering the different types of an airport passenger building, a summary of the outcome of the comparative analysis of the basic terminal concepts using Moment of Transport as described in Chapter 7 is shown in Figure 8.5.



a) Traffic volumes with more than 50% of transfer passengers.



b) Centralised Passenger Flows.

FIGURE 8.5: Application of Basic Concepts in relationship to peak hour passengers.
(Centralised Main Terminals)

The underlying rationale in Figure 8.5 is based on the analysis of Moment of Transport applicable to individual Concepts in terms of single or multi terminals. Clearly, for example, it shows the greater suitability of the Pier 1T, Remote Pier 1T and Satellite 1T concept in relation to the same concepts but with multiple terminals.

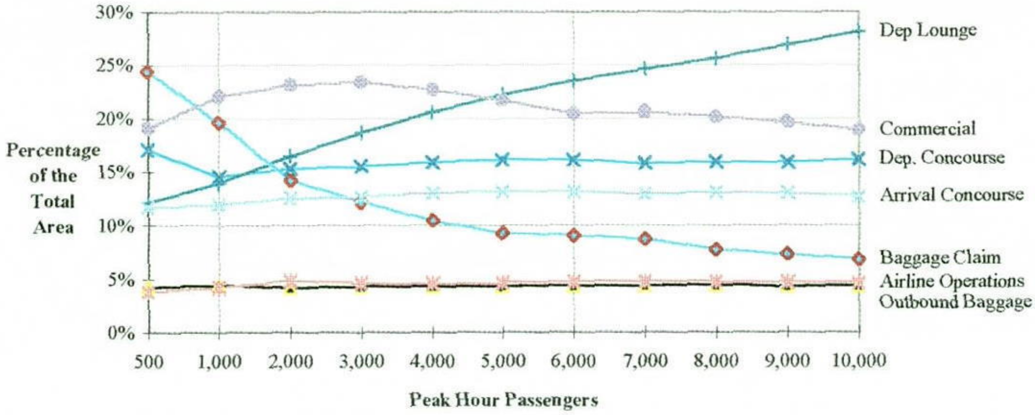
Of course that the main objective here is not to identify the best Basic Concept, but to state explicitly the pertinence of the suggested methodology for comparative analysis of terminal configurations. It has been stated elsewhere [de Neufville, 1980, 1995] that no single Concept of airport passenger buildings is best for all circumstances, and therefore a hybrid configuration should be searched; Moment of Transport is a simple and powerful framework to help in finding this configuration.

8.4 Space Sensitivity Analysis

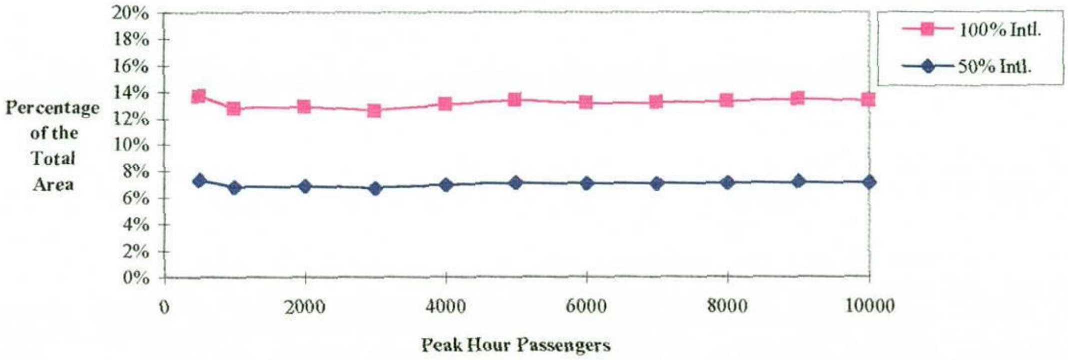
The terminal sizing process as discussed in Chapters 2, 3 and 5 is normally based upon calculation of the areas of individual facilities. The total area is therefore determined by the *summation* of all individual areas.

In this process it is interesting to observe the contribution of each facility to the terminal as a whole. There are some facilities that are more significant in terms of size than the others. For example, the departure lounges -- the holding facility for passengers before boarding the aircraft -- represent around 25 to 30% of the total area of the terminal including circulation areas. International facilities which are dependent on the percentage of international passengers expected to use the airport may constitute around 15% of the total terminal area when all passengers are international. Figure 8.6 shows these percentages in relation to total areas of the most significant facilities in terms of size.

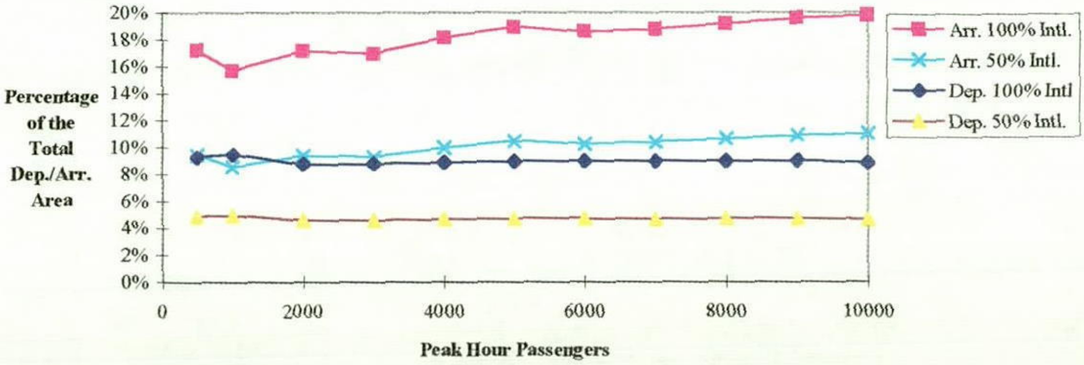
As suggested above, the growth rate is a very important factor in the design process. As the calculation of space is usually based upon peak hour passengers and the latter is consequently dependent on the rate of growth, the variation of the peak hour passengers during the life span of a project is fundamental for phasing the construction of the passenger building. Figure 8.7 shows the variation of the peak hour passengers for several traffic volumes when considering a growth rate of 7% a year. See also Figure 8.4.



a) Terminal Facilities



b) Total International Facilities



c) International Facilities located in Departure and Arrival Areas

FIGURE 8.6: Percentage of total area allocated to individual facilities in the design process.

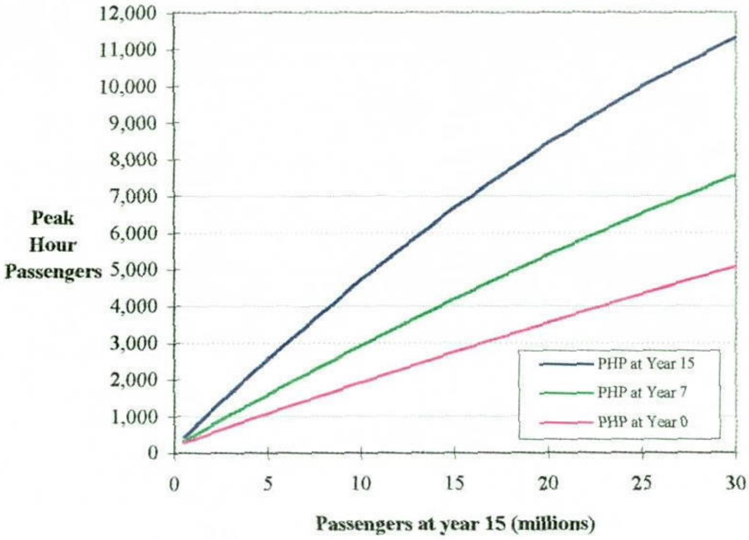


FIGURE 8.7: Variation in Peak Hour Passengers during 15 years of an airport project life span, considering an average growth rate of 7% a year and for different traffic volumes.

8.5 Recommendation for Future Research

The use of Space Syntax theory to evaluate some of the factors that affect performance of the terminal in relation to passengers may be a strong tool to permit a different approach to the evaluation of terminal concepts. For instance, the integration ratio (used in Space Syntax) may be associated to the degree of compactness viewed by an originating or transferring passenger in a very different way than when looking at compactness as a result of a geometric plan view. It seems probable that the predominant difference between the concepts is ascertained mainly by circulation areas and in the way that individual facilities are connected, consequently generating dissimilar geometric forms. In this sense the symmetry and relative asymmetry (from Space Syntax Theory) may be used to analyse for instance the directness or circuitry of passengers within the terminal, which may have significant implications in the process of generating building types.

As the main terminals designed in this research were assumed take the same for each different basic concept, the use of simulation in respect to passenger flows coupled with the application of Moment of Transport to analyse different shapes of main buildings may be a further step in the process of find the best alternative configuration. In other words, the variances that a geometric modification or arrangement in the main building may cause upon operational procedures should become apparent through the use of simulations. Simulation seems to be the only way to observe eventual differences, since the individual facilities are sized using the same method, not considering shape and geometry.

Using an average aircraft for each volume of traffic was one of the assumptions for calculating the moments of transport of each basic concept. It was assumed also that any variation in terms of delay and aircraft turnround times would be compensated by the provision of aircraft remote stands served by buses. These assumptions, although consistent with the objective of comparative analysis, may suggest two new areas for research. Firstly with respect to the provision of aircraft remote positions: it seems reasonable to question the implications of what would be the ideal solution for the number of gates served by loading bridges contrasting with those served by buses. Secondly, as pointed out earlier, the Moment of Transport methodology seems to be conceptually convenient for the designer to consider alternative strategies for gate assignment optimisation.

8.6 New Perspective

The airport has existed in various forms for some decades and it seems unlikely that there will be a ready made substitute for it. There is no doubt that the Terminal Form is in addition to everything else an expression of the attempt to adapt to the aircraft shape that operate on it, an extension of facilities that performs many complexes and interrelated functions, coupled with all aspects of passenger distribution. The perspective of the planners who approach this interrelation with some degree of empiricism is that they do not know nearly enough to plan and design intelligently for the airport of the future. As Hall (1969) said: "... plan we must because the future has caught up with us."

Moment of Transport is a 'tool' that may open the planners perspective in the sense that the difference between 'Concepts' may not only be distinguished by a number of advantages and desadvantages, but by means of a consistent analysis procedure, allowing the choice between possible alternative Terminal Concepts be made without empiricism. It is clearly an attempt to collapse many design factors to a single measurement that not only expresses the interrlelationship between these factors, but also indicates the degree of passenger concentration or passenger distribution. The framework presented in Chapter 7 allows the planner to look at Terminal Concepts in a structured way.

8.7 Summary

It has to be agreed that there is no best solution for an airport project. However, there may be a best alternative and the designer's job is to find this best alternative. Therefore the key to a successful design process is the planners' ability in generating plausible alternatives. This is accomplished by evaluating different types of buildings for the set of different types of traffic expected at a specific airport. The generation of different building configurations gives to the designer the possibility of finding the best suitable alternative for the many variables involved in the airport design process.

The main conclusion however is the pertinence of Moment of Transport as defined in the last chapter, to evaluate any configuration, not necessarily just the basic concepts outlined in this research.

The Moment of Transport gives the degree of compactness of a passenger distribution which is formed by different shapes given to the building. As for the commercial facilities a concentrated pedestrian flow pattern is essential, so the best building configuration is the one that gives the least Moment of Transport, provided that the other parameters have the same influence on all alternatives. The ideal configuration will be the one with the smaller moment, and with the centre of gravity of its processing facilities as closer as possible to the centre of gravity of its passenger distribution. The result of this is short walking distances. The basic principle in achieving this is to balance facilities and aircraft in such a way that passenger flows and layout are kept as simple as possible. An example of a well thought-out configuration is the Euro-Hub Terminal in Birmingham, in which the centre of gravity of the processing facilities is close to the centre of gravity of its passenger distribution. The rectangular (nearly a square) building shape with most of its processing facilities in the middle makes the two centres of gravity very close together.

Finally, the applicability of Moment of Transport to airport building concept evaluation can be depicted in Figure 8.8, which shows the interrelationship between the factors (variables) involved in this process, see Chapter 6.

