AN ANALYSIS OF DELAY AND TRAVEL TIMES AT SÃO PAULO INT'L AIRPORT (AISP/GRU): PLANNING BASED ON SIMULATION MODEL

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ABSTRACT

The occurrence of flight delays in Brazil, mostly verified at the ground (airfield), is responsible for serious disruptions at the airport level but also for the unchaining of problems in all the airport system, affecting also the airspace.

The present study develops an analysis of delay and travel times at São Paulo International Airport / Guarulhos (AISP/GRU) airfield based on simulation model.

Different airport physical and operational scenarios had been analyzed by means of simulation. SIMMOD Plus! 4.0, the computational tool developed to represent aircraft operation in the airspace and airside of airports, was used to perform these analysis.

The study was mainly focused on aircraft operations on ground, at the airport runway, taxi-lanes and aprons. The visualization of the operations with increasing demand facilitated the analyses.

The results generated in this work certify the viability of the methodology, they also indicated the solutions capable to solve the delay problem by travel time analysis, thus diminishing the costs for users mainly airport authority. It also indicated alternatives for airport operations, assisting the decision-making process and in the appropriate timing of the proposed changes in the existing infrastructure.

Key Words: Airports, Capacity, Simulation, Demand, and Delays

1. INTRODUCTION

An increasing number of users of air transportation in the whole world can be observed along the years (ICAO, 1999). Although the attacks in New York (United States) on September 11th, 2001 have generated conservation (in some cases fall) in these numbers, the whole aviation sector expects the retaking of the growth of indexes in a short term.

In spite of the apparent pause in the growth, traffic jams in the airspace and airports continues to happen and causes frequent delays, harming all participants of the airport system. The search for solutions mobilizes from airlines to air traffic control organizations.

To have an idea of the losses, in November 2000, the airport operations in Brazil generated losses in a Brazilian airline that reached the value of US$ 1 million (Targa, 2001). These losses,

generated in concentrated way due to delays in the flights, most of the time they were verified in the ground (airports), unchaining problems in every system, reaching even the airspace.

Due to the observation of the problem, analyses were made in possible operational scenarios in the International Airport of São Paulo / Guarulhos (AISP/GRU), main airport of South America in passengers' movement, based on a simulation model attesting its viability as a methodology in airport planning systems, varying the growth of the demand expressed for the aircraft's movement.

For this purpose it was used, the computational tool SIMMOD. A tool developed by the Federal Aviation Administration – FAA, civil aviation authority in the United States, capable to show through simulation the operation in the airspace and airside of airports, producing results that allow the analysis of such systems.

This methodology is consecrated in the field "airports operation analysis", with several works already implemented in the world (TRANSSOLUTIONS, 2000; Delcaire, B., Feron, E., 1997; Trani, A. A., Wing-Ho, F., 1997), including Brazil (Pereira et al., 2000; Barros, 1994).

The models in SIMMOD are discrete, dynamic and stochastic. SIMMOD represents airports and airspace system as a series of nodes connected by links. A node is defined as the position in a system of coordinates where the simulation evaluates the location of an aircraft with regard to other aircrafts from the system. All events happen according to the existent characteristics in the construction of such links.

The operation of the models developed in the tool is described in the Figure 1, being part of their events, attributes and entities considered as input data. In the tool there is also a great amount of information related to the operational performance of the aircrafts that can be classified as entities in the system besides an algorithm well built as for the airport operations.

2. JUSTIFICATION
The São Paulo Terminal Area, where AISP/GRU is inserted, is being reason for concerns from planners, administrators and operators of the airports, due to the "bottlenecks" existent in air operational procedures generating a traffic jam situation and problems as for its viability on the ground or in the airspace.

Due to the complexity of the problem, the users of the system are recurring to computer science more frequently, which subsidizes the development of new capacity analysis methodologies, where the simulation has its outstanding status. As main justification for the use of such a methodology, it is verified that the modeling using simulation techniques became quite efficient in the resolution of complex problems, possessing a very low cost if compared to the accomplishment of an experience with the real system. In the context of the air transportation, SIMMOD has been showing quite satisfactory results.

However the modeling of the object in study, its identification and the search for the best guidelines in the present researches were not tasks easy to be accomplished, once the main analyses were resulting of several technical visits to the control tower of the airport, exhausting dialogues with the responsible for the traffic in the ground (airside of the airport), full learning of the tool SIMMOD and, above all, the understanding and construction of operational scenarios for the new terminal of passengers (TPS - 3) and of the new track of landings and takeoffs. Their strategy of operation is still not known.

