PRELIMINARY RESULTS ABOUT THE APPLICATION OF PRM/SOIA CRITERIA AT SÃO PAULO/GUARULHOS – GOVERNOR ANDRÉ FRANCO MONTORO INTERNATIONAL AIRPORT

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ABSTRACT
This paper contains the preliminary results obtained in the application of PRM/SOIA approaches in the São Paulo/Guarulhos – Governor André Franco Montoro International Airport (GRU) using a computational simulation tool (RAMS Plus). We also show the next steps planned for this work, presently in stage of construction. Diverging of some specialists' opinions, the results obtained up to this stage of the project indicates that the current demand is already in an upper level than the capacity of the current system of runways during some periods, generating several delays that can be reduced abruptly with the implantation of PRM / SOIA. This shows the extreme importance of activities to enhance the capacity of the runways' system, supporting the demand that will be increased in the next years due the planned construction of the new terminal in this airport (RAMS Plus and ATM Analyzer utilization in this study is in accordance with the Academic Software License Agreement granted by ISA Software Ltd. to ITA).

RESUMO
Neste artigo se divulgam os resultados preliminares obtidos na implantação do PRM/SOIA no Aeroporto Internacional de São Paulo/Guarulhos – Governador André Franco Montoro (AISP/GRU) através de ferramenta de simulação computacional (RAMS Plus). Neste documento também são mostrados os próximos passos planejados para esta pesquisas, que atualmente encontra-se em fase de construção. Os resultados obtidos até o presente momento divergem da opnião de alguns especialistas, indicando que a atual demanda do aeroporto já se mostra superior à capacidade do atual sistema de pistas em alguns momentos, gerando diversos atrasos que podem ser reduzidos bruscamente com a implantação do PRM/SOIA. Tal fato mostra a relevância de ações para aumentar a capacidade das pistas, buscando atender a demanda que irá crescer significantemente com a prevista construção do novo terminal de passageirosnos próximos anos (o uso do RAMS Plus and ATM Analyzer neste estudo está de acordo com os Termos de Licença Acadêmica concedido ao ITA pela ISA Software Ltda).

1 INTRODUCTION

The capacity of the airspace system around the world is primarily constrained by the landing capacity of the busiest airports. Historically, world air traffic has been increasing at about 5 - 6% per year for many years and will likely continue that growth in the future. Therefore, increases in the number of aircraft landings will approximately triple in 20 years. In order to accommodate these landing rates, it will be necessary to increase the number of airports, increase the usable number of runways at existing airports, or both (POWELL, 2005).

Simultaneous approaches are conducted to parallel runways in order to increase arrival rates at many of today's heavily congested airports (FAA, 2003); even under bad weather conditions called Instrument Meteorological Conditions (IMC), using Instrument Landing System (ILS) that follow Instrument Flight Rules (IFR). The FAA has successfully conducted independent approaches to parallel runways for over forty years using these ILS navigation and terminal radar monitoring (FAA, 2001), where, with the navigation and surveillance systems in primary use today, this parallel runways must be separated by 4300 feet (POWELL, 2005). This operations use standard displays: standard analog and digital Automated Radar Terminal System (ARTS) green displays (MASSIMINI, 2006). This space is needed due to risk of accident in these procedures, where, under ILS approaches, the primary responsibility for maintaining separation between aircraft lays with the air traffic

controllers. However, under Visual Flight Rules (VFR), parallel runways that are separated by as little as 750 ft can be utilized, since in such procedures it is the pilots' responsibility to maintain separation from other nearby aircraft (POWELL, 2005). The Visual Flight Rules (VFR) can be followed just under good weather conditions, called Visual Meteorological Conditions (VMC).

To further increase the utilization of those runways (spaced less than 4300 feet apart) under instrumental conditions, the FAA has developed new criteria, such as the Precision Runway Monitor/Simultaneous Offset Instrument Approach (PRM/SOIA). PRM/SOIA allows simultaneous approaches to runways spaced by less than 3000 feet to as close as 750 feet apart (FAA, 2003) using two different approaches, simultaneously. A aircraft approach to one runway using the Instrument Landing System/Precision Runway Monitor (ILS/PRM) that is similar to the standard Instrument Landing System (ILS) already cited, but with the special equipments and procedures such as the PRM approaches. The other (aircraft) approaching to the other runway uses a Localizer Type Directional Aid/Precision Runway Monitor (LDA/PRM) approach, which has two main differences from the ILS/PRM procedure: an 2.5 to 3.0-degree offset localizer-type directional aid (from the ILS localizer interception until the courses are 3000 ft apart) and a visual segment in the last part of the approach.

In other paper we already examined some of these procedures of simultaneous approaches in closely-spaced runways, pointing the São Paulo/Guarulhos – Governor André Franco Montoro International Airport (GRU) as a potential place for the application of the PRM/SOIA approaches (FRAGA et al. 2009); detailing the PRM/SOIA and its application all over the world, the profits derived from this criteria and the GRU airport. This paper contains the preliminary results obtained in the application of PRM/SOIA approaches in the São Paulo/Guarulhos – Governor André Franco Montoro International Airport (GRU) using a computational simulation tool (RAMS Plus).

2 SIMULATION: MODELLING PROCEDURES AND SCENARIOS

As already shown in Fraga et al. (2009), simulation plays an important role in studies about airport capacity. Nowadays, the use of simulation tools in these studies is very common worldwide, thanks to the great variety of software available, such as SIMMOD, TAAM, RAMS Plus, ARENA and others. Fraga et al. (2009) presented some examples of airport research that rely on simulation, such as the MITRE Corporation which uses a TAAM software simulation of PRM/SOIA in Hartsfield Atlanta International Airport (ATL) (GLADSTONE et al., 2000). As regards the Brazilian scenario, Santana (2002), Hupalo (2003), Moser (2007), Oliveira (2007), Teixeira (2007), Bastos (2008), Baum (2008), Pogianelo (2008) and others have already used one of these tools in research works that focus airports in the country.

In this research, the Reorganised ATC Mathematical Simulator (RAMS Plus) tool (version 5.29.15) was used: a gate-to-gate ATC/ATM fast-time simulator tool, which helps you answer a spectrum of questions about your ATM system, from airspace design, capacity, working procedures, & safety concerns, to airport movements, capacity and delay (ISA SOFTWARE, 2003).