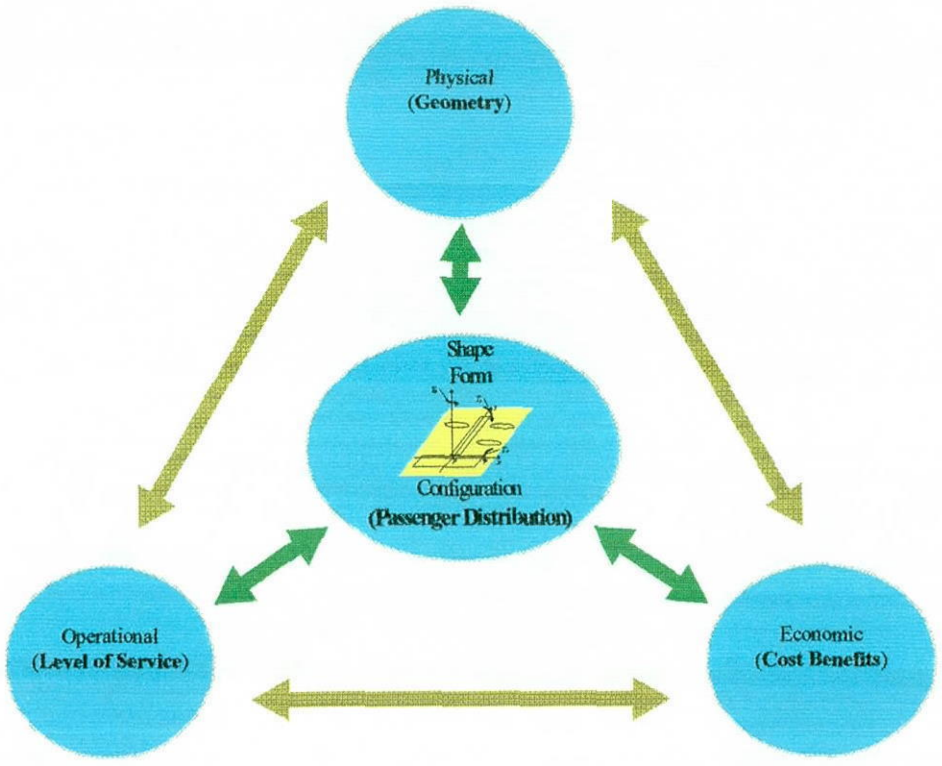


FIGURE 8.8: Factors related to passenger distribution that is associated with *Terminal Configuration* and *Moment of Transport*.

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APPENDIX A - Available Methodology in Terminal Design

Although there are many different methodologies which address distinct problems and facets of airport terminal, there are further critical issues that the current methodologies do not address. Mumayiz (1985) observed that "collective knowledge of planning practices of components of airport terminals, were obscured behind a veil of empiricism and could not scientifically support a systematic and theoretically consistent methodology". It is more prudent to say that the design of airport terminals has become a highly complex technological system, therefore it is difficult to consolidate all aspects in a few simple procedures while making it comprehensive at the same time.

The theoretical explanation described in Chapter 2, section 2.4 is rather academic, but it doesn't really state the actual steps in the process of terminal design.

For instance, when addressing the issue of layout design for airport terminals some key questions have to be answered.

- What are the logical steps that airport planners take while laying out a terminal?
- Do planners have a systematic approach for laying out the terminal?
- If so, is it possible to model this approach?
- Is it possible to lay out from individual facilities?
- What information do they need?
- What evaluations have to be carried out in the planning process?

At this point it is worthwhile performing an investigation into the current methods of analysis and design of airport terminal buildings. This examination was carried out from available literature, therefore it is not exhaustive. Consequently, it is suggested that the reader accesses the references for more details. A chronological summary of the main points is presented.

The determination of space requirements at passenger terminals was viewed by Horonjeff (1962) as the following steps:

1) *Identify access modes and modal splits*: peak-hour volume of vehicles, the access facilities used, and the duration of their use.

2) *Identify Passenger Volumes and Types*. Annual and hourly passenger volumes obtained from forecasts. Passenger Types divided into: international or domestic; arriving, departing, or transfer; with or without checked baggage; mode of access to airport; scheduled or charter; and any other characteristics that may be relevant to the particular airport in question.

3) *Identify access and passenger component demand.* Identify which passengers use each facility in the terminal building.

4) *Determine General Space Requirements.* Calculate the space proportionally to the demands for various types of facilities obtained in the previous step.

The Apron and Terminal Building Planning Report [FAA, 1976a] is a broad guideline for planning and design of an airport terminal complex, which is divided into four major elements:

a) Apron, including: Aircraft Gate Position, Aircraft Service Area, Apron-Baggage and Freight Service, Taxi Lanes, Service Roads.

b) Connector, including: Concourse, Departure Lounge, Passenger Boarding Device, Airline Operations Space, Security Inspection Space, Terminal Services Space, Corridors.

c) Terminal, including: Airline Ticket Counter/Office, Terminal Services, Lobby, Public Circulation, Outbound Baggage Space, Intraline and Interline Baggage Space, Inbound Baggage Space, Airport Administration and Services, Federal Inspection Services and Others.

d) Curb, Parking, and Roadways, including: Curb, Parking, Public Roads, Pedestrian Walkways, Service Roads and Fire Lanes.

The report pointed out six base factors that may influence sizing:

- Airport characteristics: physical size; topography; and more significant the local community socio-economics, including Population and per capita income, Geographic location and distance from other airports, Concentration of commercial activity, and Proximity of major vacation-recreation areas.

- International Service Characteristics: Tendency toward higher scheduled peaks, relative long ground-service times, government controls.

- Passenger Traffic Characteristics: Business and tourism or personal reasons.

- Station Characteristics: Three basic types, Originating/Terminating Station, Through Station, and Transfer Station are noted.

- Scheduled Service Characteristics: Scheduled airline service, domestic and international.

- Non-scheduled Service Characteristics: Charter Flights.

The approach for planning is based on the average day to the peak month for the airport under study. The peak hour aircraft movements are also developed to derive an Equivalent Aircraft (EQA) as a single number reflecting the seating capacities and quantity of aircraft. The sizing is predominantly based on the EQA. The elements are detailed in order: Apron, Connector, Terminal and Curb.

Atkins Planning (1973) undertook a study to advise on the development of the two major Midlands Airports - Birmingham and East Midlands up to the middle 80's. The methodology used to achieve the objectives was the following:

- Estimate the total potential demand for air services;
- Determine alternative development strategies;
- Assess the proportion of the total demand satisfied for each strategy;
- Assess the airport facilities required to satisfy this demand for each strategy;
- Assess the user benefits for each strategy;
- Assess the environmental impact for each strategy;
- Evaluate the various strategies in social cost benefit terms.

Passenger Terminals were assessed on the basis of facility requirements over and above those current at time. The factors influencing the passenger terminal facilities were assumed as air passenger (annual number, schedule/charter split, international/domestic split, standard busy rate) and aircraft movements (annual number, standard busy rate).

Blankenship(1974) asserts that the critical parameters in the terminal system evaluations are those associated with congestion and delays; and flexibility is the attribute that must be emphasised in any evaluation of basic terminal configurations. He defines three steps for sizing terminals:

1) *select the basic terminal configuration*;
2) *forecast flow of passengers, baggage and related support systems*; and finally,
3) *provide terminal buildings space in proportion to the demand for air travel.* The spaces have to be sized for individual facilities. The following facilities are listed: Public Lobby, Concourses, Hold Rooms, Inbound Baggage Areas, Outbound Baggage Areas, Baggage Claim, Concessions, Custom Inspection, Immigration, Security Inspection, Operations, Crew Lounges, Catering, Aircraft Maintenance, Aircraft Stores and Tools, Ground Equipment Maintenance, Line Cargo, Airline Offices, Airport Management, Public Toilets, and Observation Areas.

De Neufville (1976, 1980) emphasised that terminals should be designed with the utmost care. The initial description is concerned with conventional practice summarised as forecasting and sizing. His final suggestion is to evaluate a service system in three distinct but related phases:

1) *Obtain detailed performance of the facility in study at various levels of capacity.*

2) *Analyse this information against peaks of traffic, and develop a plan for influencing these peaks.*

3) *Evaluate the value of providing different levels of capacity instead of relying upon some arbitrary standard.*

His analysis and commentary make it clear that the traditional approaches to airport planning and the traditional solutions were no longer adequate.

Ashford (1979, 1992) states that the passenger terminal performs three different or main functions, therefore requiring three different types of area:

Function	**Activity**	**Space Required**
a) Change of mode	walking - from surface to air mode.	Circulation areas
b) Processing	ticketing & check-in the passengers, security checks, government controls, etc.	Processing areas
c) Change of movement type	waiting - hold rooms, departure lounges, departure concourse, etc.	Holding areas

The sizing of a terminal to provide these space requirements is therefore accomplished by performing the following steps:

1) *Determination of peak hour design demand* - based on the Typical Peak Hour Passenger (TPHP) used by the FAA - Federal Aviation Administration.

2) *Statement of passenger traffic by type* - is suggested as divided into domestic or international scheduled or charter, transfer or transit, business or leisure, intercontinental or short haul, and by access mode.

3) *Identification of individual facility volumes*; - is carried out in the following facilities: Airline Ticket counters, Airline Ticket Offices and Support, Outbound Baggage Room, Bag Claim, Airline Operations and Support Areas, Departure Lounges, Other Airline Space, Lobby & Ticketing, Lobby waiting Area (Departure), Lobby Bag Claim, Food and Beverage, Other Concessions and Terminal Services, Other Rental Areas, Other Circulation Areas, Heating - Ventilating - Air Conditioning and other Mechanical Areas, Structure.

4) *Calculations of space requirements.* - is presented for planning purposes, using a methodology based upon FAA (Parson's Report).

Analysis of flows through terminals is emphasised to examine the behaviour of passenger and baggage. Three methods of analysis are mentioned: Network Analysis, Queuing Theory and Simulation. Three important aspects - expandability, modularity and flexibility - are emphasised that must be taken into account when designing an airport passenger terminal.

Hart (1985) is another source that gives information on how to perform space calculations and functional layout of individual elements of the terminal, although the necessary steps for designing are not clear stated.

The Transportation Research Board [TRB, 1987] in its Special Report 215 - Measuring Airport Landside Capacity establishes eleven steps to assess capacity that would, with a few changes, comprise an interesting framework to be incorporated into any process of designing.

Step 1. Identify Goals and Objectives of the assessment or problem to be solved;

Step 2. Specify landside components for assessment

Step 3. Describe Each Component

Step 4. Describe How Components Relate

Step 5. Collect Data on Demand Characteristics and Operating Factors

Step 6. Collect Data on Community Factors

Step 7. Estimate Component and Total Service Levels

Step 8. Estimate Current and Maximum Service Volumes

Intermediate Decision: Is Landside Capacity Adequate?

Step 9. Examine trade-offs in Service Among Components

Step 10. Identify short-term measures to Improve Capacity

Step 11. Review long-term Planning and Management Implications

The committee identified the following critical landside components which may constrain capacity. (Capacity, potential service levels and service volumes can be determined on considering how individual components interact with one another and with demand):

Components	Factors influencing service level and capacity
Aircraft parking position and gate	Number of parking positions and physical layout Utilisation (Ratio of time gate is effectively occupied) Hours of operation Flight schedule and aircraft mix Airline leases and operating practices, airport management practice
Passenger Waiting Area	Waiting and circulation area *(lounge and accessible corridor)* Seating and waiting-area geometry Flight schedule, aircraft type, passenger load, and gate utilisation Boarding method Passenger behavioural characteristics and airline service characteristics
Passenger Security Screening	Number of channels, space, and personnel Type, equipment sensitivity, and airport airline/agent policy and practice Passenger characteristics (number of hand luggage, mobility, number of passengers average service time) Building layout and passenger circulation patterns Flight schedule and load
Terminal Circulation	Terminal Configuration Passenger characteristics Flight schedule and load
Ticket Counter and Baggage Check	Number and type of position Airline procedures and staffing Passenger characteristics Space and configuration Flight type, schedule, and load *Airline lease agreement and Airport management practices*
Terminal Curb	Available frontage Frontage roads and pedestrian paths Management policy Passenger characteristics and motor vehicle fleet mix Flight schedule
Baggage Claim	Equipment configuration and claim area Staffing practices Baggage load Passenger characteristics
Customs and Immigration -	Number of channels, space and personnel Inspector Passenger characteristics Space and configuration Flight schedule load
Connecting Passenger Transfer	Terminal configuration Ground transport *Passenger characteristics* Flight schedule and load factors

Estimates of service levels are made on a case to case basis. The final remarks on this report discuss the need for the terminal system be assessed as a whole. This is based on the fact that the combination of queues and short delays in each component may produce a terminal capacity problem.

