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Simulating revenue management in an airline market with demand segmentation and strategic interaction

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Abstract

This paper develops a computer simulation to investigate the consequences of revenue management by airlines on the Brazilian route Rio de Janeiro - São Paulo, in the period subsequent to the second phase of liberalisation of the industry, in 1998. The model allows demand segmentation – namely, the typology of Belobaba (1998) – and airline strategic interaction – a revenue management game. Simulation results revealed gains in efficiency and non-global conditions of superiority in comparison to the extreme alternative of "first come, first served" policy with uniform pricing.

Key words: computer simulation, airline industry, revenue management, non-cooperative games, post-liberalisation strategy.

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Introduction

> "(...) *the computer supplies a viewing equipment to the economist in a manner analogous to the microscope for biologists (however, a great amount of work goes into setting up the 'specimens' to be observed). Beyond its use as a viewing instrument, it provides a possibility for the construction and running of experiments. It has a use as laboratory apparatus. The various uses of the computer are not substitutes for economic analysis or observation. They are nevertheless supplements of considerable power.*" - Shubik (1960).

This paper develops a computer simulation model to investigate the impacts and rationality of revenue management on the Brazilian route Rio de Janeiro - São Paulo. Economic regulation of the country's domestic industry has been recently liberalised by authorities since the early nineties. As a result, airlines are in an intense process of competition although with much turbulence in terms of financial performance and stability.

Revenue management has been extensively used by airlines on the route since price liberalisation, but so far there are few academic studies assessing its impacts in the Brazilian industry and this was the main motivation for this research. The model conceived permits the analysis of its effects in market efficiency and constitutes one of the first computer simulation studies designed to reproduce revenue management on a real route under actual competitive circumstances, instead of an artificial market as in Belobaba and Wilson (1997).

Another relevant aspect is that some of the airlines so far have preferred not to perform revenue management on the route, opting for the traditional "first come first served" policy with uniform pricing. This alternative can be regarded as precisely the extreme opposite of revenue management - no product differentiation, price discrimination or seat-inventory control. In order to understand this unexpected pattern of behaviour, the paper promotes an investigation into airlines' competitive rationality towards revenue management by articulating the simulation with game theoretical modelling.

The simulation targeted to be a valid representation of the market on the route, by the definition of detailed characteristics of demand and supply, like the stochastic process of arrivals across time, actual schedules, aircraft sizes, fare products, etc. The two most significant features, however, are the modelling of the *segmentation of demand* using the typology of Belobaba (1998), and the presence of *strategic interaction* among airlines – what was called the 'revenue management game'. Model validation used historical input data and was followed by a design of experiments (simulation scenarios).

There are four sections in the paper: the first one, where it presents a historical background of the Brazilian airline industry and the route under analysis; secondly, where it details the computer simulation, describing market and model characteristics, process of calibration and validation; thirdly, where it gives details of the experiments designed and the assessment of the revenue management in the market (impacts and rationality); and the final one, with the main conclusions.

1. The Brazilian Airline Industry and the Route Rio de Janeiro – São Paulo: Historical Background

The Brazilian domestic airline industry has been inserted in a gradual and continuous process of economic liberalisation. Initiated at the end of the eighties within a broader governmental program for deregulation of the country's economy, this series of changes in the authorities' policy can be divided into three main periods: the *first phase*, with the stimulus of new airlines to enter the market and the introduction of lower and upper bounds for prices (1989-1997); the *second phase*, with more liberalisation of route entry and bounds (1998-2001); and the *third phase*, with virtually fully deregulation (from August 2001).

As a result, it was recently observed an increase in the degree of competitiveness in the industry; notably, the rivalry among airlines led to severe price reductions and market expansion since 1998. This phenomenon was exacerbated on the Rio de Janeiro - São Paulo route - the country's densest flow, with a third of the profits of the whole domestic network[1]. Traditionally it was closely associated with the cooperative structure formed by a cartel of majors (Varig, Vasp and Transbrasil), constituting a thirty-nine year-old walk-on shuttle service, one of the most durable private institutions of air transport in the world. The cartel’s rupture happened a few months after the announcement of the liberalisation measures of 1998.

Above all, one of the most important characteristics observed in the period was the tendency of price dispersion in a context of ***revenue management***. As a technological innovation created by the North-American airlines in the adjustment to the deregulation of the seventies, revenue management consists of the following three tools[2]: *price discrimination*, which is usually of a "second-degree" sort, that is, based on demand self selection (Botimer, 1996); *product differentiation*, which refers to the purchase restrictions ("fences") such as advance purchase, minimum stay, stay over Saturday nights, etc., in order to "prevent passengers with higher values of willingness to pay from purchasing discount fare products" (Botimer, 1996); and finally, the techniques of *seat-inventory control*, that is, systems to maximize total revenue given the capacity of the airline in the market (ex. Belobaba, 1987).

The following table illustrates the relevance of revenue management in the post-liberalisation environment presenting a simple measure of the degree of overall price dispersion on the route (the range between full fares and the maximum discount found in the market, in percentage):

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[1] Considering the period of 1997-1998 (yearbook of the Department of Civil Aviation).

[2] A complete survey of revenue management literature can be found in McGill and Van Ryzin (1999).

Table 1 – Price Dispersion on the Rio de Janeiro – São Paulo route*

Year	Liberalisation Period	Full Fare (Y)	Maximum Discount Fare	Maximum Discount (%)
1997	End of First Phase	145.2	-	-
1998	Second Phase	138.9	57.1	-59%
2001	Second Phase	119.4	56.3	-53%
2002	Deregulation	133.6	46.9	-65%

** prices in US$*

Table 1 permits inferring that the second phase of liberalisation triggered a wave of high price dispersion, at least if measured by the maximum range of discounts. However, associated with this tendency is the fact that the majority of airlines found *relevant barriers to impose restrictions within the context of a revenue management's fare structure*. It is argued that, on account of the route being notably characterised by business-related trips, there is a perception that passengers may have strong disutility to such impositions, constituting a relevant competitive disadvantage. For example, the dominant airline on the route, Varig, a traditional revenue management player on many other domestic and international routes, has ever been reluctant to adopt the strategy in this specific – and quite important – market.

