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SUPPLY CHAIN ANALYSIS: SPREADSHEET OR SIMULATION?

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ABSTRACT

In the last few decades, a lot of company effort has been spent in the optimization of internal efficiency, aiming at cost reduction and competitiveness. Especially over the last decade, there has been a consensus that not only the company, but the whole supply chain in which it fits, is responsible for the success or failure of any business. Therefore, supply chain analysis tools and methodologies have become more and more important. From all tools, spreadsheets are by far the most widely used technique for scenario analysis. Other techniques such as optimization, simulation or both (simulation-optimization) are alternatives for in-depth analysis. While spreadsheet-based analysis is mainly a static-deterministic approach, simulation is a dynamic-stochastic tool. The purpose of this paper is to compare spreadsheet-based and simulation-based tools showing the impacts of using these two different approaches on the analysis of a real (yet simplified) supply chain case study.

1 INTRODUCTION

The term "Supply Chain" can be broadly defined as a series of steps and operations (procurement, production, inventory, transportation) that transforms raw materials into consumable products at the customer site. A well-performed study of a company's supply chain is of vital importance for its success, since companies no longer compete alone. So the battle for the markets nowadays is among supply chains - see Archibald et al (1999).

Supply chain studies can be performed at different stages of a company and with different time horizons: strategic studies for a time horizon of one year and beyond; tactical studies for analyzing months; and operational studies for analyzing what is occurring during a very short period of time (e.g., days). For a detailed discussion refer to Ballou (1992).

There are several methods for analyzing and evaluating supply chains. Utilizing Harrel and Tumay's terminology (Harrel and Tumay 1994), these can be classified into two basic categories: methods for solution evaluation and methods for solution generation. The first category will, as the name indicates, evaluate the possible configurations of a supply chain design in a "What-If" scenario. The second category will generate the best configuration for a given objective or set of objectives. In the first group, spreadsheet-based analysis and Simulation (discrete event and systems dynamics simulation) are perhaps the most frequent occurrences, while the other group includes techniques such as Classical Optimization Methods (e.g., . Integer and Dynamic Programming) and Simulation Optimization. This classification is depicted in figure 1.

Despite Spreadsheet-based Analysis not being cited as a "formal" method for analyzing a supply chain by several authors, it's here for a simple reason: it is the most used method in practice.

The scope of this paper is to compare two evaluative methods for supply chain analysis: Discrete Event Simulation and Spreadsheet-based Analysis. Hence generative methods will not be covered here. The reader should refer to Bagchi et. al (1998), Ingalls (1998), Hicks (1999a) and Schunk and Plott (2000) for details on classical optimization methods and simulation optimization for the analysis of supply chains. It is interesting to note that the four-step methodology created by Hicks (1999b) considers the utilization of 3 techniques cited above in the supply chain planning (Classical Optimization Methods, Discrete Event Simulation and Simulation-Optimization). Anderson and Morrice (1999) investigate supply chain behavior utilizing a System Dynamic Approach - see Forrester (1958). However this approach is only suitable for the analysis of strategic supply chain issues, since it does not enter into operations in detail, serving as a macro-level approach (Mak 1992).

METHODS FOR SUPPLY CHAIN ANALYSIS

- **EVALUATIVE METHODS**
  - **Spreadsheet-based Analysis**
  - **Simulation**
    - **Discrete Event Simulation**
    - **System Dynamics Simulation**
- **GENERATIVE METHODS**
  - **Classical Optimization Methods**
  - **Simulation Optimization**

Figure 1: Methods for Supply Chain Analysis

The text in this paper is organized as follows: Section 2 provides some characteristics of both Discrete Event Simulation and Spreadsheet-based Analysis and raises a discussion on the sub-utilization of simulation methods; section 3 describes a real supply chain case that served us as test bed; sections 4 and 5 describe respectively the Spreadsheet-based Analysis and Discrete Event Simulation approaches applied to the case study; and, finally, section 6 makes the summary and conclusions.