For the construction of the scenarios it was considered the increases in the demand, forming an alliance of this criterion with the changes of the physical layout (improvement of the infrastructure), a new runway for landings and takeoffs, and implantation of a new terminal of passengers (TPS - 3). The sensibility analysis were made confronting the demand increase in the flights against the value of delays and displacement times accomplished in the operations of landings and takeoffs called as travel times, measuring all the influence of the improvement of the airport infrastructure in the simulated alternatives.

The results will be able to assist the decision making process and in the appropriate timing of the proposed changes in the existing infrastructure.

3. AIRPORT SYSTEM CAPACITY

The airport capacity is defined as "the maximum number of operations of aircrafts, established for a certain aerodrome, for specific periods, supported by the airport infrastructure" (Siewerdt, 2001). Starting from this concept the decisions taken in relation to the development of the infrastructure are decisive for the visualization of the complete increase of system capacity.

However, the capacity is also limited by the weakest factor of the system where it is inserted, since the airspace capacity, or a new runway of landings and takeoffs, or apron area, or terminal of passengers, or simply the accessibility of the passengers to the terminal.

According this information it can be noticed how big is the problem of the increase in the capacity of airport systems. As consequence, it is observed a necessity of searching solutions, for the complete system - airspace until the access to the terminal - or simply for each factor that involves it.

4. SÃO PAULO INTERNATIONAL AIRPORT (AISP/GRU)

The biggest airport complex in Brazil, AISP/GRU was conceived originally to assist the metropolitan area of São Paulo to the demand of domestic flights that used the Congonhas airport, except for the shuttle service between Rio de Janeiro - São Paulo, as well as the international flights related with the integral countries of the South Cone, also serving as an alternative for the Campinas airport.

Although it has been planned to serve a certain scenario and objective, the administration authority of the Airport couldn't maintain the initial idea, making necessary the implantation of new strategies capable to absorb the unpredicted demand.

The AISP/GRU, the Brazil's biggest "gate of entrance", is responsible for more than 70% of the international passengers (origin/destiny) processed. It concentrates, in Brazil, the largest traffic of regular passengers, the first relative placement to the total volume of freight and postal transport, besides the great movement of aircrafts of total regular traffic (INFRAERO, 2000).

4.1. New facilities
Looking forward to solve these problems that are happening, mainly in the part of infrastructure of AISP/GRU, Brazilian Airports Infrastructure Company - INFRAERO - is proposing as alternatives, the construction of a new terminal of passengers (TPS - 3), and another runway of landings and takeoffs, absorbing simultaneous operations of the aircrafts, identified as the bounding factor for the increase of system capacity.

5. METHODOLOGY - THE MODELS CONCEPTION
Starting from the definition of the problem to be studied, the first step of the methodology consists of listing the data and necessary information for the conception of the models and the means to obtain them.

For that, basically, the model demands that are detailed the inherent aspects to the demand, operation of the aircrafts (Brazilian Ministry of Aeronautics, 1987) and geometric configuration of the airport infrastructure and of the terminal airspace (Brazilian Ministry of Aeronautics, 1993) existent today. The construction of the model is a computational work in which all this information is inserted in SIMMOD (Pereira et al., 2001).

The last phase for conclusion of the basic model consists of the validation and verification of it. Some metrics are generated and selected by the simulation for comparison with real data of the airport operation, verifying if the obtained deviations are within the maximum limits of tolerance stipulated.

The conception of the models followed the plans of enlargement of the infrastructure of AISP/GRU, which have been proposed by INFRAERO.

In the study now presented were conceived 6 models, relative to two new configurations, besides the simulation of the current situation. Each one of the configurations was simulated with the present demand (registered on March of 2000) and with increments that vary from 2% to 30% on the current demand, totaling 15 increment values. The results for each one of them were converted in delays (cost), and confronted against the growth of the demand. The comparative analysis was generated from these results.

The demand on March 2000 had in its peak day 555 operations; while in February 2002 the number of operations in the peak day was 534 operations (INFRAERO, 2002). In other words, on these 2 years, the change was not significant; there was conservation in the numbers. These times were originated by facts as the attacks in New York on September 11, 2001, besides the exit of

the airline Transbrasil that paralyzed a great range of the market with domestic and international flights.