MACKAY Consultants & Norman Ashford (Consulting Engineers) LTD (1989) were commissioned by Highlands and Islands Airports to undertake a study of the future development of Inverness Airport. The objectives of the study were beyond just the Terminal expansion, and the approach to design was as follows:

1) *Collecting historical traffic data.* Aircraft movements; air transport movements; air passengers by type and nationality of operator; terminal and transit passenger (for the study, this was the most useful.).
2) *Forecasting* traffic growth at the airport over the next ten years based on economic development trends in the area and based on the views of airlines,

local businesses and tourist operators. The results were formulated in three scenarios composed of best, pessimistic and optimistic estimates.

3) Terminal *evaluation and sizing*. The terminal overall space was evaluated in relation to both peak and annual passenger throughput. For first approach the following facilities were analysed: Check-in area, Outbound Baggage, North (Security) Lounge, Domestic Arrival Baggage area, and Kerbside.
4) To allow staging of terminal facilities the process of expansion was proposed in terms of *phasing*. The expansion was divided in 6 phases.

The IATA Programme for sizing and capacity calculation is based on formulae drawn from the IATA Airport Terminals Reference Manual and Guidelines for Airport Consultative Committees [IATA, 1989, 1991, 1995] and addresses the following terminal elements: Departure Kerb, Departure Concourse, Check-in Desks, Departure Passport Control, Security Check, Departure Lounge, Gate Hold Rooms, Arrival Health Check, Arrival Passport Control, Baggage Claim Area, Number of Baggage Claim Devices, Arrival Customs, Arrival Concourse, Arrival Kerb, and Restaurant Seating Capacity. With the IATA Reference Manual (1995), the IATA Programme may be considered as a complete tool for the expansion or sizing of individual facilities for a new airport terminal building. The main steps for the designing process are not explicit, however the Manual gives useful general and specific guidelines that permit sizing and layout of a terminal. The starting point is forecasting.

Blow (1991) illustrated terminal design details, and through data sheets for the different facilities, he summarises the design process indicating:

- Policy decisions to be applied;
- Quantity Factors to be assessed;
- Typical space calculation based on choice of configuration;
- IATA Airport Terminals Reference Manual references;
- Layout example;
- Photographs of noteworthy examples.

The explanation of taxonomy of the different terminal types considerably assists the the design activity.

As can be seen in the foregoing paragraphs the designing process of an airport terminal follows traditional approaches or conventional practices and very little has been added. Therefore the question addressed at the beginning can then be summarised, see Chapter 2, section 2.5.

Appendix B : Terminal Facilities - Average Dimensions (all dimensions in metres)

		Terminal		Check-in / Airline Offices	Departure Concourse	Dep Lounge/ Gate Hold Room	Corridor	Passport Control/ Security Check	Dep Bag	Customs	Bag Claim	Arrival Concourse Waiting Area	Pier positions	Sat Pos	Pier/Sat Dimens	
		width	length	depth	depth	width	Dep./Arr.	Dep./Arr.	dim	dim	dim	width			dim	obs
Australia		66			19	9x40	7.2	9x12						4		
Birmingham	T1	100	70	7	30x40	16x30 comm	6.5	15x10	21x35	14x12	21x35	10x30	7, 4		14x180 / 8x140	
Detroit	Davey Terminal	60		10 - 25	10		15									
Detroit	Int. Terminal	68		20	7 - 15				18x		32x43 / 29x33	17x45				
Detroit	L.C. Smith Terminal	65		9	25	12	6 - 7	13x25								
Dorval		90			9 - 14		6	15x15/10x 30 / 55x15		12x30	36x60/22x 48	9	10, 8, 20			
Dublin		75	100	5			10/5	11x10	22x120	10x35	24x90	26	13	8		
East Midlands		45	80	9	18				25x40		(7-10)x12 / 25x40					
Gatwick	North	145	150	11x33 isl	145x60	120x45 comm	~ - 14	33x33 /32x55	45x150	15x40	50x100	30x120	7		14x470	
Gatwick	South	150	190	10x40 isl	70x90	50x40 common	6.0 - 11	30x30 / 40x45	85x70	28x30	50x100	40x90	8, 15	8	20x550/ 20x150/80 diam	
Heathrow	T1	90	210	5.5x12 isl	25x130	10	8. - 16	30x20 / 30x35	25x130 / 30x40	25x25	75x35	40x65	10, 16		40x440/ 20x300	2piers
Heathrow	T2	90	210		15 a 22 dep	10	4. - 10	20x20 / 12x50	60x35	10x45	22x90	15x150	7, 6		25x180/ 28x200	2piers
Heathrow	T3	dep 130	140	8x32 isl + 20 airl	20	11	7. - 15	25x40 / 40x60	40-55x130	20x50	40x150		8, 7, 10		25x350/ 25x230/ RP28x450	3piers
Heathrow	T3ar	arr 90	250													
Heathrow	T4	95	190	14	20	var	8. - 18	15x20 + 15x55 / 20x55	55x190	15x40	26x135	18	17		28x650/ or (2x)300	
Helsink		65	130	5x12 isl	10	15x50 c0mm	5	10x15	20x50	10x30	28x50	8x60	11 linear		13.5x400	
LA	B1	35 - 40	170	19	11. - 15	10	7. - 8		15x60		67x21				38x130	

Appendix B : Terminal Facilities - Average Dimensions (all dimensions in metres)

		Terminal		Check-in / Airline Offices	Departure Concourse	Dep Lounge/ Gate Hold Room	Corridor	Passport Control/ Security Check	Dep Bag	Customs	Bag Claim	Arrival Concourse Waiting Area	Pier positions	Sat Pos	Pier/Sat Dimens	
		width	length	depth	depth	width	Dep./Arr.	Dep./Arr.	dim	dim	dim	width			dim	obs
LA	B3	25	220	10 - 12	8x72(x2)		6 - 8.6		25x90					13-14	100x65	
LA	B4	18 - 28	240	10	10		7		25x70		18x77 / 18x45			#	45x120	
LA	B5			17	14	10.0-17.0	10.0 - 12	20x24	33x78		20x47 / 30x52				53x145	
LA	B6	30	300	20	8		8	13x14 Sec	30x85		18x90 / 20x58					
LA	B7 & 8	20 - 30	280	17	12.0 - 15	14	5. - 12		40x120		20x85 20x100	15x130		8. - 13	50x120	
LA	Bradley Int.	136	160	24	24x90	7.0 - 17	8	24x158	55x163	20x60(2x)	36x15 / 60x23(x2)				linear 770	
Munich II			1000	15	10.0-15	20x	5-6	15x18 (x4)	25x125 (x4)	7x45 (x5)	25x85 (x5)	10x	20 linear			
Newcastle		75	100	6	15	12x25	8		18x90		15x15 / 15x40	15				
Rio		70	480	17	15x400	25xVar	5	10x30 (x4)	15x130 / (15x140 + 15x155)	15x55 (x2)	30x100 / 25x90 (x2)	13x360				
Roma Fiumicino		107	190	5x30 Isl	14	5.5 - 12	5 - 10	10x20 (x2) / 20x45 + 37x60	65x140	23x9 (x2)	28x170	(15-18)x180	13		15	
Sao Paulo		70	250	28	30	10x30	10 & 3(x2)	30x25 / 30x20	25x50	55	40x36	18x120	11		35x200	
Schiphol		125	260		36		7 - 18	20x20(x2) / 28x40	50x125	45x55	50x83	19	8, 6, 13, 14		35x500 / 22x180 / 22x470 / 22x470	
Seattle-Tacoma	International	66 - 110		17	17	5 - 8	6 - 10		15x20 / 38x80				7, 13, 14, 5		12 - 19	
Seattle-Tacoma	North Satellite													10	57x150	
Sidney		45 - 90	210													

