At the proceedings of the Industrial Simulation Conference 2005, Fraunhofer Institute, Berlin, Germany, Jun 09-11

Using Simulation to Analyse the Procurement of Additives for Lubricants in the Oil Refinery of Porto, Portugal

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September 2004

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KEYWORDS: Simulation, Additives, Lubricants, Transport Echelons, Purchase Policy, Costs.

ABSTRACT

Data in this article results from a study of simulation about the procurement of additives for lubricants in the Oil Refinery of Porto (Portugal). Here we describe the real case under study as well as the method we have chosen to board it by means of simulation, which finally leaded us to some interesting results regarding the choices on purchasing the additives from the suppliers. Costs including transportation, holding and stockouts have been considered during the simulation as well as in the final conclusions, which let us recommend a more frequent reordering of materials at the lubricants plant. This we expect to result in the saving of around 0.3M€/year in global costs.

1. Introduction

This Oil Refinery (Fig. 1) is located in Leça da Palmeira, an important suburb of Porto, and is operating since 1970. Even if it already had been used with a processing capacity of 7.5 MTon of crude per year in 1975, since 1982 its capacity has been maintained in the 4.4 MTon/year, mainly due to the installation of a second refinery in the south of the country (GalpEnergia, 2003).

Fig. 1 View of the Refinery of Porto, Portugal

However, since its beginning the refinery included a Lubricants-Base Plant, which at the present has a producing capacity of 150 KTon/year, and where diverse kind of lubricants are produced to the industry and to the general market. The present study concerns with the procurement related with this plant, which is only a part of the refinery.

The study has been conducted with the kind participation of engineer Mr. José Carlos Fernandes, from *GalpEnergia*, the company responsible for the refinery, who at the time was in charge of the *Department of Logistics and Stock Management of Lubricants*. The main objective was to study in more detail the process of purchasing near 200 different additives for lubricant production, ordered from 10 different European suppliers, and with different transportation costs based on the quantity ordered. Notice that final lubricants normally include around 10% of additives. The Supply Chain in study was then a procurement network whose final node was this plant, as figure 2 illustrates, with the suppliers spreading from England to Spain.

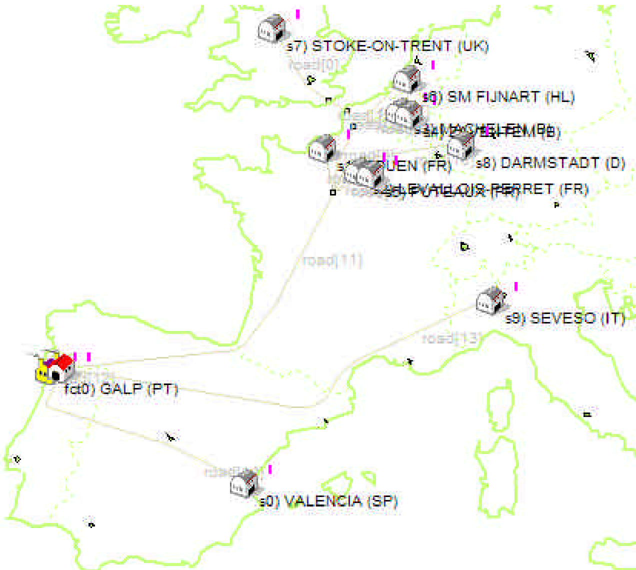

Fig. 2 The Supply Chain in study, with 10 European suppliers

The price due to the transport of one unit of product from each supplier to the plant was dependent on the supplier and on the quantity ordered, so, the primary intention was to seek for the quantity to order that would minimize theses costs at the plant's level. However, later we have opted to consider instead the costs of transportation, products, product holding and product stockouts, since total costs were considered a better financial measure to support practical decisions.

The case was also useful to help on the validation of a Supply Chain Simulator described in a previous article (Feliz-Teixeira & Brito, 2003), as well as to let us conclude about the methodology being used and about the sort of problems to face while modelling a real system of this kind.

