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Optimizing supplier selection based on price sensibility, lead time and lead time variation

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---***ABSTRACT***---
It is especially important for companies worldwide to select the right supplier in their supply chains every time they purchase raw materials or finished goods, in terms of the total cost of products to be sold. The decision of choosing among several suppliers willing to quote the raw materials and the products a company needs, is a decision-making process that becomes complex.

The objective of this work is to present an optimization model that considers the price offered, the common lead time, the lead time variation and the weighted average capital cost (WACC) of the goods a company needs to buy in order to determine from which supplier(s) the goods should be purchased.

***Key words**—Supplier selection, sensitivity analysis, lead time variation, weighted average capital cost, optimization.*

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I. INTRODUCTION

Purchasing is the logistics' process through which companies acquire raw materials, components, products, services, and other resources from suppliers to execute their operations. Supply is the whole set of negotiation processes required to purchase goods and services [1]. With global supply chains, selecting the right supplier every time a company purchases goods or services is a strategic decision, because it is where a particularly important percentage of the cost of goods is negotiated. It is known that the price is one of the most important factors to consider when analyzing a purchase, but it is not the only one, and the others could be as important as the price from a fill rate´s perspective. Some of these other factors to considerer in these negotiations are the following:

- Capital costs: In this scenario, capital costs are indexed to the lead time, the longer the lead time, the higher the capital cost, because the money will be compromised during more time, adding costs to the company. In order to include the capital cost as a part of an optimization model, it's common to use the weighted average capital costs (WACC) that includes the weighted average of the cost of the debt and the cost related to the stocks of the company. The WACC is defined as the minimum return that a company needs to achieve to satisfy all the investors, bonds and stockholders [2].
- Lead time variation: The length of this time can vary from a purchase order to another even with the same supplier. Some of the regular causes of variation are documentation process delays, manufacturing delays, logistics delays, stockouts or any special events, like natural disasters. The bigger the variation, the higher cost involved. So, for each supplier it is particularly important that the company keeps records of their mean lead time, of the lead time´s standard deviation and of the probability of having delays in a purchase order.

Due to the recent arguments, deciding which supplier to choose is a complex decision and can vary from a purchase order to the other.

II. LITERATURE SURVEY

II.1 OPTIMIZATION MODELING

Since the 1940's the development of the linear programming and the Simplex method have made a big impact in many companies, saving thousands or millions of dollars [3]. Long ago it was difficult to implement these techniques but with the advances in technology, nowadays it is more accessible for companies of different sizes, since very good mathematical and engineering tools have been created and are sold at accessible prices or are free. Even though, it is still a specialized field and requires the advice of an expert.

Optimization modeling with linear programming deals with the general problem of assignment in the best way (the optimal way, from a mathematical point of view, using only linear functions) limited resources to activities that compete among them for those resources. That means to select the level of certain activities that need the same scarce resources, then the levels of activity chosen will dictate the quantity of resources that will consume each one of them [3].

Optimization modeling includes a wide variety of techniques and algorithms beyond linear programming, but since linear programming has been widely implemented around the world, it is going to be used in this article to solve the supplier selection problem.

To create a linear programming optimization model, it is important to define the following components:

- Decision variables: Activities to which the resources could be assigned.
- Objective function: Usually to maximize profits or to minimize costs.
- Functional constraints: These define the resources needed and the resources available. In linear programming the constraints appear in three varieties: less-than constraints (to represent capacities or ceilings), greater-than constraints (to represent commitments or thresholds), and equal-to constraints (to represent material balance or consistency among related variables [4].
- Non-negative constraints: These are particularly important because they limit the value of the decision variables to non-negative values.

Once these components are defined, the linear programming algorithms (like the simplex method) searches for a feasible region where all the constraints are satisfied and then, the algorithm searches for an optimal solution based on the objective function.

III. RESEARCH ELABORATIONS

III.1 Model for supplier selection

A common situation for several companies is to choose the best supplier every time they need to place a purchase order. The factors to consider in this model are the following, related to each supplier:

- The price offered.
- The historic lead times.
- The historic lead time variation.
- The probability of delays.
- The cost of capital for the company.