The 6 models built and simulated with the tool SIMMOD were:
· M1: Current situation;
· M2: Hypothesis with the addition of the third runway of landings and takeoffs;
· M3: Hypothesis with the addition of the third runway and third terminal - first operational strategy;
· M4: Hypothesis with the addition of the third runway and third terminal - second operational strategy;
· M5: Hypothesis with the addition of the third terminal - first operational strategy;
· M6: Hypothesis with the addition of the third terminal - second operational strategy

Due to the inexistence of information about the behavior and the operation of the new terminal of passengers, in development, in this work two options of operational strategies were adopted.

5.1. Current Situation Model
The model built to show the current situation of AISP/GRU, followed the data from AIP (Brazilian Aeronautical Command, 2000). It has two parallel runways of landings and takeoffs, being one with 3000m of length (09R/27L) and the other with 3700m (09L/27R). The separation between the axes of the runways is 375m. In the direction 09, the thresholds are 500m staggered, runway 09R is used primarily for the operations of landings (85%) (IAC, 1999), and runway 09L is used most of the time for takeoff operations.

The staggered runway configuration results an effective separation among runways of 485m (addition of 30m for each 150m of staggering). However, the minimum separation suggested by ICAO is of 760m to segregated dependents operations of landings and takeoffs in parallel runways, in visual flight rules (Barros apud Nagid, 1994). Though, runways with separation larger than 300m can operate in the system dual lane, in other words, authorized takeoffs when the aircraft touch the ground. Such is the procedure adopted by AISP/GRU to optimize the use of the existent infrastructure.

The airport has 2 terminal building (finger concept), with eleven parking positions each one. Only three positions at the finger extremity can receive aircraft larger than Boeing 767. This fact is due the initial proposal in which the airport would assist only South America flights. However, INFRAERO are already modifying the structure of the aircrafts parking positions in the terminals and should conclude this stage until the end of 2003.

The 2 terminals buildings have a planned capacity to receive, each one, up to 7.5 million PAX/year.

5.2. Third Runway Model
The development of this model was directly linked to the new project that INFRAERO is developing.

The master plan of the airport established a third runway with 2025m of extension. However to implement that, it was adopted its construction inside existent patrimonial area, under the responsibility of INFRAERO as basic premise. According this, the solution was to locate the runway to 1462m from the runway 09L/27R axis, reducing the original length for 1800m.

The most appropriate position for the implantation of the third runway inside of the patrimonial limits, it was then to 1462m of the axis of the current runway 09L/27R, resulting in the dimensions of 1800m X 45m, could be enlarged for the 2025m, predicted in the master plan, by incorporation of new areas to the airport.

IAC (Civil Aviation Institute) in the report of viability of operation of the third runway of landings and takeoffs (IAC, 1999) has verified that a runway of 1800m would allow the landing and takeoff, in most of the cases with 100% of the acceptable maximum weights. Besides, as for the positioning of the runway of parallel taxi-lanes, the criterion of FAA was adopted (Federal Aviation Administration), that it establishes a removal of 120m of the axis of the new runway, compatible with aircrafts with wingspans minor or equal to the one of the Group IV (up to 52m of wingspan), that reaches Fokker 100, Boeing 737, 767, and others. The report attests that about 80% of the programmed operations to the airport can be accomplished in the future third runway, excluding only the aircrafts that accomplish international flights.

A factor that harms the operation of the third runway lives in the accessibility of the aircrafts for the accomplishment of the landing operations and takeoffs. Starting from that consideration the need was verified of doing an analysis among the values of delay and travel times.

With the entrance of the operation of the third runway, IAC (IAC, 1999) in the same study it was presented the configuration of the new mix of aircrafts to the airport together with the percentile of use of the runways as for the operation (Table 1) that was used in the conception of the model.

5.3. New Terminal of Passengers (TPS-3) Model
As well as the development of the previous model, the implantation of a new terminal of passengers in the model considered the premises of the project bid by INFRAERO, approximating to the reality the future operations.