Basically, pilots follow Visual Flight Rules (VFR) under Visual Meteorological Conditions (VMC) and Instrument Flight Rules (IFR) under Instrument Meteorological Conditions

(IMC). However, pilots often use the ILS in VMC to help guide the aircraft to a smooth landing over the last 5 miles of the approach; however, they have the option of looking out the window to line up the aircraft with the runway (POWELL, 2005). In other cases, there is no need for visual procedures due to the increased safety and dynamism that such operations offer to the system. Nowadays, visual procedures are losing space to instrument procedures (OLMOS & MUNDRA, 1999). Therefore, it is clear the importance of allowing for instrument procedures at the airports, including simultaneous approaches to airports with parallel runways.

The São Paulo/Guarulhos International Airport (GRU), our case study, does not have visual procedures, even under Visual Meteorological Conditions (VMC). Thus, scenarios have been created using all the current instrumental procedures of the São Paulo Terminal Area (TMA-SP): the terminal area where the GRU airport is inserted. As such, these scenarios include all the airports in the TMA-SP which have instrument procedures: São Paulo/Guarulhos International Airport (GRU), São Paulo/Congonhas Airport (CGH), and Viracopos/Campinas Airport (VCP). Therefore, the scenarios have been modeled using the Standard Instrument Departure (SID) and the Standard Terminal Arrival Route (STAR) charts for the three airports: the charts that include the procedures for instrumental arrivals and instrumental departures in the TMA-SP.

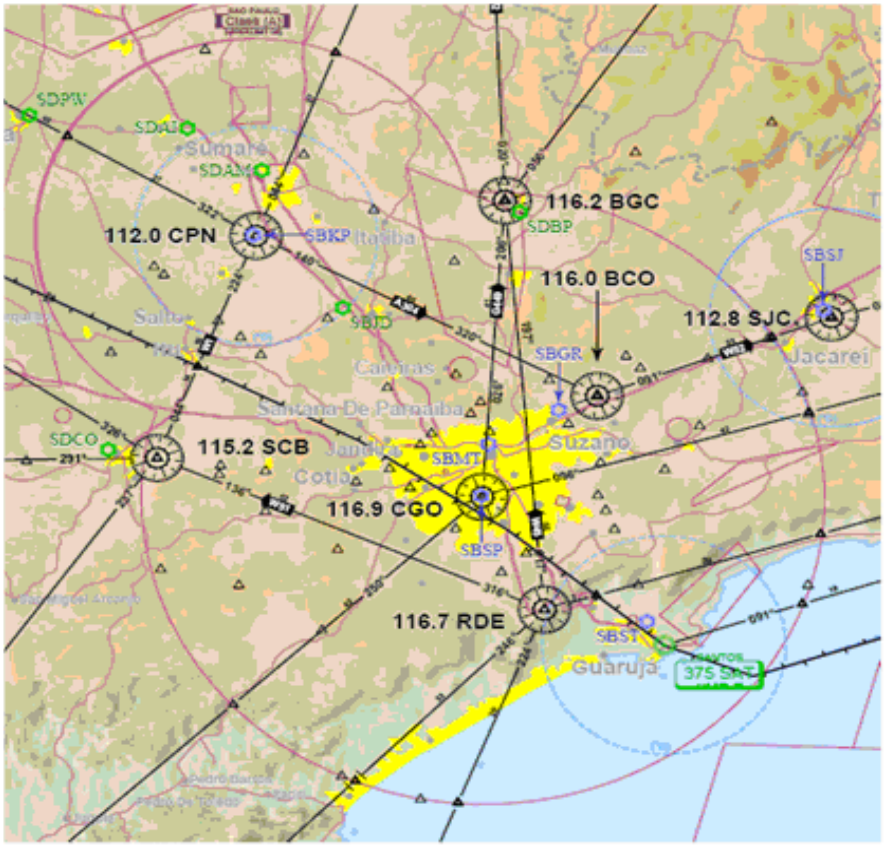


Figure 1: TMA-SP and the three airport inside this terminal with instrumental procedures: GRU (SBGR), São Paulo/Congonhas (SBSP) and Viracopos/Campinas (SBKP)

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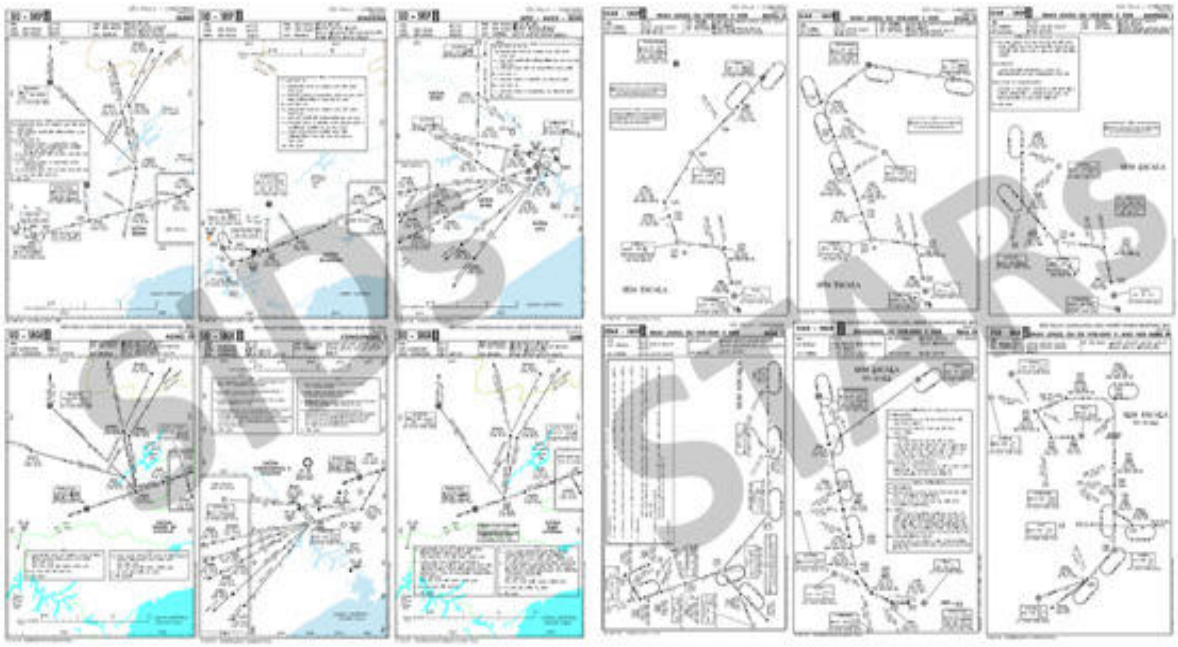


Figure 2: Some SIDs and STARs charts (six examples of each) for the three airports used in the simulation

