A DECISION MAKING TOOL AND SENSITIVITY ANALYSIS FOR LEASING SATELLITE SERVICES

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Abstract: This paper presents the results of a study concerning the evaluation of different decisions for a Satellite Operator leasing capacity to different customers requesting different services. The study was done for Hellas-Sat (the Greek satellite operator) and addresses a real situation. Data concerning the demands of several customers were collected as available from particular organizations within areas covered by Hellas-Sat. These data was first classified and statistically treated. Second a decision tree has been created where the statistical characteristics taken from the first part of the study, were used to derive optimal leasing policies/scenarios and characterize them in terms of both profit and risk. The final outcome is a decision making tool which can be used by a Satellite Operator in order to evaluate possible states, profits and associated risks. A sensitivity analysis on the input parameters was included to measure the impact of uncertainty on the key performance measures.

Keywords: Satellite Communications, Leasing Policies, Modelling, Stochastic Optimization, Sensitivity Analysis

1. INTRODUCTION

Due to the continuous growth of the satellite communications market and to the breadth of its current applications, the availability of a suitable decision support tool is becoming critical for the performance of satellite operators. A satellite provider offers a variety of services to users from different market segments. Each service has different bandwidth demand and therefore a different price. Each customer request has different characteristics (time of lease, bandwidth). We present a model that compares different scenarios/cases of combinations of customers that want to hire satellite capacity.

Each scenario leads to a decision tree where the main goal is the maximization of the profits for the satellite provider. This maximization problem is described in terms of real and expected revenues, along with the corresponding probability of achieving them. Mean values and standard deviations of the measures involved have been calculated and used to assess risk.

The aim of the provider is to maximize profit. This is an optimization problem that involves actual sub-problems typically faced by satellite operators. The ability of making real time decisions has a significant effect on the viability and on the profitability of the company in the growing and competitive satellite market. The proposed decision making model is a managerial application tool which is designed to deal with these real problems.

A mathematical model was created that takes into account the uncertainty and hence the risk associated to each decision. The model includes the recording of possible states. It allows assessing alternative courses of action depending on the required specifications of the customers. Accordingly, their quantification and analysis takes into account the possible benefits as well as the associated/corresponding risk. Depending on these outcomes, the company may follow different business decisions.

Apart from the determination of uncertainty the model incorporates the possibility of time evolution. The decisions are taken sequentially over a specified time horizon. Consequently the model is dynamic, and takes into account the evolution in time. At each time period (month), a different proportion of the satellite transponder's capacity is occupied, depending on the customers demand. This characteristic allows for the analysis of the risk of a decision in a competitive environment. This capability makes the tool applicable to the decisions of a satellite provider because this operates in an aggressive and growing market.

The international developments of the satellite market have been taken into account since pricing data for different services and thus different capacity demands have been gathered. These data have been statistically treated and produced mean values and standard deviations for each service and each bandwidth demand when needed (the majority of these data were provided by Hellas-Sat).

For the mathematical background of this work see [Bertsekas, 2005 and 2001] and [Ross, 1983]. Related theoretical works available in the open literature is not very common due to the relatively recent appearance of the satellite operator business, but nonetheless see [Guikema and Pate´-Cornell, 2002] for related work.

Finally a sensitivity Analysis was performed in order to measure the economic impact of the uncertainty of the key values. The amount of change in the output, determined by relatively small changes in the input was calculated. The results were used to assess/measure the stability of the model, because of the stochastic nature of the parameters involved [Bertsimas and Freund, 2000], [Choi and Kim, Nam-Ho, 2000].

2. STAGES OF WORK

The *first stage* of this study involved the recording and the evaluation of the pricing data coming from the international market of leasing satellite capacity as well as their statistical processing.

The goal of the proposed model, implemented in the second stage, is to enable the decision maker to determine the best possible scenario for the satellite operator, which is the scenario with the larger amount of income.

The hypothesis that a satellite operator has different lease demands from different customers is made. Each customer wants to hire satellite capacity in a specified bandwidth, for a given lease period, which has an associated cost. The model output provides guidelines on the combination of customers that is the most profitable for the operator.

A scenario can be customized by entering the characteristics of the possible customers which are: Service, that is the type of the requested service, *t start*, that is the month when the lease should begin, *t end* that is the month when the lease is supposed to end, and calculates the requested *duration of lease* (with respect to the time evolution), *w* (MHz) is the requested bandwidth, and *C* (Euros) is the corresponding cost of lease. In the structure of the model, the possibility of beginning the hire in different time periods (different months) has been included. Table 1 shows an example of the input parameters of the model.

Accession number of customer	Type of Servi ce	t start (month)	t end (month)	Duration of lease (months)	Reque sted w (MHz)
1	A	1	15	15	15
2	B	3	10	8	20
3	C	2	20	19	1
4	D	2	15	14	5
5	E	3	10	8	30
6	F	11	15	5	20

Table 1: Input parameters

The indicative cost for each service, was calculated using the data collected from the global satellite market. From the gathered data there was a classification of the possible services that a satellite operator could offer. These services correspond to different bandwidth demands and are presented in table 2. The statistical analysis included the pricing for the equivalent capacity per 36 MHz per month and the duration of lease in months. For each service, the mean value of the standard deviation and the percentage difference between the standard deviation and the mean value of these measures were determined along with their cross-correlation. Similar estimators were calculated for the duration of hire.