Starting from the knowledge of demand studies accomplished by IAC (Brazilian Ministry of Aeronautics, 1999), where it was pointed for the year 2017 a movement of passengers in the order of 39 million PAX/year, INFRAERO bid in 1996 the project for the construction of the third terminal. Their main characteristics were (INFRAERO, 2000):

· Capacity for 12 million PAX/year;
· Architectural concept should accommodate the largest possible number of aircrafts parking on nose in, with two positions dedicated to NLA's (new large aircraft) and the minimum of seven positions for aircrafts type Boeing 747-400;

· Expansion Capability, making possible the implantation of the fourth terminal with identical dimensions;
· The access circulation to the bridges was divided in two levels to separate passengers' departure and arrival flows;
· Mix of stands for aircrafts of great and medium loads;
· Semi-automated System of dockages of aircrafts.
· Construction of one more remote parking area for the aircrafts of great, medium and small load, access the third runway and still a small linear terminal, that will absorb part of the domestic traffic.

5.3.1. Operational strategies in the Third Passengers Terminal (TPS-3)

As mentioned previously, the operation of the new terminal of passengers (TPS-3) of AISP/GRU is an unknown that reaches all of the users of the system.

Once it is not the objective of the present work to point the best ways to obtain the best operation, it was decided to come up with 2 propositions of operations and to submit them to the simulation.

The 2 propositions were based in:

· Percentile Division of the operations for each airline;
· Alliances among the airlines;
· Apron Capacity - size of the aircraft and their restrictions;
- Flight Plan Characteristics;
· Operations balance within the 3 terminals.

The way 2 operational scenarios were generated where there was a proportionality to the capacity projected for the passengers' processing, TPS-1 and TPS-2 with 7.5 million PAX/year, representing 27.8% each of the passengers' demand and TPS-3 with 12 million PAX/year, representing 44.4% (Table 2). It is worth to remind that the scenarios were elaborated according to demand of March 2000 (INFRAERO, 2000).

6. DEMAND

Looking for to evaluate the study object better, and to produce results to generate significant analyses as for the capacity on the airport airside, it was verified that the variation of the demand associated to the simulations in the models would consist in the very important step.

The study "Detailed Demand Analysis of Brazilian Airports" (Brazilian Ministry of Aeronautics, 1999) indicated that a 30% demand growth on the number of operations was expected in the AISP/GRU in a 5 year-horizon. The adoption of a range of increasing demand values was influenced by the lack of an updated forecast model after the countless problems caused in the world and Brazilian aviation by the attacks in the USA, that caused the observed break and decrease of flights.

Therefore, models representing 16 demand levels, ranging from 0% to 30% demand increment, were simulated and the for each one the level of traffic and the respective delays and travel times were obtained.

The results allowed identifying the potential behavior of the average delay and average travel time, evidencing, this way, the appropriate instant to intervene in the installed infrastructure.

7. RESULTS AND ANALYSES

To generate results with statistical significance, although the experience suggests 5 iterations as enough to ensure statistically valid results (TRANSSOLUTIONS, 2000), 20 iterations of each analyzed model were performed.

After executing the simulation, the first concern was that regarding the validation of the model, turning it capable to accomplish the other proposed analyses. The validation stage was accomplished starting from the comparison of the results of the simulated system with the real system, testing logically and numerical the model.

The validation followed the criteria:

· Representative day = peak day of the data base supplied (March of 2000)
· Total Period used in the simulation = 1 day of airport operations = complete cycle
· Validation Process and verification = comparison of the generated results (Figure 2)

Besides the number of operations, the process of validation of the model of the current situation consisted of the close verification of the input data from the report of the International Consultancy MITRE Co. (MITRE, 2001) contracted by the Civil Aviation Authority (DAC). In this report, MITRE Co. mentions that the maximum capacity is between 46 and 49 operations, varying that number according to the operation type, departure or arrival. The model developed in SIMMOD obeyed exactly to these numbers, arriving in the maximum number of 50 operations with an increase in the demand of 30% reaching its capacity limit.

In Figure 2 the adaptation of the "flotation" of the number of operations was observed, besides with the proximity of the "peaks" and "valleys" operational between the real values and the simulated model.

Other metric verified was that related to the number of aircrafts in the takeoff line that coincided with the numbers of INFRAERO. In the peak hour, these values reached 9 aircrafts in the waiting line on the ground, both in the developed model and in the real operation.

7.1. Analysis of the Results

The analysis of the simulated operational models is linked to the demand and offer of the system, besides the installed capacity of the airport.

Observing Figure 3 it is noticed the influence of the third runway of landings and takeoffs firstly in the decrease of delays. It is clear the existence of the division, among the models, in 2 groups with seemed characteristics as for the variation in the evolution of the demand. They are differentiated amongst themselves just by the inclusion of the third runway in their scenarios.