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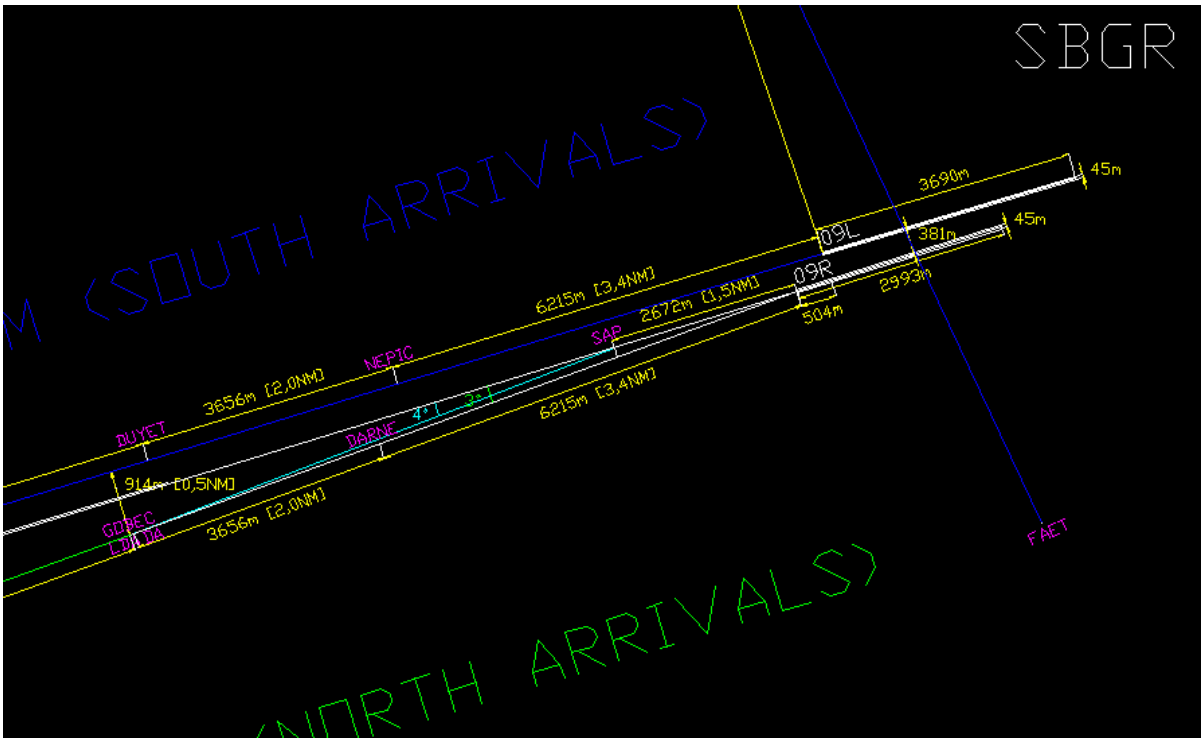


Figure 3: Last segment of the approaches modeled in AutoCAD software

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In order to devise the new procedures (PRM/SOIA scenarios) we have decided to closely emulate the procedure already established in San Francisco International Airport (SFO), but

taking into account the features of the TMA-SP, such as the relief and elevation of the runways; and using the thresholds with the most utilization rate: 09 for São Paulo/Guarulhos International Airport (GRU), 17 for São Paulo/Congonhas Airport (CGH) and 15 for Viracopos/Campinas Airport (VCP). This way, we used the PRM/SOIA charts from SFO to create the PRM/SOIA geometry for GRU. Figure 3 shows the geometry of the PRM/SOIA procedures created for GRU in one of the segments (last segment), where the LDA PRM approaches are conducted in the 09R threshold, and the ILS PRM approaches are conducted in the 09L threshold. All the segments have been modeled with the help of AutoCAD so as to achieve a level of high precision in the construction of each segment (construction of way points, routes, angles, distance between paths and other factors that have required extreme precision), to be imported into the RAMS Plus simulator.

By analyzing the construction of the new procedures, the present path of the approaches for the thresholds of GRU and CGH is displayed in the image below (Fig. 4). As a result of the path, implementing the exact way of PRM/SOIA approaches of SFO in GRU creates crossed approaches, as shown in Fig. 4. This happens because the PRM/SOIA approach established at SFO uses a final approach (the "straight line" segment of the approach) with more than 20 nm of length, while the conventional approach uses a final approach with approximately 7 nm of length.

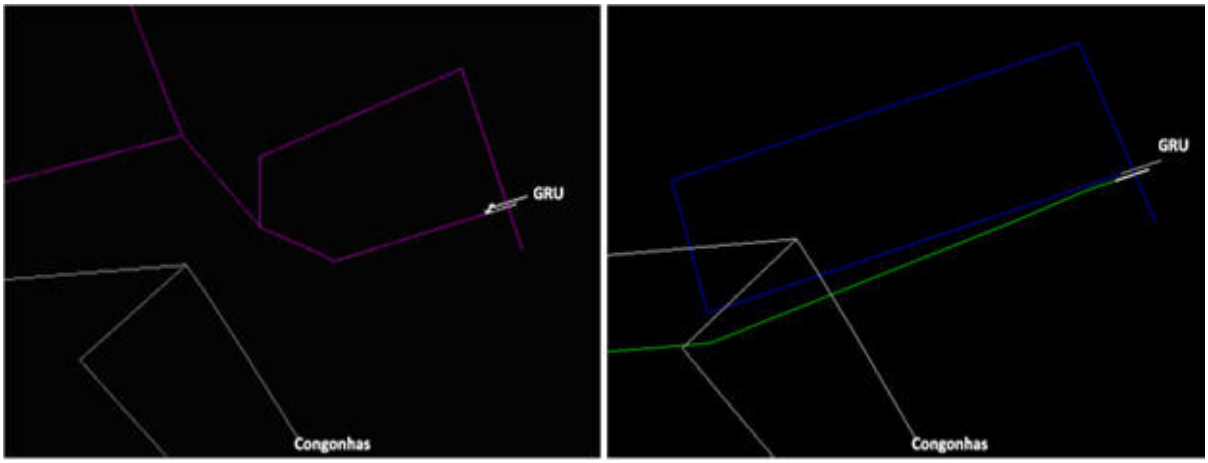


Figure 4: Differences between conventional and PRM/SOIA approaches: relationship between GRU and CGH approaches

Font: from authors, 2009

To solve this problem we have devised the scenarios with PRM/SOIA procedures in GRU with a vertical separation of the approaches in CGH (approximately 3000 ft of vertical separation). We have chosen this solution by analyzing a Brazilian case of two airports with crossed approaches: the Belo Horizonte/Pampulha-MG-Carlos Drummond de Andrade Airport (SBBH) and the Tancredo Neves/Confins International Airport (SBCF), with crossed approaches even for thresholds with high utilization rate (13 and 16, respectively). Fig. 5 below shows some crossed points in those approaches (left side of the figure), where the nearest point (ESLUT) of these thresholds (approximately 17.5 and 26 nm of distance, respectively) have a vertical separation of only 1000 ft (right side of the figure). On the other hand, we have set a vertical separation almost 3 times bigger.