2 SPREADSHEET VERSUS SIMULATION

In the previous section we cited several techniques or methods for the purpose of supply chain analysis. However none of them were formally defined. Spreadsheet-based Analysis could be interpreted as an automation of calculations on supply chain data in order to analyze supply chains. These calculations are performed mainly with the aid of spreadsheets and therefore are static (i.e., do not take into account the variation of time, except for fixed time periods – days, months or years). They are also deterministic (do not take into account the variability of the parameters) in their nature. It is possible, however, to perform stochastic modeling using software tools like @RISK (Winston 1996). These kind of tools "transforms" a deterministic spreadsheet into a stochastic ones allowing us to describe random variables with the probability profile (or "risk") associated with them. In this case, calculations now are performed with random variables. Despite this possibility, this kind of analysis is still static and only process simulation will take into consideration both stochastic and dynamic aspects of a supply chain.

A supply chain simulation could be understood as the process of creating a supply chain model and experimenting with it in order to find an acceptable configuration or policy. It is dynamic and stochastic in its nature.

As mentioned before, the value of simulating a supply chain resides in the fact of taking into account both stochastic and dynamic behavior. According to Schunk and Plott, 2000: "Simulation is one of the best means for analyzing supply chains because of its capability for handling variability" and "One of the great strengths of simulation modeling is the ability to model and analyze the dynamical behavior of a system. This makes simulation an ideal tool for analyzing supply chains because supply chains can exhibit very complex dynamical behavior" (Anderson and Morrice 1999).

Since simulation is a very applicable tool to analyze supply chains then why is its application not so frequent? In a 1996 paper, Kalansky argued that the increase of computing power and affordability would enable uses of these technologies (simulation), and static and deterministic methods would be discarded. Only five years from this envision, computer power has multiplied by 10, but static and deterministic methods still rule.

If computational power is not the problem for the application of supply chain simulation, which factors are determining the current situation? Some authors also blame the difficulty of obtaining data for simulating supply chains and the complexity of a supply chain modeling. In fact according to Ingalls and Kasales (1999), simulating a supply chain can be very complex because a model must mimic several key processes.

Since simulation is a more complex approach, it is natural to tend to avoid it and to adopt other "quick and dirty" techniques such as Spreadsheet-based Analysis. In our point of view, one major cause for not applying simulation is the misunderstandings of the variable's random nature. In fact "a basic understanding of the random nature of demand and the supply chain dynamics is needed before a decision-maker can interpret the results given by simulation" (Hieta 1998).

One of the reasons for writing this paper is to show that variability (especially on the demand side) could highly affect the supply chain performance, and if one adopts the static and deterministic approach, in certain circumstances, this could lead to distorted results. Consequently, in the next sections we will be demonstrating a supply chain case study that we are going to analyze with spreadsheet (Excel) and with a Supply Chain simulation tool (Supply Chain Guru).

3 CASE STUDY

The case study we are going to present here is from one of the largest aluminum processing companies in Brazil

(Camargo 1992). Because of data confidentiality and for simplification purposes, a simplified case is presented.

The company business is sourcing, production and distribution of aluminum roofing, used in several applications such as coverage of warehouses, hangars, gas stations and small industries structures.

The structure of the Supply Chain is the following: there are two locations mining raw material (bauxite) for aluminum roofs. The bauxite is transported to the manufacturing plant, which transforms them into the final product (aluminum roof) through lamination and conformation processes. These products are shipped to 16 distribution centers strategically located in Brazil in order to sell the roof to resellers and then reach final customers. This supply chain structure is depicted in figure 2.

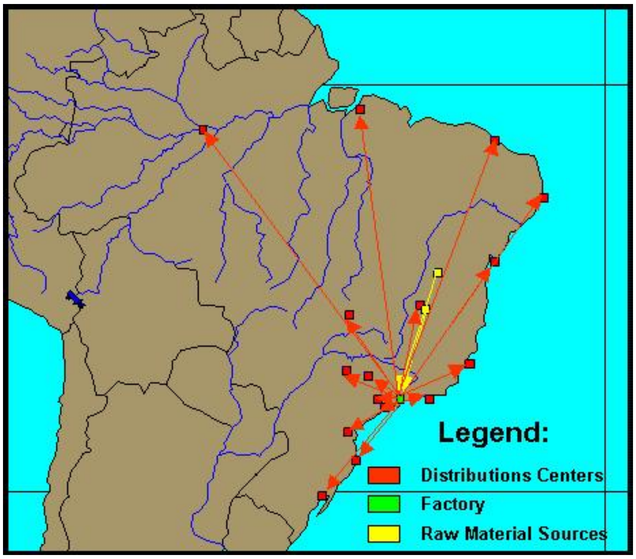


Figure 2: Case Study Supply Chain Structure

There are several kinds of roofs (according to thickness, length and format), but for the sake of this study we will consider an aggregate product "aluminum roof". The monthly average demand for this product is shown on table 1 (column 2).

