AIRCRAFT BOARDING FINE-TUNING

Emílio Capelo Júnior (UFC)
emiliocjunior@terra.com.br
José Lassance de Castro Silva (UFC)
lassance@pesquisador.cnpq.br
Menkes H. L. van den Briel (ASU)
menkes@asu.edu
J.R. Villalobos (ASU)
Rene.Villalobos@asu.edu

Reports from Boeing, one of the big companies that make airplanes in the world, inform how much time is usually demanded for the execution of all the different necessary tasks when the airplane is landed, that is, passengers' departure, fueel and water refuel, baggage loading and unloading, catering, cleaning the airplane and passengers' boarding. According to these reports, the passengers' boarding is the most time-consuming task, around 60% of the total. The present research focused on the study of the existing boarding routines, since it is the inland task that needs more time to be accomplished and, as a consequence, the one that could offer more reductions. This was an attempt to reduce its time demands and to give the same level of occurrence probability. The work was accomplished by two geographically separated groups, a Brazilian and an American one. The first group was responsible for creation and primary calculations. The second one did the validation work. According to van den Briel et al (2003), there are two basic types of impediments for the passengers to reach the seats marked in their boarding cards. They are named seat interference and aisle interference. According to Ferrari and Nagel (2005), the airline companies want to minimize the time spent in land in order to maximize their profit. So, they use many boarding strategies. A boarding strategy is a group of rules that aim at accommodating all passengers by using as little time as possible. They all believe that the minimization of interferences lead to minimization of the time spent for boarding. Each strategy needs a certain quantity of work in the boarding room for the passengers' calling. This study seeks on improving the strategy already sacred in literature as applicable and of better performance. The research is based on the Reversed Pyramid, with 10 zones of seats, with the fulfilling of a total side of the airplane to, after that, fulfill the second side. Among the strategies analyzed, 26 had the total time of boarding inferior than strategy 17, the research's benchmark. The best of all the strategies analyzed is strategy 63, with five rows in area 1, 5 rows in area two and with 20 rows in area three. Even though the reduction of the time duration achieved with strategy 63 represents only 3.08% of the duration time presented on strategy 17, the achieved *represent a lot, from the planning of enlargement of airport installations to the profit maximization from air companies. In a market where profitability is around 6%, a reduction of more than 3% of idle time is really significant. If we analyze a bit more, this redu*

Palavras-chaves: aircraft boarding simulation strategies

1. Introduction

The sector of passenger air transportation in Brazil has been through embarrassing situations in the last two years. Crowded airports, many canceled and late flights, and overbookings are some of the problems. The situation involves airline companies who try, in isolation, to maximize their profit, government executive institutions that control the public politics of the sector – apparently neglecting their function, and of course the passengers who have been affected the most by the recent episodes.

Over the last decade, most Brazilian airports have gone through meaningful structural renovations in their installations, concerning the social aspect. But the basic productive installations, such as landing and departure runways were not changed. People believe that definite solutions related to the decreasing of some airports capacity will only occur over the long term, since they depend on investments in this kind of installation, which demand much more time and resources. However, the consequences of the recent episodes could have been minimized or even extinguished.

These episodes were originated by the planning of how to use equipment and by the Brazilian airport installations. The public politics for this sector is old. The planning for a national air traffic needs technical support tools for its preparation. The implementation of a new traffic, as it happened recently, does not have any statistical study that can determine the level of trust in its operation. Reports from Boeing, one of the big companies that make airplanes in the world, inform how much time is usually demanded for the execution of all the different necessary tasks when the airplane is landed, that is, passengers' departure, fuel and water refuel, baggage loading and unloading, catering, cleaning the airplane and passengers' boarding. According to these reports, the passengers' boarding is the most time-consuming task, around 60% of the total.

This paper is focused on the study of the existing boarding routines, since it is the task that needs more time to be accomplished and, as a consequence, the one that could offer more reductions. This was an attempt to reduce its time demands and to give the same level of occurrence probability. The work was accomplished by two geographically separated groups, a Brazilian and an American one. The first group was responsible for creation and primary calculations. The second group did the validation work.

Thus, the present paper aims at offering the reader a summarized view of the main ideas that guide airplane boarding researchers nowadays. Besides, it wants to present a comparative study of the strategies used by national and international companies. Finally, the article shows the strategy created by the authors, which is based on a well-known strategy of researchers from an American university, which presents a better performance than the other strategies found in the related literature.

