Iranian Journal of Science & Technology, Transaction B, Vol. 28, No. B5
Printed in The Islamic Republic of Iran, 2004

AN OPTIMUM ANALYSIS AND DESIGN MODEL FOR AIRPORT APRONS*

M. SAFFARZADEH** AND G. MASOUMI

Dept. of Civil Engineering, Tarbiat Modarres University, Tehran, P.O. Box 14155-4838, I. R. of Iran
Email: Saffar_m@modares.ac.ir

Abstract– In order to reach an optimum analysis and design for airport aprons variables such as the area and dimensions of the apron considering the passenger and cargo, the number and dimensions of the gates depending on the different type of aircraft, parking configuration and the arrangement of aircraft in different time periods at the airport has been looked into carefully. In this research a mathematical model for the optimum analysis and design of airport aprons based on minimum transportation cost has been developed. The main parameters considered for transportation cost are user capital and operational costs. Based on these parameters, a mathematical model as well as computerized simulation software have been developed taking into consideration the actual variables of design and analysis of airport aprons. The results obtained from the computerized simulation software indicate that the policies of the airport authorities and air carriers within the context of flight scheduling, gate use strategy, planning and analyzing the operational condition of the aircraft fleet have a significant impact on the planning and design of airport aprons.

Keywords– Airport, apron, optimization, design and analysis

1. INTRODUCTION

An airport is comprised of many components which are integrated together to provide facilities for air transportation. In general, the main components of an airport are: an air traffic control system, the airside, which is comprised of a runway, taxiway and apron, the landside comprised of passengers, the cargo terminal, and access roads, as well as parking and access to networks of routes in the airport, auxiliary and logistic facilities and equipment.

The passenger and cargo apron is where the main activity of the airport and services such as deplaning and enplaning of passengers, cargoes and postal parcels, fueling, repair operations and other services are offered. Various types of apron designs are: linear, finger, satellite and transporter plans or the combination of the two mentioned plans.

The problems and difficulties which exist in the process of operation, design and analysis of an apron within the existing or under construction airports are lack of optimum use, improper location of gates and lack of operational efficiency at the stage of entry and exit and maneuvering of aircraft within the apron. Improper design and operation of an airport apron causes the existing land area to be used inefficiently, the walking distance of passengers to inevitably be increased, enplaning delay will increase during the service time as well as the cost of operations, and their inefficiency is enhanced. Due to the lack of a sufficient and comprehensive mathematical model in the description of the parts of the airport in practice and in real conditions, as well as the different variables entering the system components as a whole, the simulation approach can be used for the analysis and design of aprons.

Simulation software can be used as the preliminary stage for analyzing, design and evaluation of the actual systems.

*Received by the editors July 17, 2001 and in final revised form June 22, 2002
**Corresponding author

2. RESEARCH BACKGROUND

The literature review reveals a number of research studies that have been conducted for the design of mathematical models in order to optimize the operation of the landside and airside components of airports. Optimization of the processing operations of passenger terminals[1], demand model for the determination of the number of gates[2], a walking distance minimization model at the terminal building and an optimum airport terminal layout plan are some of the models which have been developed. Further research was carried out to analyze parameters such as passenger travel distance, waiting time, passenger comfort and convenience for the assessment of the level of performance [4, 5].

Wirasinghe & Bandara [8] have also performed extensive research work in the area of optimum configuration and gate position requirements and optimum geometric designs of airport terminals [7]. Moreover, they proposed a method to determine the optimum geometry for a terminal with automated people movers, which minimizes the sum of disutilities associated with passenger walking and waiting, as well as capital and operational costs [8].

A great deal of research has been done in the field of simulation software for the design and analysis of different parts of the airport system. The following should be mentioned: SIMMOD software for the analysis of the existing situation of the airside, ALSIM for the analysis of the landside, ATFM of Transport Canada and the FAA software of airport design 3.2 version [9,10].