APPENDIX C - 'Moment of Transport' - Programme Codes

Clipper Programme

```
declare x[52],y[52]
clear screen

sele 1
use trigon

sele 3
use pier
zap
sele 4
use linear
zap
sele 5
use satel
zap
sele 6
use remote
zap
sele 7
use cross
zap

@ 1,1 to 23,79 double
choice=" "
Px=space(3)
safety="7.5"
infospan=space(5)
lent=space(4)

Do while choice $ " 123456"

@ 2,05 say "(1)Pier, (2)Linear, (3)Satel., (4)Remote, (5)Cross, (6)All, (7)Stop .." get choice valid choice $ "1234567"
read

if choice<>"7"

@ 4,05 say "Safety .. " get safety
@ 4,22 say "Span .. " get infospan
@ 4,40 say "Pax  .. " get px
read
span=val(infospan)+val(safety)
auxsp=str(span,5,1)
@ 4,55 say "TPax Width .. " get auxsp
read
sp=val (auxsp)
pax=val(px)
@ 8,04 say "n     d   p      MT      R0      Rx     Ry    Xcg    Ycg"
```

```
v=val(choice)
if v=6
  flag=0
  v=1
else
  flag=v
endif
do while v<=5
  lin=10
  h=(span)/(2*(2^0.5))
  T=2*h+sp/2

  do case
    case v = 1
      in="05"
      @ 6,3 say "You are processing Pier... "
*       arq="pier"
    case v = 2
      in="01"
*       arq="linear"
      @ 6,3 say "You are processing Linear. "
      case v = 3
*       arq="Satel"
      @ 6,3 say "You are processing Satel.. "
      in="03"
    case v = 4
*       arq="Remote"
      @ 6,3 say "You are processing Remote. "
      in="04"
    case v = 5
*       arq="Cross"
      @ 6,3 say "You are processing Cross.. "
      in="12"
  endcase

*    sele 2
*    copy stru to &arq
*    sele 3
*    use &arq
*    zap

* if v<>6
    @ 6,38 say "aircraft"
    @ 6,30 say "from" get in
    read
* endif
  ini=val(in)

  Do case
    case v=1                    && Pier
```

```
@ 6,50 say "ACF tail -> wing tip .." get lent
read
le=val(lent)

for n=ini to ini+24 step 2
   f=int(n/2)
   for i=1 to f-1
      x[i]=T
      y[i]=(i*2-1)*span/2
   next
   x[i]=T-h
   y[i]=y[i-1]+h+span/2

   Tx=0
   Ty=0
   xcg=0
   ycg=0
   for k=1 to i
      ycg=y[k]+ycg
      Tx=Tx+x[k]^2
   next
   ycg=(2*ycg+(y[i]+h))/n
   for k=1 to i
      Ty=Ty+(y[k]-ycg)^2
   next
   Tx=Tx*2*pax
   Ty=(Ty*2+(y[i]+h-ycg)^2)*pax
   d=(span)*n
   Rx=(Ty/(n*pax))^0.5
   Ry=(Tx/(n*pax))^0.5
   M=int(Tx+Ty+.5)
   R0=( M/(n*pax) )^.5
   sele 3
   append blank
   replace nacf  with n
   replace per   with d
   replace momtra with M
   replace RPolar with R0
   replace R_x   with rx
   replace R_y   with ry
   replace X_cg  with xcg
   replace y_cg  with ycg

   replace pass  with pax
   replace env   with val(infospan)
   replace safe  with val(safety)
   replace comp  with le

   @ lin,03 say str(n,2)+"    "+str(d,6,1)+"  "+str(pax,4)+"   "+str(M,11)+"   "+;
   str(R0,6,1)+"  "+str(Rx,6,1)+"  "+str(Ry,6,1)+"  "+str(Xcg,6,1)+"  "+str(Ycg,6,1)
```

```
      lin=lin+1
    next

  case v=2                              && Linear
    for n=ini to ini+12
      Xcg=0
      ycg=0
      for i=1 to n
        x[i]=(i*2-1)*span/2
        xcg=xcg+x[i]
      next
      Tx=0
      Ty=0
      xcg=xcg/n
      for i=1 to n
        Tx=Tx+(x[i]-xcg)^2
      next
      Tx=Tx*pax
      d=(span)*n
      Rx=(Ty/(n*pax))^0.5
      Ry=(Tx/(n*pax))^0.5
      M=int(Tx+Ty+.5)
      R0=( M/(n*pax) )^.5
      sele 4
      append blank
      replace nacf  with n
      replace per   with d
      replace momtra with M
      replace RPolar with R0
      replace R_x   with rx
      replace R_y   with ry
      replace X_cg  with xcg
      replace y_cg  with ycg

      replace pass  with pax
      replace env   with val(infospan)
      replace safe  with val(safety)

      @ lin,03 say str(n,2)+"    "+str(d,6,1)+"  "+str(pax,4)+"   "+str(M,11)+"   "+;
      str(R0,6,1)+"   "+str(Rx,6,1)+"  "+str(Ry,6,1)+"  "+str(Xcg,6,1)+"  "+str(Ycg,6,1)
      lin=lin+1
    next

  case v=3                              && Satel.
    for n=ini to ini+12
      alf=180/n
      sele 1
      goto int(alf+0.5)
      tan=tangent
      R=span/(2*tan)
```

```
        Xcg=0
        Ycg=0
        Tx=0
        Ty=0
        for i=1 to n
           a=int((2*i-1)*alf+.5)
           goto a
           x[i]=R*cosine
           Tx=Tx+x[i]^2
           y[i]=R*sine
           Ty=Ty+y[i]^2
        next
        Tx=Tx*pax
        Ty=Ty*pax
        d=(span)*n
        Rx=(Ty/(n*pax))^0.5
        Ry=(Tx/(n*pax))^0.5
        M=int(Tx+Ty+.5)
        R0=( M/(n*pax) )^.5

        sele 5
        append blank
        replace nacf  with n
        replace per   with d
        replace momtra with M
        replace RPolar with R0
        replace R_x   with rx
        replace R_y   with ry
        replace X_cg  with xcg
        replace y_cg  with ycg

        replace pass  with pax
        replace env   with val(infospan)
        replace safe  with val(safety)

        @ lin,03 say str(n,2)+"    "+str(d,6,1)+"  "+str(pax,4)+"   "+str(M,11)+"  "+;
        str(R0,6,1)+"  "+str(Rx,6,1)+"  "+str(Ry,6,1)+"  "+str(Xcg,6,1)+"  "+str(Ycg,6,1)
        lin=lin+1
      next

case v=4                              && Remote
      @ 6,50 say "ACF tail -> wing tip .." get lent
      read
      le=val(lent)

      for n=ini to ini+24 step 2
         x[1]=h
         xcg=h
         ycg=0
         flg=0
```

```
    Ty=2*(T-h)^2              && 1 no inicio 1 no final
    for i=2 to (n-6)/2+1
      x[i]=2*h+(i*2-1)*span/2
      xcg=xcg+x[i]
      Ty=Ty+T^2
      flg=1
    next
    if flg=0
      i=2
    endif
    x[i]=x[i-1]+h+span/2
    x[i+1]=x[i]+h
    xcg=( (xcg+x[i])*2 + x[i+1] )/n
    Tx=0
    for j=1 to i
      Tx=Tx+(x[j]-xcg)^2
    next
    Tx=(2*Tx + x[i+1]^2)*pax
    Ty=Ty*pax
    d=(span)*n
    Rx=(Ty/((n-2)*pax))^0.5
    Ry=(Tx/(n*pax))^0.5
    M=int(Tx+Ty+.5)
    R0=( M/(n*pax) )^.5
    sele 6
    append blank
    replace nacf  with n
    replace per   with d
    replace momtra with M
    replace RPolar with R0
    replace R_x   with rx
    replace R_y   with ry
    replace X_cg  with xcg
    replace y_cg  with ycg

    replace pass  with pax
    replace env   with val(infospan)
    replace safe  with val(safety)
    replace comp  with le

    @ lin,03 say str(n,2)+"   "+str(d,6,1)+"  "+str(pax,4)+"   "+str(M,11)+"  "+;
    str(R0,6,1)+"  "+str(Rx,6,1)+"  "+str(Ry,6,1)+"  "+str(Xcg,6,1)+"  "+str(Ycg,6,1)
    lin=lin+1
  next

case v=5                          && Cross
  @ 6,50 say "ACF tail -> wing tip .." get lent
  read
  le=val(lent)
```

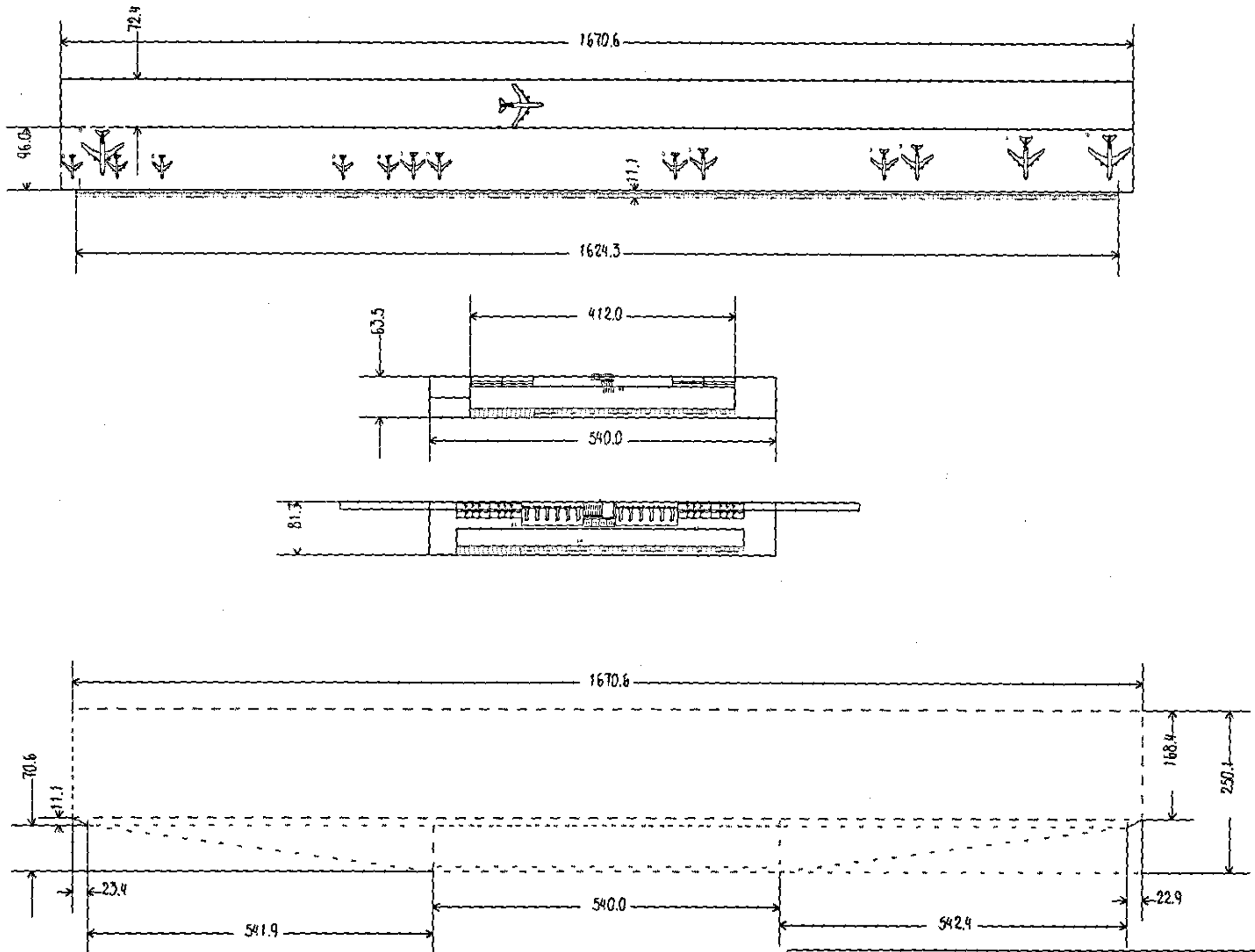
```
@ 20,2 clear to 22,78
for n=ini to ini+40 step 4
  q=n/4
  au=q-1
  x[1] =sp/2 + h
  Tx=x[1]^2
  Ty=0
  y[au]=sp/2 + h

  Do case
    case n=12
       x[2]=x[1]+2*h
       x[3]=x[2]+h

       y[au-1]=y[au]+ 2*h

    case n=16
       x[2]=x[1]+h+span/2
       x[3]=x[2]+h+span/2
       x[4]=x[3]+h

       y[au-1]=y[au]+h
       y[au-2]=y[au-1]+h

    case n=20
       x[2]=x[1]+h
       x[3]=x[2]+span/2+le
       x[4]=x[3]+span/2+h
       x[5]=x[4]+h

       y[au-1]=y[au]+h
       y[au-2]=y[au-1]+span/2+le
       y[au-3]=y[au-2]+span/2+h

    case n=24
       x[2]=x[1]+h
       x[3]=x[2]+span/2+le
       x[4]=x[3]+span
       x[5]=x[4]+span/2+h
       x[6]=x[5]+h

       y[au-1]=y[au]+h
       y[au-2]=y[au-1]
       y[au-3]=y[au-2]+span/2+le
       y[au-4]=y[au-3]+span/2+h

    case n=28
       x[2]=x[1]+h
       x[3]=x[2]
       x[4]=x[3]+span/2+le
       x[5]=x[4]+span
```

```
    x[6]=x[5]+span/2+h
    x[7]=x[6]+h

    y[au-1]=y[au]+h
    y[au-2]=y[au-1]
    y[au-3]=y[au-2]+span/2+le
    y[au-4]=y[au-3]+span
    y[au-5]=y[au-4]+span/2+h

case n=32
    x[2]=x[1]+h
    x[3]=x[2]
    x[4]=x[3]+span/2+le
    x[5]=x[4]+span
    x[6]=x[5]+span
    x[7]=x[6]+span/2+h
    x[8]=x[7]+h

    y[au-1]=y[au]+h
    y[au-2]=y[au-1]
    y[au-3]=y[au-2]
    y[au-4]=y[au-3]+span/2+le
    y[au-5]=y[au-4]+span
    y[au-6]=y[au-5]+span/2+h

case n=36
    x[2]=x[1]+h
    x[3]=x[2]
    x[4]=x[3]
    x[5]=x[4]+span/2+le
    x[6]=x[5]+span
    x[7]=x[6]+span
    x[8]=x[7]+span/2+h
    x[9]=x[8]+h

    y[au-1]=y[au]+h
    y[au-2]=y[au-1]
    y[au-3]=y[au-2]
    y[au-4]=y[au-3]+span/2+le
    y[au-5]=y[au-4]+span
    y[au-6]=y[au-5]+span
    y[au-7]=y[au-6]+span/2+h

case n=40
    x[2]=x[1]+h
    x[3]=x[2]
    x[4]=x[3]
    x[5]=x[4]+span/2+le
    x[6]=x[5]+span
    x[7]=x[6]+span
```

```
    x[8]=x[7]+span
    x[9]=x[8]+span/2+h
    x[10]=x[9]+h

    y[au-1]=y[au]+h
    y[au-2]=y[au-1]
    y[au-3]=y[au-2]
    y[au-4]=y[au-3]
    y[au-5]=y[au-4]+span/2+le
    y[au-6]=y[au-5]+span
    y[au-7]=y[au-6]+span
    y[au-8]=y[au-7]+span/2+h

case n=44
    x[2]=x[1]+h
    x[3]=x[2]
    x[4]=x[3]
    x[5]=x[4]
    x[6]=x[5]+span/2+le
    x[7]=x[6]+span
    x[8]=x[7]+span
    x[9]=x[8]+span
    x[10]=x[9]+span/2+h
    x[11]=x[10]+h

    y[au-1]=y[au]+h
    y[au-2]=y[au-1]
    y[au-3]=y[au-2]
    y[au-4]=y[au-3]
    y[au-5]=y[au-4]+span/2+le
    y[au-6]=y[au-5]+span
    y[au-7]=y[au-6]+span
    y[au-8]=y[au-7]+span
    y[au-9]=y[au-8]+span/2+h

case n=48
    x[2]=x[1]+h
    x[3]=x[2]
    x[4]=x[3]
    x[5]=x[4]
    x[6]=x[5]+span/2+le
    x[7]=x[6]+span
    x[8]=x[7]+span
    x[9]=x[8]+span
    x[10]=x[9]+span
    x[11]=x[10]+span/2+h
    x[12]=x[11]+h

    y[au-1]=y[au]+h
    y[au-2]=y[au-1]
```

```
    y[au-3]=y[au-2]
    y[au-4]=y[au-3]
    y[au-5]=y[au-4]
    y[au-6]=y[au-5]+span/2+le
    y[au-7]=y[au-6]+span
    y[au-8]=y[au-7]+span
    y[au-9]=y[au-8]+span
    y[au-10]=y[au-9]+span/2+h

  case n=52
    x[2]=x[1]+h
    x[3]=x[2]
    x[4]=x[3]
    x[5]=x[4]
    x[6]=x[5]
    x[7]=x[6]+span/2+le
    x[8]=x[7]+span
    x[9]=x[8]+span
    x[10]=x[9]+span
    x[11]=x[10]+span
    x[12]=x[11]+span/2+h
    x[13]=x[12]+h

    y[au-1]=y[au]+h
    y[au-2]=y[au-1]
    y[au-3]=y[au-2]
    y[au-4]=y[au-3]
    y[au-5]=y[au-4]
    y[au-6]=y[au-5]+span/2+le
    y[au-7]=y[au-6]+span
    y[au-8]=y[au-7]+span
    y[au-9]=y[au-8]+span
    y[au-10]=y[au-9]+span
    y[au-11]=y[au-10]+span/2+h
endcase

Xcg=0
Ycg=0
for i=1 to au
  Tx=Tx+x[i+1]^2
  Ty=Ty+y[i]^2
next
auxt=Tx+Ty
Tx=2*auxT*pax
Ty=Tx

Rx=(Ty/n)^0.5
Ry=(Tx/n)^0.5
M=int(Tx+Ty+.5)
d=(span)*n
```