2. Methodology

The research used the experimental method, since it aimed at investigating if the variation in the size of the ten seat zones, for each analyzed strategy, would cause effects in the total duration of the passengers' boarding. The research also used the statistical method, because it wanted to measure these effects. These classifications follow the theory present in Barbosa

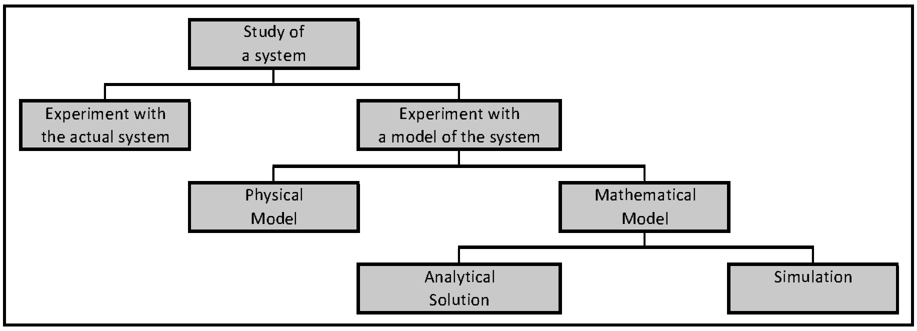
(2001) and Fachin (2001). The laboratory research was developed in a computer science environment, by using the Monte Carlo Simulation Method. IBM PC Pentium Core 2 Duo E4500 2,2 GHz with 1 gigabyte of RAM computers were used. The execution of each of the simulations lasted around 50 minutes.

The team of researchers was divided in two groups. The first one, in Brazil, made the experiments in its primary phase. The second one, in the United States, accomplished the validation of the results, working with a model, which was already tested in a previous research. The validation phase was very important because it found errors in the new model at the beginning of the research.

3. Theoretical reference

3.1. Monte Carlo Simulation

We can understand the classification of the study of systems though Figure 01, found in Law and Kelton (1991), as it follows.



Source: Law e Kelton (1991)
Figure 01 – Systems Study Classification

According to Correia, Moura and Forte (2002,4), “Projection is the process of previewing the future, previewing what can happen and considering the consequences over time. Projection also means to plan an expected behavior of what is going to happen”.[i] They also affirm that “the probability methods have the advantage of considering the effect of the risk in the projection. (...) Three forms of projection that consider the risk are the Sensitivity Analysis, the Scenery Analysis and the Monte Carlo Method of Simulation”.[ii]

The Monte Carlo Simulation method consists of giving a value to a certain parameter through the lottery of a lottery number, between zero and one and of obtaining the correspondent number in a distribution of accumulated probability. This way, at each simulation instant, the independent variable assumes a new value, generated randomly, but following a rule of formation given by the distribution.

According to Casarotto and Kopittke (2001,344), “simulation is a powerful tool, but one must be careful with defining types and parameters of distribution and each variable, or completely useless results may be obtained.”[iii]. According to Lustosa, Ponte and Dominas (2004, p. 268 *in*: CORRAR; THEÓPHILO (Org), 2004), simulation is a quantitative technique which permits the realization of various experiments in a model through the manipulation of critical variables and that permits the one who makes decisions to choose one of the action alternatives through the analysis of the results obtained.

According to Capelo Júnior (2006), "the purpose of simulation is to describe the distribution and characteristics of the possible values of a dependent variable, after the possible values and behaviors of the related independent variables are determined."[iv]. The experience in a real environment is more accurate, but it usually takes a lot of time and costs a lot of money. Simulation, on the other hand, is a fast and cheap way to acquire the results that are normally obtained through the real experience. (MOORE; WEATHERFORD, 2005, p. 428).

The word simulation refers to a method whose intention is to imitate some real system, mainly when other analytical methods are mathematically too complex. A system is a group of components that act and interact among them, aiming at a certain purpose. The study of a system can be done through observations in the real system or from the elaboration of a model that permits its comprehension and a prevision of its behavior under certain conditions. (LUSTOSA; PONTE; DOMINAS, 2004, p. 244).

3.2. The Air Boarding Problem

According to van den Briel et al (2003), there are two basic types of impediments for the passengers to reach the seats marked in their boarding cards. They are named seat interference and aisle interference, as shown in figure 02, as follows.

The first one, the seat interference, occurs when a passenger, after reaching the row where his seat is and putting his baggage away, sees that there is another passenger already seated, blocking his progress. In this case, there will be a delay for all the passengers who are in the aisle. The passenger who is seated will have to stand up for the other passenger to sit down. As an example, in case passenger (4) has seats 6A or 6B in his card, he will have to wait for the passenger (1) to stand up and let him pass. The passengers (5) and (6) will have to wait until they can go to their seats. In case the seat reserved for passenger (4) is any seat from line 3, 4 or 5, or even seats 6D or 6E, he does not have to wait.