The inventory policy for the distribution centers is an order-up-to-replenishment system. The period for revision is one month. So in this case, the request for re-supply will always be an amount that completes the target maximum inventory level for each site.

All chain transportation is via highways and the transportation policy for finished products is LTL ("Less then Truck Load") i.e., shipment does not "wait" to complete a full load and is dispatched immediately. Since the distance of the distribution centers varies drastically from the factory (see figure 2), a shipment can take 2 or 3 days to nearer regions or even almost 2 weeks in case of distant points. Table 1 (column 3) shows the average transportation times from the factory to the distribution centers including the time needed to process transportation papers required by legislation. Shipment is made on a monthly basis, starting from the factory at the end of each month.

Table 1: Monthly Average Demand for Each Distribution Center and Average Transportation Times

Distrib. Centers	Monthly Demand (tons)	Transportation Times (days)
CTB	30	2.5
PAL	35	3.5
REC	29	7.0
RJ	30	2.5
GO	18	3.5
BEL	23	7.5
MAN	14	14.5
FTZ	19	7.0
FLO	12	3.0
VIT	14	4.0
BH	11	3.5
SJRP	14	2.5
SLV	11	4.0
SP	15	2.5
RIB	12	2.5
CAMP	9	2.5
Total	**296**	

The factory has a monthly capacity to produce 630 tons. It holds also some safety stock to prevent product shortage from production problems. Looking at the total demand (table 1), it can be seen there are no capacity constraints.

The price per ton of the finished product is USD 2,720 and the total cost is USD 2,090 per ton (including the cost of bauxite considered in this case as USD 1,300 per ton).

4 SPREADSHEET-BASED APPROACH

Using the data provided in the previous section, a scenario configuration was built using an Excel Spreadsheet. The aim is to determine Supply Chain Costs, Revenues and Total Margin, based on the given deterministic demand. Results of this analysis are shown in appendix A for a one-year period.

The inventory policy is still our order-up-to-replenishment system with monthly periodic revision and maximum level of stock calculated as described. The maximum stock level for each site was calculated considering the monthly demand and transportation times. For instance, if the monthly demand is 30 tons for a specific distribution center and the transportation time is ½ month from the source than the maximum "flat" stock will be set to 30+15 = 45. A safety stock policy was also adopted, calculated with the aid of a safety factor relative to demand and a safety factor of transportation times (to take into account possible "fluctuations" on the demand and transportation times). We adopted a 10% level of safety factor, so in our example the safety stock will be 30x10% + 15x10% = 4.5 tons. Hence the maximum stock will be set to 45+4.5=49.5.

Based on this monthly demand (which is assumed constant for the rest of the year), unit production costs and unit transportation costs, the total costs of the chain, were calculated. Having the revenue per unit and monthly demands, the total revenue of the chain was calculated. The total yearly margin, considered simply as the difference between revenues and costs, was also determined. For simplicity, the effect of taxes on the financial performance of the chain was not included. For the same simplicity reason, handling costs at distribution centers were considered fixed and were not computed in the calculations. Table 2 summarizes the financial results obtained by this analysis. So the real net margin could be calculated by deducting the taxes and handling costs.

This form of analysis considers infinite capacity and therefore, stock levels can be calculated from the demand, presupposing no shortage or lack of products. In other words, all requested products are sold and delivered.

This ideal scenario could be different if the demands or transportation times varies. This is what will be shown in next section, i.e., this analysis is now made by means of discrete event simulation.