Services
VSAT
Telephony
IP Gateway
Corporate
Broadcast
Video Contribution
Media company
Government

Table 2: Types of services

3. CONCEPT OF THE MODEL

The model compares at most 6 customers with maximum required lease duration of 60 months, corresponding to a typical level of demand. However, these figures can easily be expanded to account for more customers requiring satellite capacity for more than 2 years. All the possible combinations of customers are calculated (see figure 1 Group A) where a description of these combinations is given in terms of feasibility of implementation or not. Specifically, there is an indication of Possible, Not Possible or Negotiable Combination for each combination of customers.

A *Negotiable Combination* is the combination of customers that exceeds by 1 MHz at most the highest possible capacity that a transponder can serve i.e. 36 MHz, which can probably constitute an issue of negotiation between the provider and the consumer. A *Possible Combination* is the feasible combination of customers from the point of view of the maximum capacity of the transponder and a *Not Possible Combination* is a not feasible one. The proposed tool gives the benefit of sorting by the Description of the combinations so as to present all the Possible combinations (see figure 1 Group B). The next step is to decide which of these possible combinations are the best to compare, by examining the most promising ones. This is done by selecting the combinations with the highest amount of total occupied capacity, which is the sum of the requested capacity of each customer in the combination. Obviously, the more bandwidth is occupied from a transponder the more profit there will be for the firm. These are the '*Real Revenues'* (see figure 1 Group C).

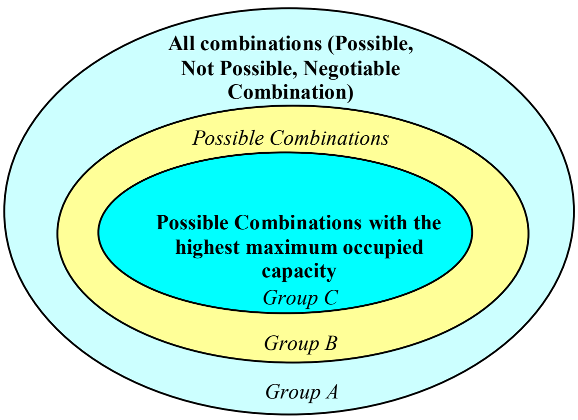

Figure 1: Possible combinations of customers

The next step is to decide which of these combinations with high occupied capacity is the most profitable. The criteria that can be used to lead to the choice of the optimal combination are:

a) The amount of *Real Revenues*, which are the revenues that an operator will gain from the hire of capacity to the customers for each combination.

b) The calculation of additional expected future profits for the satellite operator taking into consideration the standard deviation of the prices and consequently the corresponding risk.

Each combination has different time of maximum requested capacity hire. Therefore, in order to properly compare different scenarios it is necessary to reduce them to a same time period i.e. to the same month of maximum hiring. It is then possible to calculate the additional income that can be generated by the (left over) free capacity that is called 'Remaining Capacity' (*C Remaining*). It is also possible that at specific months not all the available capacity of the transponder of the satellite will be occupied with each combination. This leads to the undesirable effect of not having maximum occupancy of the transponder of the satellite in each month. So the satellite operator could probably hire this available capacity to another possible future customer that is not included to the combination and gain more revenues. This is called 'Empty Capacity' (*C Empty*)

Let us examine the following example involving two cases that a satellite operator may want to compare to assess which one leads to larger revenues. These are Scenario 1, which includes the combination of the customers number 1, 2 and 3 (figure 2) and Scenario 2, which includes the combination of the customers number 4, 5 and 6 (figure 3) with the characteristics shown in table 1.

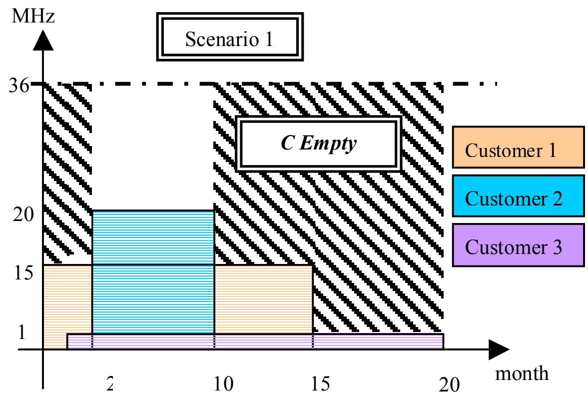

Figure 2: Scenario 1

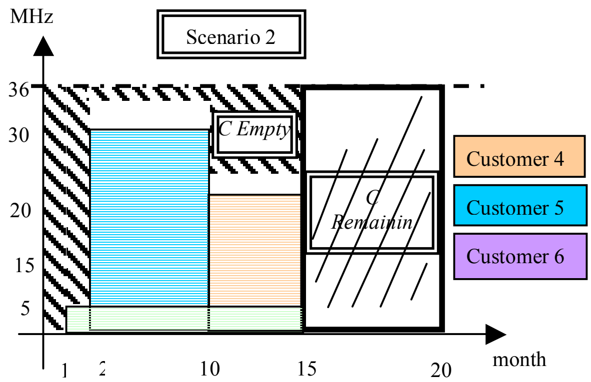

Figure 3: Scenario 2

In Scenario 1 the maximum demand on the transponder's capacity occurs during the 20th month, while in Scenario 2 it occurs during the 15th month. The additional possible income that can be acquired from the respective left over free capacity is calculated. This is called 'Remaining Capacity' *(C*

Remaining) and is shown as the erased region in figure 3.