The second interference, in the aisle, occurs when a passenger walks towards the row where his seat is and is stopped by another one, who is standing in the aisle, putting his baggage away in the upper compartments. As an example, in case passenger (4) has marked in his card any seat from the row 8, that is, seats 8A, 8B, 8C, 8D, 8E or 8F, he will have to wait for passenger (3) to finish putting his baggage away, and then keep walking. In this case, passengers (5) and (6) will have to wait also.

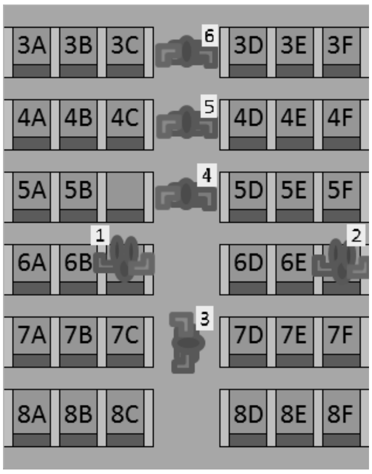


Figure 02 – Interferences

According to Ferrari and Nagel (2005), airline companies want to minimize the time spent on the ground in order to maximize their profit. So, they use many boarding strategies. A boarding strategy is a group of rules that aim at accommodating all passengers by using as little time as possible. They all believe that the minimization of interferences lead to minimization of the time spent for boarding.

This paper uses a graphic form to describe the strategies. This form is the same used in the international literature. In figure 03, we see the layout of a typical airplane, having three seats on the left of the aisle, identified by A, B and C, and three seats on the right side of the aisle, identified by D, E and F. We can also observe the numbers on the 30 seats.

The color code serves to establish a calling order for boarding each of the zones. First they call passengers with seats marked in the yellow zones, then in the blue ones, orange, green and finally pink. When there is a difference in tonality, the zones in the lighter tones have priority in boarding, compared to the zones in darker tones. Passengers from the same zone can be in any position in the line.

Each strategy needs a certain quantity of work in the boarding room for the passengers' calling. The higher the number of zones of seats in the airship, the longer it takes to organize a line. It is considered an applicable strategy when the difficulty and work levels imposed demands less time than the necessary to the passenger's accommodation. It is also necessary to be worried about the passengers' opinions to a possible discomfort perceived by them.

Strategy 5 exposed below in figure 03 calls all the passengers to the flight to board at the same time. This way there is a high number of interferences, in the seat and in the aisle.

	R o w s																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
F																														
E																														
D																														
C																														
B																														
A																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Figure 3 - Strategy 5

Strategy 7, exposed below in figure 04, calls the passengers to board divided in three zones. First, the passengers in the window seats. Second, the passengers in the middle seats, and third the passengers in the aisle seats. With this strategy, interferences among the seats will be avoided, but there are still some interferences in the aisle.

	R o w s																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
F																														
E																														
D																														
C																														
B																														
A																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Figure 4 - Strategy 7

Strategy 12, exposed in figure 05, calls the passengers to board in six zones. First to board the airplane are the passengers in the window seats, but only the ones in column A. Right after that, the passengers from the middle seats, but only in column B, and at last the passengers from the aisle seats in column C. Afterwards, the passengers from the window seats, column F. After that, the passengers in column E, the middle, and, at last the passengers in column D, aisle. In this way, interferences in the seats are avoided and the interferences in the aisle are reduced, but not completely avoided.

Strategy 13, exposed in figure 06, calls the passengers to the board divided in two zones. First, to board the airplane are the passengers in the second half of the airplane, which are the seats in the bottom part. Second, the passengers in the first half of the airplane board the airplane, which are the seats in the front part. The aim of this strategy is to reduce interferences in the aisle. But the number of interferences among the seats is still high.

Strategies 15 and 17, exposed in pictures 07 e 08, are adaptations of the strategies found in Ferrari and Nagel’s work (2005). Strategy 20, exposed in figure 09 is an adaptation of Van Den Briel et al (2005). These adaptations were necessary to turn them compatible to A320’s capacity operating in Brazil, which is of approximately 180 passengers.