The SIMMOD software is limited to the analysis of the existing airports with specific parts and sections so that the airport will be defined with fixed specifications. The airport analysis is according to the flight schedule and the volume of estimated demand in different parts of the airside.

Furthermore, the FAA has introduced a software called Airport Design 3.2. By using this software, the necessary dimensions of the critical areas and surfaces of the runway such as the pavement surface length, runway shoulder, blast pad, runway safety area, obstacle free zone and runway approach surface can be calculated [11].

Despite the capabilities and advantages of the above mentioned software, they also contain some inefficiencies. These are mostly related to passenger processing trends, demand analysis, movement and servicing within the terminal building and their optimum layout planning within the airport. The simulation software is mostly limited to the analysis of the existing airports with known factors. Therefore, they cannot be used for the design of the airside sections or the apron for new airports.

This paper discusses the process of analyzing different types of aprons and the geometrical design requirements in different parking situations, as well as the operational conditions of the airlines in order to reach an optimum alignment and parking allocation within the apron.

3. OPTIMUM ANALYSIS AND DESIGN ISSUES

In order to establish the optimum analysis and design of the apron, the following points should be assessed more carefully:

1. Optimum area and dimension of the passenger and cargo apron.
2. Optimum number of parking positions as well as their arrangement according to different kind of entry and exit operations.
3. Location of the aircraft within the aprons at different time periods according to the flight schedule of airlines.
4. Establishment of parking positions within the apron on the basis of the travel costs including effective parameters such as the passenger characteristics and their behavior, passenger terminals and the cost parameters.
5. Giving the most suitable plan from a technical, operational and economic point of view according to the requirements and characteristics of each airport.
6. Accurate analysis and assessment of capability and efficiency of the existing situation of the aprons.

The capacity of the existing apron can be assessed in order to satisfy the required positions using the simulation software. The airport administration and aviation companies would be able to prepare and formulate all of their future development plans according to the specifications of the aprons.

The suggested software should be able to calculate the number and type of required parking bays, the allocation of each parking bay for each air line, the ramp diagram chart of the apron as well as the diagram of the productivity range of each position.

In addition to the flight schedule, the allowable minimum time between the exit of an aircraft from one position and the entry of the other aircraft into the same position, as well as the number and dimensions of the position with exclusive use, and the airline owning the said position would be determined in this stage.

The three design concepts introduced, linear, single or double finger, satellite and transporter can be used either individually or combined to produce an optimum design. The arrangement of airline positions within the apron can be optimized using the proposed mathematical model. Different types of designed aprons can be compared with each other based on the type of terminal design and the requirements of the aircraft's entry and exit operations, e.g., parking nose in, angled at (30-60) and parallel parking. Figure 1 shows the methodology of optimum analysis and design of aprons.

4. DEVELOPMENT OF THE MATHEMATICAL MODEL

By considering and analyzing the mathematical model initially, the exact dimensions and size of the parking positions in different forms of aircraft stopping such as; nose-in, nose-out, parallel or angles at (30–60) with increments of 5 degrees can be calculated.

As shown in Fig. 1, the aircraft positions (comprised of 68 types) will be determined within the developed mathematical model by accurate geometrical calculations. After the calculation of the dimensions and the size of positions, the number of required parking positions for the peak hour can be determined.