The difficulties related to revenue management implementation on the route led to the situation of poor financial performance in this market, contrary to common sense about that strategy. This was confirmed by the observed decrease in the average yield of the route in 1998 when compared with 1997 (R$ 0.309 versus R$ 0.390 per pax-km). It may suggest that revenue dilution was really present and was surely generated by inefficiently-designed fare structures (inadequate "fences"). Besides that, it can also mean that revenue management may not constitute dominant rationality in the market - that is, it is more profitable than uniform pricing only for a subset of airlines and not for the entire market -, contrary to what was suggested by Belobaba and Wilson (1997). The present paper intends to provide support to both arguments.

Before finishing, it is important to make clear some of the main concepts used above. This section presented a broader definition of revenue management (as in Botimer, 1996). Typically, however, the term "revenue management" refers only to the control of reservations with seat allocations and booking limits. In this sense, it would cause confusion to compare revenue management with uniform pricing unless we define the latter as "lack of both differential pricing and seat-inventory control". By defining in this way, the remaining of the paper considers implicit the association of "uniform pricing" with the "first come first served" policy[3]. The result is that the comparisons between strategies made here, use two extreme situations: revenue management (multi-fare structure with booking control) versus complete absence of revenue management

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[3] FCFS is the situation where the airline accepts "any and all booking requests until the total capacity of the flight leg is reached" (Belobaba and Wilson, 1997).

elements (uniform pricing, no booking control). The term “uniform pricing” will then be used to represent the latter in the remaining of this paper.

2. The Simulation of the Route Rio de Janeiro - São Paulo

2.1 Modelling: Entities, Life Cycles, and Consumer Choice

In order to provide a competition model for the route Rio de Janeiro – São Paulo, considering all components of revenue management described in section 1, this paper follows Belobaba and Wilson (1997) and uses a computer simulation approach.

The simulation developed has three basic characteristics: it is *dynamic*, as "the passage of time plays a crucial role" (Banks, 1998); it is a *discrete-event simulation model*, that is, "one in which the state variables change only at those discrete points in time at which events occur" (Banks, 1998); and it is *stochastic*, that is, "one whose behaviour cannot be entirely predicted, although some statement may be made about how likely certain events are to occur" (Pidd, 1998).

Table 2 presents the main characteristics (parameters) of the simulation. It was programmed in Visual Basic and the stream of random numbers used was the same of the simulation language SIMAN (on seeds and parameters cf. Law and Kelton, 2000). Model variables are in Table 3.

The following subsections give details on the two most important steps of the modelling: the definition of the entities of the model and their interaction (2.1.1), and the definition of the algorithms of passengers’ rationality (2.1.2).

Table 2 - Parameters of the Model

Passengers	
Average number of passenger per day	*3,387*
Number of passengers for the experiments (demand generation model)	*Pax = 682.09 - 2.882 AverageFare +* *+ 0.451 SeatsAvailable - 105.056 DummyRecession90 + Residuals* *(which implies a price-elasticity of demand equal to -0.46 (average since 1993)*
Arrival of passengers (reservations) across time	*Non-homogeneous Poisson Process, as in Weatherford, Bodily and Pfeifer (1993).* *Intensity Function:* $\lambda(t) = 3.3137 + \exp(-10.308+0.495\,t),\ t = \{1, 2, ..., 30\}$
Segmentation	*four segments of demand, according to the tipology of Belobaba (1998):* S_{01}*: insensitive to price and sensitive to time;* S_{11}*: sensitive to price and to time;* S_{10}*: sensitive to price and insensitive to time;* S_{00}*: insensitive to price and time;*
Frequent Flyer status distribution	*Probabilities estimated by the field research: P[FFStatus = 1] =* *= { 0.679 for* S_{01}*; 0.370 for* S_{11}*; 0.368 for* S_{10}*; 0.625 for* S_{00} *}*
Cognitive Status	*Full knowledge of prices and schedules of all airlines;* *no bounded rationality in the choice model;*
Number of passengers by segment	*Intensity functions by segment of passengers (used to provide a proportion of segment arrivals across time):* S_{01}: $l(t) = 0.0943 + \exp(-3.2011 + 0.5447\,t)$ S_{11}: $l(t) = -0.1964 + \exp(-2.7237 + 0.4425\,t)$ S_{10}: $l(t) = 0.1299 + \exp(-3.9367+ 0.5527\,t)$ S_{00}: $l(t) = 0.1800 + \exp(-12.1207 + 0.9374\,t)$
Airlines	
Relevant market	*Single-leg represented by the airport-pair Congonhas (São Paulo) - Santos Dumont (Rio de Janeiro); both centrally located in the cities; majority of travelers with business purposes;*
Number of Airlines	*5: TAM, Varig (VRG), Rio-Sul (RSL), Transbrasil (TBA) and Vasp (VSP)*
Number of Code-Share Agreements	*2: {VRG/RSL, VSP/TBA}*
Number of Effective Players	*3:* $\{A_1$ *= TAM,* A_2 *= VRG/RSL,* A_3 *= VSP/TBA}*
Fare Structure	*up to five different fare products for each airline(as in September, 1998);* A_1*: {full fare, - 17%, -34%};* A_2*: {full fare, -14%, -28%, -35%, -42%};* A_3*: {full fare}*
Price discrimination	*Second degree (self selection)*
Seat-Inventory Control Algorithm	*The extension of the Littlewood's rule made by Belobaba, 1987;*
Learning process	*agents need a 'warm up' period to build their demand database; the learning process does not affect the decision process in the consequent game, as the convergence to a maximization rule is fast;*
Fare Restrictions	*Availability, Purchase in advance (lack of other relevant Revenue Management restrictions)*
Flight Schedule	*The actual schedule as it was in 15 August 1998 on the airport-pair Santos Dumont (Rio de Janeiro) - Congonhas (São Paulo)*
Aircraft type and size	*Boeing 737-300 (132 seats) and Fokker-100 (108 seats)*
Diversion	*Present: passengers with low sensitivity to price are allowed to buy lower prices, depending on the availability;*
Overbooking; Cancellations; No-Show; airport competition; hub structure	*Absent: potential extension to the model.*