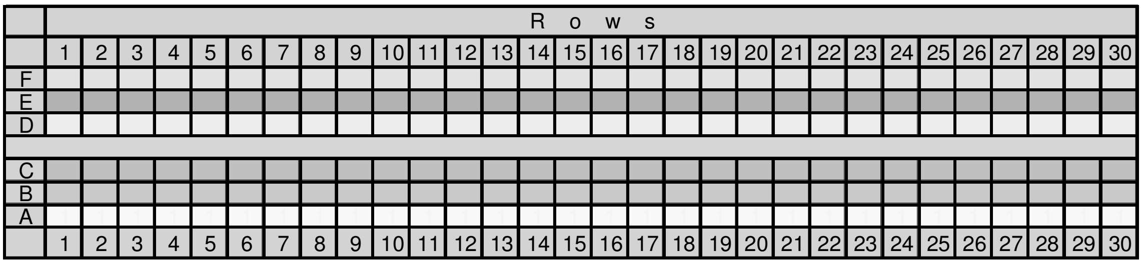


Figure 5 - Strategy 12

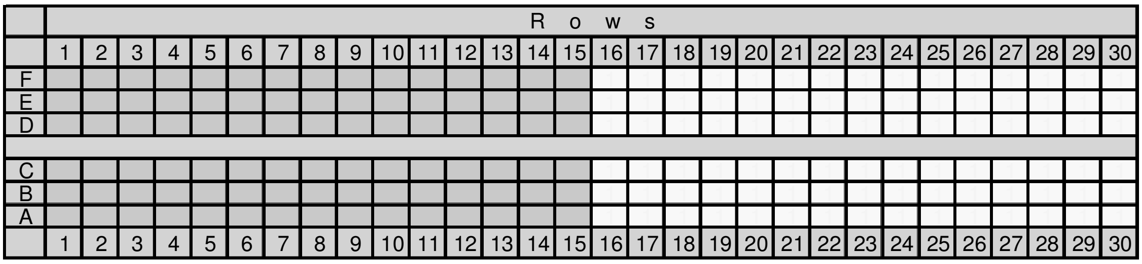


Figure 6 - Strategy 13

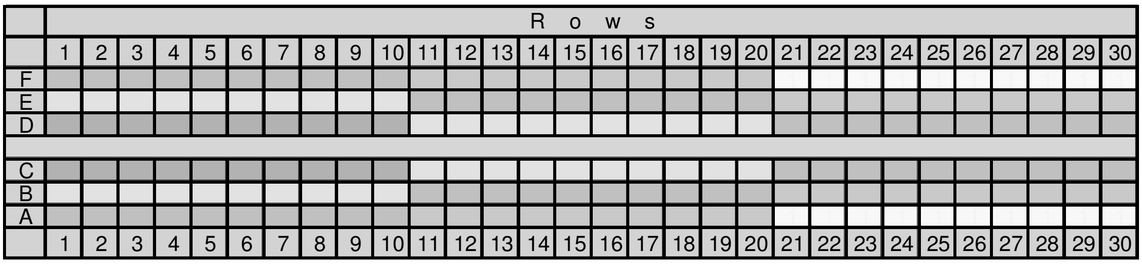


Figure 7 - Strategy 15

Strategy 2, exposed in table 01, is the known case of better performance, but is not applicable. It works in a very close way to strategy 7, with the additional implementation of the decreasing order of seats in each of the six zones. In a practical way, it is considered that a strategy has 180 zones since every person has his own specific order of boarding. The complexity level to operate this strategy is really high, what makes it impractical.

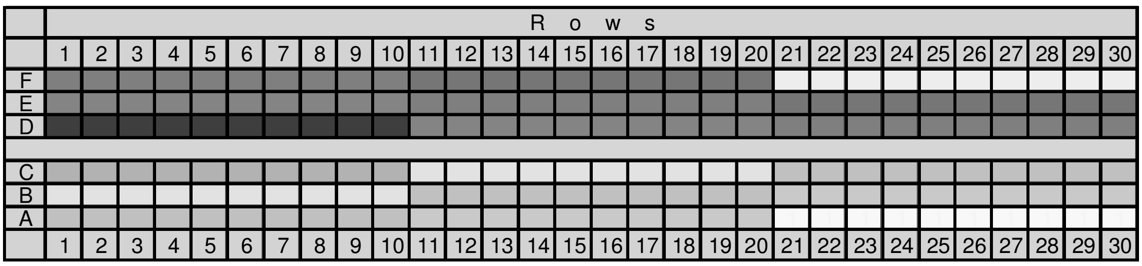


Figure 8 - Strategy 17

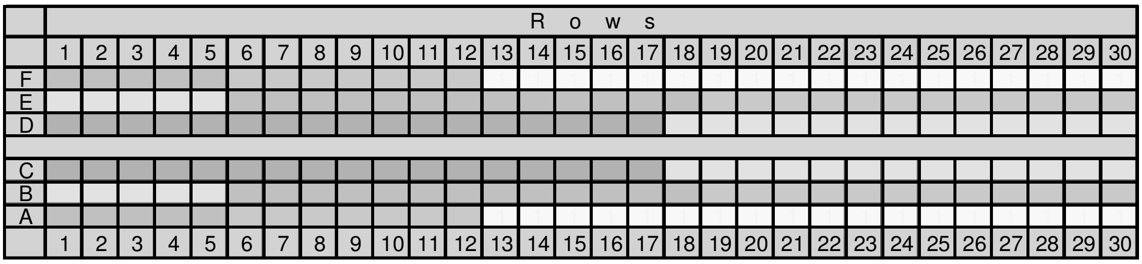


Figure 9 - S t r a t e g y 20

Estrategy	Time spent	Zones	Iteractions
2	293	180	3000
17	779	10	3000
12	817	6	3000
7	835	3	3000
15	848	5	3000
20	864	5	3000
5	1051	1	3000
13	1153	2	3000

