Application of linear programming methods to determine the best location of concrete dispatch plants

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Introduction:

I just remember those words from my previous boss when I started working for Argos, the leader in the Colombian cement and concrete industry; "anybody can make concrete….. you just need cement, stone, sand, water and a bucket with a shovel to mix it". This words are especially true in the third world countries, where the labor cost is so low, that for construction companies is cheaper to "handmade" their own concrete on the work place, than buy the ready mix from a concrete distributor.

The two main costs of the ready mix concrete are the raw materials such as the cement, stone and sand (which can be more than 70% of the total cost), and the distribution costs. Since the costs of the raw materials are almost fixed, the planning and logistics department of the concrete business has to work on the optimization of the distribution, which one of the few costs that we can be minimize in order to achieve higher profits. To optimize the distributions costs, our plants (factories) should be as close as possible to our actual and potential clients, so that we can distribute more concrete using an smaller amount of resources, such us the mixer trucks, fuel, tires, just to name a few.

The purpose of this paper is to show how the application of some methods of linear programming can be extremely helpful to determine the ideal location of concrete dispatch plants in big cities, based on the forecast of the location of the market in the future, the creation of theoretical times curves from possible plants locations to the market's position, and the legislation of the city that tell us where we are allow to open a new concrete factory.

Problem description:

As we mentioned on the introduction, one of the main problems for the logistics planning department in a concrete company is to determine the ideal location of the production plants in order to minimize the distributions costs. In the particular case of Concrete Argos, we have been developing some computational tools that help this decision process, based on the information that we have access to, such as the historical location of the market (with this we can make a good approach to forecast the market location in the future; as shown in Figure 1) , the actual production capacities of the different existing plants and the regulation laws for the use of the land (see Figure 2). Also we have developed a small complementary program to generate the theoretical time curves from a given point of the map, to all the others locations, based on the speed constraints given by the roads and topography of the city that we are analyzing (see Figure 3).