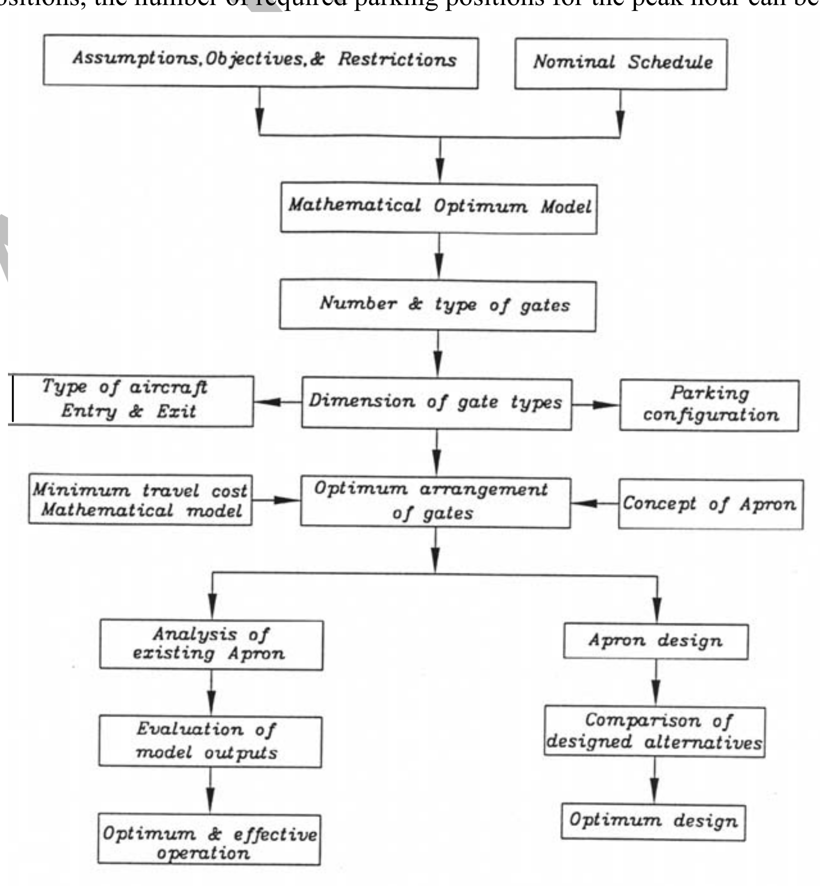

Fig. 1. Methodology of optimum analysis and design of aprons [1]

Subsequent to this stage, the type of terminal design, as well as the apron, should be determined until the calculated positions are established at the apron's area according to the specific geometrical specifications of each apron. The aircraft positions within the apron's area should be arranged in a manner that not only provides the maximum efficiency and productivity of the existing limit, but also reaches the most suitable and compatible arrangement.

As mentioned earlier, efficiency and productivity of the system depend on parameters. These include the arrangement of gate positions, the utilization of each gate, the walking distance of passengers, and expected passenger mix.

However, in this research, it was assumed that passenger walking distance can be a major factor in determining the optimum design of aprons. An attempt has been made to develop an analytical expression for the passenger walking distance given the size of the apron in terms of the number of parking positions. The criterion of passenger walking distance is based on the expected passenger mix, i.e., arrival, departure, transfer, gate spacing requirement, type of terminal, maneuvering space and aircraft mix.

The quantitative analysis index of this criterion in transport planning is subject to the transportation cost. The general form of this equation is as follows:

$$FT = \sum_{n=1}^{N} P_n \overline{V} \tag{1}$$

where P_n = Average passenger capacity of each airplane, and $\overline{V}$ = Average walking distance of passengers.

In Eq. (1), the passengers who come off the aircraft should be processed and categorized. These categories are enplaning, passenger transfer deplaning. The transfer passengers are those who will directly proceed to the airplane after deplaning. The indirect passengers are those who after deplaning will proceed to the processing unit within the terminal in order to collect their baggage and prepare for the next flight.

Therefore, the average walking distance of all direct transfer passengers corresponds to

$$\overline{V_H} = c\overline{V}_{H_1} + (1-c)\overline{V}_{H_2} \tag{2}$$

where $\overline{V}_{H_1}$ = Average distance of the direct transfer passengers whose exit gates have been determined earlier, $\overline{V}_{H2_1}$ = Average distance of the direct transfer passengers who may possibly use the same gate of the terminal building for departure, and C= Percentage of the direct transfer passengers whose exit gates have been determined prior to all the direct transfer passengers.