To explain the model, let us assume that a company needs to purchase their most important raw material and they have five possible suppliers with the following data:

Supplier	Unit price	Lead time	Lead time with delay	Delay probability	Expected lead time	Total cost
1	1	6	7	0,1	6,1	$ 1,02
2	0,9	13	13	0,07	13	$ 0,93
3	1,1	8	10	0,03	8,06	$ 1,13
4	0,95	10	11	0,05	10,05	$ 0,98
5	1,13	4	5	0,02	4,02	$ 1,14

Figure 1. Supplier data

They need to purchase 600.000 units of this raw material and they have the possibility to buy it all from only one supplier or from several suppliers (all of them have enough capacity to supply all the units).

The column named unit price is the price that each supplier is offering, the lead time refers to the offered lead time (in weeks), the lead time with delay, accounts for the mean lead time each time they have a delay (gathered from historic records), the delay probability is the known probability of having a delay (from historical data) and the total cost column is the annual WACC expressed in weeks (0.29% per week for this example) multiplied by the delay lead time, using the following formulas:

$$ELT = (1 - dprob) * (L) + (dprob) * (Lwd) \qquad (1)$$

Where:

$$ELT = Expected\ lead\ time$$
$$dprob = delay\ probability$$
$$L = Lead\ time$$
$$Lwd = Lead\ time\ with\ delay$$

$$TC = UP * (1 + WWACC * ELT) \qquad (2)$$

Where:

$$TC = total\ cost$$
$$UP = Unit\ price$$

$$WWACC = weekly\ WACC$$
$$ELT = Expected\ lead\ time$$

The model is defined in the following generic format [5]:
Objective function:

$$Minimize\ Z = \sum_{j=1}^{n} c_j x_j \ (3)$$

Subject to constraints (i):

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \qquad (4)$$

$x_j \geq 0$ (5)
The decision variables are:
$x_j = quantity\ of\ units\ to\ assign\ to\ supplier\ j$, where j = 1 to 5.

$$c_j = total\ cost\ per\ unit\ related\ to\ supplier\ j$$
$$a_{ij} = constraints\ coefficients\ related\ to\ x_j$$
$$b_i = weekly\ units\ cummulative\ requirements$$

The specific objective function is:

$$Min\ Z = 1.02 * X_1 + 0.93 * X_2 + 1.13 * X_3 + 0.98 * X_4 + 1.14 * X_5$$

Their planning horizon is 13 weeks long, but they need the order quantities to cover from week 6th to 13thand the requirements are 50.000 units per week, so they must consider the cumulative requirements for these weeks (6th to 13th) at the moment where they place the purchase order.

	Weekly requirement	**Cumulative requirement**
Requirement for week 6	50000	50000
Requirement for week 7	50000	100000
Requirement for week 8	50000	150000
Requirement for week 9	50000	200000
Requirement for week 10	50000	250000
Requirement for week 11	50000	300000
Requirement for week 12	50000	350000
Requirement for week 13	50000	400000

Figure 2: Weekly and cumulative requirements

The optimization model to solve is:

Variable declaration:

X1	Units to purchase from supplier 1
X2	Units to purchase from supplier 2
X3	Units to purchase from supplier 3
X4	Units to purchase from supplier 4
X5	Units to purchase from supplier 5

		X1	**X2**	**X3**	**X4**	**X5**			
	Lead time	6	13	8	10	4			
	Price	1	0,9	1,1	0,95	1,13			
	Assignment								
Objective function:	**Total cost**	$1,02	$0,93	$1,13	$ 0,98	$1,14	**$ -**		
Constraints:									
Total purchase (Units)	Week	1	1	1	1	1	0	>=	600000