In the past, some studies showed that, without this vertical separation, the PRM/SOIA in GRU decreases the capacity in CGH, making the system unviable. As a result, we choose to consider this separation between decent traffics, even if these procedures are not frequently used nowadays.

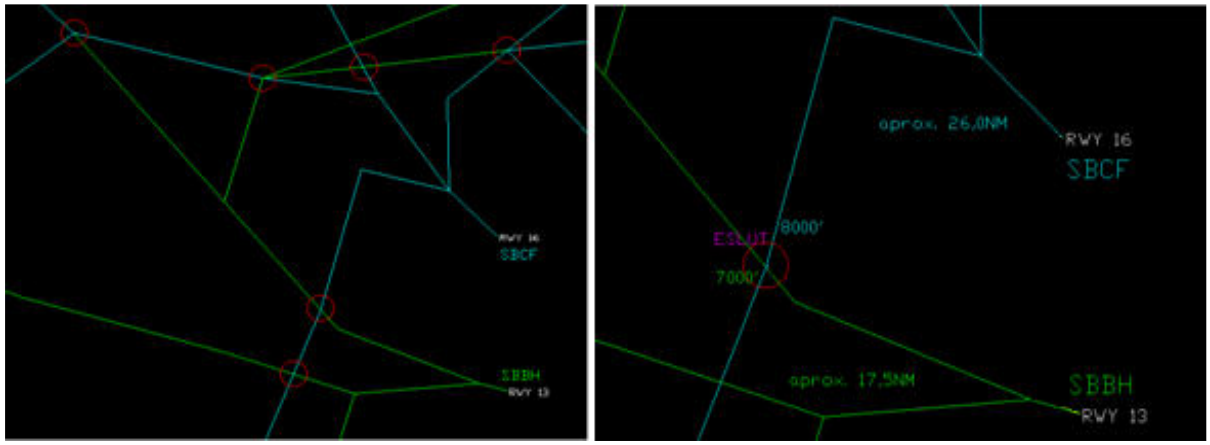


Figure 5: Separation between current approaches in SBBH and SBCF

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Besides, some alternative constructions emphasizing safety has been created, consisting in changes in the CGH approaches that reduce the crossed points between the approach paths. Figure 6 below shows one of these alternatives constructions, which make it easy to understand the differences in a comparison between Fig 6 below and Fig 4 above. The right side of the figure shows the distance of the nearest point between the approaches.

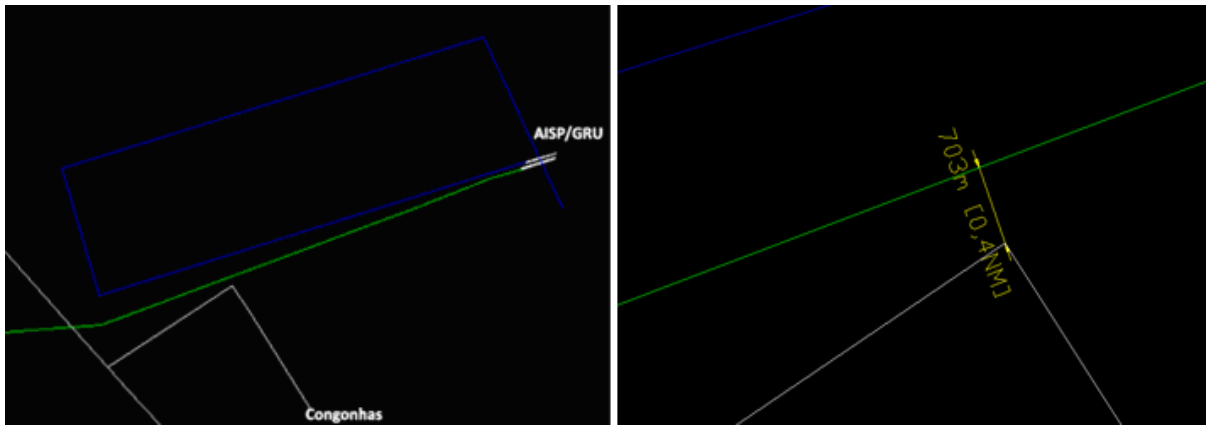


Figure 6: Changing the CGH approach to reduce the crossed points between the approaches of GRU e CGH

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However, trying a lot of alternative constructions as new scenarios, we concluded that all the alternatives (as this one showed in Fig. 6) are not able to solve the problem of the crossed approaches. As a result, this little separation is not enough, this is, we only could create very small separations: always less than 1 NM, when the minimum to warrant safety operations is 5 NM.

In this way, we have two different scenarios, a scenario modeling the current procedures and one scenario modeling PRM/SOIA procedures:

- Scenario 1: simulation of the current procedures in the TMA-SP.
- Scenario 2: PRM/SOIA simulation in GRU and current procedures in the others two airports modeled (CGH and VCP).

We have followed the ICAO rules to construct these procedures (ICAO, 1999; ICAO, 2006; ICAO, 2007), considering a RNAV system that uses satellite technology, requiring a semi-width of 2.5 nm. Therefore, for these approach segments, the separation between the approaches needs to be at least 5 nm, as shown in the ICAO rules (ICAO, 1999; ICAO, 2006; ICAO, 2007). The Figure 10 shows these separations and the soft angles of the constructed routes.