2. The process of building the model

The first important aspect to have in mind when preparing to simulate a real system is to dominate the process of building the model, beginning by the simulation tool. The tool used here was developed in C++ during the Ph.D. studies of Feliz-Teixeira and it was specifically oriented to Supply Chain Simulation, being therefore prepared to represent in a very easy way the elements of this kind of systems. With this tool, to build the model could be reduced to the following 5 procedures:

(1) The representation of the facilities in the "theatre of operations": the facilities have been located in the simulation window without any special geographic precision, as that aspect was irrelevant to the present study. Anyhow, each facility was placed carefully enough to maintain a relative fidelity to its real location, with the help of a map previously drawn in the simulator window (see figure 2). To help on this, *GalpEnergia* has made available a document with the post addresses of the suppliers.

(2) The definition of the transport paths connecting the facilities: these paths have also been traced without great precision in the simulator window, as in this particular case the transport costs were already defined at each supplier by a list of prices per unit transported. In those transport costs the factor distance was already included. Anyhow, the transport paths traced on the simulator try to follow the most probable lines of delivery used by the suppliers, and serve to give an idea of the delivering times as well as to introduce extra variability on the supplier's lead-times. *GalpEnergia* has made available a document with the expected lead-time for each supplier.

(3) The definition and characterization of the products available to the system: this important step let us insert into the simulator, using a dialog like the one of figure 3, the first relevant information about the 195 different additives with which the plant usually works. Notice that, as it was considered the *product unit* (SKU) for all the products the standard barrel of 200 Kg, the maximum number of SKUs per truck (of 24000Kg) was assumed to be 120.

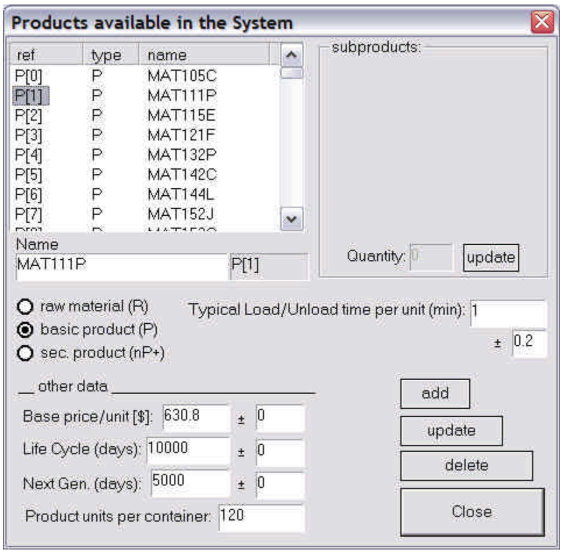

Fig. 3 Dialog Box to insert the products into the simulator

In each product one also included its reference-name and its base price (at the supplier's level), and this list was several times carefully inspected to ensure no mistakes were inserted in the simulation from the base. This data was primarily provided by *GalpEnergia* in the form of an EXCEL document, and directly retrieved from the plant's data base.

(4) The configuration of each facility, including the transport policy and the material's reorder model: once the system was geographically "represented" on the simulator and the available products inserted, the general configuration of each facility had to be established, including the definition of its transport cost policy and the material's reorder model.

In the first case, the suppliers have been configured to use *cost echelons of transport*, which were provided by *GalpEnergia* in the form of costs per Kg based on different ranges of weight, which then have been transformed to express the costs referred to the percentage of occupation on a truck of 24000Kg, considering each SKU a barrel of 200Kg. This data was assigned to the correspondent facility by means of a 5 echelon attribute filled in by the dialog shown in figure 4. The final transport cost of a certain order could therefore be automatically computed as long as its percentage of occupation in the truck was known. More than 100% occupation was made to incur in 10% extra costs, as many real suppliers establish.

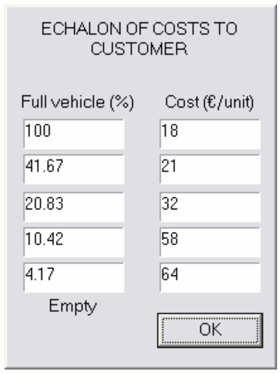

Fig. 4 Dialog Box to define the transport cost echelons

On the other hand, the definition of the material's reorder model and other information related with this aspect was inserted at each facility by means of a dialog like the one shown in figure 5. Each product was chosen to use the reorder model (r, Q), and then it was defined the amount of *safety-stock* and the *quantity to order*, as well as the *setup-cost*, the *Time for Full Satisfaction (TSF)*[1] and, finally, the *supplier*. This was done manually to the 195 products in the list, even if only 108 could be linked to a valid supplier and finally simulated. The suppliers were considered being supplied by perfect instantaneous delivering suppliers.