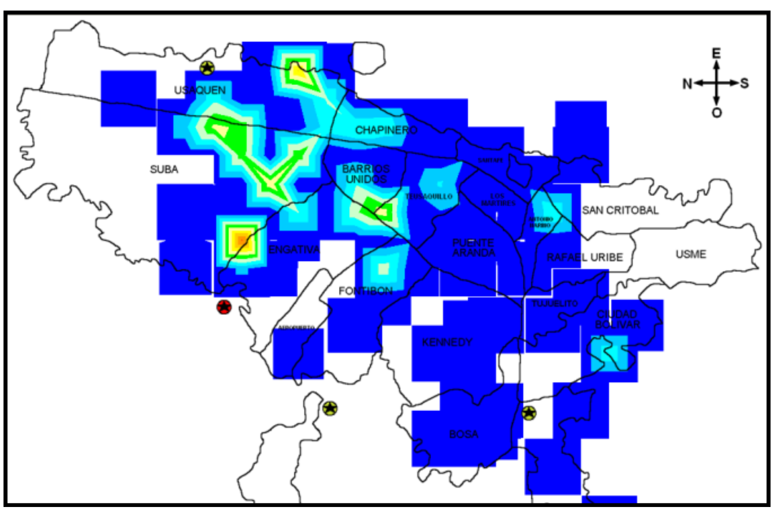


Figure 1 Historical market location for Bogotá

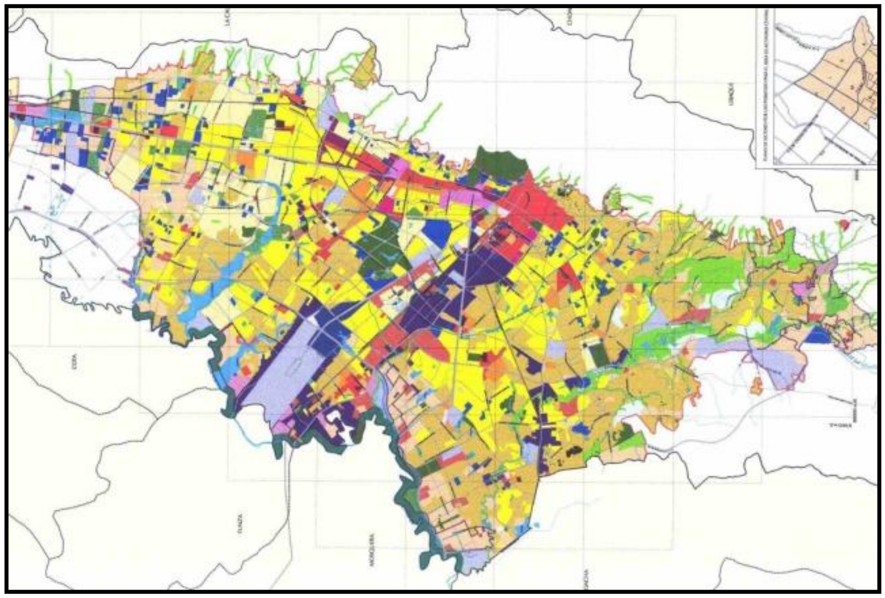


Figure 2 Land usage according to the law

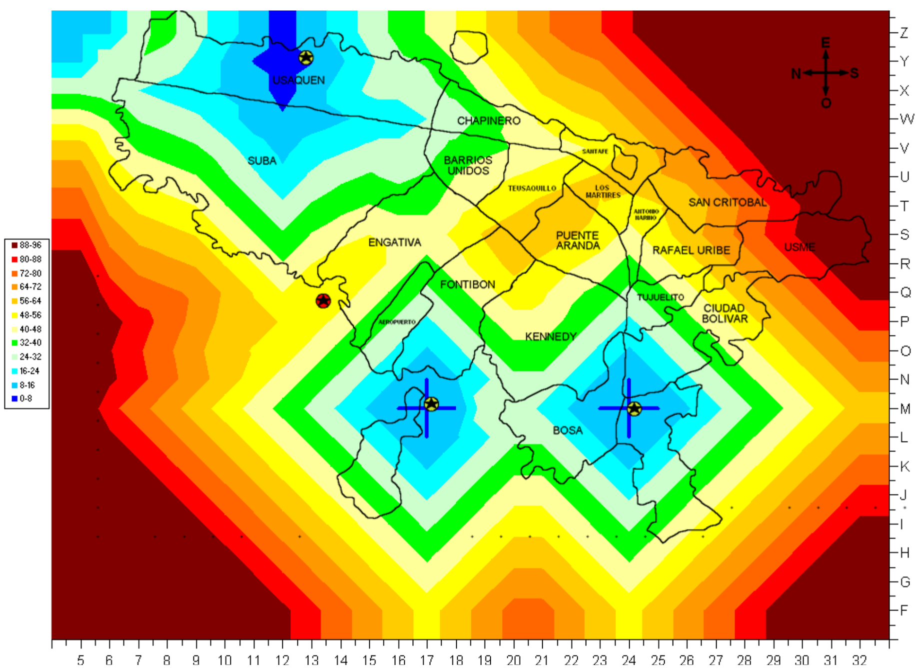


Figure 3 Time curves from the actual plants

<u>Solution for the problem:</u>

Our approach for the solution of problem can be explain in the box diagram from Figure 4, which has the inputs of the location of the market, the allowed locations to build a plant, all the possible time curves for the actual and possible future plants and de production capacities.

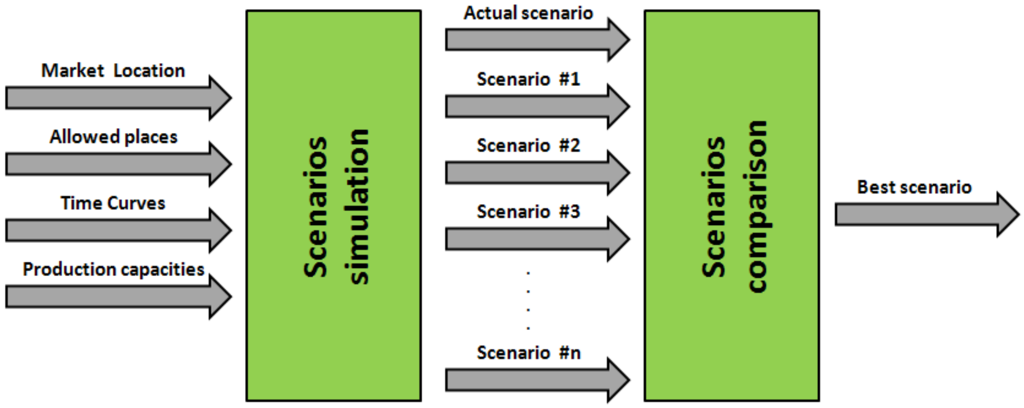


Figure 4 Black box Diagram

From this input variables we get some preliminary results based on the scenarios that we ask the program to simulate, and after we have simulate all the different scenarios we can compare them to see which one is the best solution. We can say that the linear programming remains in the first process (the simulation of the scenarios), since the second one is made by other areas of the company that analyze the value of the land, the ROI of the project, and so on. Thus, our main goal is to tell them what is the best scenarios, and how much time can they save in every one of those in comparison to the actual situation (based on some distribution costs that we have for the different cities we can convert those minutes into money for the financial analysis).