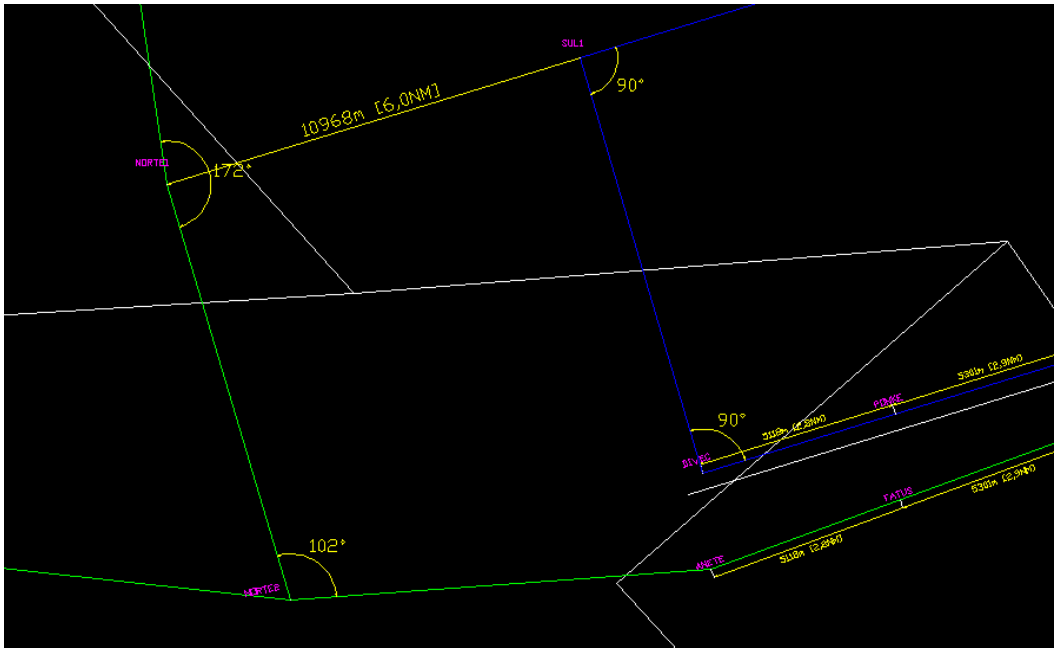


Figure 10: Separations between STARs for CGH and GRU, with the angles of the turns

Font: from authors, 2009

About the missed approach maneuvers, we considered the mountains in the northeast sector of the GRU airport, proposing that the two simultaneous approaches can execute simultaneous missed approach maneuvers with one of them following a straight direction (09L) and the other turning to the right (09R). Besides, due to the high utilization rate of the 09 thresholds (FRAGA et al., 2009), we modeled only these procedures, disregarding the approaches for the 27 threshold. In this way, we also disregarded the aprons of the airport in the construction of the scenarios, due to reasons of easy expansions of these facilities as new aprons can be constructed in the northeast area (the aprons of the 3rd and 4th passenger terminals). Nowadays, some airports decide to construct the aprons before its terminal, decreasing apron's congestions.

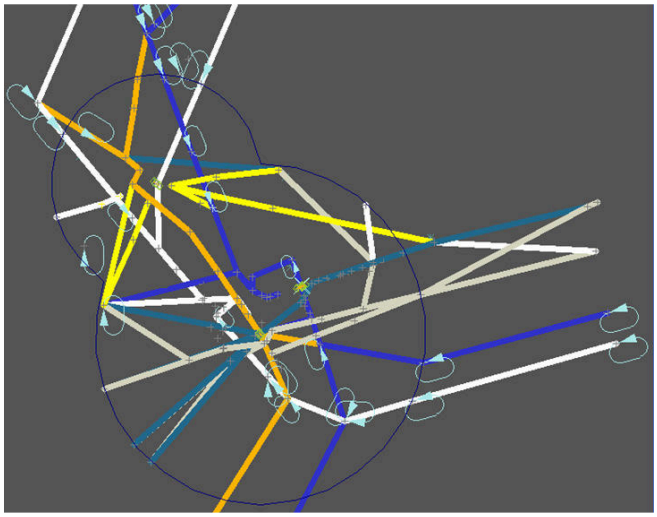


Figure 11: TMA-SP: current IFR procedures modeled in RAMS Plus

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3 LIMITATIONS

We found a lot of problems in RAMS Plus to devising the PRM/SOIA approaches, due some limitations and incompatibility of the software to modeling these procedures. One of the most problematic limitations is that the current version of the software is unable to set a reduced separation just for a pair of aircrafts in a specific segment, creating reduced separations during the whole terminal area between a series of aircrafts.

To solve these problems we divided the approaches in two groups: STARs from south and STARs from north/west, allowing the reduced space just in the intersection point between these groups. As a result, the aircrafts maintain a conventional (standard) separation during the whole procedures, only reducing the separation between aircrafts of different groups; and this reduction only happens if, in the intersection point, the separation between these two aircrafts is smaller than 5 nm. In this case, both aircrafts will adjust its approach speed to make reduced-spaced approaches, executing a PRM/SOIA procedure, as shown in the Figure 11.

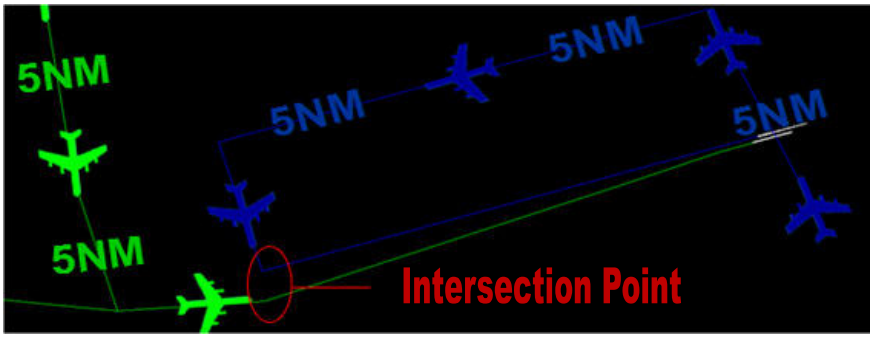


Figure 11: Intersection point between STARs from south and STARs from north/west: the reduced-spaced separation begins here

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However, this configuration can also underestimate the profits derived from PRM/SOIA procedure, due to the impossibility to conducting PRM/SOIA procedures by aircrafts with the same origin point. Besides, another problem is about the determination of the leading and the trailing aircrafts: the software does not support reduced separations between a specific trailing/leading aircrafts, as established in the manual: "when using this 5th optional field, the order of following and leading SID/STAR is not relevant, instead the SID/STAR combination is treated in any order" (ISA Software, 2006). As a result, sometimes the leading and the trailing aircrafts execute the PRM/SOIA procedures in changed position; where, regarding the PRM/SOIA concept, the trailing aircraft must execute the LDA/PRM approach and the leading aircraft must execute the ILS/PRM approach.

4 RESULTS

In this first stage of the research, we simulated the scenarios using a data-bank of only one day: 6/03/2008, a typical day, with 1030 movements in the TMA-SP for the three airports analyzed (arrivals and departures). Related with the stochastic tasks, each scenario was simulated 10 times, and the stochastic tasks are: aircraft performance, runway occupancy, task weight, controller window, airport taxi. These tasks varies in a normal distribution with mean = 1 and standard deviation = 0.03; this is, basically, varying from approximately 90 to 110% of the normal condition (Fig 12).