It is also demonstrated in the same Figure 3, that the percentile growth of the delays doesn't depend a lot on the choice of the operational strategy for the third terminal of passengers (TPS-3). The behavior is identical considering or not the existence of the third runway of landings and takeoffs. However, in both cases, they accompanied the tax of percentile growth of the delays.

As expected, the results generated starting from the simulation of the models 3 and 4 those that presented the minor values were when applied to the increase of 30% in the demand of aircrafts. Almost 75% of delays increase in the models 3 and 4, against 495% in the model 1 (current situation of infrastructure).

Completing the analyses of the study is necessary to confront the delays against the travel times accomplished by the aircrafts in their courses in the ground.

The third runway of landings and takeoffs possesses a small problem as for its operation already described previously. The aircrafts to reach the "new" runway threshold 09 will face a long taxi distance increasing therefore the travel time on the ground.

The aircraft would be less subject to the delays (happened in the gates, in the taxi-lanes and aprons), once the itineraries would not conflict with the existent procedures in the current taxi-lanes. However, the traveled time to the runway threshold 09 "new", in the case of takeoffs, would be high. The time spent for the arrival procedures would not be so accentuated, once the largest difficulty would be to reach the runway threshold 09 "new" for takeoff.

The results were practically the same, where the differential once again was the inclusion of the third runway of landings and takeoffs. The demand usually varied and the travel time also in the same way, in accordance with the same growth taxes.

On Figure 4, it is verified that the tax of growth of the travel time proceeded exactly to the tax of growth of the demand, generating a constant graph for their average values. Once constant, the difference can be measured by the average time the aircraft spent in the models where there is the inclusion of a new runway of landings and takeoffs and in the models in that the operations follow all for the same runway.

This time observed in Figure 4 is of 2 minutes. In other words, in the models where the new runway is considered, the operations were added by 2 minutes in relation to those that didn't considered the third runway.

According to Table 2, where the models differ for the existence of the new runway of landings and takeoffs, and of the new terminal of passengers, it can be verified that starting from an

increase of 14% in the demand of the operations in the Airport, the difference among their average delays passes 2 minutes. This value had been mentioned as the reference pattern on the average time of trip spent by the aircrafts that use the new runway of landings and takeoffs.

On Figure 5, it is noticed that when increasing 30% in the demand of the movement of aircrafts, the difference among the average values of delay for operation passes 5 minutes.

However, for demand values up to an increase of 14%, the delay among the models 2 and 5, and 2 and 6, turns smaller difference than 2 minutes, resulting non effective the construction of the third runway of landings and takeoffs, once the average travel time stayed constant in 2 minutes for any demand increase.

The installed capacity was not completely used for any of the mentioned cases. However there is a great tendency, starting from 30% in the increase of the demand of the movement of the aircrafts, that AISP/GRU, reach its operation limit quickly, above all in the model 1 that represents the operation situation lived in the days today, with many points of operational conflict.

However, one of the great problems visualized now at the airport regards the concentration of flights in certain schedules, causing excessive delays in certain hours of the day. The existence of idleness during other hours of the day made possible the operations in the simulations, although with many delays.

8. CONCLUSIONS

The viability of use of the methodology as an aid to the decision-making in airport planning is observed.

The study suggests that the construction of a third runway of landings and takeoffs, along with taxi-lanes, would bring more benefits in the long run (30% demand increase) of the operation of the airside as opposed to the solely construction of a new terminal of passengers (TPS-3).

However, the best option would be the construction of the 2 facilities, the new terminal of passengers and the new runway of landings and takeoffs. For an increment of 30% in the demand, the impact on delays would be very small, once the average delays would reach values close to the ones observed in 2000.

The new terminal of passengers alone would be operationally more effective than the third runway of landings and takeoffs up to 14% increase in the demand of the Airport.