Then, the average walking distance of all the passengers would be as follows:

$$\overline{V} = (1-A)\overline{V}_A + A(1-B)\overline{V}_N + AB\overline{V}_H \tag{3}$$

where

$\overline{V}$ = Average walking distance of the enplaning and deplaning of passengers, $\overline{V}_N$ = Average walking distance of the indirect transfer passengers, A= Ratio of the transfer passengers to all passengers, and B= Ratio of the direct transfer passengers to all the transfer passengers.

In the optimum model of design and analysis of the apron, the arrangement of parking positions is in such a way that the range of FT equation in terms of the quantitative criterion of the passenger-meter will be minimized.

In this research, a more comprehensive view of the travel cost equation has been considered and analyzed so that it comprises the most important and effective transport parameters related to passenger terminals and those pertinent to the passengers and their behavior. Through the studies conducted in this research, and with respect to the terminals of the finger design, the cost equation of the model has been calculated under the two following conditions, i.e., with and without land limit conditions.

a) Without land limit conditions

In these conditions, the accessibility and the land availability are not considered as effective and restrictive parameters in the process of the optimum design and arrangement of the apron parking positions in terms of the minimum walking distance and the travel cost.

$$FT_k = \sum_{k=1}^{7} FT = FT_1 + FT_2 + FT_3 + ... + FT_7 \tag{4}$$

$$FT_1 = \frac{\lambda_w}{L}(1 + A - 2AB)\left[\sum_{i=1} \frac{x_i^2}{3} + y^2 + ay + \frac{a^2}{8}\right] \text{ and, } L = \frac{GS_g}{2}, y = \frac{g_t s_g}{4} \tag{5}$$

where, FT_1 = Average cost of walking for enplaning, deplaning and transfer passengers at the terminal area, λ_w= Transfer cost of each walking passenger per kilometer, n= Number of terminal building piers, x_i = Length of each terminal building pier, a= Longitudinal dimension of terminal in front of the apron, g_b = Number of apron gates in front of the main terminal building, and g_t = All the apron gates in front of the pier attached to the terminal building.

$$FT_2 = \frac{\lambda_w}{L} ABC\left[\sum_{i=1}^{n} \frac{x_i^2}{3} + F(y)\right] \tag{6}$$

where FT_2 = Average cost of walking for direct transfer passengers whose exit gate has been determined earlier and C = Percentage of direct transfer passengers whose exit gate has been determined earlier, compared with all the direct transfer passengers.

$$F(y) = \left[\frac{8y^3}{3} + 3ay^2 + a^2 y + \frac{3}{12}\right] / \left[2y + \frac{a}{2}\right] \tag{7}$$

$$FT_3 = \frac{\lambda_w}{L} AB(1-C)\left[\sum_{i=1}^{n} \frac{x_i^2}{2} - \sum_{i=1}^{n} \frac{x_i^3}{6L} + \sum_{i=1}^{n} \frac{x_i}{L}\left(2y(a+y) + \frac{a^2}{4}\right) + \frac{F(y)}{L}\left(2y + \frac{a}{2}\right)\right] \tag{8}$$

where FT_3 = Average cost of walking for direct transfer passengers who don't leave through the same entrance.

$$FT_4 = \frac{\lambda_R}{L}(1 + A - 2AB)\left[\sum_{i=1}^{n} x_i^2 (iD)\right] \tag{9}$$

where FT_4 = Average cost for transportation of the enplaning, deplaning and indirect transfer passengers, λ_R = Transportation cost for each passenger per kilometer, and D = Average distance between the terminal building piers.

$$FT_5 = \frac{\lambda_R}{L} AB(1-C)D\left[\sum_{i=1}^{n} \frac{x_i}{L}\left[\sum_{k=1}^{i} (i-k)x_k + \sum_{k=i+1}^{n} (k-i)x_k\right] + \frac{2}{L}\left[L - \sum_{i=1}^{n} x_i\right]\sum_{i=1}^{n} ix_i\right] \tag{10}$$

where FT_5 = Average transportation cost of the direct transfer passengers.

$$FT_6 = (1 + A - AB(1 + C))\lambda_A \tag{11}$$

where FT_6 = Average waiting and access cost of passengers, λ_A = Cost of waiting and access for each passenger.

$$FT_7 = n\lambda_o \text{, and } \lambda_o = \lambda_c + \lambda_m D \tag{12}$$

where FT_7 = Average operational cost of passengers and other parameters defined earlier, λ_c = Investment cost per passenger for each pier of the terminal building, λ_m = Operation and maintenance cost for each passenger per kilometer, and n =Total number of passengers processed.