Table 3 - Model Variables

Passenger	
MySegment	*the segment of demand of the passenger generated; [1 if* S_{01}*, 2 if* S_{11}*, 3 if* S_{10}*, and 4 if* S_{00}*];*
MyFFStatus	*frequent flyer attribute of the passenger [1 if true, and 0 if false];*
MyDesiredTime	*passenger's desired time of departure;*
MyPreferredAirline	*passenger's preferred airline in case MyFFStatus = 1;*
MyFlightTable [n]	*set of n flights with departure times close to MyDesiredTime; n is the size of the table and it varies depending on MySegment;*
MyAirline	*airline chosen;*
MyPrice	*fare obtained by the passenger;*
MyFlightTime	*departure time of the chosen flight;*
MyScheduleDelay	*[= MyDesiredTime - MyFlightTime].*

Airline	
FlightSchedule	*the entire schedule of flights offered on the route;*
RMFlightSchedule	*schedule of airlines using revenue management;*
FullFlightStatus	*full flight attribute [1 if full, and thus the flight is unavailable for new reservation requests, and 0 if not full];*
FullFlightsTable	*list of all full flights*
FlightsAvailableTable	*set of all flights excluding those with FullFlightStatus = 1; this table provides the basis for the generation of MyFlightTable;*
FareProducts	*the fare structure for each airline;*
AircraftSize	*size of the aircraft for each scheduled flight;*
SeatAvailabilityStatus	*[1 if available, 0 if not available]*
SeatsSold	*number of seats with SeatAvailabilityStatus = 1 in each scheduled flight*
FareProductOpenStatus	*[1 if open, 0 if not open]*
FareProductNSeats	*Number of seats allocated for each fare product in each flight*
EMSR	*Expected Marginal Seat Revenue (Belobaba, 1987)*

2.1.1 The Entities of the Model and Their Interaction

The modelling required the definition of the main features of the system to be represented (the airline market), and, especially, the description of the role of each of its entities. One important tool to "allow the modeller to map out the main interactions and principal behaviour of the entities in a system that is to be modelled using discrete simulation" is the *activity cycle diagram* (Pidd, 1998). By using the activity cycle diagram (Figure 1) it is possible to show the life cycle of each class of entity and to graphically display their relation.

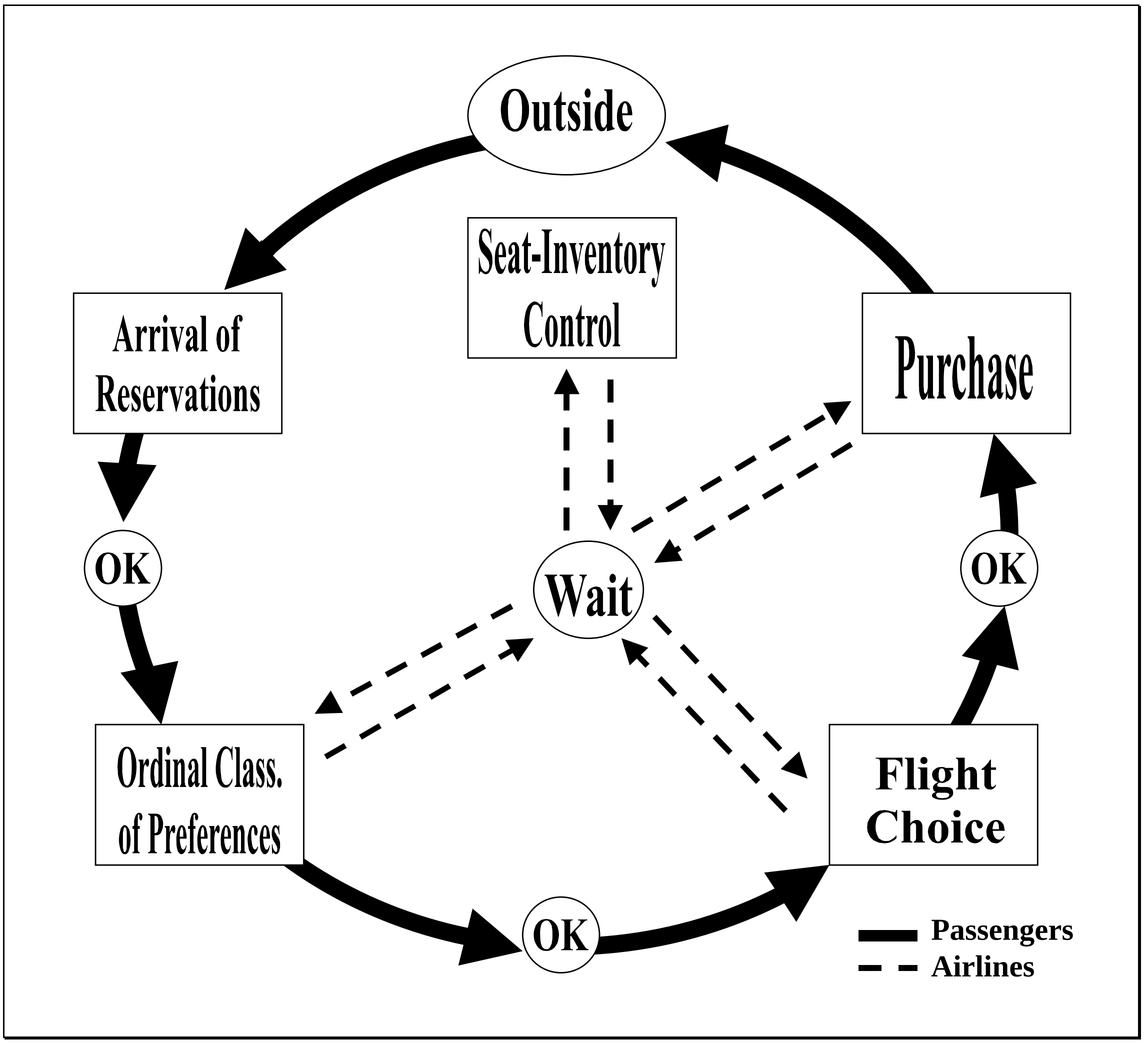

Figure 1 - Activity Cycle Diagram of the Airline Market

Basically, there are two classes of entity in the model: the ***passengers*** (temporary entities, created to enter and exit the model during the run) and the ***airlines*** (permanent entities). It is the interaction of these elements of demand and supply that permits market virtual observation and the collection of results.