Cumulative Requirement for week 6	6	1	0	0	0	1	0	>=	50000
Cumulative Requirement for week 7	7	1	0	0	0	1	0	>=	100000
Cumulative Requirement for week 8	8	1	0	1	0	1	0	>=	150000
Cumulative Requirement for week 9	9	1	0	1	0	1	0	>=	200000
Cumulative Requirement for week 10	10	1	0	1	1	1	0	>=	250000
Cumulative Requirement for week 11	11	1	0	1	1	1	0	>=	300000
Cumulative Requirement for week 12	12	1	0	1	1	1	0	>=	350000
Cumulative Requirement for week 13	13	1	1	1	1	1	0	>=	400000

Figure 3: Optimization model

The functional constraints are:

- The total units to purchase should be at least 600.000.
- The cumulative units sold for each week, from week 6th to week 13th (the coverage horizon) must be equal or greater than the cumulative requirements.
- The non-negative constraints are:

$$X_j \geq 0$$

IV. RESULT AND DISCUSSION

IV.1 Optimization model solution using MS Excel® Solver

Using MS Excel® Solver to solve the problem, specifying "Simplex LP" to use the Simplex method, these are the results:

Variable declaration:

X1	Units to purchase from supplier 1
X2	Units to purchase from supplier 2
X3	Units to purchase from supplier 3
X4	Units to purchase from supplier 4
X5	Units to purchase from supplier 5

		X1	X2	X3	X4	X5	
	Lead time	6	13	8	10	4	
	Price	1	0,9	1,1	0,95	1,13	
	Assignment	200000	250000	0	150000	0	
Objective function:	**Total cost**	$ 1,02	$ 0,93	$ 1,13	$ 0,98	$ 1,14	**$ 583 588**

Constraints:

Total purchase (Units)	Week	1	1	1	1	1	600000	>=	600000
Cumulative Requirement for week 6	6	1	0	0	0	1	200000	>=	50000
Cumulative Requirement for week 7	7	1	0	0	0	1	200000	>=	100000
Cumulative Requirement for week 8	8	1	0	1	0	1	200000	>=	150000
Cumulative Requirement for week 9	9	1	0	1	0	1	200000	>=	200000

Cumulative Requirement for week 10	10	1	0	1	1	1	350000	>=	250000
Cumulative Requirement for week 11	11	1	0	1	1	1	350000	>=	300000
Cumulative Requirement for week 12	12	1	0	1	1	1	350000	>=	350000
Cumulative Requirement for week 13	13	1	1	1	1	1	600000	>=	400000

Figure 4: Solved model

Purchase plan:

- $Supplier\ 1\ (X_1) = 200.000\ units$
- $Supplier\ 2\ (X_2) = 250.000\ units$
- $Supplier\ 3\ (X_3) = 0\ units$
- $Supplier\ 4\ (X_4) = 150.000\ units$
- $Supplier\ 5\ (X_5) = 0\ units$

The optimization model recommends purchasing 200.000 units from Supplier 1 and that will cover weeks 6th to 9th, then the company will sell 150.000 units for weeks 10th to 12th bought from supplier 4 (their lead time is 10, just in time!) and for week 13ththey will sell 50.000 units bought from supplier 2. The remaining quantity should also be purchased from supplier 2 since the lead time is feasible according to the requirements and the price is the lowest of all.

It's important to analyze that the model minimizes the total cost (US$583.588) considering the prices offered and the lead times in a way that covers all the requirements, so no stockouts should occur (unless the presence of a special event).

Sensitivity analysis in linear programs involves linking results and conclusions to initial assumptions. Instead of asking how a particular change in the decision variables would affect the performance measure, we might search for the changes in decision variables that have the best possible effect on performance [4].

In this model the performance measure is the total cost of purchase and sensitivity analysis calculates the limits of the costs (prices, from the supplier stand point) offered by each supplier, and thus, value can be added in a negotiation because the company knows the required discounts and so, they can ask a supplier for a discounted price, a threshold price that will make the optimization model assign more units to that supplier changing the optimal solution. Since this is a bid, the company will achieve better results.