The variables of the above equations can be divided into three categories: terminal, passenger and cost parameters. The parameters of the passenger terminal comprise the number of apron gates, average distance between piers of the terminal building and the longitudinal dimension of the terminal building.

The passenger parameters comprise a percentage of the transfer passenger to the total passenger, a percentage of the direct transfer passenger to the total transfer passenger, and a percentage of the direct transfer passenger whose exit gates have been determined earlier, compared with the total number of passengers. The cost variables also comprise the highest walking cost of a passenger per kilometer, the ride transfer cost of each passenger per kilometer, and the access and waiting cost for each passenger.

b) With land limit conditions

In the case of a land limit for the construction of an apron, the demand volume for using the apron compared with the land obtainable should be analyzed. This would determine the maximum number of parking positions that can be accomodated in the existing apron. The most important guidelines that can be used to reach suitable conditions are: modification of the geometrical specifications of different parts of the apron such as the length and number of the terminal piers of the finger type chosen for the model presented in this research, as well as the modification of the flight schedule on the design day, or changing and optimizing the operational specifications of the apron and the way it is used. Taking into consideration the aforementioned conditions, the equation to calculate the total transportation cost can be written as follows:

$$FT_k = \sum_{k=1}^{7} FT = FT_1 + FT_2 + \ldots + FT_7 \tag{13}$$

It should be noted that the parameters presented in Eq. (13) are the same as those in Eqs. (1-5), with the difference being that in this equation, the average range of walking distance and the transfer distance of passengers as well as the different highest costs of their transfer have been calculated under the conditions of land limit.

Therefore, the new equations should be developed taking into consideration the aforementioned constraints.

$$FT_1 = \frac{\lambda_w}{L}(1 + A - 2AB)\left[\sum_{i=1}^{j}\frac{x_i^2}{4} + \sum_{i=j+1}^{n}\frac{x_i^2}{4} + y^2 + ay + \frac{a^2}{8}\right] \tag{14}$$

where J = Number of terminal building piers with a certain length, x_j = Number of parking positions in front of each side of the terminal pier with a certain length.

$$L = 2y + \frac{a}{2} + \left[\sum_{i=1}^{j} x_i + \sum_{i=j+1}^{n} x_i\right] \tag{15}$$

$$FT_2 = \frac{\lambda_w}{L} ABC\left[\sum_{i=1}^{j}\frac{x_i^2}{3} + \sum_{i=j+1}^{n}\frac{x_i^2}{3} + F_m(y)\right] \tag{16}$$

where a_1 = Transverse dimension of the terminal building.

$$FT_3 = \frac{\lambda_w}{L} AB(1-C)\left[\sum_{i=1}^{j}\frac{x_i^2}{2} + \sum_{i=j+1}^{n}\frac{x_i^2}{2} - \sum_{i=1}^{j}\frac{x_i^3}{6L} - \sum_{i=j+1}^{n}\frac{x_i^3}{6L}\right.$$

$$\left. + \left(\sum_{i=1}^{j}\frac{x_i}{L} + \sum_{i=j+1}^{n}\frac{x_i}{L}\right)\left(2y(a_1 + y) + \frac{a^2}{4}\right) + \frac{F_m(y)}{L}\left(2y + \frac{a}{2}\right)\right] \tag{17}$$

$$FT_4 = \frac{\lambda_R}{L}(1 + A - 2AB)\left[\left(\sum_{i=1}^{j} x_i^2 + \sum_{i=j+1}^{n} x_i^2\right)(iD - D_o)\right], D_o = D - D_1 \tag{18}$$

where D = Average distance between the terminal building piers, D_1 = Distance between the terminal building and its first pier.