Passengers' life cycle is described by some crucial events: the first one is the probabilistic *arrival of demand* in the airlines' reservation systems. This step requires the generation of entities and the definition of their attributes (variables in Table 3).

Following the arrival, the next event is the *ordinal classification of preferences*, which means that each entity will be able to classify the flights available in degrees of preference and to choose that with the highest one, according to individual tastes and factors of choice given. For this to happen there must be an interaction of entities in order to make passengers prompt to analyse each flight' attributes of in the available schedule.

The third event is the *flight choice*, another interaction of transitory and permanent entities. At this stage, reservation requests can be accepted or refused, depending on seat availability in the flight chosen. If the request is refused by the airline, a routine enables the entity to make its choice unfeasible, and them it will choose the second best option. This process continues in a loop until the request is finally accepted.

After the reservation request is accepted, the airline makes the respective seat unavailable for future consumers. It is then followed by the *purchase* of the ticket and the generation of revenue to the firm (third interaction, as in Figure 1). This completes the life cycle of the passenger, which is sent outside the simulation.

Intermittently during the simulation run, airlines that practice the revenue management have to promote the updating of their systems, by using new information on the recent arrivals of passengers. At these moments, the simulation makes the permanent entities to change from the status of inactive to active, in order for them to promote routines of *seat-inventory control*, one of the components of the revenue management (this is done without interaction between entities). The algorithm used was the expected seat-marginal revenue (EMSR, an extension of the Littlewood's rule, as in Belobaba, 1987).

The pseudo code of the application, containing the routines created for the ordinal classification of preferences, flight choice and seat-inventory control, can be found in the appendix.

2.1.2 Demand Segmentation and the Rationality of Segments

This paper uses the demand segmentation proposed by Belobaba (1998), with four types of travellers: those with high sensitivity to time and low sensitivity to price (S_{01}), high sensitivity to time and to price (S_{11}), low sensitivity to time and high sensitivity to price (S_{10}), and low sensitivity to time and to price (S_{00}). This paper extends this framework by also considering *strong airline preference* (due to frequent flyer programs, tradition, in-flight amenities, perceived comfort, etc). Data on both segmentation and strong preference were collected by a field research at the Airport of São Paulo (CGH), and details can be found in Oliveira (2000)[4].

Basically, there were three algorithms of flight choice for each demand segment. The first algorithm was the one assigned to segment S_{01} (passengers with high sensitivity to time and low sensitivity to price). As the price of the airline k in the flight j, p_j^k, has either low or none influence on the choice behaviour of this segment, its ordinal classification of preferences was then designed to be based on the schedule delay, Sd[5]. The more is the schedule delay, the more is this segment of demand's disutility, and thus its choice was based on the criterion of minimisation of that variable.

The second algorithm used was defined for the segments with higher sensitivity to price (S_{11} and S_{10}). In those cases, the ordinal classification used a table of flights - a list of flight times with the lowest schedule delay (the closest to the desired departure time). Once the table was generated, there is an additional ordinal classification based on price minimisation, which means that the choice of those segments targets the best price

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[4] In that field research, 402 questionnaires were collected from the passengers at the airport.

[5] The delay, measured in time units, that the flight departure time represents in relation to the passenger desired departure time.

among the flights with the lowest schedule delay. The difference between S_{11} and S_{10} is the size of the table, that is, the number of flight times with the lowest schedule delay considered in order to make the price ordinal classification – which is higher in the latter segment.

Finally, the third algorithm used was assigned to the segment S_{00}. As the field research (Oliveira, 2000) concluded that this segment has very reduced participation in the market, there was a problem of inference about its behaviour. In this case, the best standard of choice defined was to create another table of flight times, and them to randomize its choice within it. Under circumstances of uncertainty on the behaviour, the uniform distribution was preferred as a proxy.

Undoubtedly, other criteria of choice could be used in order to develop the algorithms to deal with the rationality of the passengers' choice - this represents an advantage of computer simulation, as it can experiment with many patterns of possible behaviour. For the present application, however, the algorithms described above were considered efficient in terms of the tests of hypotheses, validation, and market reproduction.

2.2 Calibration and Validation of the Model

The step of calibration involved the feeding of the simulation model with input data. There were two main groups of inputs: *demand data* (total passengers, total passengers across time, total passengers across a day, and passenger segmentation) and *supply data* (airline schedule, size of aircraft, fare products and algorithm of seat-inventory control). The main sources for both groups were the yearbooks of the Department of Civil Aviation, the airlines and a field research performed in January 2000 at the departure lounges of the Airport of São Paulo (CGH).

This paper developed a sequential sample size estimator in order to promote the validation of the simulation model – as suggested by Kleijnen (1975) and Law and Kelton (2000). The basic idea of this process of validation is to promote t-Student tests for the sample average of the output variables, building confidence intervals, given a significance level of α. Thus, it is designed a number n $\{n = n_0, n_0 + 1,...\}$ of model replications, increasing in one the number of runs until the sample variance to be satisfactorily low – what is controlled by comparing the calculated interval $\theta(n,\alpha)$ around the average, with a desired interval θ_d, previously determined:

$$\theta_d \geq \theta(n,\alpha) = t_{n-1,1-\alpha} S_X \big/ \sqrt{n} \qquad (1)$$

Where θ_d is the desired precision (interval), $t_{n-1,1-a}$ is the t-Student value and S_X is the sample variance of the output variable X. As soon as condition (1) is satisfied, the number *n* of replications designed, $n^*(\theta,\alpha)$, is the sample size that determines, with a level of significance α, one estimate of sample average with a confidence interval less than a desired precision. In case the average of the variable collected in the system is within the upper and lower limits of the intervals, the model is *considered validated* by this criterion – that is, the hypotheses test do not reject the null hypothesis that the simulation model represents adequately the real system.

Law and Kelton (2000) recommend the use of n_0 equal or higher than ten, and a maximum value of θ_d of fifteen percent of the sample average - rules followed by the present paper.