Each Scenario does not lead to maximum occupancy of the transponder of the satellite in each month. The Empty Capacity (*C Empty*) is shown as the shaded region of figures 2 and 3. For instance, in Scenario 1 (figure 2) there are 21 MHz of empty capacity during the 1st month, 20 MHz during the 2nd month, 0 MHz during the 3rd month (white area in figure 2) etc. The expected profits from empty capacity are included in our calculations.

4. CALCULATION OF REVENUES FROM C REMAINING

For each scenario the possible revenues from the potential leasing of the Remaining Capacity are calculated. This calculation of the theoretical potential revenues is categorized depending on the type of service. Therefore the decision tree, as shown in figure 4, arises for each scenario.

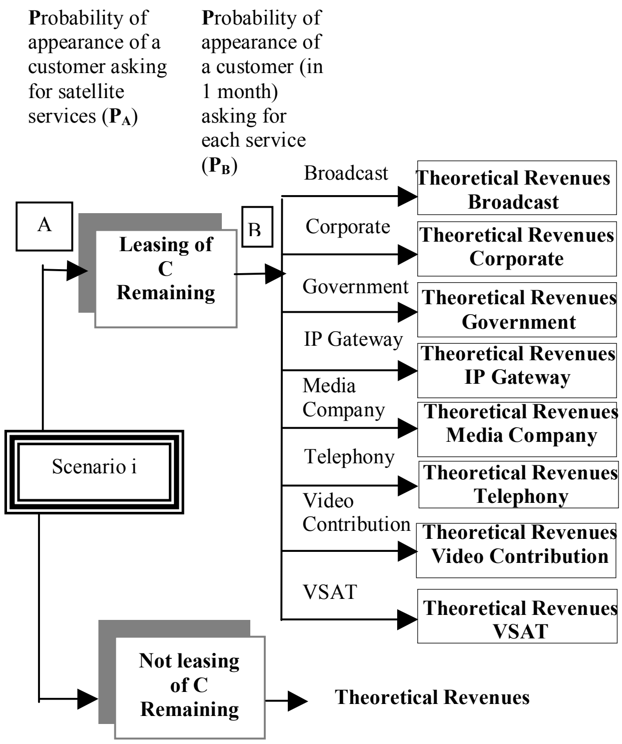

Figure 4: Revenues from C Remaining

The Expected Values of the theoretical income from the Remaining Capacity depend on the type of service and are calculated as:

***P**robability of appearance of a customer (in 1 month) asking for each service (P_B)**
Mean value Price/36 MHz/month
Number of months
****P**robability of appearance of a customer asking for satellite services (P_A)*

The expected revenues for each service, which are called Theoretical Revenues, are calculated and categorized for each service as:

*Mean value Price/36 MHz/month**
**Number of months*

The Expected Values of these revenues are calculated as intermediate volumes that are used only for comparison purposes among the Scenarios. Such revenues incorporate the corresponding risk, while the values of Theoretical Revenues are the real amounts of Euros that can be acquired following each branch of the decision tree.

The Mean monthly (value) Price per 36 MHz is the mean value of pricing for each service referred to the 36 MHz bandwidth, which has been statistically calculated.

The standard deviation for the Expected Values and the Theoretical Revenues for each service are also calculated in order to have an estimate of the risk involved.

All the calculations of probabilities as well as the mean values of the prices of lease and their standard deviations are based on real data for the international market.

5. Calculation of revenues from C Empty

Calculations similar to the ones described in the previous section apply to all possible revenues (Expected Values and Theoretical Revenues) that can result from the leasing of the 'Empty Capacity' up to the 36 MHz bandwidth.

This calculation is categorized depending on the amount of bandwidth that is not used each month by the customers of each combination. This 'Empty Capacity' could potentially be hired and generate revenues.

The selected ranges of capacity in MHz are shown in figure 5 along with the corresponding probability of appearance of a new incoming customer demand for each BW range within the month. This value has been statistically computed based on the available gathered data. A decision tree arises for each scenario.

The Expected Values of the theoretical income for the ‘Empty Capacity’, depending on the not-leased bandwidth during each time period, are calculated as:

***P**robability of appearance of a customer (in 1 month) asking for each bandwidth(**P_c**)**
**Mean value Price/MHz/month **
**number of MHz of Empty C **
**number of months **
*****P**robability of appearance of a customer asking for satellite services (**P_A**)*

While the Theoretical Revenues depending on the number of MHz that are not used are calculated as:

*Mean value Price/MHz/month **
**number of MHz of Empty C **
**number of months*

The standard deviation for the Expected Values and the Theoretical Revenues for each bandwidth are also calculated.