$$FT_5 = \frac{\lambda_R}{L^2} AB(1 - C)\Bigg[\Bigg(\sum_{i=1}^{j} x_i \left(\sum_{k=1}^{j}(i-k)x_k + \sum_{k=j+1}^{i}(k-i)x_k + \sum_{k=i+1}^{n}(k-i)x_k\right)$$

$$+ \sum_{i=j+1}^{n} x_i \left(\sum_{k=1}^{j}(i-k)x_k + \sum_{k=j+1}^{i}(i-k)x_k + \sum_{k=i+1}^{n}(k-i)x_k\right)$$

$$+ \left(L - \sum_{i=1}^{j} x_i + \sum_{i=j+1}^{n} x_i\right)\left(\sum_{i=1}^{j} ix_i + \sum_{i=j+1}^{n} ix_i\right)$$

$$+ \left(2D_o\left(L - \sum_{i=1}^{j} x_i + \sum_{i=j+1}^{n} x_i\right)\left(\sum_{i=1}^{j} x_i + \sum_{i=j+1}^{n} x_i\right)\right) \tag{19}$$

$$FT_6 = \left(1 + A - AB(1 + c)\right)\lambda_A, \qquad FT_7 = n\lambda_o \tag{20}$$

where the value of n would be in conditions of non-limit and n+1in conditions of land limit.

Figure 2 shows the apron gate of the finger concept with some of the related characteristics within the model.

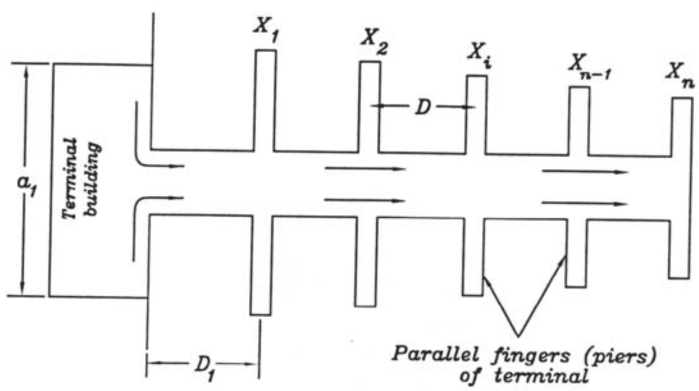

Fig. 2. Specifications of the geometrical design of the terminal area and apron gate of the finger concept [12]

Due to the complexity of the mathematical equations of the minimum travel cost, as well as the variables and stochastic character of demand and the parameters entering into the system, resolving the model would not result in the geometrical analysis or design of the apron. Therefore, by using the mathematical fundamentals of the proposed model and taking into account the real conditions of the design and the characteristics of transport variables, as well as its calibration and validation, the simulation software of the apron has, consequently, been presented. The simulation software will be defined as the laboratory example of the system which can be used as the most suitable method for the analysis, design and evaluation of the real systems. The utilization of the simulation would result in the simultaneous and comprehensive realization of the mathematical conditions and characteristics of the model presented for the analysis and design of this component of an airport.

5. DEVELOPMENT OF SIMULATION SOFTWARE

This section presents the analysis and development of a simulation software based on mathematical background [12]. Simulation is considered as the laboratory version of the system on which experiments can be performed as a first step to design, analysis, and performance assessment. Outputs can be obtained and inference can be drawn about the operation of a real apron without the need to actually physically build, disturb, or destroy the system. Comprehensive research was undertaken to find a simulation package on which the performance of a mathematical model can be assessed [13]. Due to a lack of adequate software, a decision was made to design a new software aimed at simplicity, speed, interaction, and ease of use, without compromising accurate representation of the airport apron. The concept of optimum design in terms of minimum transportation cost on the basis of passenger walking distance is integrated into the simulation software. The software comprises three basic sections such as input, processor, and output.