Therefore, the simulation of each scenario (including the actual situation) is going to find the ideal supply for the demand of market given the fixed locations and capacities of the plants…. just like the transportation problem that we saw on homework #5. In the next formula we can see the numerical formulation of our particular transportation problem.

$\mathbb{C}_{i,j} =$ Time matrix (this represents the time in minutes from fractory i to location j)

$\mathbb{X}_{i,j} = Supply\ matrix\ (this\ represent\ the\ volumen\ dispatch\ from\ factory\ i\ to\ location\ j)$

$\mathbb{b}1_i = Plants\ Capacity\ vector\ (Maximun\ production\ capacity\ for\ plant\ i)$

$\mathbb{b}2_j = Market\ Demand\ vector\ (Volume\ demanded\ from\ location\ j)$

$$Min\ (Z) = Min \sum_{i=1}^{8}\sum_{j=1}^{25}(\mathbb{C}_{i,j}) \times (\mathbb{X}_{i,j})$$

$Such\ That:$

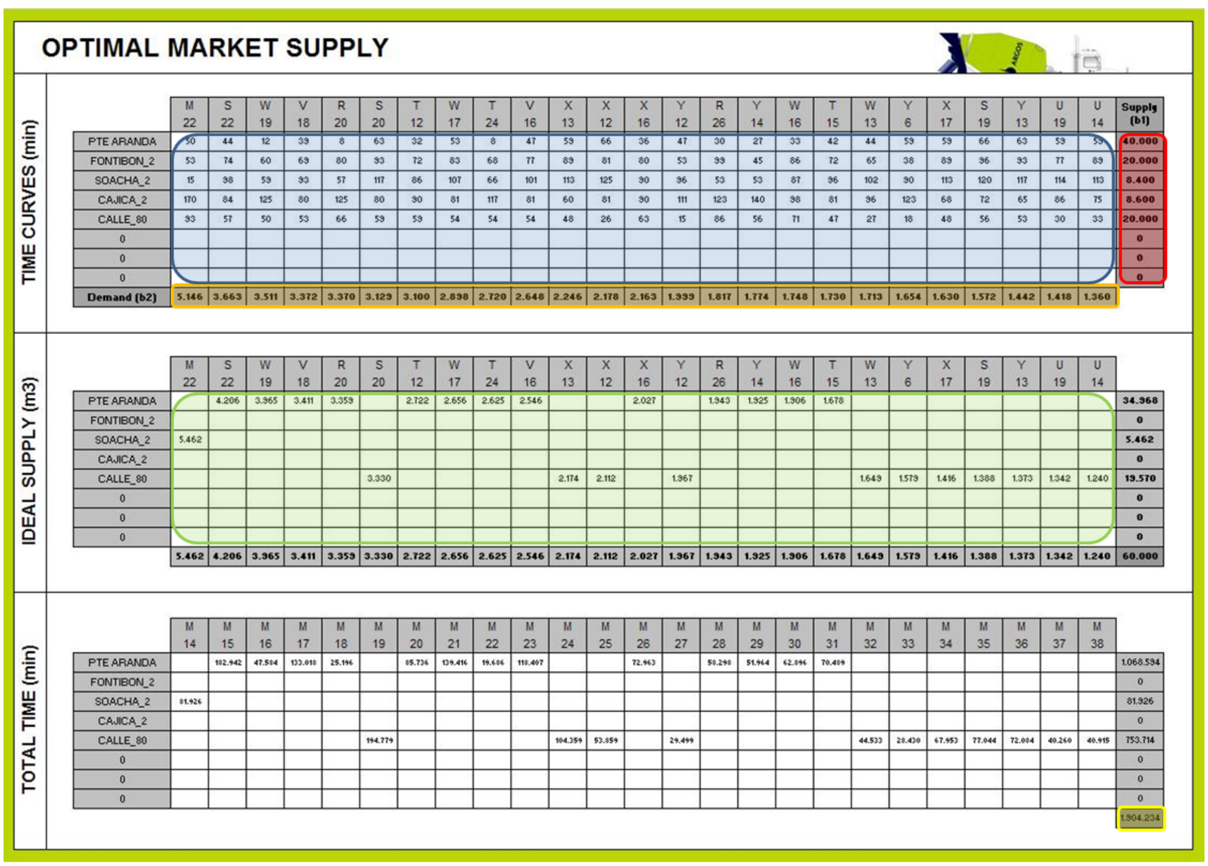
$$\sum_{j=1}^{25}\mathbb{X}_{i,j} \leq \mathbb{b}1_i \quad \forall \quad 1 \leq i \leq 8 \qquad (This\ is\ the\ maximum\ capacity\ restriction)$$