6. OUTPUT OF THE MODEL

All of these evaluated data are presented in the form of a unified decision tree (figure 5), which is the output of the model.

The amount of Total Expected Revenues that will estimate the optimum policy for the firm is the sum of all potential revenues. This sum consists of the Real Revenues, plus the Expected Value resulting from the leasing of the Empty Capacity plus the Expected Value resulting from the leasing of the Remaining Capacity including their standard deviations. The Total Expected Revenues give a range of values, defining the best and worst case scenario for the revenue of the satellite operator.

Total **E**xpected **R**evenues=
Real Revenues **+**
(Expected Value from *C Empty* ±
Standard Deviation Expected Value *C Empty)* **+**
(Expected Value Revenues from *C Remaining* ±
Standard Deviation Expected Value *C Remaining)*

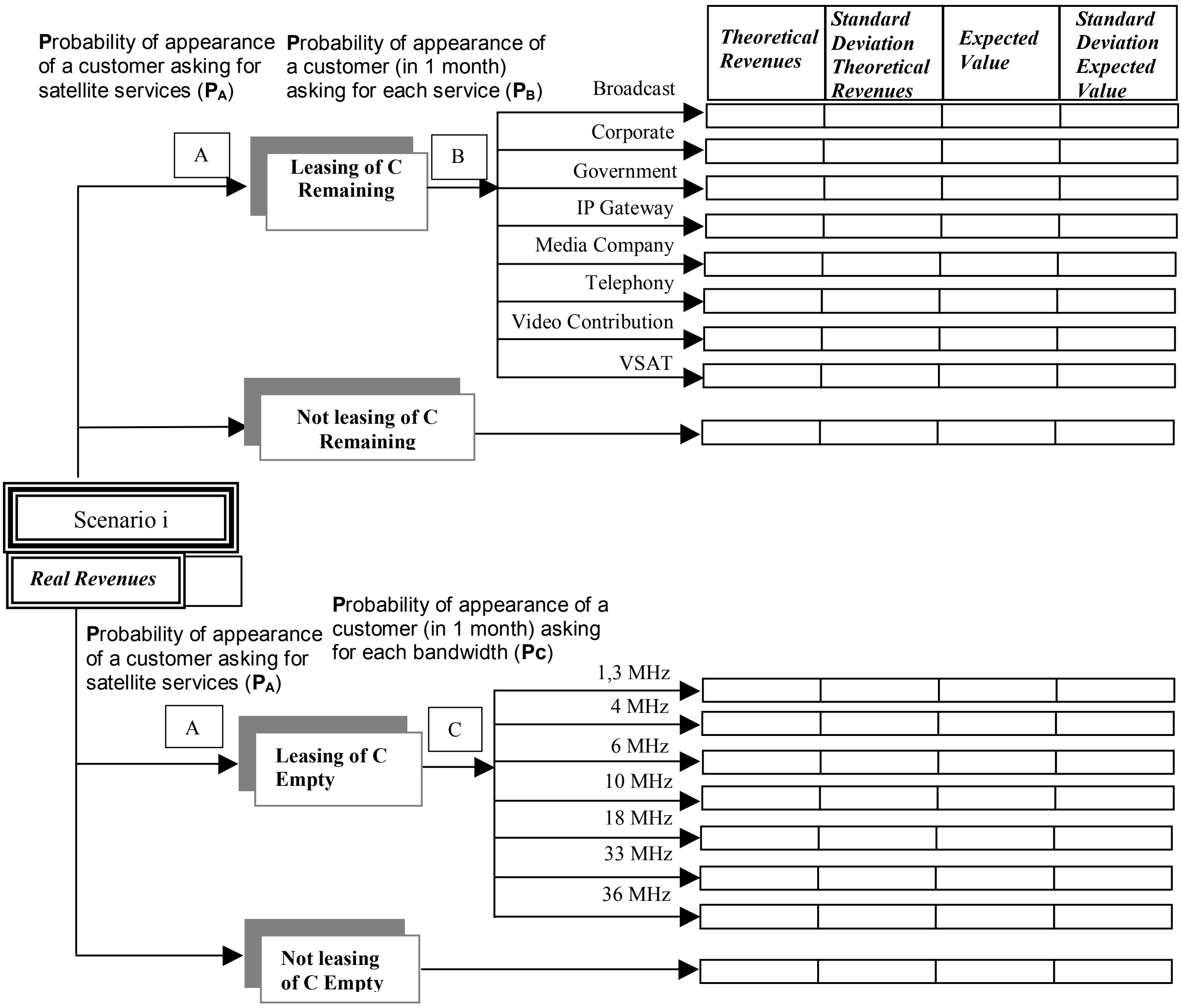

Figure 5: Output of the model Decision Tree

The real amount of money that will result to the satellite operator is:

Total **R**evenues=
Real Revenues **+**

(Theoretical Revenues from *C Empty* ± Standard Deviation Theoretical Revenues *C Empty)* **+**
(Theoretical Revenues from *C Remaining* ± Standard Deviation Theoretical Revenues *C Remaining)*

This gives the opportunity to the manager of the satellite provider to determine which is the most profitable combination for the present and in the future. The decision is made using the amount of Total Expected Revenues. This is not the real revenue that can be made, but it is an intermediate amount, which takes into account the corresponding probabilities, and is used for the purposes of comparison among scenarios. The Total Expected Revenues is a decision quantity that incorporates profits and associated risk. Higher profits come with higher risk. This amount gives an estimate of the extent/worthiness of the risk.