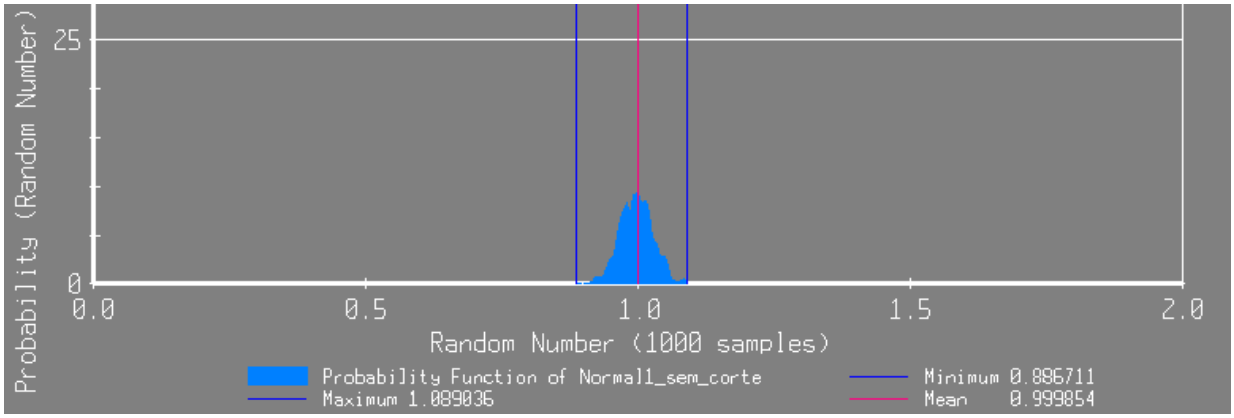


Figure 12: Normal distributions of the stochastic tasks
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The averages of the results (10 replications) are displayed in the tables and graphs below, showing the variations in percentage for scenario 2 in comparisons with the scenario 1 (the baseline scenario, simulating the current procedures). All the averages showed a standard deviation less than 15% (of the average).

Table 1: Operational times of the simulations

Scenarios	Index	Total airborne flight delay	Mean Delay	Standard Deviation	Total actual airborne flight distance (NM)
Scenario 1	Average of all replications	10638.15	10.32	17.15	89757.68
Scenario 2		5206.75	5.05	8.48	94847.33
Difference		**51%**	**51%**		**-6%**

Font: from authors, 2009

Table 2: Departure Queue of the simulations

Scenarios	Index	GRU - Mean departure queue time (in seconds)	CGH - Mean departure queue time (in seconds)	Total ground departure queue delay (in minutes)	Total duration on ground for all ground operations - arrivals (in minutes)
Scenario 1	Average of all replications	624.70	546.40	3933.79	467.22
Scenario 2		695.30	557.50	4443.70	361.05
Difference		-11%	-2%	-13%	23%

Font: from authors, 2009

According to the table 1, the delays airborne (analyzing the entire scenarios or only the TMA-SP area) decreased in 51% and the time of arrivals' taxi decreased in 23% (table 2) for the PRM/SOIA scenario (in a comparison with the current conventional approaches). This happens even with the increase in the total flight distance of 6% in the PRM/SOIA scenario (in a comparison with the current conventional approaches), due to the enlargement of approach path required in the PRM/SOIA procedures.

As a result, the average delay airborne per aircraft registered in the simulation of the current procedures is approximately 10.5 minutes, while, for the PRM/SOIA procedures, this value is around 5 minutes, analyzing the entire scenario. This happens even with the increase in the total flight distance, where the average flight distance per aircraft in the scenario 1 is around 87 nm, and increase for approximately 92 nm in the scenarios 2.

As noticed in Fraga et al. (2009), we already expected that PRM/SOIA can extend the average time on the ground for the departing aircrafts, increasing the queues for takeoff due to an increase in the arrivals. In this way, the results in table 1 and 2 show this increasing phenomenon ("GRU Mean departure queue time" and "the total ground departure queue delay").

The mean departure queue time at Congonhas Airport (CGH) basically did not changed, this means that, with our vertical separation between crossed approaches, the PRM/SOIA implementation in GRU do not affect CGH. The table 3 shows this phenomenon, where the maximum number of arrivals/hour in CGH is 23 in both scenarios. The maximum number of departures/hour in CGH is 20 in the scenario 1 and 21 in scenario 2 (this is, higher in scenario 2) but the average between the top 5 departures is almost the same for both scenarios. Finally, the number of movements/hour in CGH (this is, Arrivals + Departures) is higher in scenario 1, but the average between the top 5 departures is higher in scenario 2. As a result, we can conclude that the implementation of PRM/SOIA in GRU do not affect CGH, because of the vertical separation between crossed approaches.

Table 3: Maximum hour rate and average between the top 5 rates for each scenario - CGH

Congonhas Airport (GRU)	Arrivals		Departures		Movements (A+D)	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Max	23	23	20	21	40	38
Top 5 Average	20.4	20	18.6	18.8	35.2	36.6

Font: from authors, 2009

The table 4 shows the same metrics for GRU, and, for this airport, we can observe big differences between. The arrivals maximum rate and the top 5 arrivals average increases by 26% and 20% in the scenario 2, respectively (in a comparison with the scenario 1). The departure maximum rate and the top 5 departure average decreases by 4% and 2% in the scenario 2, respectively (in a comparison with the scenario 1). These opposite values between arrivals and departures produce the semblance in the number of movements: the same values for maximum hour rate and top 5 departure average.

Table 4: Maximum hour rate and average between the top 5 rates for each scenario - GRU

Guarulhos Airport (GRU)	Arrivals		Departures		Movements (A+D)	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Max	19	24	23	22	34	34
Top 5 Average	15.8	19	20	19.6	32.2	32.2

Font: from authors, 2009

The Figure 13 displays also the same metrics of tables 1 and 2 in a unit comparison, presenting the sum of these times in the right axes. In this way, it is easy to see the relevant difference between the scenarios PRM/SOIA (scenarios 1 and 2) and the baseline (scenario 1), as the semblance between both scenarios with PRM/SOIA procedures (scenarios 1 and 2).