Table 2: Summarized Financial Performance of the Case Study by Spreadsheet-based Analysis

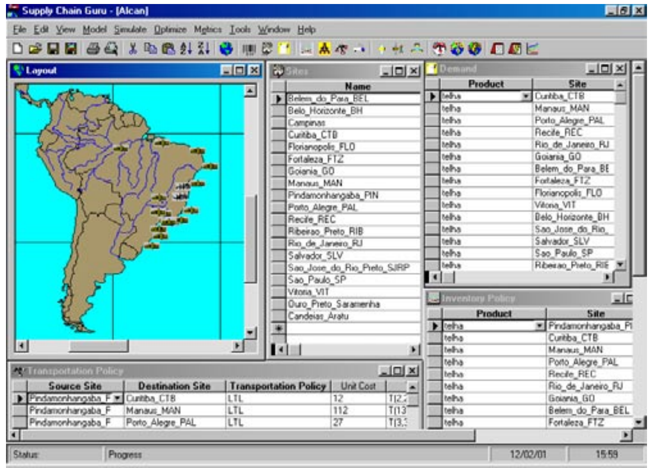
	USD/ Year
Total Revenues	**9,790,259**
Total Production Costs	**7,522,662**
Transpo. Costs	**167,577**
Total Margin	**2,100,020**

5 DISCRETE EVENT SIMULATION APPROACH

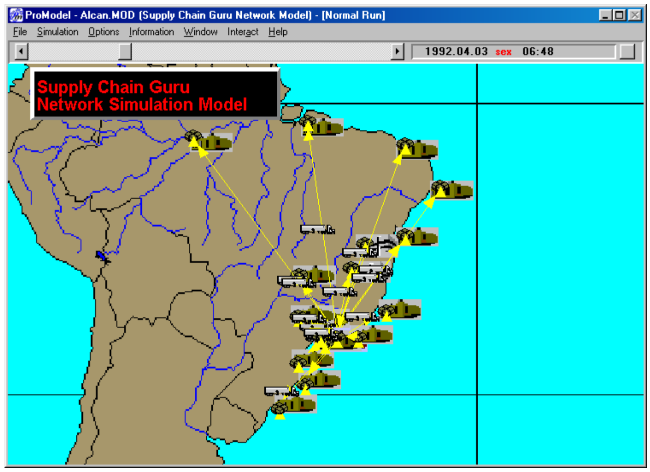
For this analysis a supply chain simulator "Supply Chain Guru" version 1 was used. Supply Chain Guru is a software that enables the input of the data from the supply chain in Access type Spreadsheets (like demand, inventory policies, transportation policies, etc). Then it automatically generates a model in Promodel Simulation Software language, and gets the results from its runs. For a more detailed description on Supply Chain Guru, see Hicks (1999a). Figure 3 shows some screen shots of this software for our case study. Figure 3 (a) shows some of the input data, figure 3 (b) shows the simulation model running and figure 3 (c) shows some results from the simulations runs.

The stock quantities (considering all the "safety factors") calculated by the static approach were fed into the model. All simulations were run for a one year simulated time period and all stocks were initialized in such a way as to mitigate initialization bias.

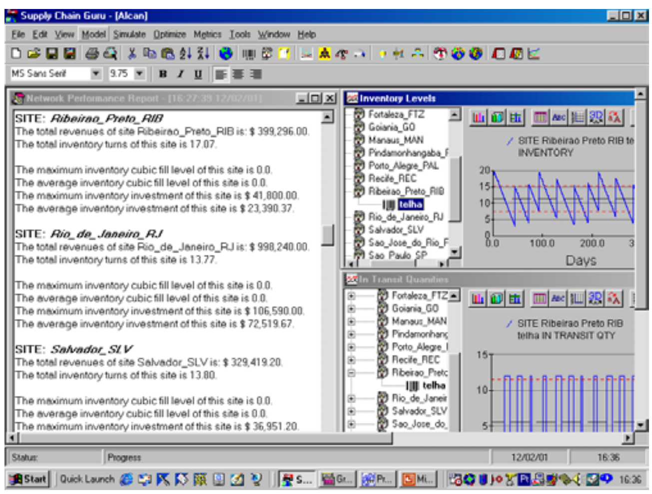
In order to compare the simulation results with the Spreadsheet-based Analysis, a deterministic simulation was performed. The result of the simulation run deviated less than 1% (probably due to round and trunc's operations) and is shown on table 3. In addition, a 1-year period



(a)



(b)



(c)

Figure 3: Some Supply Chain Guru's Screen Shots of the case study

was considered. The next step was to study the financial performance of the chain introducing some variability.