The decision making process starts from the identification of the highest Real Revenues, then the possible additional revenues are considered with their corresponding standard deviation that measures risk.

This result to a range of Expected Revenues with central value: *Real Revenues* **+**Expected Value from *C Empty* **+**Expected Value Revenues from *C Remaining*,
upper limit: *Real Revenues* **+**Expected Value from *C Empty* **+**Expected Value Revenues from *C Remaining* **+**Standard Deviation Expected Value *C Empty* **+** Standard Deviation Expected Value *C Remaining,*
and lower limit: *Real Revenues* **+**Expected Value from *C Empty* **+**Expected Value Revenues from *C Remaining* **-** Standard Deviation Expected Value *C Empty* **-** Standard Deviation Expected Value *C Remaining*.

This final decision depends on the level of risk that the firm is willing to take and on the particular policy that it wants to apply. For a risk-inclined/taking decision maker the policy generating the highest **T**otal **E**xpected **R**evenues will be chosen. A risk-neutral decision maker will take the policy with the central value, whereas for a risk averse decision maker the policy generating the lowest of **T**otal **E**xpected **R**evenues will be chosen. The real income that will result from each decision is the amount of **T**otal **R**evenues for the corresponding scenario.

7. SENSITIVITY ANALYSIS

Sensitivity analysis is necessary in validating the efficiency of a model. Due to the stochastic nature of the input parameters, we calculate the variance in the output of the model, caused by small variation of the input. The statistical processing/analysis of the pricing data gathered from the international market, provided us with pricing details in the form of probability parameters, which were used for the implementation of the model. These parameters include 3 categories:

- pricing and probability data concerning the Remaining Capacity,
- pricing and probability data concerning the Empty Capacity and
- the Probability of a new incoming customer asking the Satellite provider for satellite services (P_A).

These parameters are shown in tables 3 and 4.

Parameter Data for C Remaining			
BW, MHz	**Probability of appearance of a customer (in 1 month) asking for each service (P_B)**	**Mean value Price/ 36MHz/ month**	**Standard Deviation Mean value Price/36 MHz/month**
Broadcast			
Corporate			
Government			
IP Gateway			
Media company			
Telephony			
Video Contribution VSAT			

Table 3: Parameter data concerning the Remaining Capacity

Parameter Data for C Empty			
BW, MHz	**Probability of appearance of a customer (in 1 month) asking for each bandwidth (P_c)**	**Mean value Price/MHz/ month**	**Standard Deviation Mean value Price/MHz/ month**
1.3			
4			
6			
10			
18			
33			
36			

Table 4: Parameter data concerning the Empty Capacity

The sensitivity analysis for these input parameters was done by creating a small perturbation for each one of them. The value of each parameter was varied by ± 2% and the corresponding change in the output, the **T**otal **E**xpected **R**evenues, was observed. Two cases were considered. The best case scenario, which is the scenario generating the larger amount of expected revenues. This was identified by choosing for the calculations of the Remaining Capacity those that result from the Media Company Service, since it is the one with the highest pricing. The second case considered was the worst case scenario. This case accordingly resulted from the choice of Broadcast Service for the calculations of the expected revenues of the Remaining Capacity, which is the one with the lowest pricing. For each of these cases the calculations were extended to considering the upper limit and the lower limit of the **T**otal **E**xpected **R**evenues. A sensitivity analysis was performed for these 4 cases.

Using this small variation for each of the input parameters and for each case, we calculated 20 points of the output of the decision model, corresponding to different percentages of change of the input parameters between the ranges of ± 2% of the central value (table 5).

1	2,00%
2	1,80%
3	1,60%
4	1,40%
5	1,20%
6	1,00%
7	0,80%
8	0,60%
9	0,40%
10	0,20%
11	0,00%
12	-0,20%
13	-0,40%
14	-0,60%
15	-0,80%
16	-1,00%
17	-1,20%
18	-1,40%
19	-1,60%
20	-1,80%
21	-2,00%

Table 5: Points of percentage of difference of the input parameters

For each change of input, the change of the output was calculated. This change has the form of the percentage of difference of the value of the output calculated for each of the 20 points of change to the input, minus the value of the output at the central point (11th point, with zero alteration), normalized to this central value.

The bar charts of the sensitivity analysis for the best case scenario are shown in figures 6 to 25. For each of the 20 different input sets we calculated the output on the four most profitable scenarios. Scenario 1 is the scenario with the higher amount of **T**otal **E**xpected **R**evenues, Scenario 2 is the one with the second higher amount of **T**otal **E**xpected **R**evenues and so on.

7.1 Sensitivity Analysis of the Parameters of C Remaining

The sensitivity analysis on the Parameters of the Remaining Capacity is performed for the best case scenario.