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ANNEXES
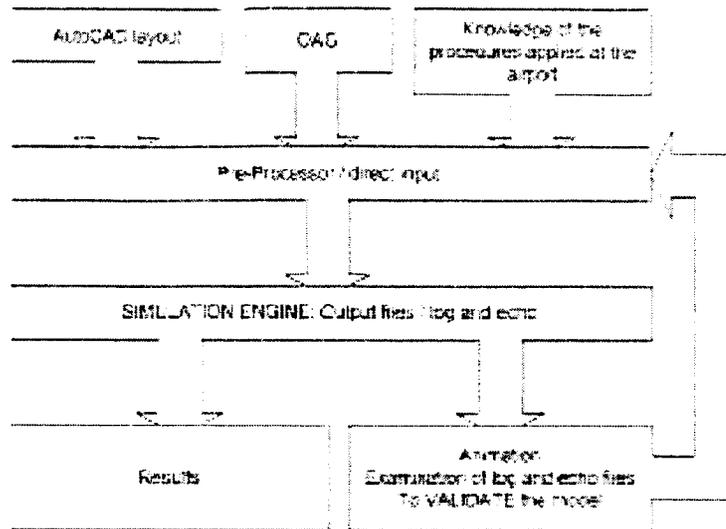
Figure 1. The Simulation Framework from SIMMOD Tool
Source: Delcaire &Feron, 1997
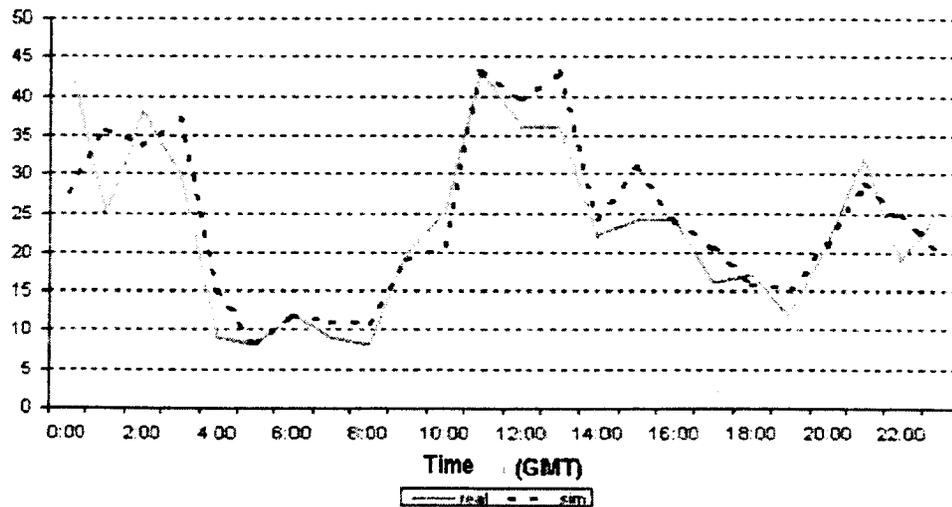
Figure 2. The Simulation Validation and Verification

Delays against Current Situation Model Scenario Base
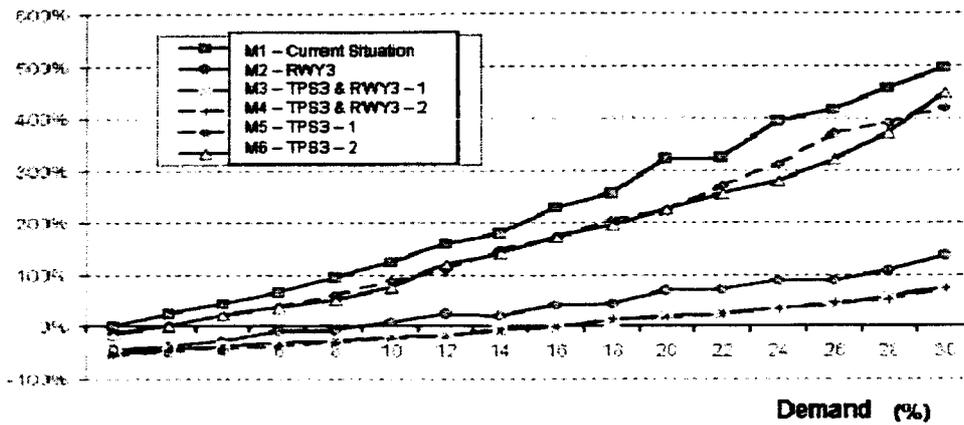
Figure 3. Simulation Results from 6 Models