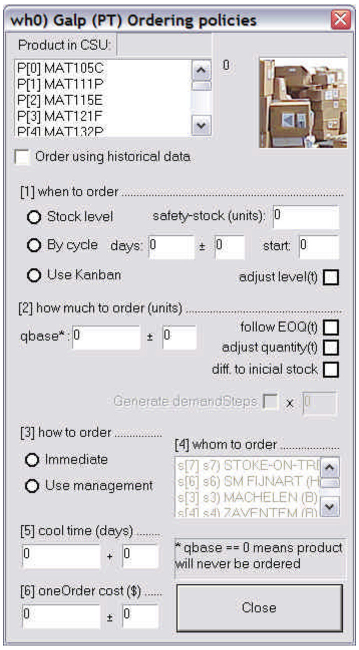

Fig. 5 Reordering Policy configuration

All the facilities were made to operate with an 11.5%/year *bank lending rate*, and null business *margin*, meaning that the purchase cost was only affected by the basic product cost and transport cost.

[1] This simulator uses this measure to retrieve a quantitative idea of clients "satisfaction", applying it not only to last customers but also to any facility in the supply chain. Once established the *Time for Full Satisfaction (TFS)*, any order arriving from the supplier within this delay will be considered 100% satisfaction, otherwise the satisfaction decreases proportionally to the extra time spent…

(5) The characterization of the demand at the plant: the demand information was obtained from documents of the real plant consume during the year of 2003. This data was a monthly historical record. Then, based on such data, two main approaches have been chosen to simulate the case:

1) *Inserting directly the historical demand into the simulator.*
2) *Using a* Normal *statistical approach of this historical data as the demand to insert in the simulator.*

Obviously, in the first case the demand had to be considered monthly, as it is in reality, but, in the second case, by means of the statistical approach, we also could "hint" the consume as if it would be sampled two in two weeks or even weekly. This let us compare results using different frequencies to sample the real demand. However, before inserting this information into the simulator it was needed to transform the 195 lines of original historical data, which were in Kg, into a monthly consume of barrels of 200Kg. Of course, this implied a rearrangement on de monthly demand pattern, as the old demand had to be integrated in time till reaching the amount of a new barrel. This work has been done with the help of a little C program developed to compute such demand transformations for all the 195 independent lines of historical data. Finally, as a result from this approach, we could create the following 4 basic scenarios to be simulated: *hist(30)*, which was driven by the original monthly demand, *stat(30)*, driven by the *Normal* statistic version of the monthly demand, *stat(15)*, considering the statistical demand sampled fortnightly, and *stat(7)* representing the statistical demand sampled weekly. These basic scenarios could later be compared by simulation, each one tested under the 5 different *transport cost echelons* previously considered.

3. Model validation and corrective factors

The simulation process has been planned to help us on reaching two main objectives: first, the confirmation of the validity of the results obtained with the simulator, at least for the present case; and, second, the studying of different approaches to purchase the products, considering the 5 different *transport cost echelons* with which the suppliers operated. This section relates with the first process, that is, the model validation.

The process of validation was restricted to the fact we only had access to documents about the monthly *plant's consume*, *average cost of each product* and *actual inventory level* at the plant's warehouse. From these values we could calculate the *average plant consume* as well as the *accumulated plant consume*, the *accumulated costs of products* and the *average inventory level at the plant's warehouse*, regarding the activity on the year of 2003. These were the 4 realistic parameters with which we later could compare the simulation output in order to validate the model. The following "real" data have been retrieved from documentation based on the 108 products that definitely could be simulated (the others had no assigned a valid supplier inside the network in study):

- Average[2] inventory in 2003 (barrels) = 2484.8
- Average plant consume in 2003 (barrels) = 477.7
- Accumulated plant consume in 2003 (barrels) = 5731.8
- Accumulated costs of products in 2003 (K€) = 2835.3

With the intention to compare this data (*Rj*) with the simulator output data (*Sj*), each of the 4 basic scenarios previously referred was made to run for one year of simulated operations, considering null the transport costs. In each case the results were obtained in the form represented in the next two figures (Figs. 6 and 7), where from data could then be obtained to fill table 1. Notice that the *accumulated cost of products* was considered the *purchasing costs* plus the *stockout costs* (as the unit stockout cost was simply made equivalent to the product cost in this model).

