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Allocation of fixed capacity service infrastructures - hotel and health sectors

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Resumen

This paper discusses the approach taken in a MICIN-funded research project aimed at developing flexible decision support systems for the effective assignment of fixed-cost infrastructures. It analyzes the initial set of technology-oriented decisions and presents and discusses preliminary results. It particularly focuses on the development and implementation of initial "triads" of Assignment process model/Tailored assignment algorithm/Specific forecasting requirements, to explore the interaction among these three elements. Experimental design is applied to a simulation environment comprising a baseline "triad" and several variations, to study this interdependence and to explore the issues involved in comparing and evaluating alternatives.

Keywords: Resource Allocation, Yield management, Optimization, Simulation

1. Fixed capacity service infrastructure allocation challenges

The sustainable development of an increasingly service-based economy, such as the Spanish economy, requires the efficient allocation, to the various existing user classes, of service infrastructures with essentially fixed costs, whose value potential is wasted if not utilized (e.g., in a vacant hotel room), since those services can not be stored.

The Yield / Revenue Management algorithms were developed, initially in the airline industry, to face these issues. The results obtained by this research team in previous projects confirmed the potential benefits to be gained from the use of advanced optimization techniques and algorithms to guide those assignments. However, they also revealed a set of barriers that strongly hinder their practical application:

– Each service organization uses a different business process design for infrastructure assignment. Since the appropriate algorithm is contingent on that design, organizations must tailor their algorithms or redevelop them from scratch.

– Given the currently prevailing non-systematic approach to algorithm development, this adaptation requirement imposes a stiff hindrance, particularly to the SME.

– The effectiveness of a new or modified algorithm is hard to ascertain. Its effectiveness must thus be evaluated in a simulated environment that closely resembles reality.

– Revenue Management techniques try to maximize the economic profit. In many service environments, such as Health Care, that objective must be balanced with several others.

2. Project objectives and approach

A new research project has therefore been established to look for a solution for these challenges, thus allowing the extension of the potential benefits of effective infrastructure assignment techniques to the various service segments, regardless of the size of the company involved. Having secured support from the MICIN [*], the project is working towards its stated objectives:

– Development of a reference metamodel (in the M2, "metamodel layer", of the Object Management Group architecture) of the generic service infrastructure assignment process, out of which, for each specific case, it is possible to instantiate an integrated and coherent set of: a) Specific assignment process model b) Tailored assignment algorithm / procedure c) Specific forecasting requirements.

– Development of a Benchmarking Platform based on Intelligent Multi-Agents to evaluate and compare the relative performance of each set (process model / algorithm / forecast) through a credible simulation of the user behaviour

– Fully embed, in the previous elements, a multicriteria approach, as a prerequisite for expanding their applicability into sectors such as Health Care.

This set of objectives have led to the integration in the research team of researchers from different backgrounds (Industrial Engineering, Health ...), as well as to establishing partnership agreements with supporting companies, both potential "users" from both sectors (hotel and health) and IT based solution providers. Due to the educational potential of the project, students conducting supervised research at the engineering and the master level have also been engaged, both in Spain and interacting with their peers in the USA and India which are working on related issues.

3. Progress to date

This paper further discusses this approach, analyzes and justifies the initial set of decisions taken on the technologies to be used, and presents and discusses preliminary results.

Two major lines of activity have been tackled in this first phase of the project.

- Development of a Benchmarking Platform based on Multi-agent simulation, using Repast.net / C# and RepastJ / Java. This initial work has focused in the procedures for creating a coherent population of software agents, each agent representing a potential customer/patient and possessing a set of traits (age, profession, preferences...). This population should exhibit internal coherence (i.e., positively correlated traits would normally be present in the same agents) as well as external coherence (i.e., distribution of trait values in the agent population should reflect the distribution observed in the system being modeled).
- Development and implementation of initial "triads" of Assignment process model/Tailored assignment algorithm/Specific forecasting requirements. The main purpose for these initial implementations is to explore the interaction among these three elements, as well as between them and the Benchmarking Platform-based

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evaluation procedure. The rest of this paper will concentrate on this particular line of activity.

4. Baseline "triad" modeled and implemented

A major intermediate objective in this project is to explore and model the bidirectional interactions between the three components of a "triad":

- The "Business process model" through which that particular infrastructure element is assigned to one of its potential uses. In the example of a hotel, that would be the design of the room reservation process: Alternative distribution channels through which rooms can be reserved, quota allocation and reallocation to each channel, cancellation procedures and penalizations, pricing process (prices that can only increase as the execution/ arrival date approaches vs. prices that can go either up or down), etc.