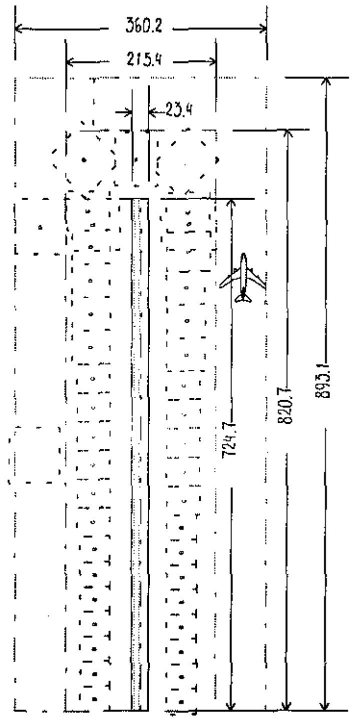
```
        R0=( M/(n*pax) )^.5
        sele 7
        append blank
        replace nacf  with n
        replace per   with d
        replace momtra with M
        replace RPolar with R0
        replace R_x   with rx
        replace R_y   with ry
        replace X_cg  with xcg
        replace y_cg  with ycg

        replace pass  with pax
        replace env   with val(infospan)
        replace safe  with val(safety)
        replace comp  with le

        @ lin,03 say str(n,2)+"   "+str(d,6,1)+" "+str(pax,4)+"  "+str(M,11)+"  "+;
        str(R0,6,1)+" "+str(Rx,6,1)+" "+str(Ry,6,1)+" "+str(Xcg,6,1)+" "+str(Ycg,6,1)
        lin=lin+1
      next
  endcase
  if flag=0
    v=v+1
  else
    v=6
  endif
enddo

wait ""
@ 3,2 clear to 22,78

endif

enddo

return
```

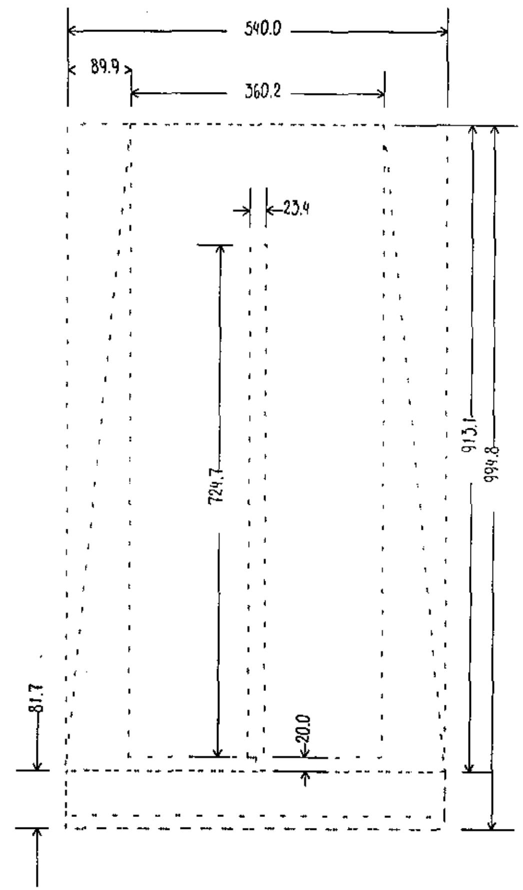


APPENDIX D

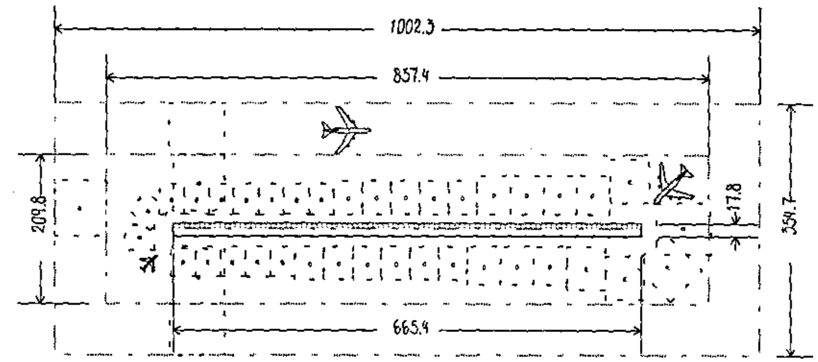
Peak Hour:	5,000 Pax
Title:	Linear
Date:	

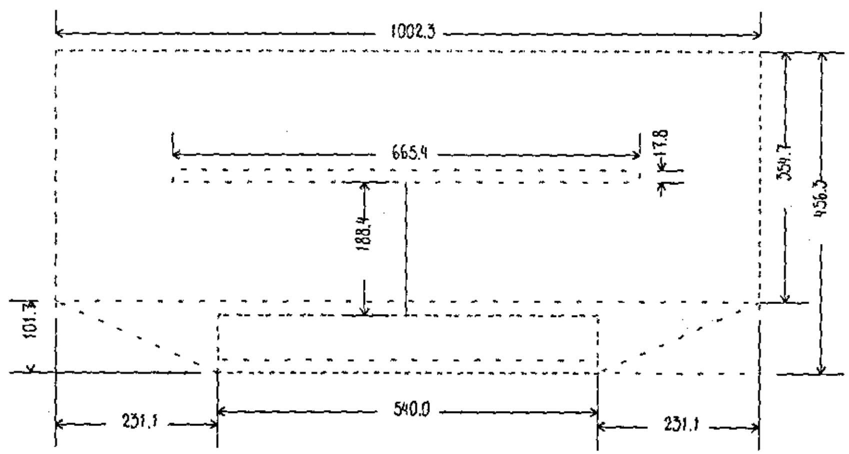
Scale 1 = 10,000
DRG No. 100.060





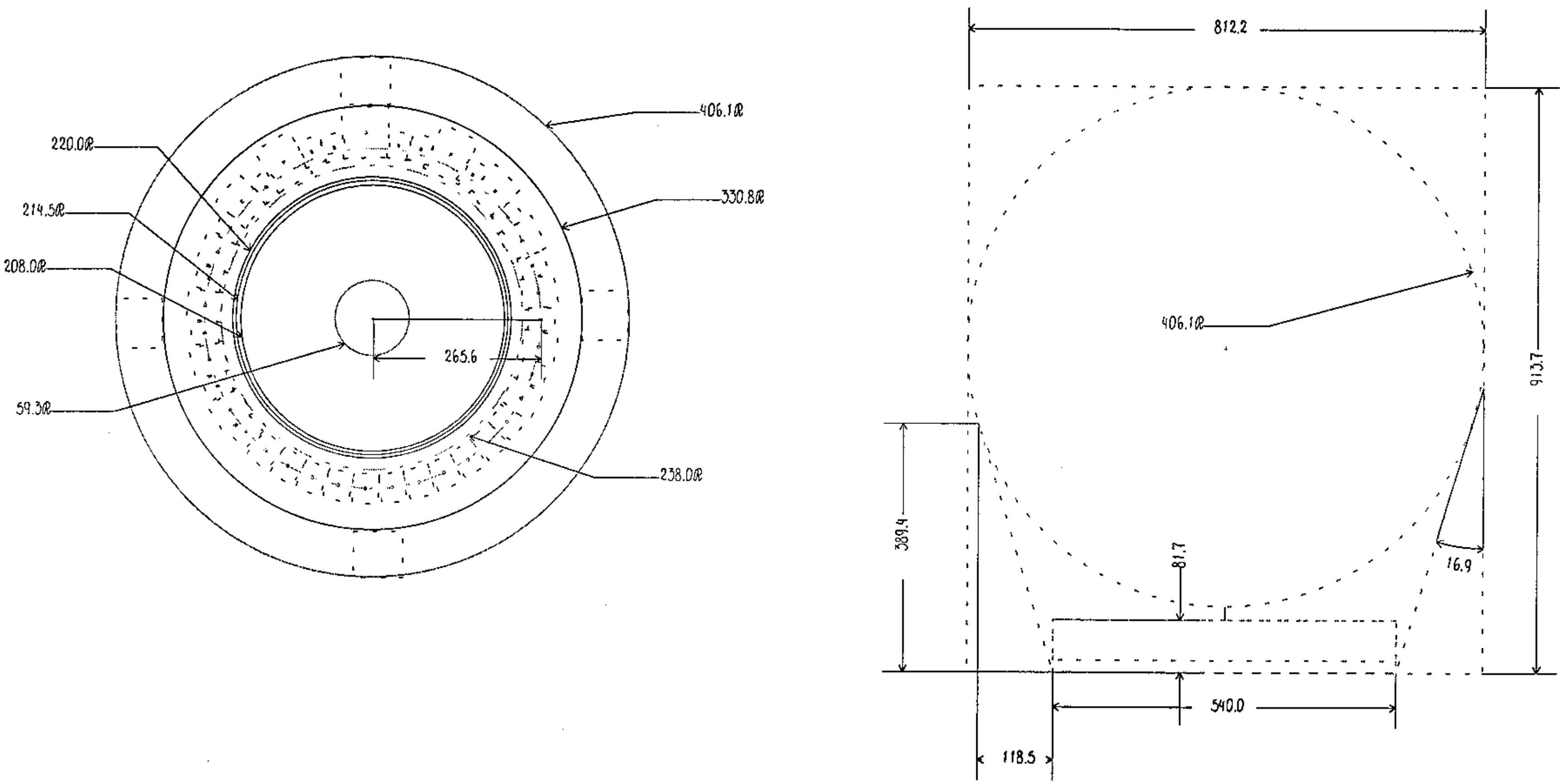
		APPENDIX D	
		Peak Hour:	5,000 Pax
	Scale 1 = 10,000	Title:	Pier
	DRG No. 100.061	Date:	