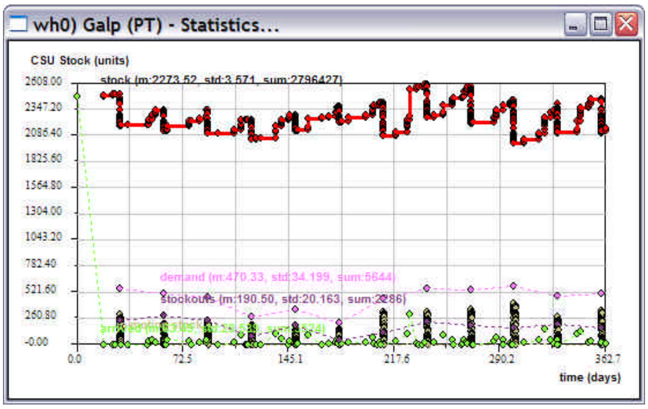

Fig. 6 First view on the inventory level and demand achieved by simulating the scenario *hist(30)* for one year of operations

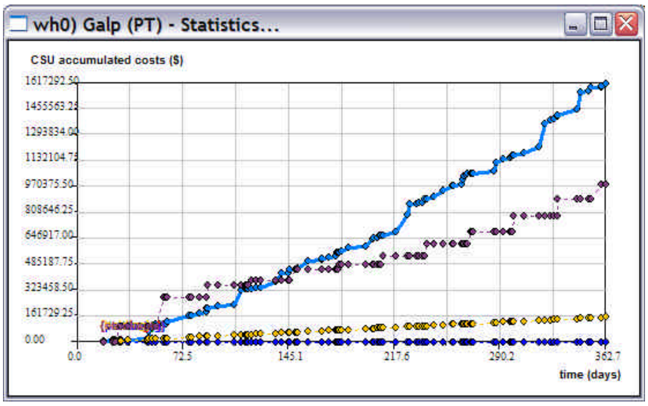

Fig. 7 Accumulated costs obtained by simulating the scenario *hist(30)*, where purchase, stockout and holding costs are represented

	hist(30)	*stat(30)*	*stat(15)*	*stat(7)*
avrg inventory level (barrel)	2273.5	2069.9	2067.1	2096.1
avrg consume (barrel)	470.3	495.2	184.8	70.1
acc consume (barrel)	5644	6437	5358	4607
acc costs of products (K€)	2771.1	2984.9	2491.6	2089.8

Table 1 First results achieved by simulation, for comparing with real data

From the data of this table (*Sj*) and the real data (*Rj*) another table was built (table 2) in which the percent deviations in relation to the real values could be estimated, applying the formula:

$$dev\% = 100\ (Rj - Sj)/Rj \qquad (1)$$

[2] Not really averaged, but instead estimated as the stock level in June 2004

	hist(30)	*stat(30)*	*stat(15)*	*stat(7)*
avrg[3] inventory level (%)	-8.5	-16.7	-16.8	-15.6
avrg consume (%)	-1.5	3.7	-61.3*	-85.3*
acc consume (%)	**-1.5**	**12.3**	**-6.5**	**-19.6**
acc costs of products (%)	**-2.3**	**5.3**	**-12.1**	**-26.3**