Model's validation and tests were conducted by the use of *market share* as the output variable. Thus, a simulation scenario was built exclusively aiming validation, and used actual 1997 input data (SC_{97}); this step was then followed by the collection of simulated market share data and comparison with 1997 figures (Table 4).

Table 4 - Results of Model Validation - Scenario SC_{97}

	(1)	(2)	(3)	(4)		Confidence Interval		(5)
Airline	Simulated Market Share MS	Variance $S^2[MS]$	calculated θ ($n = 15$; $\alpha = 5\%$)	desired θd	(3)/(1)	MS Lower Limit	MS Upper Limit	Actual Market Share (97)
VRG	*40.6%*	0.29%	0.19%	0.50%	1.23%	40.1%	41.1%	*40.1%*
VSP	*24.4%*	0.56%	0.36%	0.50%	2.05%	23.9%	24.9%	*24.5%*
TBA	*16.0%*	0.36%	0.23%	0.50%	3.13%	15.5%	16.5%	*15.9%*
RSL	*6.5%*	0.32%	0.21%	0.50%	7.68%	6.0%	7.0%	*6.7%*
TAM	*12.5%*	0.27%	0.17%	0.50%	4.02%	11.9%	12.9%	*12.8%*

Finally, the model was considered validated, given α equal to 0.10, and θ_d equal to 0.50%. The total number of replications required was $n^*(\theta,\alpha) = 15$. It is possible to observe that all values in column (5) of Table 4 (actual market shares in 1997), are within the confidence interval developed (market share lower and upper limits), as required by this specific form of validation procedure.

3. Experimentation: An Assessment of the Revenue Management in the Market

Last section described how the scenario SC_{97} was built and validated. Once this phase was concluded, one advantage permitted by the simulation is to perform some convenient experimentation with the elements of the model, in order to infer about the effects and sensitivity of them to the output variables.

Thus, the main exercise of experimentation here was to insert the set of components that form the revenue management, as SC_{97} had only "first come first served", uniform pricing characteristics[6]. This allowed the assessment of revenue management's impacts in the economic efficiency of the market and also some inferences of its rationality as a strategy in the market.

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[6] Revenue management was introduced only in 1998 on the route Rio de Janeiro-Sao Paulo (section 2).

The model was then replicated the number of times necessary to make it statistically significant, and the following output variables were collected: quantity of passengers per airline (Qd_k), market share in quantities (MS_k^{qd}), total revenues yielded (TR_k), market share in revenues (MS_k^{TR}), average revenue yielded (AR_k), profits (Π_k), load factor by airline (LF_k), and average price and average schedule delay by each segment of passenger (P_i and Sd_i); this procedure was implemented for each experimental scenario.

The following sections report two main steps of the experimentation:

1. assessment of impacts in market efficiency, by the development of two scenarios: SC_{RM}, in which the airlines used *revenue management* in the same condition that was done in 1998; and SC_{UP}, in which the airlines used *uniform pricing*, in the same condition prior to the introduction of the revenue management;

2. analysis of revenue management rationality, by the development of six additional scenarios, which could represent possible "strategic moves" by the airlines (investigation into the *strategic interaction* of the airlines).

In fact, the first step represents the main goal of the present computer simulation while the second one is an extension to the model – an articulation of a simulation with an analytic model, demonstrating that they can be complementary in economic analysis, and not only substitutes[7].

3.1 Analysis of the Impacts in Market Efficiency

In order to assess the impacts in the economic efficiency caused by revenue management on the route, scenario SC_{RM} was created. In this scenario airlines have a fare product structure along with a booking control algorithm whereas in scenario SC_{UP} they use a “first come, first served” with uniform pricing policy. It is important to emphasise that both scenarios were set with the values and standards effectively used in the market[8].

Tables 5 and 6 present a comparison between results of simulated scenarios SC_{UP} and SC_{RM}. Results were disaggregated by segment of consumer (S_{01}, S_{11}, S_{10}, and S_{00}) and by group of airline that had code share agreements in 1998. Four criteria were considered: average prices (disbursement), schedule delay, profits and passengers carried:

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[7] This paper then follows the suggestion of Judd, 1997.

[8] As described in Table 2.

Table 5 - Summary of Results of the Scenarios SC_{UP} and SC_{RM} (Demand)

Criterion 1: Disbursement (Avg. Price)	*Scenario of Unif. Pricing (SC_{UP})*	*Scenario of Rev.Managmt. (SC_{GR})*	**SC_{GR}-SC_{PU} (%)**
Segment S_1	115.4	109.9	*- 5 %*
Segment S_2	115.3	95.5	*- 17 %*
Segment S_3	115.1	94.8	*- 18 %*
Segment S_4	115.5	106.2	*- 8 %*
Demand	**115.4**	**107.1**	**- 7 %**

In 1998 R$

Criterion 2: Schedule Delay	*Scenario of Unif. Pricing (SC_{UP})*	*Scenario of Rev.Managmt. (SC_{GR})*	**SC_{GR}-SC_{PU} (%)**
Segment S_1	1:16	1:13	*- 4 %*
Segment S_2	0:47	1:49	*+ 130 %*
Segment S_3	1:06	1:54	*+ 72 %*
Segment S_4	5:31	5:21	*- 1 %*
Demand	**1:17**	**1:24**	**+ 10 %**

In hours

Table 6 - Summary of Results of the Scenarios SC_{UP} and SC_{RM} (Supply)

Criterion 3: Profits	*Scenario of Unif. Pricing (SC_{UP})*	*Scenario of Rev.Managmt. (SC_{GR})*	**SC_{GR}-SC_{PU} (%)**
A_1: TAM	1.5	0.8	*- 46 %*
A_2: VSP - TBA	18.1	14.5	*- 20 %*
A_3: VRG - RSL	13.5	11.6	*- 14 %*
Supply	**33.1**	**26.8**	**- 19 %**

In 1998 R$ (million)

Criterion 4: Seats Sold	*Scenario of Unif. Pricing (SC_{UP})*	*Scenario of Rev.Managmt. (SC_{GR})*	**SC_{GR}-SC_{PU} (%)**
A_1: TAM	96.6	99.6	*+ 3 %*
A_2: VSP - TBA	475.3	513.7	*+ 8 %*
A_3: VRG - RSL	508.0	491.0	*- 3 %*
Supply	**1,079.9**	**1,104.4**	**+ 2 %**

In number of seats (thousands)

One can observe that the decrease in the average price charged to the segments of passengers and to the demand in general (Criterion 1) was concomitant with the decrease in the profits of the three groups of airlines (Criterion 3). Indeed, all the groups of airlines had relevant profit losses of at least 14%, due to lower revenue[9].