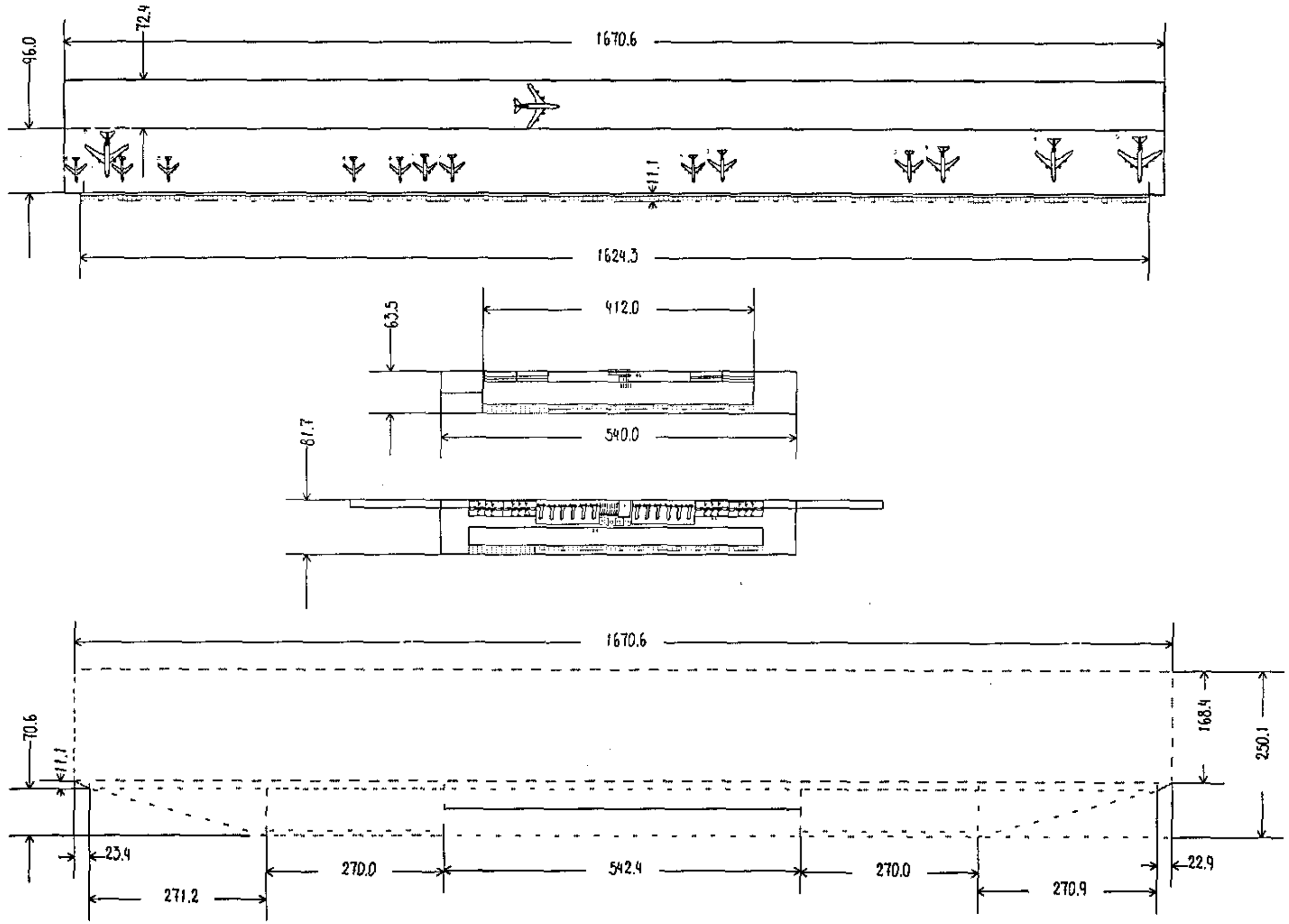
APPENDIX D

		Peak Hour:	5,000 Pax
Scale 1 =10,000		Title:	Remote Pier
DRG No. 100.062		Date:	



APPENDIX D

		Peak Hour:	5,000 Pax
Scale 1 = 10,000		Title:	Satellite
DRG No. 100.063		Date:	

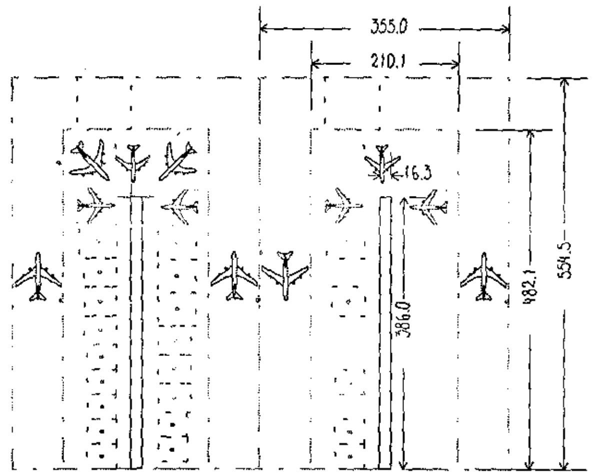


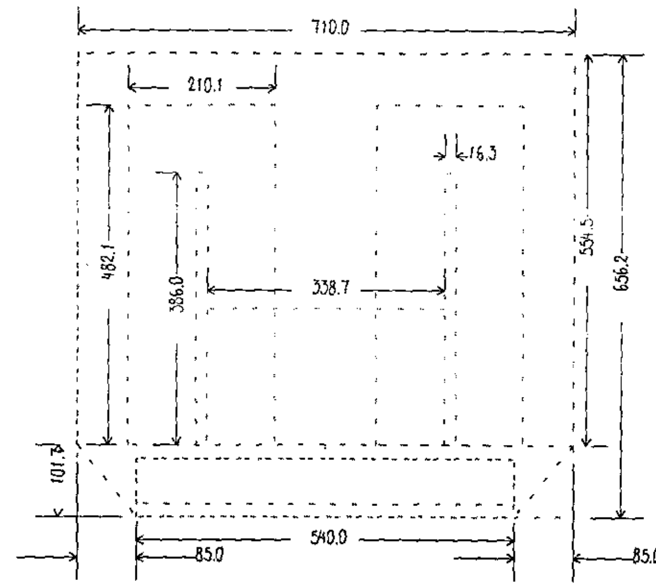
APPENDIX D

Peak Hour:	5,000 Pax
Title:	(Decentr) Linear
Date:	

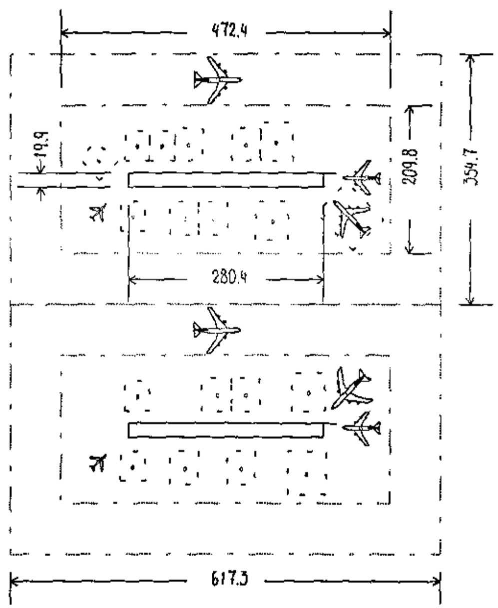
Scale 1 = 10,000

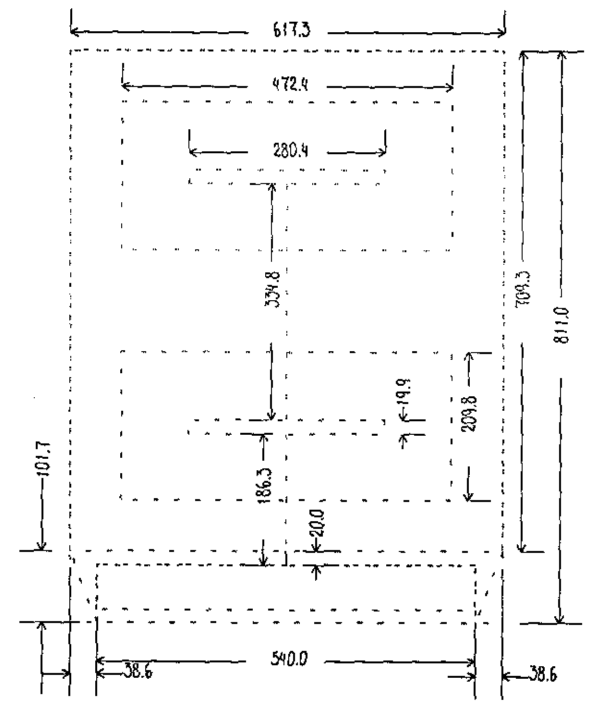
DRG No. 100.064



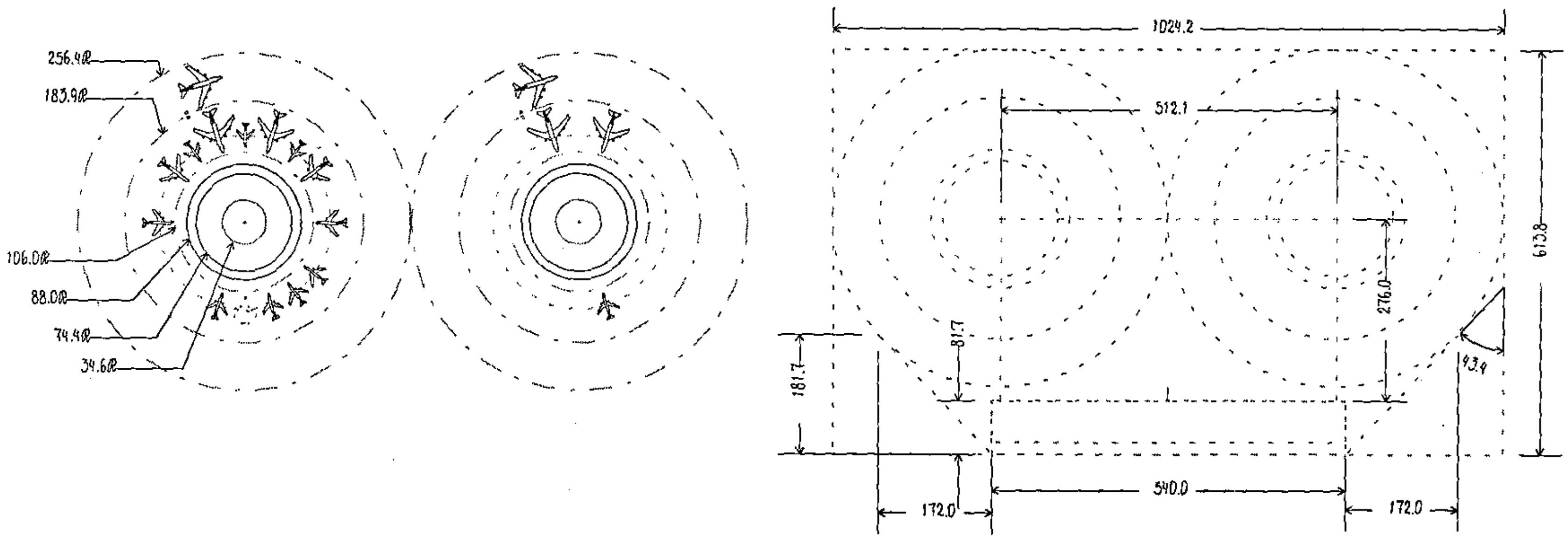


		APPENDIX D	
		Peak Hour:	5,000 Pax
	Scale 1 = 10,000	Title:	Multi-Pier
	DRG No. 100.065	Date:	