Table 2 Estimated deviations between simulated data and real data

Based on these results we could already make some idea on what to expect from future deviations in each scenario. Actually, from this we could conclude to expect a deviation from the real values of less than 3% in the *hist(30)* scenario (what can already provide a validation for the model), as well as expect that the *stat(30)* scenario will inflate the results, while the *stat(15)* and *stat(7)* will deflate them. Consequently, a corrective factor must be applied to each of these scenarios in order that in the end their results can be compared in terms of the same scale of measures. Thinking on *Kj* as the factor by which each parameter must be multiplied to approach its "real" value, we simply have decided to calculate it from the expression:

$$Kj = \text{Average}(Rj/Sj) \qquad (2)$$

Where the *Average()* function was applied only to the accumulated values, since they are considered to be more reliable for validation than simple values, as they act like the *summation of control* used in spreadsheets. By means of such calculations, the following corrective factors have been found:

hist(30)	stat(30)	stat(15)	stat(7)
K_1	K_2	K_3	K_4
1.02	**0.92**	**1.10**	**1.30**

Table 3 Corrective factors for the different scenarios

Which later have been applied to the preliminary results.

4. The simulation's strategy

As the main objective of this study was to find the best purchasing approach based on the *transport echelons* established by suppliers, each scenario have been simulated according to seven different product occupation levels in a truck of 24000Kg. Each level was indirectly establishing the *minimal order quantity* to purchase to the supplier in each particular *order*, as each product quantity on that *order* was increased with steps of 1 unit (SKU) till the entire *order* reached the level's "mark". Notice that the same order can contain several products. Thus, these occupation levels were in fact forcing the *minimal truck occupation* to a certain predefined value. Anyhow, in the same simulation the predefined level was maintained the same for all the suppliers in the network, and not different levels to different suppliers were considered. The following truck occupation levels were tested in the study:

MinOccupLevel = 0%, 4%, 8%, 16%, 32%, 64% and *100%.*

Once the 0% level was chosen, the scenario was made to run during 365 days of simulated operations, along five replications, before data was collected. Then, the new level was chosen and the same process was repeated till the last level (full truck) was simulated. This was done for each of the scenarios in study. Results like those shown in figure 8 were obtained with the simulation of each scenario.

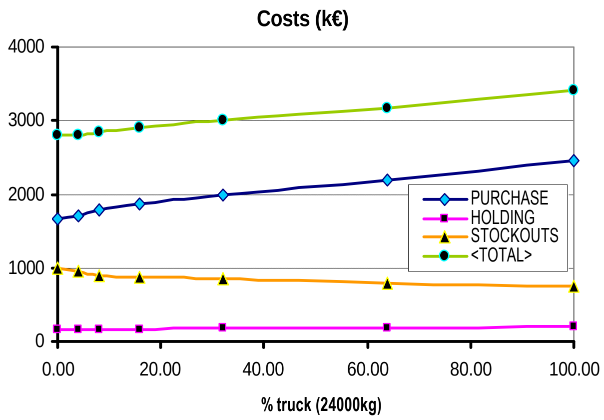

Fig. 8 Variation of costs with different truck minimal occupation levels, obtained by simulating the scenario *hist(30)*

From this graph, the <u>*best occupation level*</u> was chosen as the one which minimized the total costs, which in this case corresponds to 0%, meaning the best option is to purchase exactly what the inventory model requests without worrying about any transportation effects.

Along with these results, also the *average inventory* level was calculated and plotted graphically, as the example of figure 9 shows for the case of scenario *hist(30)*.

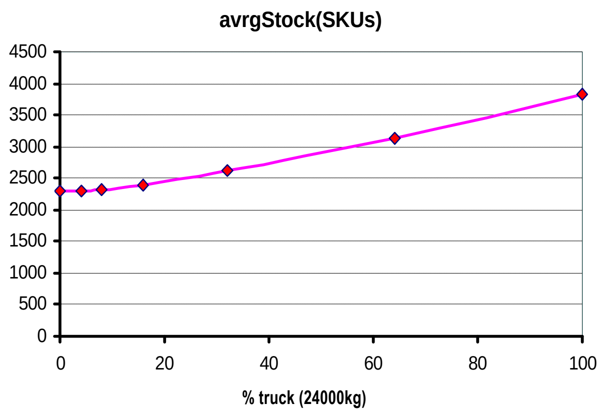

Fig. 9 Variation of average inventory level at the plant's warehouse with different truck minimal occupation levels, obtained with scenario *hist(30)*

And, finally, also the average values and variations observed during simulation on the plant's warehouse performance were computed, in terms of some standard logistic metrics (fig. 10), in this case mainly focused on the *variable costs*, *turnover*[4], *service*

[3] Only used as a qualitative measure

* Notice that increasing the demand sampling rate implies a decreasing on the average demand. These values have no special interest for the model validation.