Variability was introduced into the chain by two means: variability of the demand and variability of transportation times. In the first case it was considered that the monthly demand was normally distributed with the same mean as the deterministic value with a standard deviation of 15% to the mean (hence the coefficient of variation defined by the ratio of the standard deviation to the mean is 0.15). In this case, its real value fluctuates around the mean, and the higher the coefficient of variation, the higher the fluctuations levels. In order to illustrate the fluctuation of demand, figure 4 shows an example of normally distributed demands (with average of 100) and standard deviations of 15%, 30% and 45% to the mean (c.v = 0.15, 0.3 and 0.45 respectively).

Table 3: Summarized Financial Performance of the Case Study by Simulation with Deterministic Values

	Simulation (deterministic)
Total Revenues	9,818,792
Production Costs	7,524,000
Transpo. Costs	166,038
Total Margin	2,128,754
Deviation (Static)	1%

For the transportation times two configurations were considered, with and without including fleet breakdowns and other problems that could increase the delay of the transport from the factory to the distribution centers. In both cases transportation times were modeled by a triangular distribution, with the difference that, in the case of breakdowns, the upper limit of the distribution was altered. Table 4 shows these parameters for the triangular distributions for each site.

Backorders were not allowed in this model. This means that if any retailer intends to buy aluminum roofing from the distribution centers and it is not available at that moment, the order is canceled and the sale is lost, reducing the revenue.

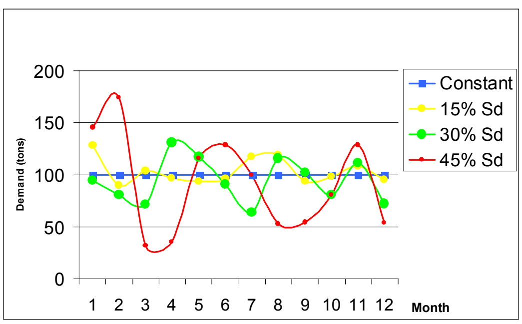


Figure 4: Example of Demand's Variability

Initially 4 different scenarios were analyzed. Scenario 1 considered a deterministic demand (no variation) but triangular distributed transportation times. Scenario 2 considered the same pattern of transportation times as scenario 1, but with the demand following a normal curve with 15% standard deviation to the mean. Scenario 3 considered triangular distributed transportation times (i.e., fleet breakdowns) and a deterministic demand and finally, scenario 4 considered triangular distributed transportation times (with breakdowns) and a normally distributed demand (with c.v = 0.15).

Table 4: Parameters for a Triangular Distribution for Transportation Times from the Factory

SITES	Parameters for Triangular Distribution (days)			
	min	mode	max	max*
CTB	2.0	2.5	3.0	6.0
PAL	3.0	3.5	4.0	7.0
REC	5.0	7.0	9.0	13.0
RJ	2.0	2.5	3.0	6.0
GO	3.0	3.5	4.0	7.0
BEL	6.0	7.5	9.0	13.0
MAN	13.0	14.5	16.0	20.0
FTZ	5.0	7.0	9.0	13.0
FLO	2.0	3.0	4.0	7.0
VIT	3.0	4.0	5.0	8.0
BH	3.0	3.5	4.0	7.0
SJRP	2.0	2.5	3.0	6.0
SLV	3.0	4.0	5.0	8.0
SP	2.0	2.5	3.0	6.0
RIB	2.0	2.5	3.0	6.0
CAMP	2.0	2.5	3.0	6.0

*** Considering fleet breakdowns**

The results of simulation runs are depicted on table 5. Note that all relative comparisons were made to the Spreadsheet-based Analysis results (table 2). "Margin Loss" was simply defined by the loss of margin in percentage and "Sales Loss" is analog; but the loss is only regarding "Sales" (revenues). The projected Sales are the sum of all potential sales generated for the period. The values in brackets correspond to the half width of the 95% confidence interval.

As can be seen from table 5, the variability on transportation practically did not interfere in the financial performance of the chain, in opposition to the scenarios that were taking into account variability on the demand (scenario 2 and 4). In this case a margin reduction of 12 % was achieved due to the loss of sales. This represents almost a loss of USD 260,000 per year due mostly to the variability (15%) of the demand.