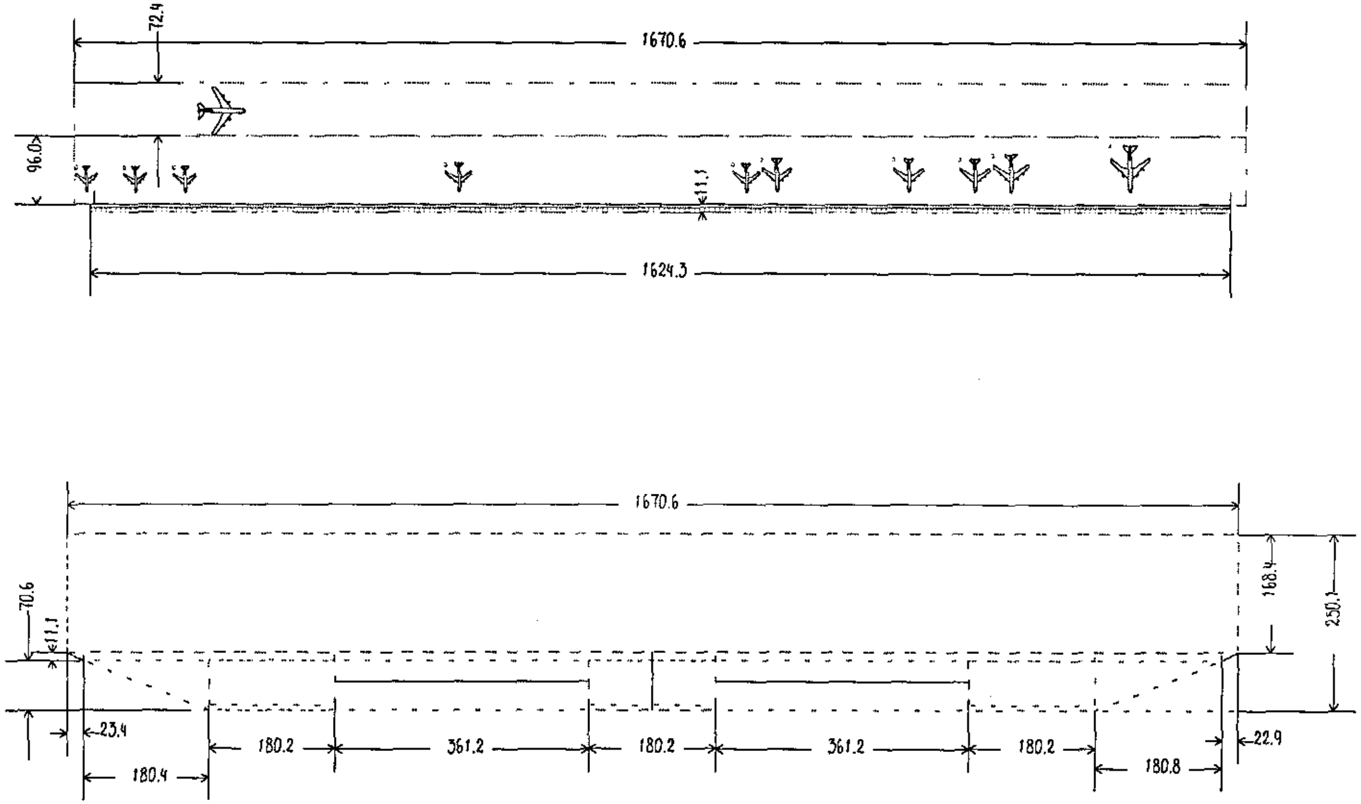


		APPENDIX D	
		Peak Hour:	5,000 Pax
Scale 1 =10,000		Title:	Multi-Remote Pier
DRG No. 100,066		Date:	



APPENDIX D	
Peak Hour:	5,000 Pax
Title:	Multi-Satellite
Date:	

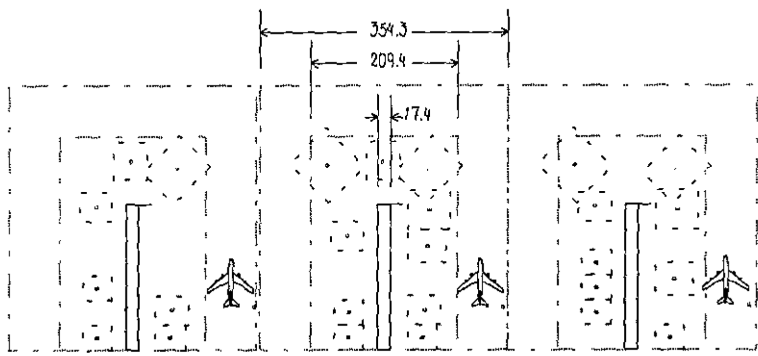
Scale 1 = 10,000
DRG No. 100.067

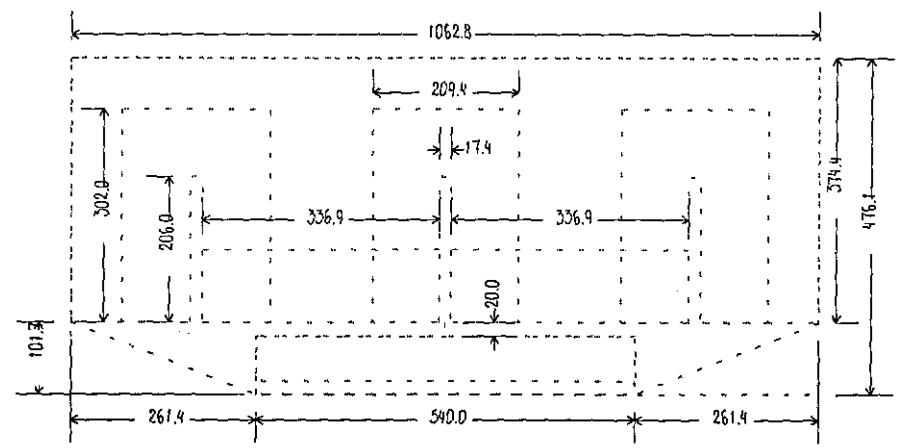


APPENDIX D	
Peak Hour:	5,000 Pax
Title:	Dec. Linear (3T)
Date:	

Scale 1 = 10,000

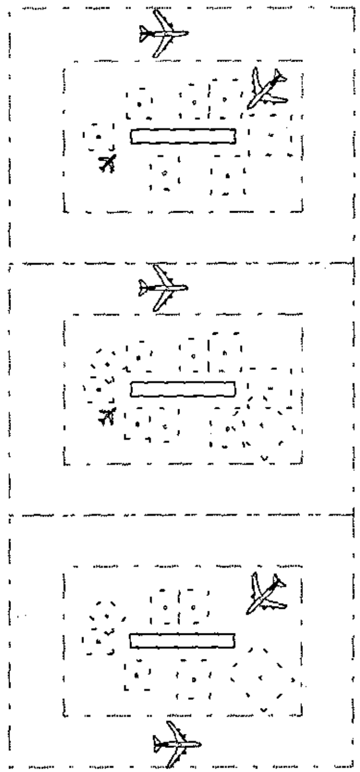
DRG No. 100.068

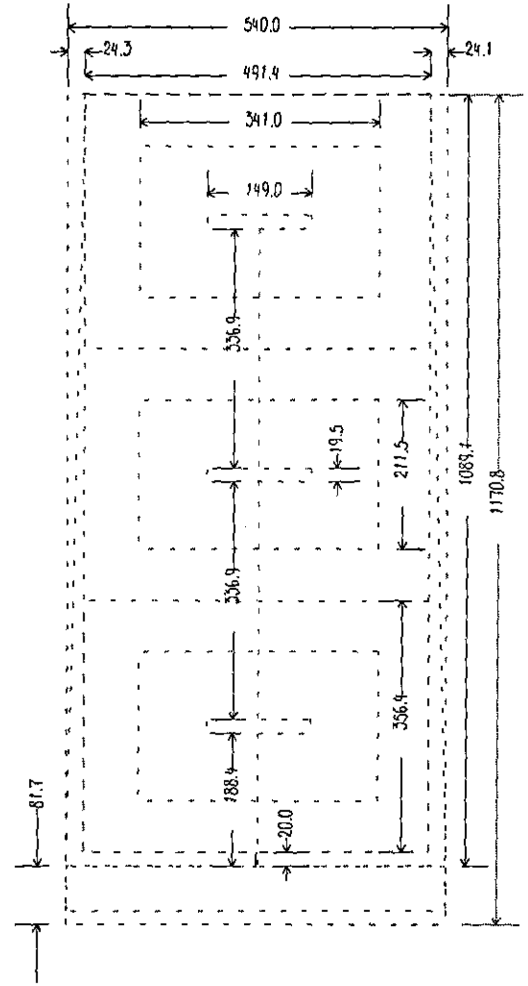




APPENDIX D

		Peak Hour:	5,000 Pax
Scale 1 = 10,000		Title:	Multi-Pier (3T)
DRG No. 100.069		Date:	





APPENDIX D

	Peak Hour:	5,000 Pax
Scale 1 =10,000	Title:	Multi-R Pier (3T)
DRG No. 100.070	Date:	