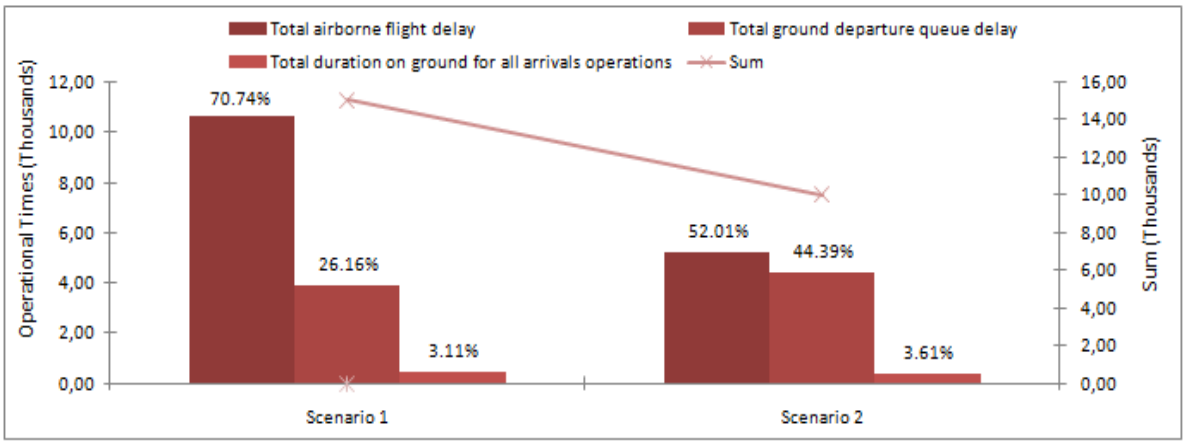


Figure 13: Times registered in each scenario (models)

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In the Figures 14, 15 and 16, below, we can observe that, in the simulation of current procedures (scenario 1), the peaks of operations/hour are lower than the peaks operations/hour in the scenario 2 for the arrivals but higher in scenario 1 for the departures, creating a very similar graph for both scenarios in the number of movements/hour (fig 16), this is, arrivals + departures. This shows exactly what we explained in the table 4 above.

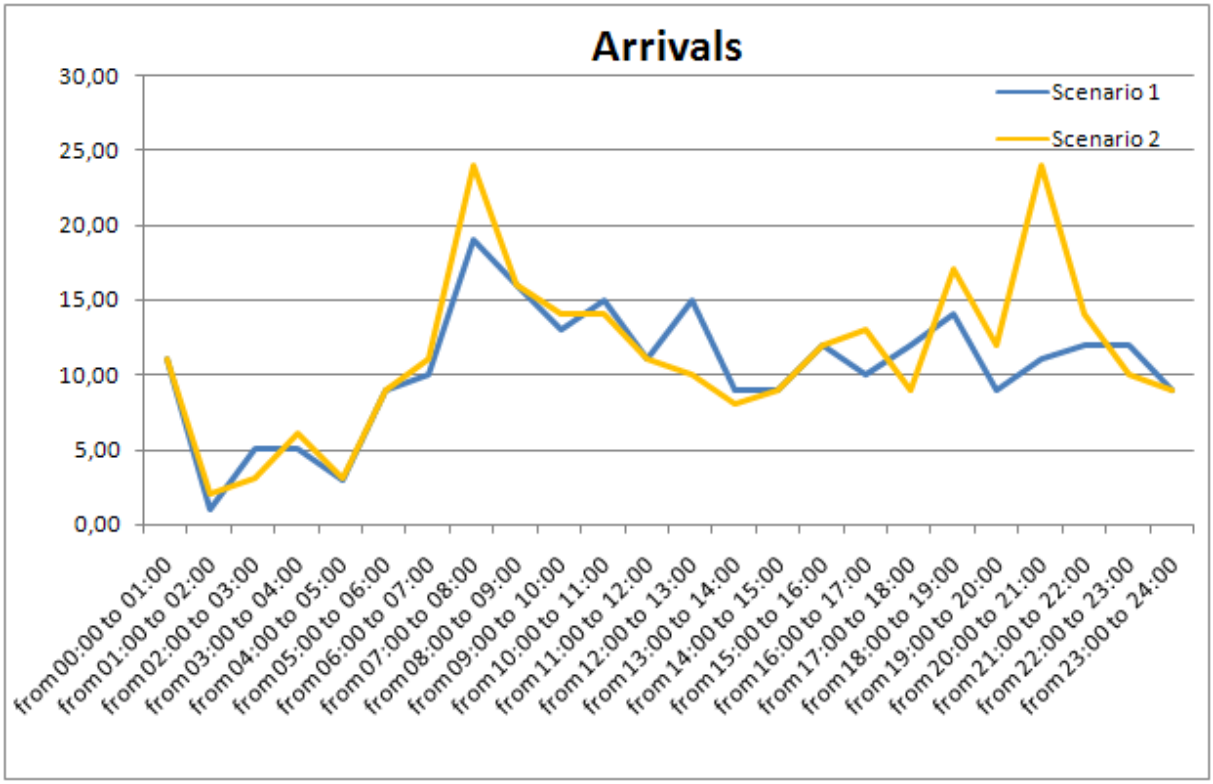


Figure 13: Arrivals/hour in GRU: Current vs. PRM/SOIA

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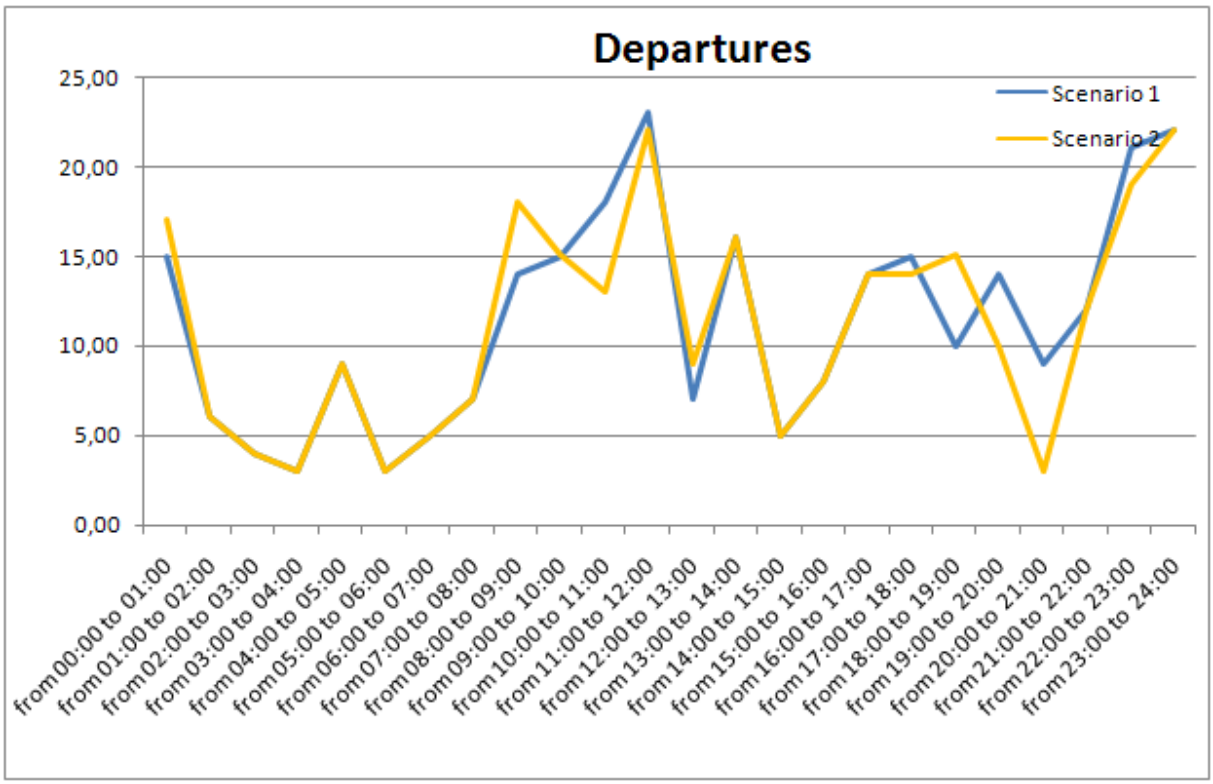