In this model, prices must be less than the ones shown in the following table (obtained using sensitivity analysis):

Supplier	Discounted price
Supplier 1:	$ 0,98
Supplier 2:	N/A
Supplier 3:	$ 1,02
Supplier 4:	$ 0,93
Supplier 5:	$ 1,02

Figure 5: Discounted prices required to compete

The "N/A" displayed for supplier 2 is because the optimization model already assigned all the feasible units, according to the lead time constraint.

These prices are obtained subtracting the allowable decrease from the actual price the supplier is offering (cost coefficient from the company´s point of view). The allowable decrease data can be found in the sensitivity report after the optimization model is solved.

Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
Supplier 1	200000	0	**1,02**	0,11	**0,04**
Supplier 2	250000	0	**0,93**	0,04	**0,93**
Supplier 3	0	0,11	**1,13**	1E+30	**0,11**
Supplier 4	150000	0	**0,98**	0,04	**0,04**
Supplier 5	0	0,13	**1,14**	1E+30	**0,13**

Figure 6: Sensitivity report (partial)

Every time a supplier accepts the new price, the company must solve the optimization model again and run the sensitivity analysis to calculate the prices to negotiate.

The same analysis could be made using the lead time variable, but since prices are usually more dependent on company's decisions, in this work the model was solver based on the price variable. In future works, the sensitivity analysis can be solved based on the lead time variable or in both, the price, and the lead time variables.

IV.2 OPTIMIZATION MODEL SOLUTION USING OR BRAINWARE DECISION TOOLS

Among the efficient tools available, stands OR Brainware [6], developed by Dr. Marcos Moya which is a powerful and easy to use tool for optimizing models. In the following figure are shown the results of this model using this software in the linear programming module using five decision variables and nine constraints:

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5			
	200000	250000	0	150000	0		Max o Min X0 =	583 587,9
Total in units	1	1	1	1	1	600000	>=	600000
Cum. Req. W6	1	0	0	0	1	200000	>=	50000
Cum. Req. W7	1	0	0	0	1	200000	>=	100000
Cum. Req. W8	1	0	1	0	1	200000	>=	150000
Cum. Req. W9	1	0	1	0	1	200000	>=	200000
Cum. Req. W10	1	0	1	1	1	350000	>=	250000
Cum. Req. W11	1	0	1	1	1	350000	>=	300000
Cum. Req. W12	1	0	1	1	1	350000	>=	350000
Cum. Req. W13	1	1	1	1	1	600000	>=	400000
Objective Function	1,02	0,93	1,13	0,98	1,14			

Figure 7: OR Brainware solution

The results are the same and it is a very user-friendly tool. Also, if the user wants to develop optimizations models coding all the functions and relations, there are several free powerful options, like R or Python.

V. CONCLUSIONS

Linear programming can help companies negotiate with their suppliers to get better deals, and, with the calculations obtained from sensitivity analysis, companies can estimate the prices that each supplier need to offer in order to win a part or the whole deal. This can become an important negotiating tool for every company, especially for recurrent purchases where several suppliers compete.

This optimization model can also calculate the required lead times for a supplier to gain a part, or even the whole deal. This can be accomplished through the sensitivity analysis, so this model can help companies to balance price and lead time to be more competitive.

This optimization model can be modified to consider other variables, like the inventory carrying cost and stockout costs and that can also be done with linear programming, that is how powerful these techniques are.

With the advance of technology and the availability of several accessible tools, companies must consider increasing the use of optimization models in their everyday decisions, to be more competitive.

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BIOGRAPHY

Marco Antonio Arias Vargas is an Industrial Engineer and has a Magister Scientiae (M.Sc.) degree in Industrial Engineering from the University of Costa Rica (UCR), with honor distinction in his graduation thesis. He also has a master's in business administration degree (MBA)from INCAE Business School, where he achieved the highest distinction.

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Mr. Arias has worked for twenty years in several private companies, in positions like Logistics Manager, Supply Chain Director, Finance Director and Corporate General Director. For the last four years, he has been working as a Consulting Partner and Managing Director for Macrologistica, a company that he co-founded.
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