[4] The *turnover* was computed here like in a single product inventory, thus there will be a quite difference from the value one expects from practice

level and *stockout ratio*. This way one could record the behaviour of each measure along the entire spectre of purchasing policies. For example, from this panel one can expect to observe, along these seven different policies, an average value for *service level* of 66.2% with a variation extending from 50.8% to 76.8%.

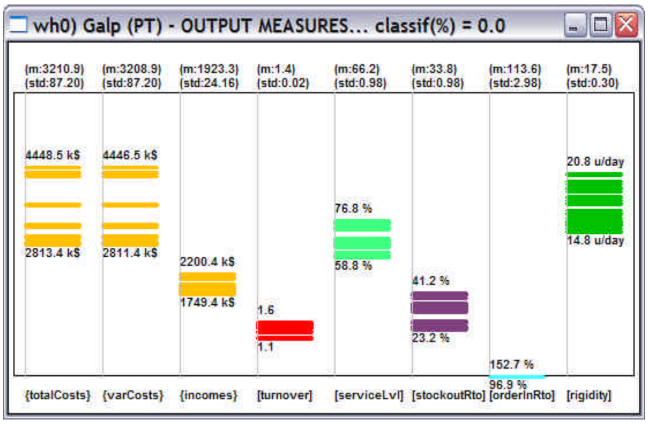

Fig. 10 Plant's warehouse performance obtained with scenario *hist(30)* along the entire spectre of purchasing policies (total runs = 30)

The *best results* obtained with each scenario were then chosen, and this data organized per scenario and joined together in a new table. Finally, the respective corrective factors (*Kj*) were applied to this table and the *final results* obtained, which will be presented in the next section.

Before passing to the next section, however, it is important to make noticed that also the following conditions were considered in the models:

- *BusinessMargin* = 0 at all the facilities, meaning the costs of the products were precisely the same as provided by *GalpEnergia*.
- *No Backorders*.
- *PurchasingCosts* = *ProductCosts* + *TransportCosts*.
- *BankLendingRate* = 11.5 %/year.
- Transportation always available at the suppliers, no need to wait for the arrival of a truck.
- *OrderSetupCosts* = 0, because they were in practice almost null in comparison with the products costs.
- *TimeForFullSatisfaction (TFS)* at the plant was considered 3 ± 0.5 days (indirectly rules the *stockout ratio*)
- *TimeForFullSatisfaction (TFS)* at the plant's warehouse was considered 30 ± 3 days.
- Reorder model *(r=ro, q = Q(t))*, with *ro* the actual safety stock and *Q(t)* to follow the maximum between *average demand* and the *accumulated demand between supplies*.

5. Final results and comments

The four basic scenarios were operating with the inventory model *(r=ro, Q(t))*, as previously referred. Anyhow, to let us test this model with other values, after each of these scenarios has been simulated the *average demand* during the 365 days of operations was computed, as well as the *accumulated demand between supplies*. Then, the original scenario was copied into a new scenario on which a change would be made in the inventory model: *ro* was replaced by this *average demand* and *Q* was substituted by the *accumulated demand between supplies*. Then, the scenario was also simulated. For this reason, the final simulated scenarios became the following eight:

1) *hist(30)* – original historical data, model (r=ro, Q(t)).
2) *hist(30)_ss_qq* – historical data, model (r=avrgDem, Q=accDemSuppl)
3) *stat(30)* – statistical data, model (r=ro, Q(t)).
4) *stat(30)_ss_qq* – statistical data, model (r=avrgDem, Q=accDemSuppl)
5) *stat(15)* – statistical data, model (r=ro, Q(t)).
6) *stat(15)_ss_qq* – statistical data, model (r=avrgDem, Q=accDemSuppl)
7) *stat(7)* – statistical data, model (r=ro, Q(t)).
8) *stat(7)_ss_qq* – statistical data, model (r=avrgDem, Q=accDemSuppl)

And the graph presented in figure 11 shows the results before correction obtained precisely with these scenarios, numbered from 1 to 8, considering their *best occupation level*.