The input data to the software includes the flight schedule, passenger characteristics, airport concept, and facility information [14-16]. The processor was developed based on the equations summarized in the previous section. The output of the software is a graphic plan view of the apron and terminal building complex on the basis of the concept chosen by the operator. In addition, the software produces a report which includes such information and statistics as the number of gate positions, the total gate area, the width and length of the terminal building, radius of satellite terminal, distance from the main terminal to the satellite, type of aircraft parking, and the type of concept with minimum walking distance.

The simulation software will be performed under Microsoft Windows 95, developed by Visual Basic 4.0 programming language. The software package developed has an automatic installation engine and is user friendly.

Generally, the intended software pursuant to the presented model has step by step stages so that after the generation of the airport flight schedule on the design day and then the determination of the number and type of parking positions, the program will enter the process of analysis and design. In this phase, one type of apron design such as linear, semi-circular, triangular, single and double finger, satellite, hybrid and transporter concepts can be selected and by using the results obtained from the previous stage, the process of design and analysis will be accomplished.

In other words, the main objectives in the design of this simulation software is to see the performance of the mathematical model in real conditions and for different airports with different flight schedules. Ultimately, the best design alternative in terms of the given specifications will be determined. Other major characteristics of the afore-mentioned software are: the graphic capability of the program in displaying the designed or analyzed apron and the maneuvering of the optimum parking of airplanes based on the equation of the minimum travel cost during the 24 hours of the design day in the computer environment. In addition, the software is capable of converting the files designed by this program to graphic files displayable in the Autocad Release 14 version.

With regard to high graphic capabilities of Autocad, the developed software is flexible enough to carryout various changes at the design stage. Another capability of the software is to design and draw runways, taxiways, and landside components in an AutoCAD environment. As an example, a sample of the design process of the apron at an airport with a certain flight schedule on the design day which possesses the combined satellite concept is explained.

A plan view of a satellite apron concept as an output of simulation software developed for a hypothetical example is shown in Fig. 3. In addition to the optimum concept, the software is able to arrange and locate different types of aircraft based on a typical flight schedule.

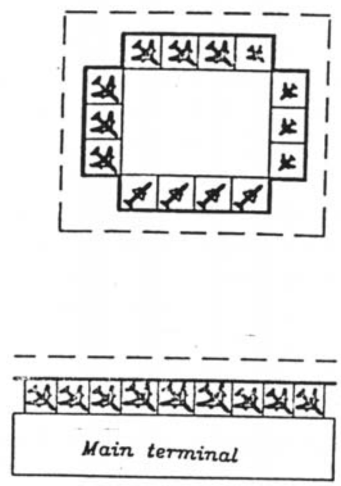

Fig. 3. Plan of the satellite concept as an output of the simulation software [12]

6. CONCLUSIONS AND RECOMMENDATIONS

According to the specifications given for the optimum model presented in this paper for the design and analysis of the apron and the evaluation and testing of the model by use of the simulation software, the following conclusions can be reached:

It would be a suitable method for the optimum analysis and design of different kinds of aprons in different operational conditions for airports, and ultimately reaching an optimum alternative is using simulation according to the theoretical and logical fundamentals governing the mathematical model of the minimum travel cost.

The results obtained from the proposed model and its testing and evaluation indicates that the policies and guidelines of the airport authorities and airlines within the context of flight schedules, gate use strategy, the mix of the air fleet of the airport during the planning process, operational conditions, servicing and economic considerations have significant impacts on the quality of the design or analysis of the aprons.

The arrangement of airplanes within apron gates on the basis of the minimum travel cost model will considerably reduce the walking distance of passengers from the airplane to the terminal or vice-versa.

Based on the outputs of the simulation software, it was found that passenger walking distance can be a major factor in determining the geometry of an airport apron as well as the terminal building. It can also be concluded that the number of aircraft parking positions and the expected passenger mix are important variables to be considered in planning new airport aprons or terminal buildings.