The percentage of change in the output, for each point of change in the input parameter of *Probability of appearance of a customer (in 1 month) asking for each service (P_B)* for the Media Company Service is shown in figures 6 to 9.

Figure 7 shows no change since for the second scenario the Remaining Capacity is zero and thus the change of the corresponding probability (P_B) has no impact to the results.

The probability change (P_B) for the Media Company was implemented with analogous change to the probabilities of the other Services in order to maintain the summation of probabilities of all Services constant.

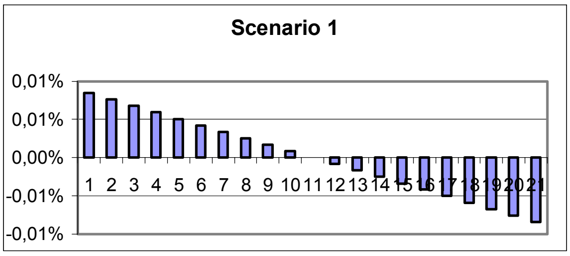

Figure 6: Sensitivity analysis of the parameter P_B, for Scenario 1

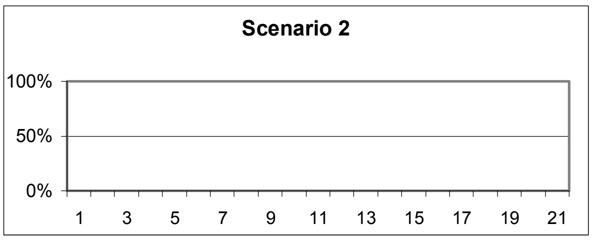

Figure 7: Sensitivity analysis of the parameter P_B, for Scenario 2

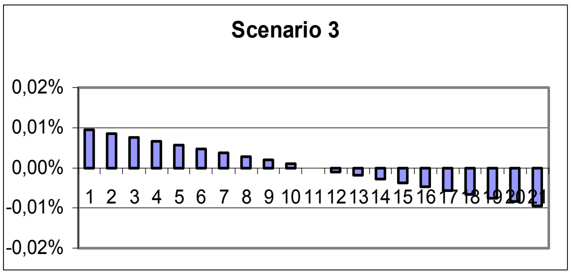

Figure 8: Sensitivity analysis of the parameter P_B, for Scenario 3

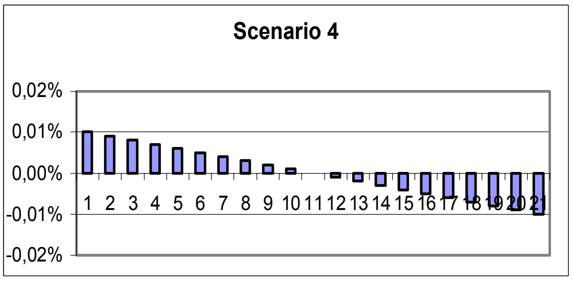

Figure 9: Sensitivity analysis of the parameter P_B, for Scenario 4

The percentage of change in the output, for each point of change in the input parameter of *Mean value Price/36 MHz/month* for the Media Company Service is shown in figures 10 to 13. Scenario 2 has not any remaining time so figure 11 shows no change.

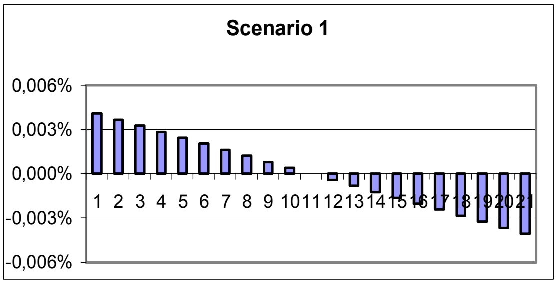

Figure 10: Sensitivity analysis of the parameter Mean value Price/36 MHz/month, for Scenario 1

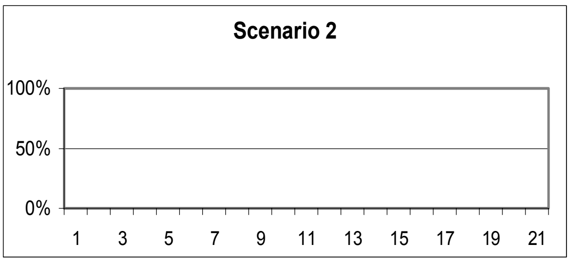

Figure 11: Sensitivity analysis of the parameter Mean value Price/36 MHz/month, for Scenario 2

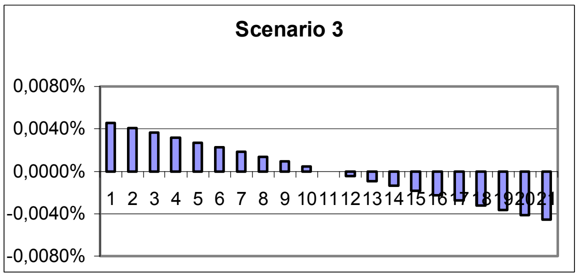

Figure 12: Sensitivity analysis of the parameter Mean value Price/36 MHz/month, for Scenario 3

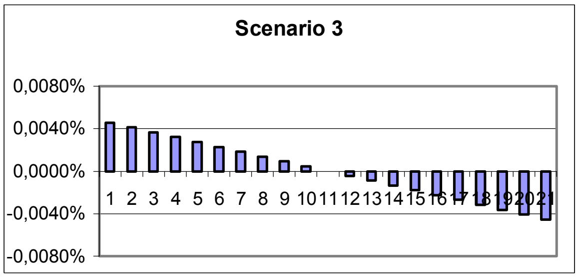

Figure 13: Sensitivity analysis of the parameter Mean value Price/36 MHz/month, for Scenario 4

7.2 Sensitivity Analysis of the Parameters of C Empty

The sensitivity analysis of the Parameters of the Empty Capacity is performed for the best case scenario.