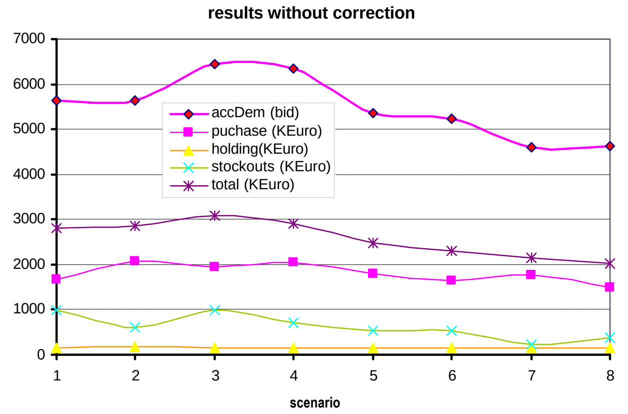

Fig. 11 Results before applying the corrective factors

From this figure the behaviour predicted earlier is now evident. As expected, *stat(30)* scenario inflates the results, while *stat(15)* and *stat(7)* scenarios deflate them. Much of this is a consequence from the slightly differences at the demand generated pattern that accumulate along the 365 days of operations, as also can be noticed from the figure. The upper line represents, in fact, this *accumulated demand*, which ideally should be a horizontal line. It is thus obvious that no conclusions could be retrieved from this data before applying the corrective factors. Doing so, we finally obtain the following costs figure:

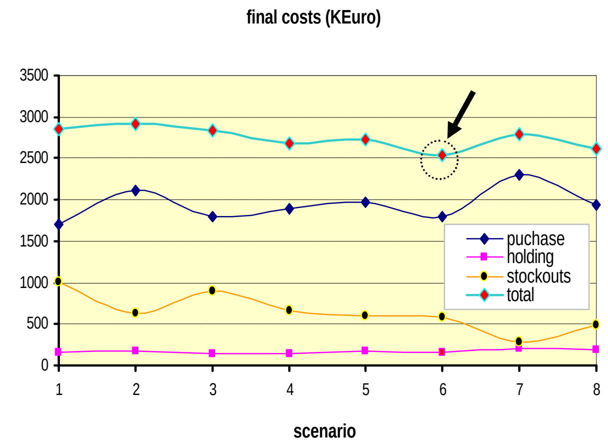

Fig. 12 Final results, concerning accumulated cost during a year

Notice that if this correction would not be applied we could have been induced in mistake by choosing the *stat(7)* scenario as the most interesting option on the preliminary results. In fact, the most interesting is scenario 6, known as *stat(15)_ss_qq*, since it obviously leaded to the minimal total costs accumulated along the year. Compared with the actual situation, this would mean a save of around 300 K€, measured by the figure. As it was also observed that the *best truck occupation level* for this scenario was 8%, one can finally conclude:

"The best approach to operate the plant's warehouse would be to ensure a fortnightly inspection of its inventory and, once operating with the inventory model (ro, Qo), to set ro as the average demand (at each product) and Qo the respective expected accumulated demand between supplies, not forgetting to order always at least 8% of a truck. The total expected saves would be around 300 K€ in one year of operation".

IMPORTANT REMARK: One must not forget that these results have been obtained considering only 108 of the 195 products previously inserted in the simulator, which would represented a more realistic view on the plant's demand.

6. CONCLUSIONS

Any conclusions must count with this last remark. Only those products which could be linked to the list of suppliers considered in these models have been simulated. Consequently, the results presented here will obviously express this fact, meaning that the conditions of their validity do not reflect the overall plant's demand and, probably, they will not fit perfectly with those obtained in practice. Anyhow, they seem consistent and quite interesting, as they confirm important values previously calculated from real data, and seem to point to a higher frequency on inventory revision with the objective of reducing total costs, a trend of nowadays on trying to minimize forecast inaccuracies. Actually, it is in general more difficult to forecast for a long period of time that for a shorter one, at least when the demand is "well behaved" like in the present case.