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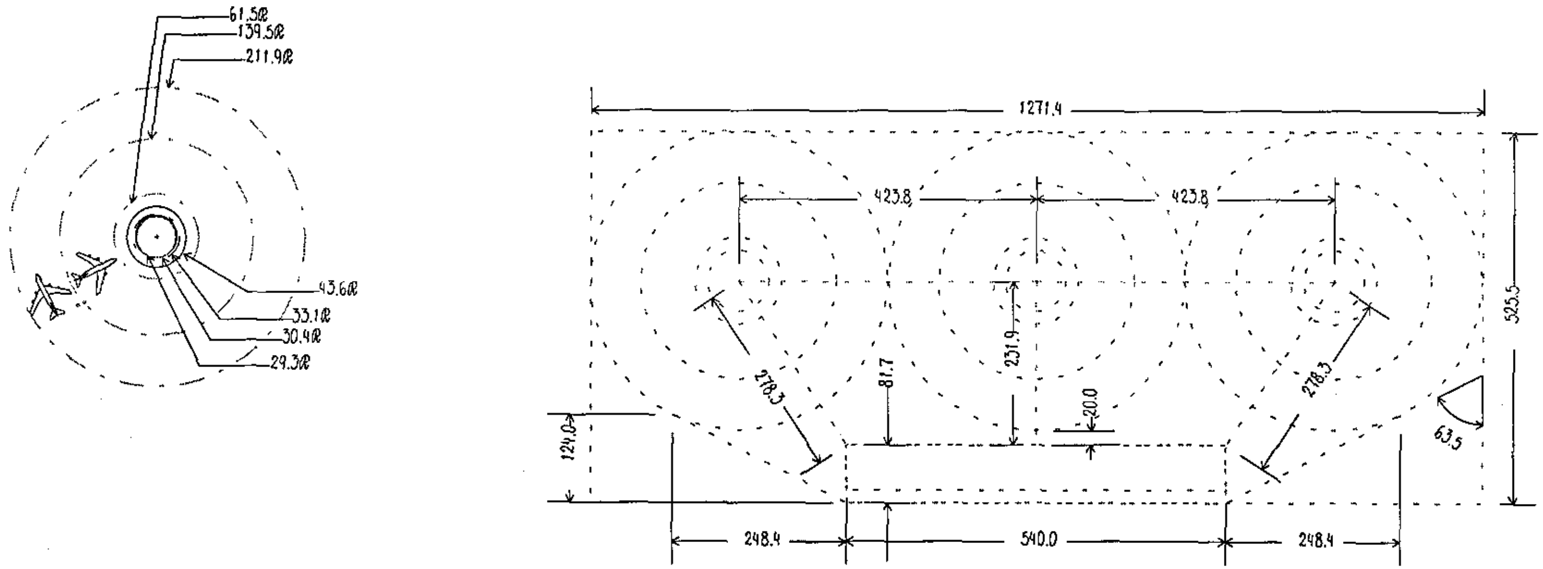
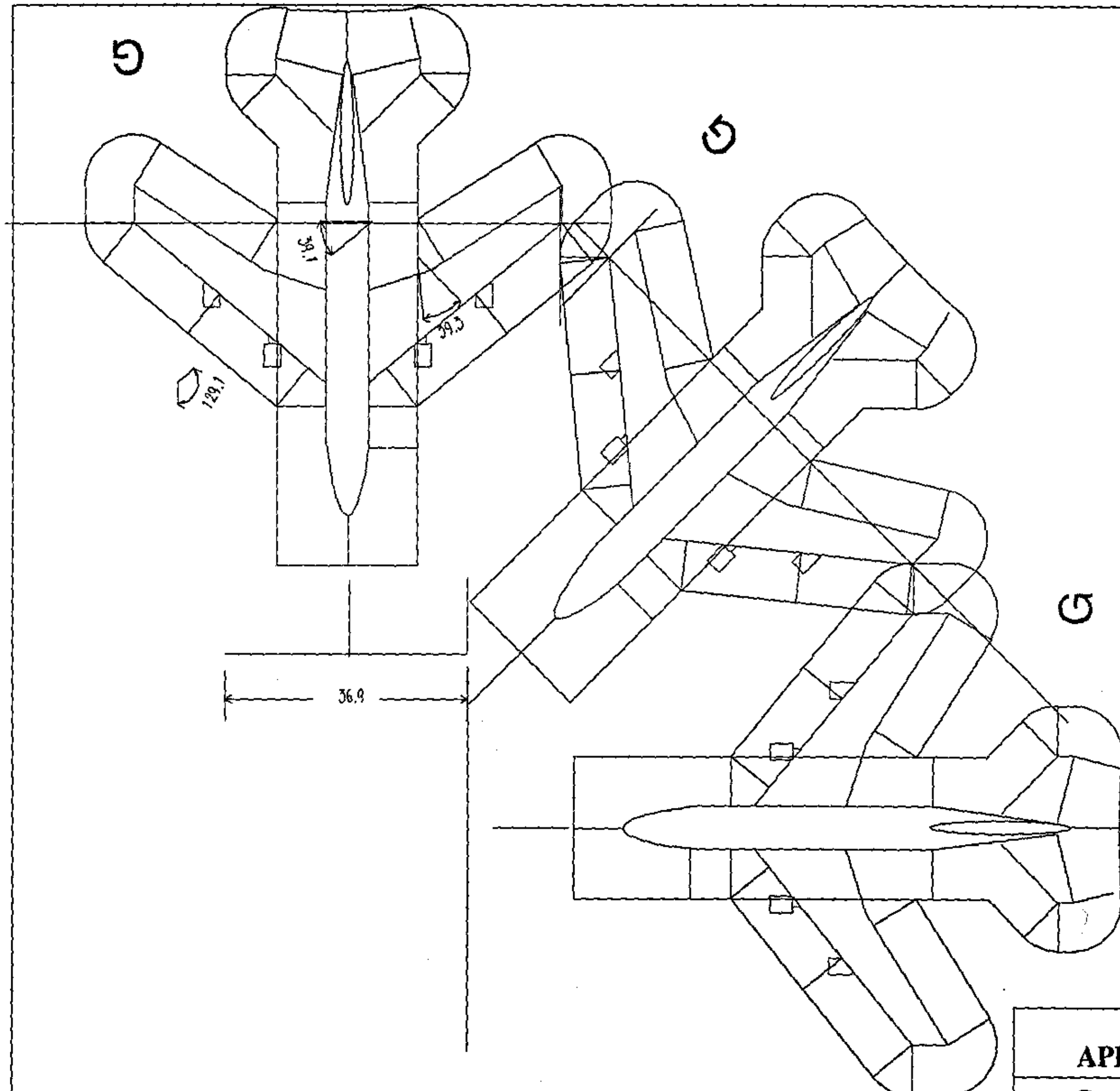
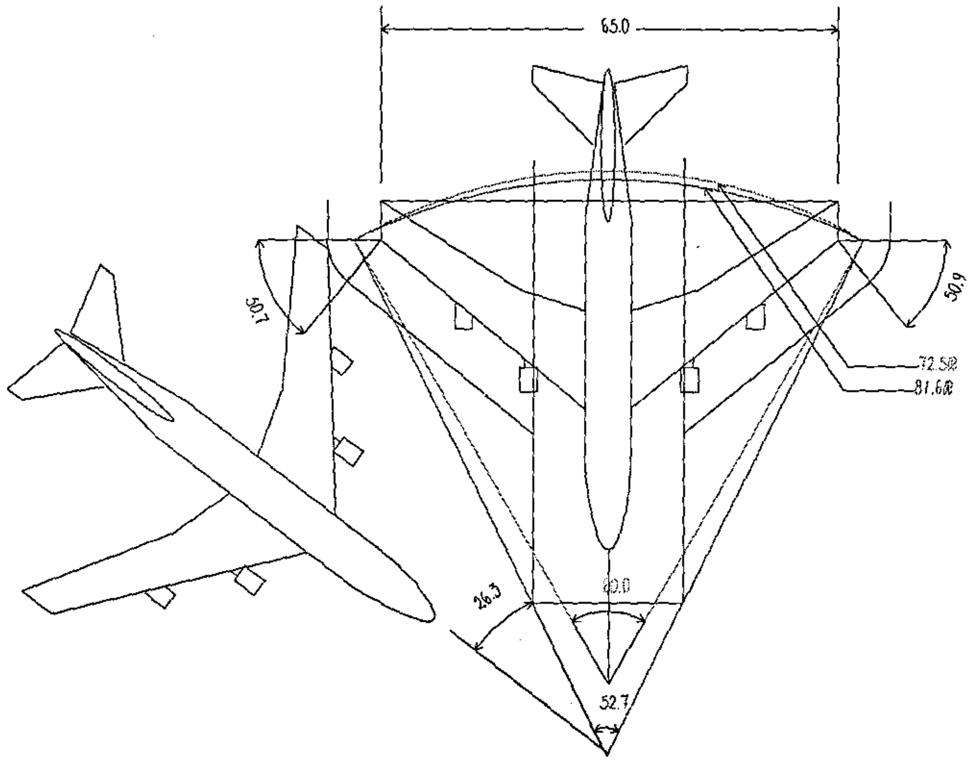


APPENDIX D

		Peak Hour:	5,000 Pax
Scale 1 = 10,000		Title:	Multi-Satellite (3T)
DRG No. 100.071		Date:	

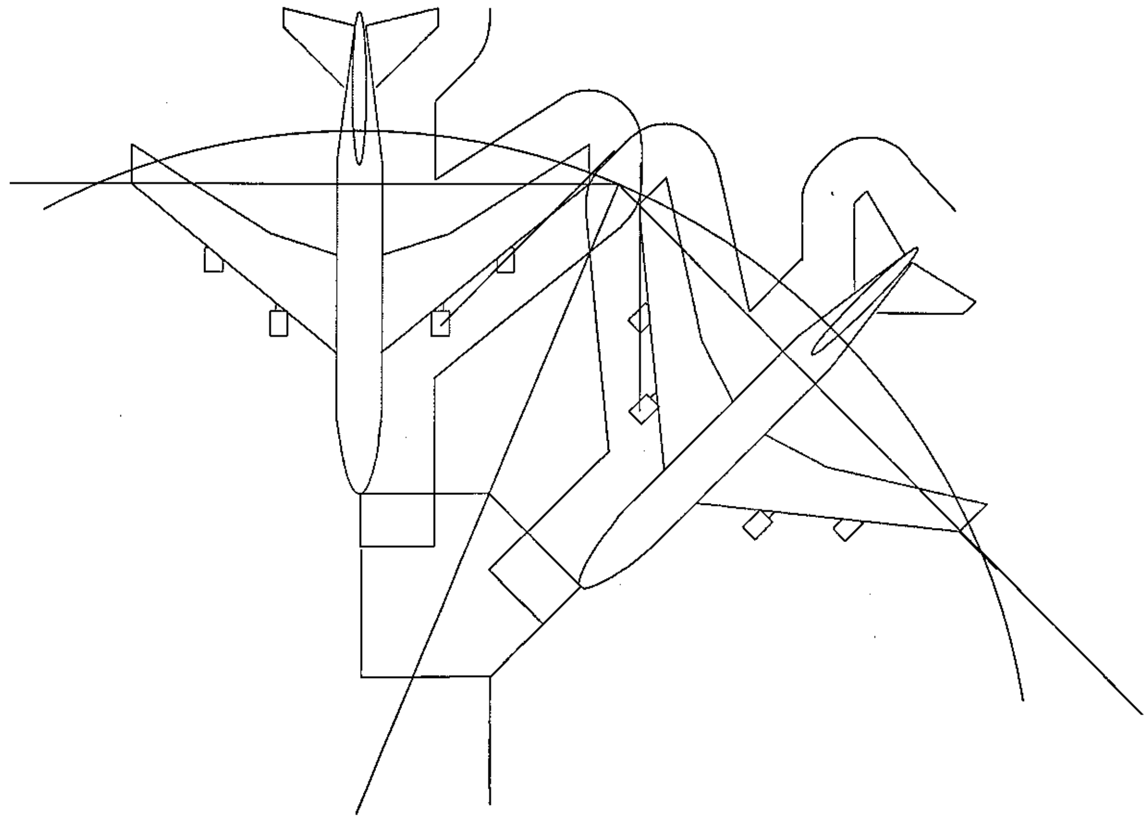


	APPENDIX D	
	Drawn by:	
Scale 1 = 100	Title:	Aircraft Clearances
DRG No. 101.161	Date:	

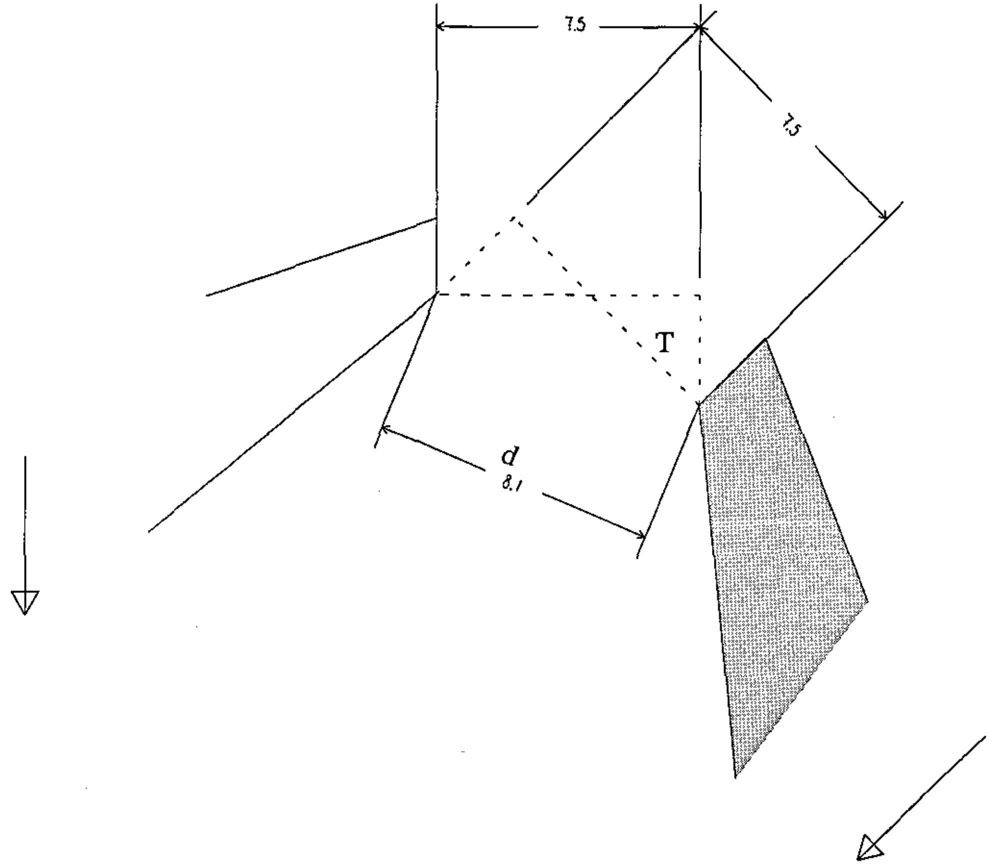


APPENDIX D

		Drawn by:	
Scale 1 = 100		Title:	Aircraft Stand Analysis
DRG No. 101.045		Date:	



		APPENDIX D	
		Drawn by:	
	Scale 1 = 100	Title:	Wingtip Analysis
	DRG No. 100.148	Date:	



	APPENDIX D	
	Drawn by :	
Not to Scale	Title:	Wingtip Analysis
DRG No. 100.149	Date:	

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