This aspect of poor financial performance in the supply side, observed in the scenario SC_{RM}, has the at least justification: the effects of the "weak", inadequate product differentiation. Revenue management is a known instrument of revenue optimisation, which undoubtedly increases the chances for profits to increase[10]. However, if there is imperfect demand segmentation (meaning product differentiation inefficacy), the tendency is to the gains in profitability to be reduced by *revenue dilution*[11]. Without an efficient introduction of purchase restrictions ("fences"), not only based on the advance in the reservation and flight time - as in this case - the scheme of second degree price discrimination with self selection can be ruined. This phenomenon tends to be worse on routes like Rio de Janeiro - São Paulo, in which there is not much advance of the arrival of reservations.

Thus, dilution in revenue was the main problem found in scenario SC_{RM}, as well as in all scenarios where revenue management was present. Table 7 illustrates this point by presenting the diversion of segment S_{01} to discount fares, which accounted for up to 24% of total revenues[12]:

Table 7 – Distribution of Diversion to Discout Fares (Segment S_{01})

Airline	Total non-diverted (Full fare)	Diversion to deep discounts (30-50%)	Diversion to moderate discounts (<30%)	Total diversion
A1 (SC_4)	77%	*5%*	*18%*	23%
A2 (SC_2)	76%	*10%*	*14%*	24%
A3 (SC_1)	82%	*7%*	*11%*	18%

in % revenues

Another quite relevant issue to consider normatively is the increase in passengers carried (Criterion 4 of Table 6). This is important specially because air transport is not a popular mode of transportation in Brazil as it is in other countries, due to low average income and relative prices of the alternatives.

The final point is the analysis of the *efficiency in allocation* (Botimer, 1996) as a second best for the market welfare. Revenue management generated an allocation of the service

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[9] It is important to emphasise, however, that SC_{RM} is not the scenario where *all* airlines use revenue management. As can be seen in Table 2, in this scenario only A_1 and A_2 uses the strategy (as in September, 1998). This does not change the results because scenario SC_6 in Table 8 (Section 3.2), in which all airlines have revenue management, also contains the characteristic of generalised financial performance.

[10] Check, for example, Belobaba (1987), Belobaba (1989) and McGill and Van Ryzin (1999).

[11] As emphasised by Oliveira and Serapião (2000) in a study of the Brazilian market.

[12] SC_1, SC_2, SC_4, and all other experimental scenarios are described in 3.2.

in a more adequate way for the consumers who value it the most. Criteria 1 and 2 permit observing this effect in a proper way: thus, to the segment of consumers S_{01} - the most representative on the route -, which is more sensitive to time, there was the allocation of flights in times closer to their desired time of departure (schedule delay reduction, Criterion 2), what certainly increased their welfare. What is more, to the segment of consumers S_{10}, more sensitive to prices, it was allocated lower priced flights (Criterion 1), which contributed to the increase in their welfare as well. Both gains represented increases in general efficiency in allocation of the market.

The conclusion achieved is that revenue management on the route Rio de Janeiro - São Paulo was an important instrument of welfare generation, mainly when considering the concept of welfare in allocation (demand side). It also permitted a significant increase in the average load factor (supply side). The strategy had, however, negative impacts in relation to relevant variables such as revenues and profits. On account of that, it can be concluded that the correction of problems related to revenue dilution should be stimulated by the airlines and by the authorities in charge of the industry.

In order for revenue management to have its positive welfare impacts optimized, there must be an effective reinforcement of its three basic components. Thus, there must be the promotion of better designed price discrimination schemes, higher investment in more sophisticated systems of seat-inventory control, and, last but not least, a more adequate use of product differentiation, by the imposition of better mechanisms of segmentation - purchase restriction or "fences" - in order to avoid the phenomenon of revenue dilution.

3.2 Analysis of Airline Strategic Interaction

A final issue addressed by the simulation model was the investigation into the rationality of the airlines in relation to revenue management. Section 2.1.2 described the rationality of demand agents (segments of passengers) through the development of algorithms of choice. With regard to the airlines, the element of rationality considered was the revenue maximisation target, as permitted by the routines of seat-inventory control. In fact, it was permitted a learning process in order for airlines to build their demand database, and thus to achieve that target (check Table 2); however, the convergence to the maximization rule was fast enough for the strategic decisions to be affected.

However, a problem not explained so far was the motives of actual revenue management utilisation on a route like that, with characteristics of “shuttle service markets” - high inelasticity to price of demand and low advance of the arrivals of reservations. Is there a *dominant rationality*, that is, in all possible competitive cases the strategy of revenue management has advantage over its alternatives (ex: Belobaba and Wilson, 1997, and Smith, Leimkuhler and Darrow, 1992)? And what about uniform pricing[13]? Are there cases in which, depending on the competitive conditions, it can be more advantageous than revenue management?

In order to answer these questions it was implemented a relevant characteristic of computer simulation models: their possibility of articulation with analytic models. With the purpose of demonstrate this potentiality of complementary between both kinds of approach, the present paper developed some experimental scenarios in order to feed an analytic model – a game theoretical model of the competition on the route, called "the revenue management game".