Table 01 – Comparative of performance

4. Procedures

This study seeks to improve a boarding strategy that was shown to have good performance in the previous literature. The research is based on the Reversed Pyramid, with 10 zones of seats, with the fulfilling of a total side of the airplane to, after that, fulfill the second side. Such strategy, number 17, based on the work of Ferrari and Nagel (2005), was already shown in figure 08, above.

Several assumptions were made, similar to the ones found in referenced articles. Among them, it is necessary to highlight the inexistence of different speeds of dislocation from the passengers in the line to find their own seats, the inexistence of different level of difficulty to keep each volume of hand luggage, the inexistence of intervals on the line of passengers boarding the plane, the maximum capacity of 30 passengers stood up in the aisle and in the treatment of special care people such as old people, pregnant, minor ages ones and difficult locomotion passengers. In all the experiments the airplane was full, which means the boarding of 180 passengers.

The probable variations that could interfere in the stock process were the quantity of volume in the hand luggage and the number of seats marked for each passenger. It is necessary to highlight that the frequency distribution for the variable hand luggage is compatible to the national reality. It is also necessary to mention that the program works with a penalty table, for the cases of seat interference. The referred table was only used in the calculation of the times of interference already found in literature, exposed in the theoretical references. The strategies proposed and analyzed by the authors did not use the referred table since they do create seat interferences, which is one of the main characteristics of the Reversed Pyramid strategy.

The occupation of the ten zones of seats, in all the analyzed strategies, follows the same order exposed in figure 10. What distinguishes one strategy from the other is the size of each of the three areas. Best remark that all the six columns of seats, what means the two columns of the windows (A and F), the two columns of the middle (B and E), have the same quantity of seats in each of the three areas, which is applied to all the analyzed strategies.

It is also necessary to emphasize that the main strategies found in the literature, exposed in the theoretical references, were adapted for the use of the 180 passengers configurations. It is usual to observe A320 airplanes operating abroad with the 26 rows and 6 columns layout, totaling 156 passengers. In domestic operations, the same airplane suffered successive changes in its configuration, presenting today the 28 and 29 rows per column, totaling 168 to 174 passengers. The study was elaborated with 30 rows of six columns, trying to anticipate these new modifications.

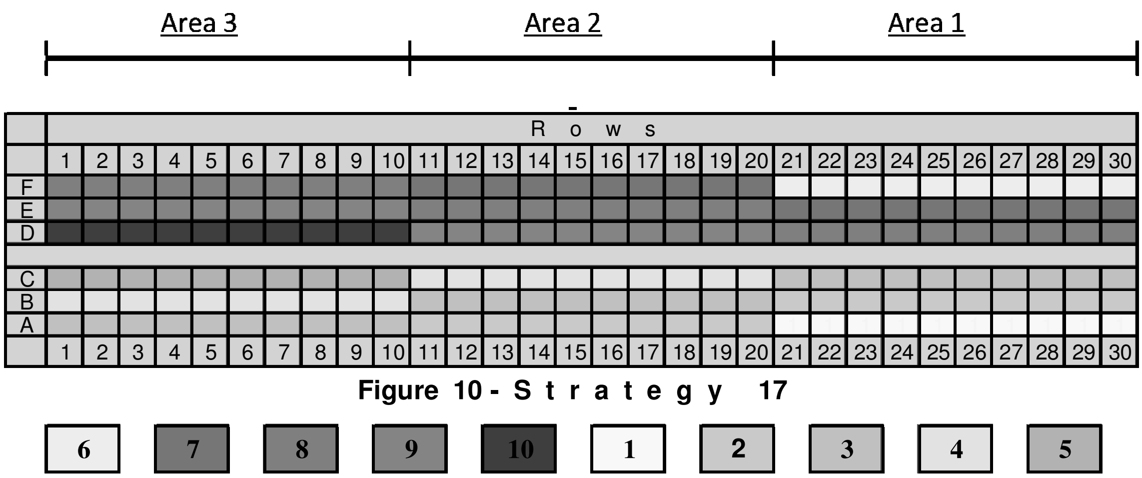


Figure 10 - Strategy 17

50 variations of strategy 17 were analyzed, divided in 4 groups. For each one of them, the experiment consisted of 3.000 runs. The independent variables were the size of the three areas and the dependent variable was the duration of the boarding. The total number of possibilities for each study, with three areas of different sizes, is of 406. From these, 50 were studied with a higher possibility of success.