- Assignment algorithm. To extract maximum "value" (potentially in a multi-objective environment) of the existing infrastructure, an effective assignment algorithm or procedure must be designed, that provides support to the decisions involved in the aforementioned Business process model and is compatible with it. In the example of a hotel, this could be a Yield/Revenue Management algorithm adjusted to its particular reservation process design.

- Specific forecasting requirements. A key input to the assignment algorithm will be a demand forecast. Each assignment algorithm will have different forecasting requirements. On the other hand, the "value" that the algorithm can add is contingent on the "richness" and accuracy of the forecasts that can be made. In the example of a hotel, the assignment algorithm that we will discuss later requires a forecast not only of how many potential customers will show interest in staying in the hotel in a given night, but also whether they are willing to pay the full price or just the discounted price and the anticipation with which they make the reservation.

Understanding this interdependence is considered a prerequisite for the development of the reference metamodel of the service infrastructure assignment process, out of which coherent "triads" can be instantiated.

Therefore, a simplified initial "triad" was developed and implemented, to be used as a baseline. While keeping the business process model constant (to facilitate the analysis), variations / improvements were introduced by refining the algorithm/forecasting requirements dyad, thus leading to a set of alternatives that could be compared. Then, a structured comparison/ comparative rating was carried out, again to explore and to develop approaches to tackle the various issues involved in such an evaluation. In the following sections this is discussed in more detail.

4.1. Business process model

The "Business process model" chosen for this initial proof-of-concept was the room reservation process for a hotel. The hotel had a given capacity of identical rooms for a given night. Bookings were accepted up to 20 days in advance. Only one reservation channel was considered. Two pre-specified prices (full and discounted) could be assigned. Price for a given night could change from discounted to full, but not vice versa (i.e., price for a given night could be either always full, or always discounted, or initially discounted and then changed to full during the 20-day period). When a potential customer calls, asking for a quotation for a given night, if rooms are still available he will be given the currently prevailing rate (full or discounted). If that quotation is accepted, it is counted as revenue. If all rooms are booked, the customer is turned down.

4.2. Forecasting requirements – baseline case

The baseline forecasting requirements for this business process model can be summarized as a forecast of how many customers willing to pay the full price (who would also be happy to pay the discounted price) and how many willing to pay the discounted price but not the full price (customers not willing to pay even the discounted price have no impact under this business process model, thus there is no need to forecast them) will call each day for each night.

If the following notation is used:

i: day of stay; day whose night will be spent in the hotel

j: nº of days of anticipation/lead time; e.g. i=212, j=7, customer calls on day 205 and wants to spend in the hotel the night of the 212

k: customer's willingness to pay. k=1: willing to pay the discounted price (DP) but not the full price (FP); k=2: willing to pay FP (or DP)

Then the forecast will be: X(i, j, k) ; X (217, 15, 1)=4 implies a forecast that on day (217-15=202) 4 customers will call to make a booking for day 217, willing to pay DP but not FP.

4.3. Assignment algorithm – baseline case

From the business process model it follows that the decision to be taken, for which the assignment algorithm must provide support, is when to switch from discounted price (DP) to full price (FP) for any given night, to maximize expected revenue. It may be before bookings are accepted (i.e., price rice for that night would always be FP), never (always DP), or at some point during the 20-day period (initially DP and then changed to FP).

Let N be the number of available rooms. An algorithm to decide how many rooms, m(i), will be offered at DP for night i (0≤ m(i)≤ N) would be:

First, compute the accumulated bookings forecast matrix Y (i, j, k)

Y(i, j, k) is the forecasted number of booking inquiries with willingness to pay "k" that take place from period "(i-j)" until "i-1". Thus, Y (217, 15, 1) =76 implies a forecast that, between day (217-15=202) and day 216, 76 customers will call to try to book a room for day 217, willing to pay DP but not FP.

Y (i, j, k) = summation from l=j until l=1 of X (i,l,k).

Thus, Y (i, 20, k) would be the total number of booking requests forecasted for night i, either willing to pay DP but not FP (k=1) or willing to pay either (k=2).