By using three players (A_1, TAM; A_2, VSP-TBA; and A_3, VRG-RSL) and two strategies (either to play uniform pricing, UP, or revenue management, RM), 2^3 experimental scenarios were needed. Two of them were already developed in section 3.1. Six additional scenarios, presenting other possible strategic subsets for the airlines, were then built. Table 8 presents the scenarios developed:

Table 8 - Experimental Scenarios Designed in the Simulation

Scen.	Description	Scen.	Description
SC_{UP}	The three players play UP (Mar/98)	**SC_{RM}**	A_1, A_2 play RM, whereas A_3 plays UP (Sep/98)
SC_1	A_1, A_2 play UP Whereas A_3 plays RM	**SC_4**	A_1 plays RM whereas A_2, A_3 play UP
SC_2	A_1, A_3 play UP Whereas A_2 plays RM	**SC_5**	A_1, A_3 play RM whereas A_2 plays UP
SC_3	A_1 plays UP whereas A_2, A_3 play RM	**SC_6**	The three players play RM
Legends: A_1 - Player 1 (TAM); A_2 – Pl. 2 (VSP-TBA); A_3 – Pl. 3 (VRG-RSL); *UP: Uniform Pricing; RM: Revenue Management.*			

Suppose that after the liberalisation of the beginning of 1998, the problem of analysis of the airlines' rationality could then be posed as a simultaneous non-cooperative game (as in Figure 4). The payoffs of the players (airlines) in the game are disposed under the terminal nodes of the tree diagram and represent the results of each scenario simulated; they are expressed in terms of an index of profits π_k, k =1,2,3 (π_2 in SC_{PU} equal to 100):

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[13] Remember that uniform pricing was defined in the last paragraph of section 1 as the antithesis of revenue management.

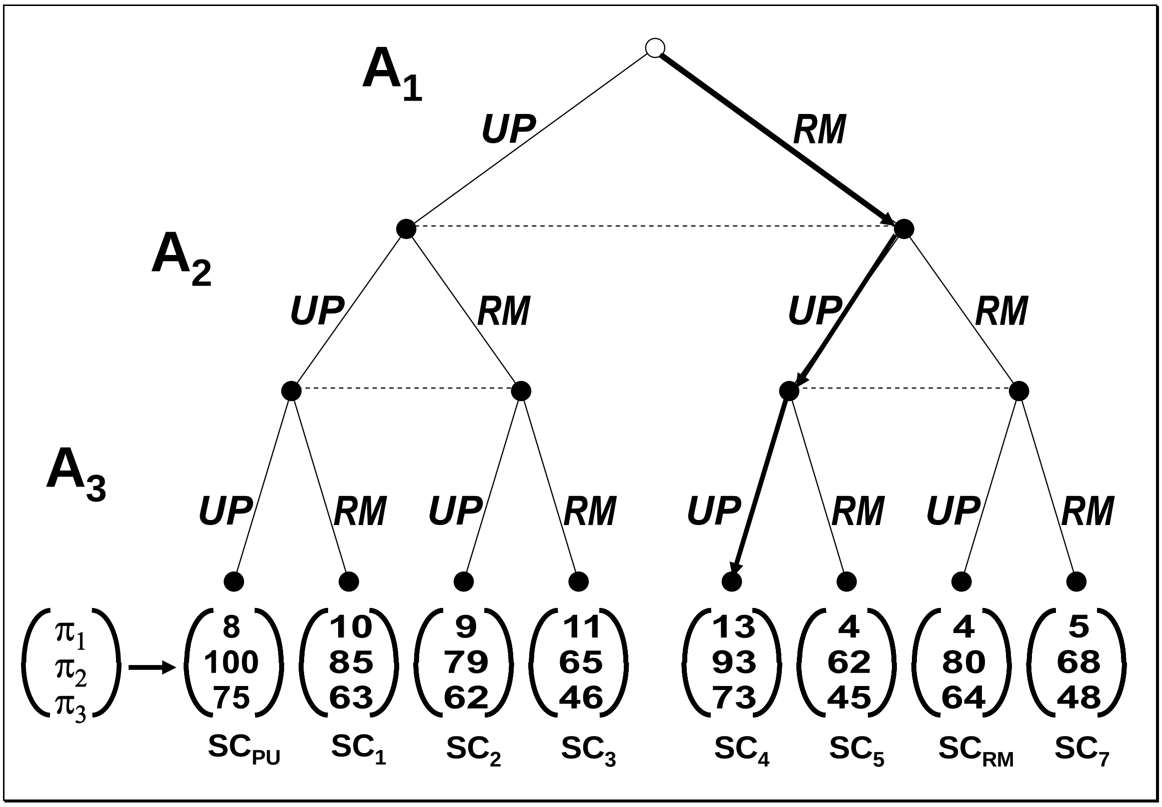

Figure 2 – The Revenue Management Game

The solution of the game can be obtained by Backward Induction[14], presented by (2). σ_{A1}, σ_{A2}, and σ_{A3} are the strategic profiles of solution[15] for each player:

$$\begin{bmatrix} \sigma_{A1} \\ \sigma_{A2} \\ \sigma_{A3} \end{bmatrix} = \begin{bmatrix} \text{RM} \\ \text{UP},\ \forall \sigma_{A1} \\ \text{UP},\ \forall \sigma_{A1}, \sigma_{A2} \end{bmatrix} \tag{2}$$

The results in (2) make clear that revenue management is dominant – that is, played independently of the other players' moves – only for A_1, but not for the remaining airlines, for which uniform pricing is dominant. Thus, solution (2) leads to the conclusion that RM is not globally advantageous and that it depends on the competitive conditions and revenue capabilities to be better than the traditional practice of uniform pricing. These results contrast to the ones achieved by the simulation of Belobaba and Wilson (1997), where “effective yield management results in revenue increases for the users of YM in virtually all competitive situations”.

One important issue to emphasise, however, is that (2) was built based on the development of the simulation model in the same way as was performed on the route, that is, using a ‘weak’ product differentiation scheme (inefficient purchase restrictions). However, even disregarding the ‘dilution effect’, the results clearly indicated that

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[14] For the definition of this concept, check Mas-Colell, Whinston and Green, 1995.

[15] That is, the SPNE (Subgame perfect Nash Equilibrium).

revenue management was only locally advantageous and permitted profit gains to only a subset of airlines[16]. The Rio de Janeiro-São Paulo route was then considered a fine case study of a market less sensitive to price and with homogeneous patterns of demand arrivals in reservation systems, which may roughly explain the poor financial performance recently observed, even under the presence of a strategy supposed to enhance firm's profits in most of the situations.

Another relevant difficulty in comparing the present approach with the one of Belobaba and Wilson (1997) is that they do not adopt uniform pricing as firms' alternative to revenue management. Their "no yield management" situation means "no seat-inventory control in a multi-fare pricing structure". Here I consider "uniform pricing" as one extreme alternative to revenue management, as explained in the last paragraph of section 1.