What concerns the original objective of analyzing the costs variations with the different *echelons of transport*, it was observed that in all the scenarios except the *stat(15)_ss_qq* the best approach was the 0% *minimal truck occupation*, meaning it was to purchase exactly what the inventory model would request without worrying with any transportation effects. For that reason this problem was naturally absorbed by the problem of sampling the demand with different rates, which during the simulation was getting more relevancy than the former issue. This was due to the fact that in most of the cases the original truck occupation was already naturally high, as figure 13 shows for the case of *hist(30)* scenario, with an average value between 30 and 60 %. Lower levels of occupation were thus automatically "ignored" by the simulation, turning this issue less relevant.

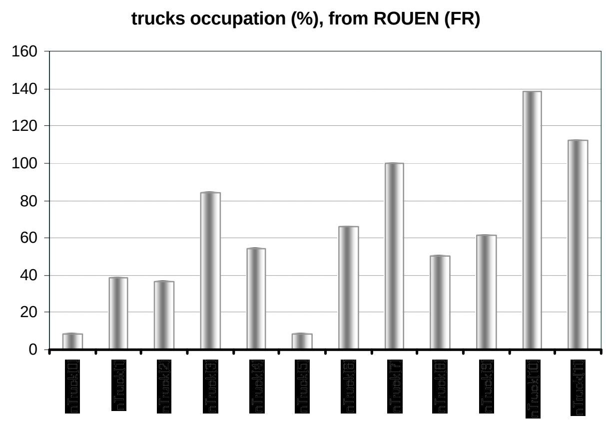

Fig. 13 Original truck occupation in the *hist(30)* scenario

In respect to the methodology, it appeared to be firm and good, and leading to an interesting way not only of validating the model but also of making possible the comparison of different scenarios by means of applying some *corrective factors*. Also the verification of certain aspects of the simulator could be done, because with this study some "bugs" were detected in its software and later repaired, mainly in the procedures for computing the *holding* and the *purchasing* costs.

The most important issue, however, in what concerns a more serious study of this plant, is related with the fact that not all the important products on the real demand could be simulated and that for sure implied a deviation on the results from real data. As shown in figure 14, it was observed that some of the products were extremely expensive and other relatively cheep, but not all of those expensive ones could be simulated in this study. From this figure one can also get an idea of the probable deviation that could have been committed in this approach because of this problem.

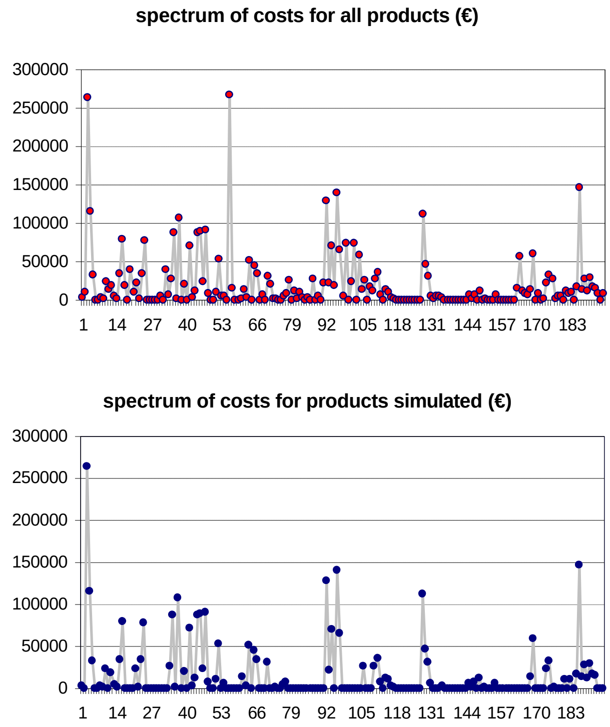

Fig. 14 Comparison of costs involving all the 195 products in the plant and the 108 simulated products

It seems obvious that for future studies first we will have to ensure that the most economical significant products will be represented and turned able to be simulated. In order to improve the simulation of this interesting case, we would in the future need to focus the attention in the following main aspects:

- Ensure the simulation of all A type and B type products.
- Improve the statistical demand generator, maybe.
- Count with more costs: stocking, order setup, etc.

We hope that a more accurate study on this case can be completed in the future, perhaps following the careful analysis of these results that at the present is being made at *GalpEnergia*,

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