The best layout of apron and terminal type changes depends on the number of parking positions, fractions of different passenger categories, distance between piers or satellites with the main terminal building, and some other terminal characteristics. It was also found that for a given terminal type, the minimum walking distance is not necessarily the only criterion for the optimum geometry of the terminal complex.

The outputs of the proposed model and simulation software should only be used as a guideline to select suitable layouts for the consideration of detailed design. The procedure developed in this research could be used to eliminate any arbitrary selection of apron concepts for a detailed geometric design. Furthermore, the capability of studying the effects of operational changes in the early stage of planning could save money and time during the detailed design process.

Since the economic criterion is the most important parameter in planning, design, selection and execution of each project, the airport planners and authorities should, through an exhaustive consideration of different parameters such as the costs of increasing of the required land, construction costs of different kinds of plans, a provision of the push-out machinery and its special equipment, as well as the evaluation and comparison of all the presented alternatives based on the results of the pertinent software, reach a suitable and economical model which is compatible with the characteristics of the airport under study.

However, further research is required to investigate other parameters which could not be included in this research. Some of these variables are the integration of the land side section of the airport, effects of conveyor belts, and automated people movers at the operation terminals. A sensitivity analysis can be performed to investigate the effects of changes in the variables to the optimum design of an apron and terminal building.

REFERENCES

1. Saffarzadeh, M. (1995). A practical procedure for the optimum operation of airport passenger terminals. Ph. D. Thesis, Carleton University, Ottawa.
2. Hassounah, Mazen, I. & Steuart, G. N. (1993). Demand for aircraft gates. paper No. 93. of 72^{nd} *Annual Meeting, Transportation Research Board*, Washington, D.C, January.
3. Braaksma, J. P. (1977). Optimum airport terminal layout planning. *Engineering Optimization Journal*, *3*, 1-15.
4. Mumayiz, S. A. (1991). Evaluating performance and service measures for the airport landside. Transportation Research Record, 1296.
5. Svrcek, T. (2000). Policy-level decision support for airport passenger terminal design. Transportation Research Record.
6. Bandara, S. (1989). Airport terminal–optimum configurations and gate position requirement. Ph.D. Dissertation, Department of Civil Engineering, The University of Calgary, Calgary, Alberta, Canada.
7. Bandara, S. (1990). Optimum geometries for satellite type airport Terminal. *Transportation and traffic theory*, Masaki Koshi-Editor, Elsevier, New York, 409-428.
8. Wirasinghe, S. C. & Bandara, S. (1992). Remote pier airport terminal with APM system. *The 71st TRB Annual Meeting*, Washington, D.C.
9. McKelvey, F. X. (1989). A review of airport terminal system simulation models. Transportation System Center, U.S. Department of Transportation, November.
10. Horronjeff, R. & McKelvey, F. X. (1994). *Planning and design of airport*. Fourth Edition, Mc Graw Hill.
11. Mumayiz, S. A. (1991). Interactive airport landside simulation: An object oriented approach. *The 70^{th} Annual Meeting of Transportation Research Board*, Washington, D. C., Jan.
12. Masoumi, G. (1997). Development of a computer software for the design of airport apron. M.S. Eng. Thesis, Faculty of Engineering, Tarbiat Modares University, Tehran.
13. Setti, A. R. J. (1990). Passenger terminal simulation model. Ph. D Thesis, Dept. of Civil Engineering, University of Waterloo, Waterloo, Ont.
14. International Civil Aviation Organization, DOC 9157-AN1901. (1983). *Aerodrome design manual*. Part 2: Taxiways, aprons and holding bays. Second Edition.
15. International Air Transport Association. (1995). *Airport development reference manual*. 8^{th} Edition, Montreal, Canada.
16. Federal Aviation Administration-AC 150/5360-13. (1988). Planning and design guidelines for airport terminal facilities.