Under the simplifying assumption that each day "i-j" all customers with k=1 call before customers with k=2 (Note: a modification has been introduced in the algorithm currently used to eliminate the need for this simplifying assumption; it has not been included here for the sake of clarity / readibility),

For each i

For each j

Calculate FP* min (N, Y(i,j,2)) + DP * min (N- min (N, Y(i,j,2) , Y (i, 20, 1)-Y(i,j-1,1)+Y (i, 20, 2)-Y(i,j,2))

Select the value of j that yields a higher value for this expression (for a given "i")

Now calculate m(i):

m(i)=min[N-min(N,Y(i,j,2)), Y(i,20,1)-Y(i,j-1,1)+Y(i,20,2)-Y(i,j,2)]

5. Alternative "triads" derived through modifications to the baseline

As previously discussed, variations / improvements were then introduced by refining the algorithm/forecasting requirements dyad, while keeping the business process model constant (to facilitate the analysis), thus leading to a set of alternatives that could be compared with the baseline.

The "baseline" algorithm was executed only once for each night, before the start of the booking period, on the basis of the forecast available at that point in time. It did not incorporate the information gained, during the booking period (set to 20 days in our example), as actual bookings came in that generally were not equal to the forecasted bookings.

To create the first variation, the forecasting requirements were modified, so that, as the booking period passed, the forecast for previous periods was replaced by the actual data, as kept by the bookings system. It allowed for some delay in that update. It required some modifications of the structure, since the hotel would not actually know whether a customer's k was 1 or 2 if he was offered DP (in the new structure, for past periods only the sum of k=1 and k=2 was kept; that was not an issue, since for these periods the algorithm only used the sum). It did not change the forecast for future periods. The algorithm was then suitably modified. This created an alternative dyad that could be compared, in terms of performance, with the baseline. For the purposes of this initial, proof-of-concept phase this had the advantage that the relative performance of the alternative under various circumstances could be estimated beforehand, thus helping in the debugging and tuning of the evaluation system.

A second change involved updating, at each re-execution, not only the past forecasted data but also the remaining future forecasted data. This could be done externally to the system (e.g., through a new forecasting exercise) or by "tuning" the previous forecast, based on the actual booking data available at the time of the re-execution, to correct the deviation deemed as "systematic". This involved the definition of various parameters, allowing the system administrator to gauge the degree to which observed deviations were considered systematic, depending on the percentage of the booking period (or of N) that had already elapsed, as depicted in Figure 1. The algorithm was again suitably modified. This created an additional alternative dyad. It should be noted that each of these two dyads include a number of parameters, thus they are better understood as "families" rather than instances.

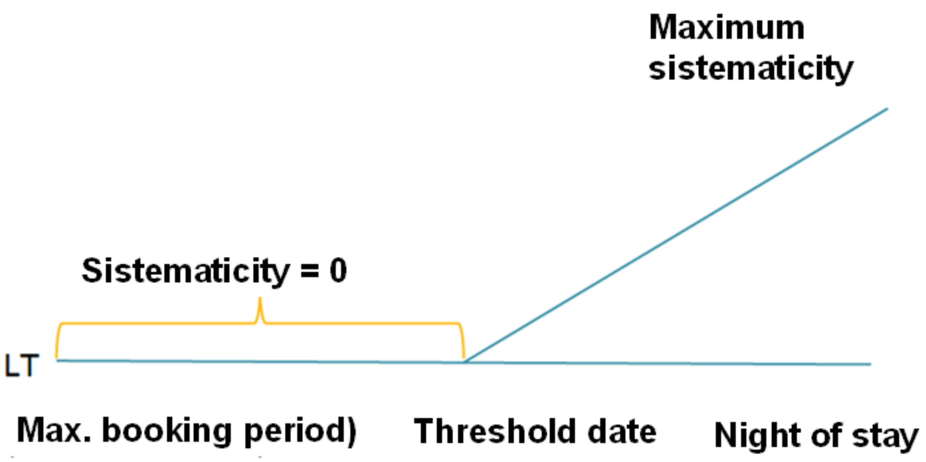

Figure 1. Degree of sistematicity vs. % of booking period elapsed

6. Evaluation and comparison. Experimental design issues

The next step has been to carry out a structured comparison/ comparative rating was carried out, again to explore and to develop approaches to tackle the various issues involved in such an evaluation. Actual implementation of the tests has been carried out by graduate student Jacob García Hwung, under the author's supervision. Even though this abstract does not provide enough space to describe the testing in full, some sample results are provided below, and some of the issues faced will be mentioned.

Various traits were evaluated; we will concentrate here on the comparison of Robustness (how does each alternative approach perform when actual demand deviates from forecasted demand).

Three "dyads" were evaluated against the baseline ("PBRM1"). "PBRM1.2" re-executes the algorithm incorporating actual data. "PBRM1.2+simple correction" additionally adjusts "future" forecasted data to compensate the systematic error. "PBRM1.2+ correction" gauges the correction factor depending on the percentage of the booking period already elapsed.