Since variability of demand impacted hugely on profit, another study was performed in order to further analyze its influence on the results of the chain. Four additional scenarios were established, keeping transportation times deterministic and varying the standard deviation to the mean of the demand . The results obtained are shown in table 6.

Table 5: Supply Chain Simulation for the Various Scenarios Analyzed.

	Simulation Sce1**	Simulation Sce2**	Simulation Sce3**	Simulation Sce4**
Total Revenues	9,818,792 [0]	9,537,344 [94,480]	9,795,406 [2,824]	9,397,766 [118,212]
Production Costs	7,524,000 [0]	7,524,000 [0]	7,524,000 [0]	7,398,600 [0]
Transpo. Costs	166,038 [0]	161,516 [1,866]	165,503 [135]	158,552 [2,018]
Total Margin	2,128,754 [0]	1,851,828 [92,934]	2,105,903 [2,741]	1,840,614 [116,403]
Margin Loss* (%)	1%	-12%	0.3%	-12%
Projected Sales	9,818,792 [0]	9,876,128 [120,976]	9,818,792 [0]	9,765,363 [111,121]
Sales Loss* (%)	0%	3%	0.2%	4%

* Relatively to Static Calculations
** Mean value of 12 replications

Table 6: Supply Chain Simulation for Studying the Effect of the Variability of Demand.

	Simulation sd = 10% mean**	Simulation sd = 20% mean**	Simulation sd = 40% mean**	Simulation sd = 60% mean**
Total Revenues	9,635,632 [78,761]	9,486,964 [111,184]	8,778,689 [119,376]	8,247,872 [267,299]
Production Costs	7,524,000 [0]	7,524,000 [0]	6,897,000 [0]	6,520,800 [0]
Transpo. Costs	163,178 [2,018]	161,079 [3,274]	151,784 [3,353]	143,810 [5,325]
Total Margin	1,948,454 [77,237]	1,801,885 [109,037]	1,729,905 [118,458]	1,583,262 [262,337]
Margin Loss* (%)	7%	14%	18%	25%
Projected Sales	9,743,312 [79,727]	9,836,913 [120,746]	9,739,248 [317,104]	9,679,206 [909,487]
Sales Loss* (%)	1%	4%	10%	15%

* Relatively to Static Calculations
** Mean value of 12 replications

Table 6 confirmed that the variability on demand can strongly affect the performance of a Supply Chain, even if the average demand is the same as spreadsheets calculations. Results showed that the event of a high variability (60%) around the mean could lead to a total margin reduction of one forth. This would represent more than 0.5 million dollars per year. So this effect is not negligible and has to be taken into consideration. Figure 5 better illustrates the "deterioration" of the supply chain financial performance due to the variability of demand.

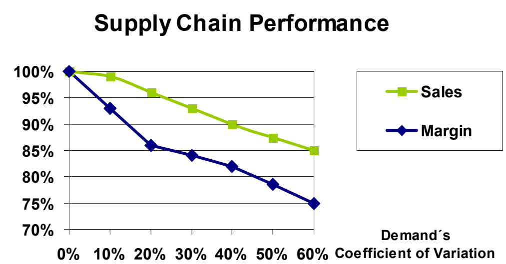


Figure 5: Supply Chain Results Considering Demand's Variability.

6 SUMMARY AND CONCLUSIONS

This work presented two evaluative techniques for the analysis of supply chains: Spreadsheet-based Analysis and Discrete Event Simulation. While the first is very easy and straightforward to implement, it does not consider dynamic behavior of the chain and does not account for variability. On the other hand, simulation is a tool which allows us to consider these elements in the analysis of a supply chain.

By comparing these two approaches on a case study of a large aluminum-processing firm in Brazil, we arrived at the following conclusions:

1) The effect of considering variation in some parameters of the Supply Chain like transportation times could not interfere significantly in the results of the chain. In this case both analysis methods would give equivalents results;
2) The variation in demand plays a key role in the performance of the chain. Hence, in this case, any supply chain analysis should be performance by means of simulation; otherwise the static analysis from spreadsheets could show misleading results.

It is interesting to note that, regarding point 2, Vos and Akkermans (1996) reached the same conclusion (demand fluctuations have a great impact on financial performance), by making a "Systems Dynamic Simulation" of a Supply Chain.