The percentage of change in the output, for each point of change in the input parameter of *Probability of appearance of a customer (in 1 month) asking for each bandwidth (Pc)* for the case of Empty Bandwidth of 33 MHz, is shown in figures 14 to 17.

The probability change (P_C) for the specific Empty BW of 33 MHz was implemented with analogous changes to the probabilities of the other Services in order to maintain as constant the summation of probabilities of all Services.

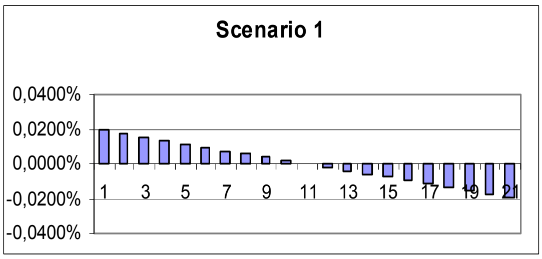

Figure 14: Sensitivity analysis of the parameter P_C, for Scenario 1

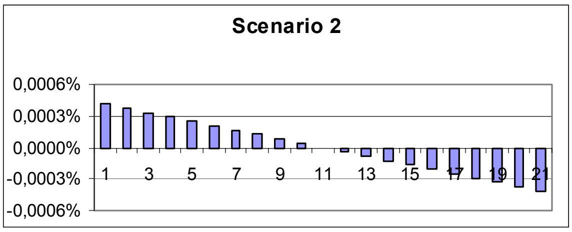

Figure 15: Sensitivity analysis of the parameter P_C, for Scenario 2

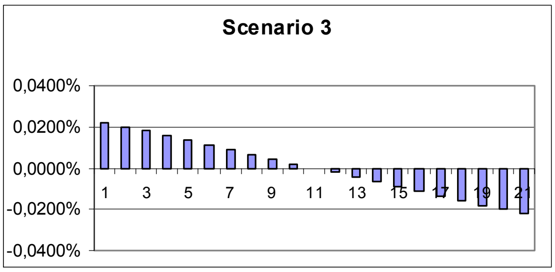

Figure 16: Sensitivity analysis of the parameter P_C, for Scenario 3

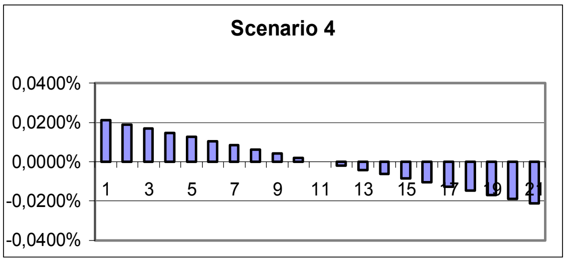

Figure 17: Sensitivity analysis of the parameter P_C, for Scenario 4

The percentage of change in the output, for each point of change in the input parameter of *Mean value Price/36MHz/month* is shown in figures 18 to 21.

Figure 19 is empty because there is not any Empty Capacity, thus the variation of the pricing parameter does not affect the output.

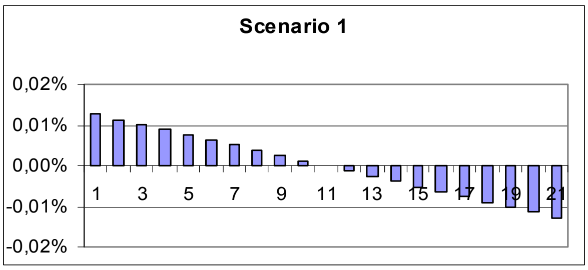

Figure 18: Sensitivity analysis of the parameter Mean value Price/MHz/month, for Scenario 1

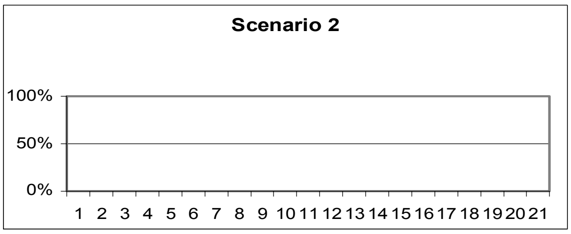

Figure 19: Sensitivity analysis of the parameter Mean value Price/MHz/month, for Scenario 2