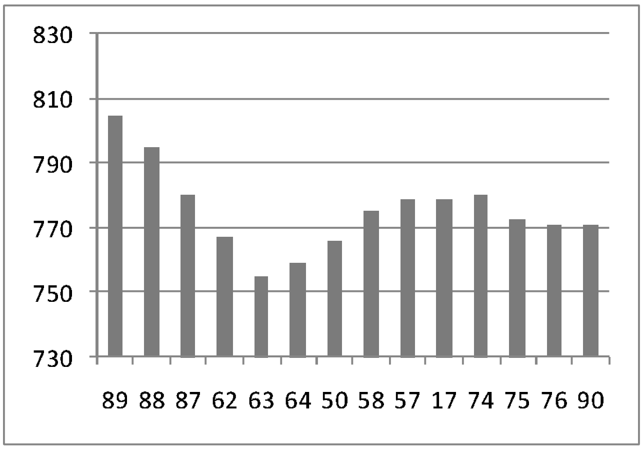
5. Result

Among the strategies analyzed, 26 had the total time of boarding inferior than strategy 17, which is used as the benchmark. The best of all the strategies analyzed is strategy 63, with five rows in area 1, 5 rows in area two and with 20 rows in area three, related to group 1 and exposed on figure 11.

Group 1 had as formation criteria to keep areas 1 and 2 in the same size while area 3 is with the rest of the 30 total rows. Graphic 01 shows that there is a minimum point in function of time duration, exactly in strategy 63.

Num	Size of divisions			Time	Gen	Group
Sim	1	2	3	Simul	class	Class
89	1	1	28	805	45	14
88	2	2	26	795	40	13
87	3	3	24	780	33	11
62	4	4	22	767	16	4
63	5	5	20	755	1	1
64	6	6	18	759	6	2
50	7	7	16	766	12	3
58	8	8	14	775	25	8
57	9	9	12	779	30	9
17	10	10	10	779	32	10
74	11	11	8	780	34	12
75	12	12	6	773	23	7
76	13	13	4	771	19	5
90	14	14	2	771	20	6

Table 02 – Group 1 results



Graphic 01 – Group 1 results

Group 2 had as formation criteria to keep areas 1 and 3 in the same size while area 2 is with the rest of the total 30 rows. Graphic 02 shows that there is a minimum point if function of time duration, exactly in strategy 51. Figure 12 shows the characteristics of the winner strategy in this group.

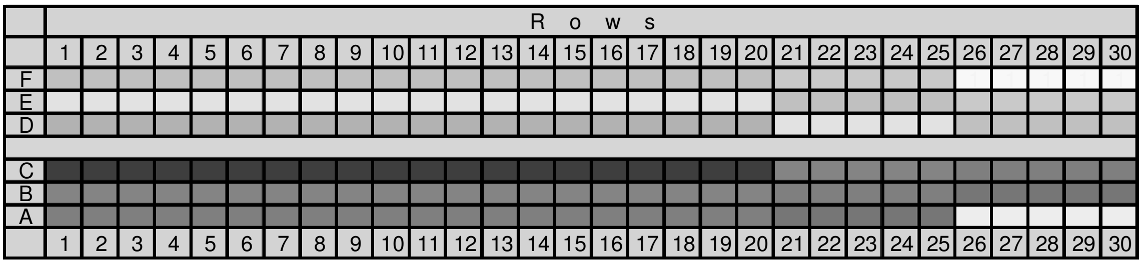
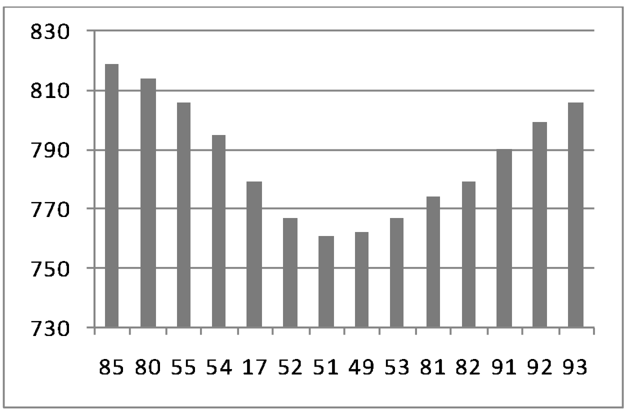