So making an analogy to an old U.S military saying: "if it moves salute it; if it doesn't, paint it", we can now answer our title question by: "if it varies simulate it; if it doesn't, lucky you !!!"

APPENDIX A: SPREADSHEET BASED ANALYSIS

SITES	M0NTHLY DEMAND	DAILY DEMAND	TRP. TIMES (DAYS)	SAFETY STOCK Flat	SAFETY STOCK Sf	SAFETY STOCK Nom	MAXIMUM STOCK Flat	MAXIMUM STOCK Sf	MAXIMUM STOCK Nom
CTB	30	1.00	2.5	2.50	1.1	2.8	30	1.1	33
PAL	35	1.17	3.5	4.08	1.1	4.5	35	1.1	38.5
REC	29	0.97	7.0	6.77	1.1	7.4	29	1.1	31.9
RJ	30	1.00	2.5	2.50	1.1	2.8	30	1.1	33
GO	18	0.60	3.5	2.10	1.1	2.3	18	1.1	19.8
BEL	23	0.77	7.5	5.75	1.1	6.3	23	1.1	25.3
MAN	14	0.47	14.5	6.77	1.1	7.4	14	1.1	15.4
FTZ	19	0.63	7.0	4.43	1.1	4.9	19	1.1	20.9
FLO	12	0.40	3.0	1.20	1.1	1.3	12	1.1	13.2
VIT	14	0.47	4.0	1.87	1.1	2.1	14	1.1	15.4
BH	11	0.37	3.5	1.28	1.1	1.4	11	1.1	12.1
SJRP	14	0.47	2.5	1.17	1.1	1.3	14	1.1	15.4
SLV	11	0.37	4.0	1.47	1.1	1.6	11	1.1	12.1
SP	15	0.50	2.5	1.25	1.1	1.4	15	1.1	16.5
RIB	12	0.40	2.5	1.00	1.1	1.1	12	1.1	13.2
CAMP	9	0.30	2.5	0.75	1.1	0.8	9	1.1	9.9
Total	**296**								
YEAR	**3552**								

COSTS

SITES	M0NTHLY DEMAND	UPC (USD)	UTC (USD)	TPC USD/Mth	TTC USD/Mth
CTB	30	2,090	12.0	62,700	360
PAL	35	2,090	27.0	73,150	945
REC	29	2,090	115.0	60,610	3,335
RJ	30	2,090	22.0	62,700	660
GO	18	2,090	32.0	37,620	576
BEL	23	2,090	60.0	48,070	1,380
MAN	14	2,090	112.0	29,260	1,568
FTZ	19	2,090	138.0	39,710	2,622
FLO	12	2,090	17.0	25,080	204
VIT	14	2,090	31.0	29,260	434
BH	11	2,090	21.0	22,990	231
SJRP	14	2,090	16.0	29,260	224
SLV	11	2,090	78.0	22,990	858
SP	15	2,090	9.0	31,350	135
RIB	12	2,090	14.0	25,080	168
CAMP	9	2,090	9.0	18,810	81
Total	**296**			**618,640**	**13,781**
YEAR	**3599.36**			**7,522,662**	**167,577**

REVENUES

SITES	M0NTHLY DEMAND	UREV (USD)	TREV (USD)
CTB	30	2720.00	81,600
PAL	35	2720.00	95,200
REC	29	2720.00	78,880
RJ	30	2720.00	81,600
GO	18	2720.00	48,960
BEL	23	2720.00	62,560
MAN	14	2720.00	38,080
FTZ	19	2720.00	51,680
FLO	12	2720.00	32,640
VIT	14	2720.00	38,080
BH	11	2720.00	29,920
SJRP	14	2720.00	38,080
SLV	11	2720.00	29,920
SP	15	2720.00	40,800
RIB	12	2720.00	32,640
CAMP	9	2720.00	24,480
Total	**296**		**805,120**
YEAR	**3,599**		**9,790,259**

Observations

Demand Given in tons
UPC - Production Cost per Unit
UTC - Transportation Costs per Unit
UREV - Revenue per Unit
TREV - Total Revenue
TC - Transportation Costs
TPC - Total Production Costs

MARGIN

TOTAL YEARLY MARGIN	**2,100,020**

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