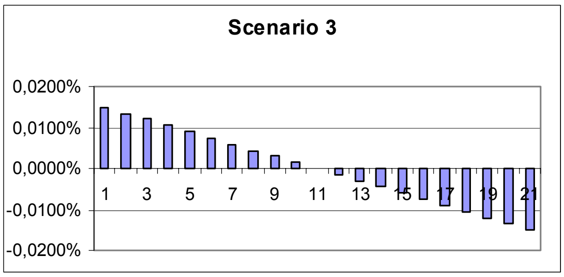

Figure 20: Sensitivity analysis of the parameter Mean value Price/MHz/month, for Scenario 3

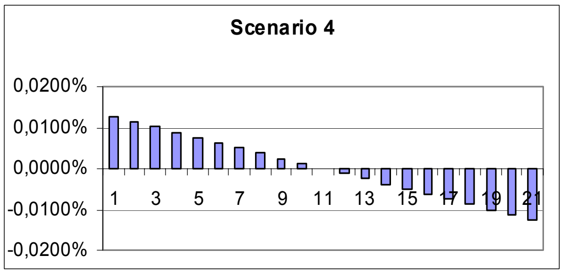

Figure 21: Sensitivity analysis of the parameter Mean value Price/MHz/month, for Scenario 4

7.3 Sensitivity Analysis of the Probability of appearance of a customer at the Satellite provider asking for satellite services (P_A).

The percentage of change in the output, for each point of change in the input parameter of *Probability of appearance of a customer at the Satellite provider asking for satellite services (P_A)* is shown in figures 22 to 25.

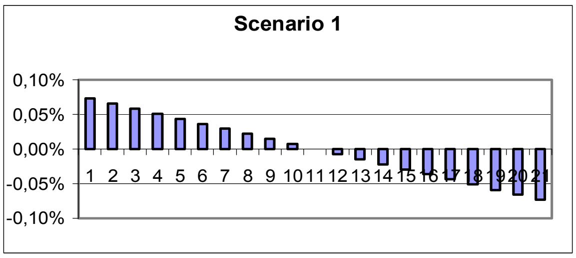

Figure 22: Sensitivity analysis of the parameter P_A, for Scenario 1

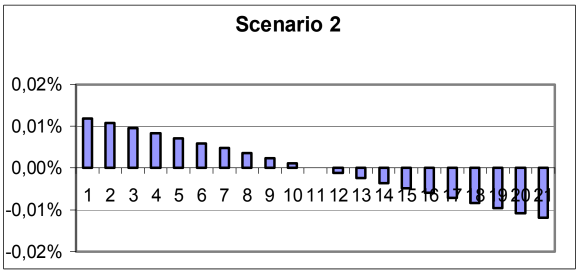

Figure 23: Sensitivity analysis of the parameter P_A, for Scenario 2

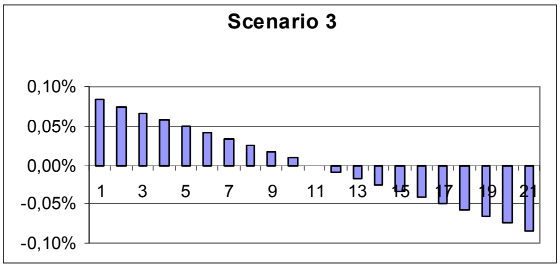

Figure 24: Sensitivity analysis of the parameter P_A, for Scenario 3

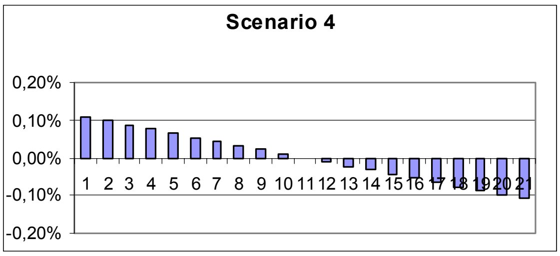

Figure 25: Sensitivity analysis of the parameter P_A, for Scenario 4

The calculations were made for all 46 input parameters, categorized as shown in tables 3 and 4, extended to all 4 cases. The most characteristic ones were presented. We considered changes to parameters from the data of the Remaining capacity, the Empty capacity along with the probability of appearance of a customer asking for satellite services. The results were shown similar. The analysis showed very low sensitivity of the output to changes in the input parameters. This means that a small change to the pricing and to the probability parameters will not significantly change the output of the model. This is a very desirable feature, resulting from the good balancing of the proposed model. Even if the parameter data are not exactly accurate the decision will not be affected.

8. CONCLUSIONS

A decision making model considering different customer demands for a satellite operator was created. This is a tool for an operator providing satellite services to determine the most profitable scenario and make decisions depending on the company policy. The sensitivity analysis showed a very small impact of the uncertainty of the input parameters on the final decision. This analysis could also be extended on simultaneous changes of several combinations of input parameters. Sensitivity analysis could also be performed not only in isolated parameters, but also by changing the value of two or more parameters at the same time and monitoring the output change. The effect of the correlated input parameter change, is an issue for future work.

The benefits of the model and of the analysis presented here for any satellite operator are clear. The same benefits may apply to relate areas of activity where leasing of specific volumes to customers is the essence of the business enterprise.

Finally, let us note that an extended version of the work presented in this paper, including all the mathematical details (discrete time stochastic dynamic programming formulation and solution) will be available in the forthcoming Phd Thesis of the first author, together with the related code.

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