Conclusions

The present paper developed a computer simulation model to analyse the impacts of revenue management in a recently liberalised airline industry, Brazil, focusing on its most important route, Rio de Janeiro - São Paulo. This is a business market widely recognised as having a highly price-inelastic demand. For that purpose, it used real data for model calibration, and performed a process of validation – a different methodology from the hypothetical markets of Belobaba and Wilson (1997).

The conclusions are that revenue management had positive impacts in terms of *efficiency in allocation*, that is, in "ensuring that a scarce resource is provided to the members of the population who intrinsically value it most" (Botimer, 1996). Thus, to the segments of passengers with demand highly time-sensitive (and therefore with higher reservation prices), were allocated seats closer to their desired time of departure. Moreover, to the segment highly price-sensitive, it permitted an allocation of seats with lower prices. In both cases, the welfare of passengers was increased. In the supply side, there was an overall increase in load factors in the market.

In spite of these positive aspects, it was observed much *revenue dilution* on the route, caused by inadequate purchase restrictions ("fences", which are fundamental elements of product differentiation, necessary for the revenue management to be effective). In fact, the airlines in the market only implemented restrictions of advance purchase and flight time availability. This certainly was the cause of much revenue loss in a route characterised as a 'shuttle service market' – low rates of arrivals in advance on account of the high service levels[17]. Hence, this paper highly recommends the introduction of more adequate elements of fare restriction in order to correct the 'weak' product differentiation and to enhance revenue management capabilities.

Another relevant aspect of the modelling is that uniform and differential pricing used here were precisely the same as observed in practice. This led to the definition of a

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[16] The figures of the scenarios disregarding revenue dilution can be found in Oliveira (2000).

[17] This was observed for all demand segments.

uniform fare equal to the undiscounted fare in the differential pricing scheme, as adopted by airlines on the route. This could represent a potential underestimation of revenue generation by the latter[18], especially because previous studies of differential pricing have assumed multiple fares involving both lower and higher fares than the single uniform pricing strategy. In the end, however, the comparison between strategies permitted by the model could reproduce the same competitive dilemma on the route.

One additional objective of this paper was the analysis of airline rationality in introducing revenue management. This was motivated by the fact that some of them preferred to maintain uniform pricing (and so, to have a “first come, first served” policy), and not to react. By using an articulation of experimental scenarios and game theoretical model, it was possible to indicate that revenue management was not really a dominant and/or a stable strategy for some of the players.

The final conclusion is about the methodology of computer simulation, as an alternative to more usual analytical models of competition. It permitted the development of crucial details in the modelling of the agents in the market, mainly on the issue of the rationality of the passengers. It also permitted the consideration of relevant characteristics of the airline market, such as probabilistic arrival of reservations, demand segmentation, capacity optimization algorithms, and price discrimination, which would be complex to treat simultaneously in any analytical model. Thus it was considered satisfactory as it allowed the better understanding of decision-making process and firms rationality, as well as permitting the design of experiments for the analysis competition in airline markets.

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[18] Which could be worse if we take into account the low price-elasticity of demand (check demand estimation in Table 2).

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Appendix: Simulation Pseudo Code

```
Procedure [Ordinal Classification of Preferences and FlightChoice]

Begin

  Repeat until no more passengers

      Read Passenger (MySegment, MyDesiredTime, MyFFStatus,      ' collect demand
      MyPreferredAirline)                                         attributes;

      FlightsAvailableTable = FlightSchedule - FullFlightsTable  ' exclude full flights;

      If MyFFStatus = 1                                          ' exclude other airlines if
          MyFlightTable = MyFlightTable - Airlines different from  it is a frequent flyer;
          MyPreferredAirline
      Endif

      Calculate MyScheduleDelay                                  ' classify all flights in
      Sort MyFlightTable (MyScheduleDelay; Descending)            terms of schedule delay
                                                                  in relation to the
                                                                  variable MyDesired
                                                                  Time (ordinal
                                                                  classification of
                                                                  preferences for $S_{01}$);

      Switch PassengerSegment

          Case $S_{11}$:                                         ' ordinal classification of
              MyFlightTable = MyFlightTable - All flights with    preferences for $S_{11}$;
              MyScheduleDelay > than the first 5 least
              Sort MyFlightTable (Price; Descending)

          Case $S_{10}$:                                         ' ordinal classification of
              MyFlightTable = MyFlightTable - All flights with    preferences for $S_{10}$;
              MyScheduleDelay > than the first 3 least
              Sort MyFlightTable (Price; Descending)

          Case $S_{00}$:                                         ' ordinal classification of
              MyFlightTable = MyFlightTable - All flights with    preferences for $S_{00}$;
              $MyScheduleDelay_{ij}$ > than the first 10 least
              Assign random number ~U(1,10) to each flight
              Sort MyFlightTable (U; Descending)

      Endcase

      MyFlight = The first in MyFlightTable                      ' generate the flight
                                                                  choice;
      SeatAvailabilityStatus = 1                                 ' register passenger's
                                                                  choice
      If Flight is Full                                          ' check if flight is now
          FullFlightStatus = 1                                    full;
      Endif
```

Figure 3 - Pseudo Code of Ordinal Classification of Preferences and Flight Choice

```
Procedure [Seat-Inventory Control]

Begin

    RMFlightSchedule = FlightSchedule - FullFlightsTable - Flights    ' exclude full flights and
    Airlines with Uniform Pricing                                      uniform price flights;

    Suspend passengers arrivals in the reservation

    Repeat until no more flights in the RMFlightSchedule

        Read Flight (FareProductOpenStatus, SeatsAvailable)           ' collect data from the
                                                                       reservation system
                                                                       (update seat-inventory
                                                                       control system with
                                                                       recent arrivals);

        Repeat until no more FareProducts in the Flight

            Calculate Averg [SeatSold], Var [SeatSold], EMSR          ' apply the EMSR
            Generate FareProductNSeats                                 Rule for each fare
                                                                       product available in
                                                                       each flight

        Next FareProducts

    Next Flight

End
```

Figure 4 - Pseudo code of Seat-Inventory Control