Figure 14: Departures/hour in GRU: Current vs. PRM/SOIA

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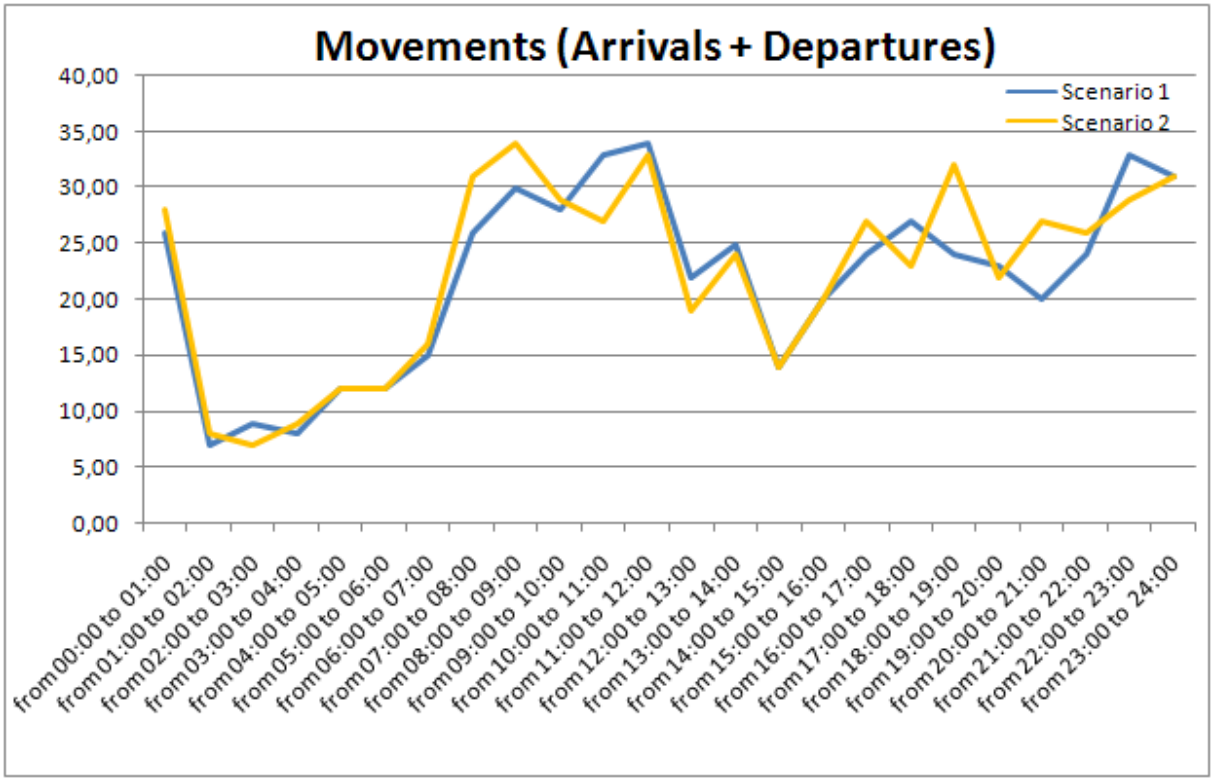


Figure 15: Movements/hour in GRU: Current vs. PRM/SOIA

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5 CONCLUSIONS AND NEXT STEPS

For produce this study, we established some premises, as a supposed vertical separation between crossed approaches that, in practice, it is rarely used. We believe that, with the technological progress and some operational changes, these procedures can be frequently used. In the past, some studies showed that, without this vertical separation, the PRM/SOIA in GRU decreases the capacity in CGH, making the system unviable.

The results obtained up to this stage of the project contradict the opinions of many specialists about the current problems of the São Paulo/Guarulhos – Governor André Franco Montoro International Airport (GRU), indicating that the reason for the several present delays is directly related to the capacity of the runway system, just as stated by Santana (2002).

The simulation shows that the TMA-SP really presents huge congestions in airspace, in agreement with specialists' opinion, but a share of them are related to the current runway system of GRU that makes unfeasible simultaneous approaches, due to the reduced separation between the centre-lines of the runways. As already shown elsewhere in this paper, allowing for the simultaneous approaches of aircrafts coming from different locations in the TMA-SP, the separation in the airspace between this pair of airplanes can be reduced in the final segment of the approaches, increasing the capacity of the airspace. The PRM/SOIA approaches also increases the number of arrivals/hour, but with a little decrease in the number of departures/hour.

This work also shows that airport capacity cannot be treated in an isolated way, disregarding the relationships between the subsystems. Following this line of thought, our example shows the great impact that runway capacity has on the airspace system.

Due to limitations of the simulator, the results can be a little bit overestimated.

As already stated, this paper is a preliminary research report. The next step consists in, for instance, carrying out a large number of new simulations to account different enter times of the aircrafts in the simulation, instead of just a single specific day. The larger number of data will facilitate the statistics analyzes allowing for a more trustworthy interpretation of the results.

Besides, we are analyzing more subjects such as metrics to validate the scenarios, searching similar and different methods of validation for the scenario with current conventional approaches and the scenarios with new PRM/SOIA procedures, including verifications of the simulations by specialists (operators such as air traffic controllers and commercial pilots) and statistics tests. In this way, we are also analyzing the meteorological registries of the area to better express the possibility of PRM/SOIA's implementation in GRU, as well as the complexity of the new scenarios.

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