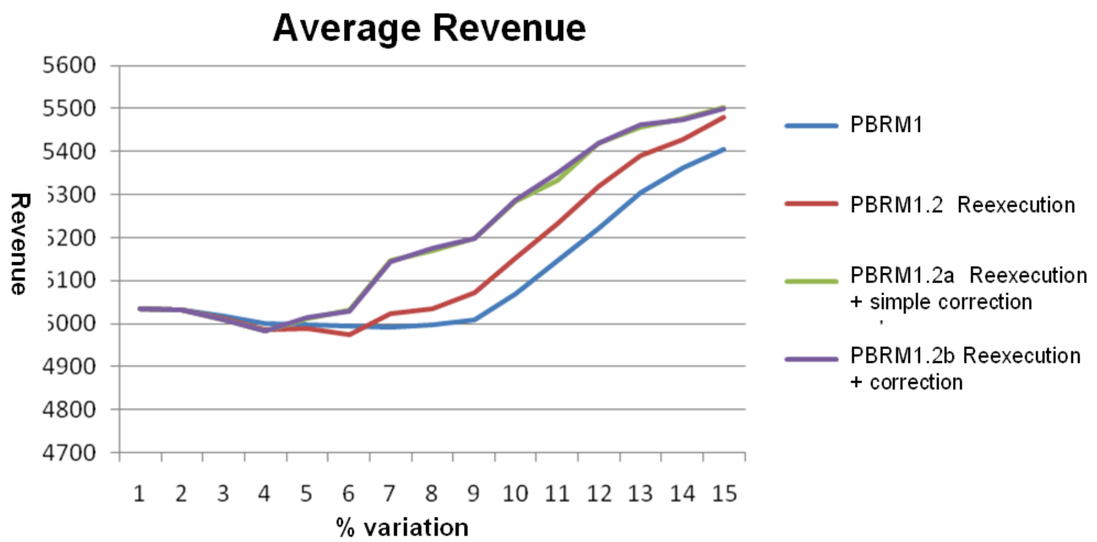

Figure 2. Average income for each dyad, depending on the forecasting error

Figure 2 depicts the relative performance of each alternative, averaged over 100 data sets, and how it evolves with the average deviation, in each data set, between the forecasted demand and the actual demand (15 indicating a more accurate forecast).

Among the issues faced, a major one was the creation of test data sets that, on the one hand, resembled the patterns found in actual hotels, and, on the other hand, highlighted the relative strengths of the approaches being evaluated. This was particularly acute in the generation of the "pairs" forecasted data / actual data. As an example, if the deviation introduced was randomly generated, it distorted the potential value of systemic error correction. It it followed a pattern, it overstated that value. This ended up requiring the utilization of the project's other line of research, focusing on the creation of coherent populations of software agents, each agent representing a potential customer/patient. Based on the models developed there, internally coherent sets of test data were generated.

7. Conclusions

This paper presents preliminary results of a project aimed at developing flexible decision support systems for the effective assignment of fixed-cost infrastructures. These preliminary results confirm the interdependent nature of the three related elements in that assignment process (i.e., business process design/decision algorithm/forecasting requirements) and the usefulness of the simulation approach to test their effectiveness, and highlights some of the hurdles that must be overcome, including issues around the experimental design to use to carry out the evaluation of alternative options.

References

Bertsimas, D.; de Boer, S. (2005). Simulation-based booking limits for airline revenue management. Operations Research, Vol. 53, pp. 90–106.

Chiang, W.C; Chen, J.C.H.; Xu, X. (2007). An overview of research on revenue management: current issues and future research. Int. J. Revenue Management, Vol. 1, No 1, pp. 97-128.

Feng, Y.; Xiao, B. (2006). Integration of pricing and capacity allocation for perishable products. European Journal of Operational Research, Vol. 168, pp. 17–34.

Gutiérrez, M.; Durán, A.; Cocho, P. (2006). An Alternative Approach to the Standard Enterprise Resource Planning Life Cycle: Enterprise Reference Metamodeling. Lecture Notes in Computer Science, Vol 3982, pp. 964- 973

Oddoye, J. P.; Yaghoobi, M. A.; Tamiz, M.; Jones, D. F.; P Schmidt, P. (2007). A multi-objective model to determine efficient resource levels in a medical assessment unit. Journal of the Operational Research Society, Vol 58, pp. 1563 - 1573