Figure 11 - S t r a t e g y 63

Num	Size of divisions			Time	Gen	Group
Sim	1	2	3	Simul	Class	Class
85	14	2	14	819	54	14
80	13	4	13	814	53	13
55	12	6	12	806	46	11
54	11	8	11	795	39	9
17	10	10	10	779	32	7
52	9	12	9	767	14	3
51	8	14	8	761	8	1
49	7	16	7	762	10	2
53	6	18	6	767	15	4
81	5	20	5	774	24	5
82	4	22	4	779	29	6
91	3	24	3	790	37	8
92	2	26	2	799	41	10
93	1	28	1	806	47	12

Table 03 – Group 2 results



Graphic 02 – Group 2 results

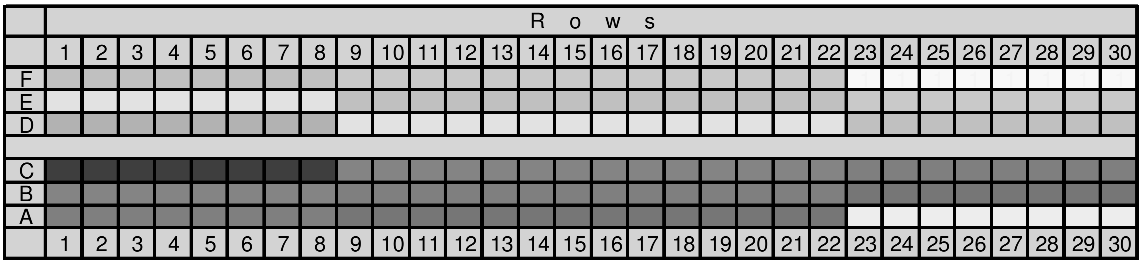
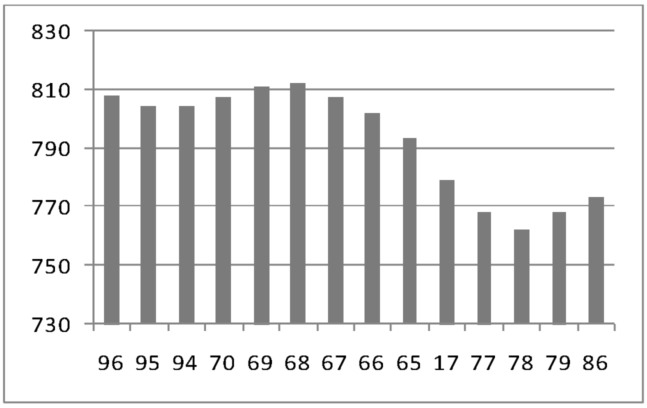


Figure 12 - S t r a t e g y 51

Group 3 had as a formation criteria to keep areas 2 and 3 in the same size while area 1 remains with the rest of the total 30 rows. Graphic 03 shows that there is a minimum point if function of time duration, exactly in strategy 78. Figure 13 shows the characteristics of the winner strategy in this group.

Num Sim	Size of divisions			Time Simul	Gen Class	Group Class
	1	2	3			
96	28	1	1	808	50	12
95	26	2	2	804	43	8
94	24	3	3	804	44	9
70	22	4	4	807	48	10
69	20	5	5	811	51	13
68	18	6	6	812	52	14
67	16	7	7	807	49	11
66	14	8	8	802	42	7
65	12	9	9	793	38	6
17	10	10	10	779	32	5
77	8	11	11	768	17	2
78	6	12	12	762	9	1
79	4	13	13	768	18	3
86	2	14	14	773	22	4

Table 04 – Group 3 results



Graphic 03 – Group 3 results

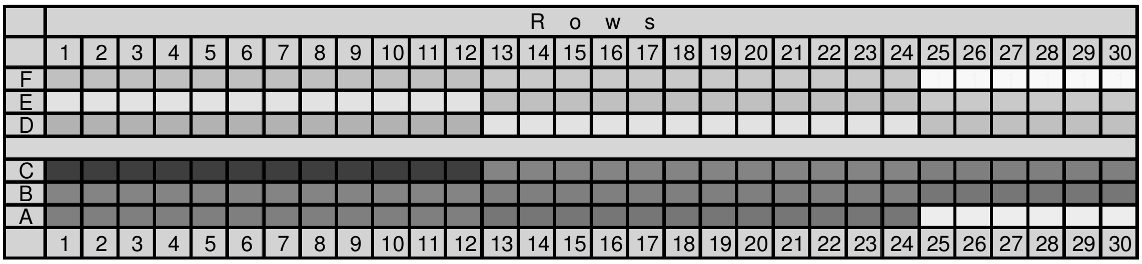
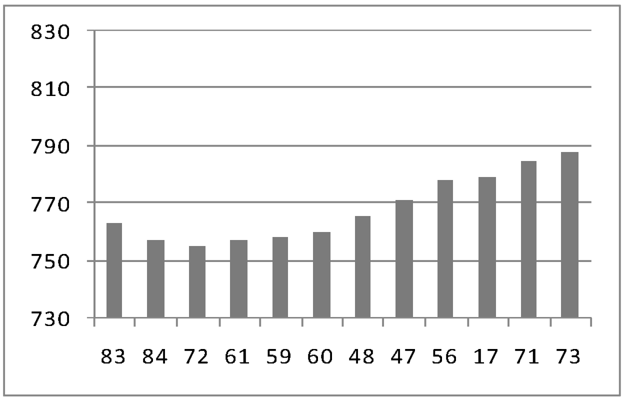