TRAVEL TIMES – ARR + DEP (AVERAGE)
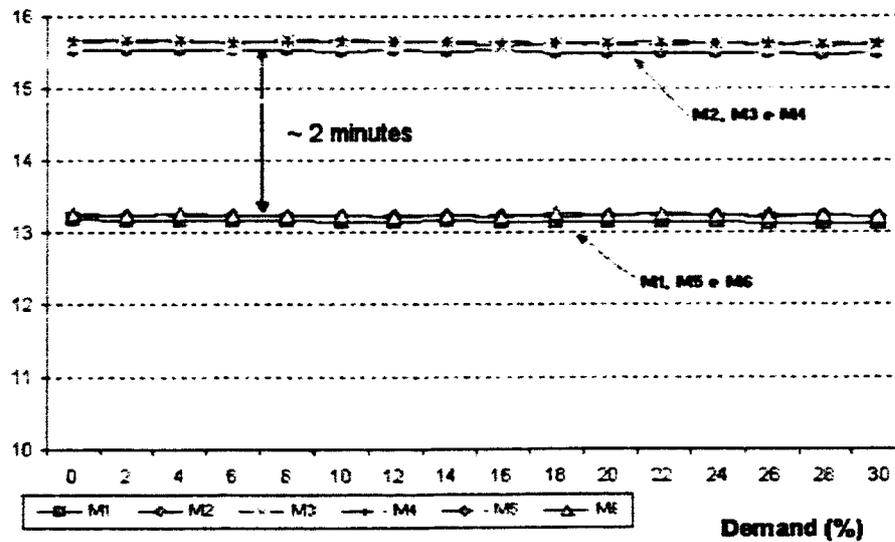
Figure 4. The Simulation Results – Travel Times (average) – 6 Models

DELAY – Min/OPER (ARR + DEP)
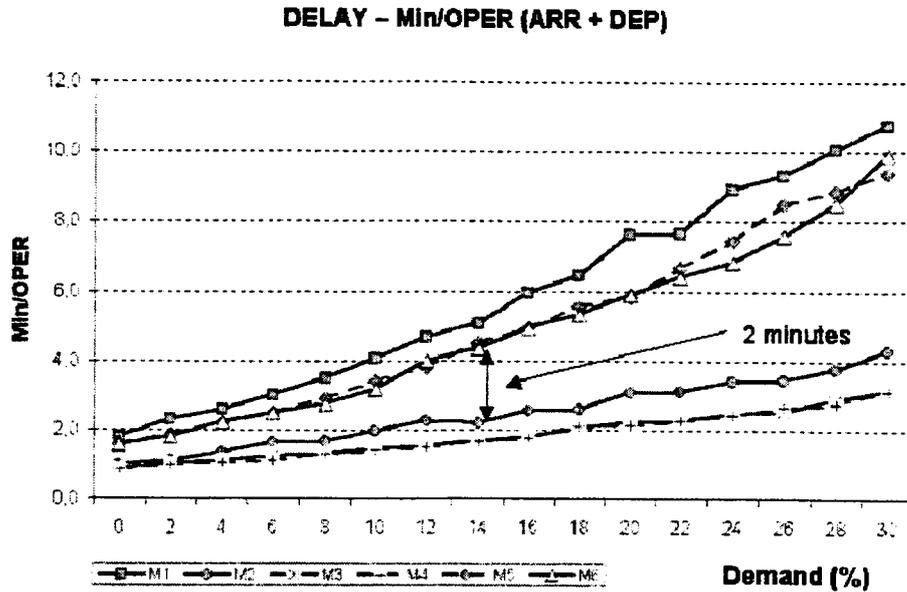
Figure 5. The Simulation Results – Delays (average) – 6 Models

Table 1. Aircraft's Operational Mix to AISP/GRU

Runways Using Percentile			
Aircraft	*Third Runway*	*09L/27R*	*09R/27L*
B737	100% arr	35,13% dep	64,87% dep
F100	100% arr 37,4% dep	62,6% dep	-
E120	100% arr and dep	-	-
F50	100% arr and dep	-	-
B767	26,56% arr	100% dep	73,44% arr
MD11	-	100% dep	100% arr
B747	-	100% dep	100% arr
A300	-	100% dep	100% arr

Table 2. Operational Mix for Third Passengers Terminal at AISP/GRU

Scenario 01	**Star Alliance and others**	43.91%	**TPS-3**
	TAM e Group	28.01%	**TPS-2**
	Vasp e Group	28.09%	**TPS-1**
Scenario 02	**Long Haul Flights and Brazilian airlines**	43.76%	**TPS-3**
	Vasp e Group	28.15%	**TPS-2**
	Domestic and Int. South America	28.09%	**TPS-1**

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