Figure 13 - S t r a t e g y 78

Group 4 had as formation criteria to keep area 2 with 10 rows, to initiate area 1 with 1 row and area 3 with the rest. The number of rows increased in area 1 with the consequent reduction of quantity in area 3. Graphic 04 shows that there is a minimum point if function of time duration, exactly in strategy 51. Figure 14 shows the characteristics of the winner strategy in this group.

Num Sim	Size of divisions 1	2	3	Time Simul	Gen Class	Group Class
83	1	10	19	763	11	6
84	2	10	18	757	3	2
72	3	10	17	755	2	1
61	4	10	16	757	4	3
59	5	10	15	758	5	4
60	6	10	14	760	7	5
48	7	10	13	766	13	7
47	8	10	12	771	21	8
56	9	10	11	778	26	9
17	10	10	10	779	32	10
71	11	10	9	785	35	11
73	12	10	8	788	36	12

Table 05 – Group 4 results



Graphic 04 – Group 4 results

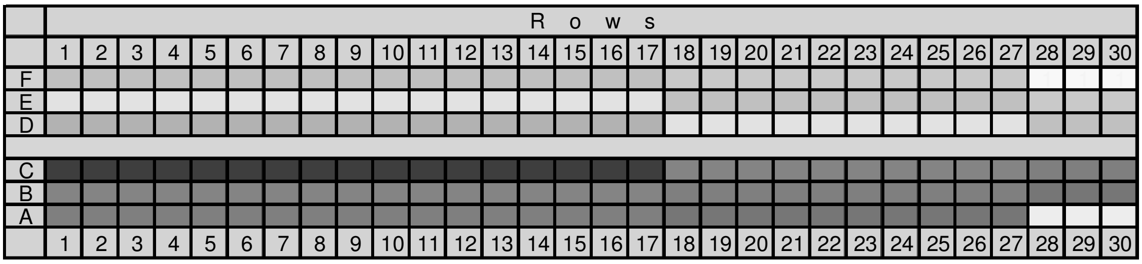


Figure 14 - S t r a t e g y 72

6. Final Considerations

Even though the total boarding time achieved by strategy 63 improves only 3.08% over the total boarding time by strategy 17, the achieved result is significant considering the planning of enlargement of airport installations to the profit maximization from airline companies.

Modifying procedures to reach the best punctuality levels creates a competitive differential to the air company without any costs. The analysis of financial consequences shows that the affirmations made by Ferrari and Nagel (2005), already mentioned, are correct. Each minute stopped to an airplane represents damage. To operate punctually, with no delays is in a marketing view positive and the implementation of a new efficient strategy has no, at first, additional costs.

In a market where profitability is around 6%, a reduction of more than 3% of idle time is really significant. If we analyze a bit more, this reduction is more important as less is the relation time flight and total time. In other words, the profitability in shorter flights will be more positively interfered than the profitability in longer flights.

All the 406 possibilities will be analyzed in a near article, as the introduction of a new concept of the boarding problem, absorbed in Goldratt´s Theory of Constraints. The referred research is already in effective conduction.

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[i] “Projetar é um processo de previsão do futuro, de antever o que pode acontecer e os desdobramentos que se sucederão ao longo do tempo. Projetar também significa traçar um comportamento esperado para algo que ainda vai acontecer”.
[ii] “os métodos probabilísticos têm a vantagem de considerar o efeito do risco na projeção. (...) Três formas de projeção considerando o risco são a Análise de Sensibilidade, a Análise de Cenários e o Método de Simulação de Monte Carlo”.
[iii] “a simulação é uma arma poderosa, mas muito cuidado deve-se ter ao definir tipos e parâmetros de distribuição e cada variável, sob pena de se obter resultados totalmente inúteis”
[iv] “o objetivo da simulação é descrever a distribuição e características dos possíveis valores de uma variável dependente, depois de determinados os possíveis valores e comportamentos das variáveis independentes a ela relacionadas”