$$\sum_{i=1}^{8}\mathbb{X}_{i,j} \geq \mathbb{b}2_j \quad \forall \quad 1 \leq j \leq 25 \qquad (This\ is\ the\ demand\ restriction)$$

$$\mathbb{X}_{i,j} \geq 0 \quad \forall\ (1 \leq i \leq 8)\ and\ (1 \leq j \leq 25) \qquad (This\ is\ the\ nonegative\ restriction)$$

As you could see on the previous formulas, the upper limits for the summations are fixed, and this is because of the software that we used to solve the model. We decided to use Microsoft Excel (with the solver complement) because almost all the computers in the company have it, so beyond the fact that did not have to pay an extra license to use different software, anybody who wanted to use it in their computer could make their own simulations. Unfortunately the bad side of using this software is that it has some restrictions, and one of it are the maximum number of variables that you can use (you can use at most 200 variables), so we decided to limit the program to make analysis with at most 8 different plants (today the city that has most plants in our country has 4) and the 25 most representative squares (the 25 with the highest concrete volume), so that is the reason of the upper bounds of the summations of 8 for the plants variables and 25 for the squares variables.

Even though the Excel file has a lot of worksheets, the heart of the program remains in the worksheet named “SOLUCION”, that is where we call the Excel solver application to find the optimal values for the “X” matrix. In Figure 5 we can see the structure of this sheet; recalling from the previous formulas, the matrix in blue correspond to the “C” matrix, the red one is the vector “b1”, the orange one is the “b2” vector, the green one is the “X” matrix, and finally the yellow highlighted is the final value of the objective function (Z).



TIME CURVES (min)

	M 22	S 22	W 19	V 18	R 20	S 20	T 12	W 17	T 24	V 16	X 13	X 12	X 16	Y 12	R 26	Y 14	W 16	T 15	W 13	Y 6	X 17	S 19	Y 13	U 19	U 14	Supply (bI)
PTE ARANDA	50	44	12	39	8	63	32	53	8	47	59	66	36	47	30	27	33	42	44	59	59	66	63	59	59	40.000
FONTIBON_2	53	74	60	69	80	93	72	83	68	77	89	81	80	53	99	45	86	72	65	38	89	96	93	77	89	20.000
SOACHA_2	15	98	59	93	57	117	86	107	66	101	113	125	90	96	53	53	87	96	102	90	113	120	117	114	113	8.400
CAJICA_2	170	84	125	80	125	80	90	81	117	81	60	81	90	111	123	140	98	81	96	123	68	72	65	86	75	8.600
CALLE_80	93	57	50	53	66	59	59	54	54	54	48	26	63	15	86	56	71	47	27	18	48	56	53	30	33	20.000
0																										0
0																										0
0																										0
Demand (b2)	5.146	3.663	3.511	3.372	3.370	3.129	3.100	2.898	2.720	2.648	2.246	2.178	2.163	1.999	1.817	1.774	1.748	1.730	1.713	1.654	1.630	1.572	1.442	1.418	1.360	

IDEAL SUPPLY (m3)

	M 22	S 22	W 19	V 18	R 20	S 20	T 12	W 17	T 24	V 16	X 13	X 12	X 16	Y 12	R 26	Y 14	W 16	T 15	W 13	Y 6	X 17	S 19	Y 13	U 19	U 14	
PTE ARANDA		4.206	3.965	3.411	3.359		2.722	2.656	2.625	2.546			2.027		1.943	1.925	1.906	1.678								34.968
FONTIBON_2																										0
SOACHA_2	5.462																									5.462
CAJICA_2																										0
CALLE_80						3.330					2.174	2.112		1.967					1.649	1.579	1.416	1.388	1.373	1.342	1.240	19.570
0																										0
0																										0
0																										0
	5.462	4.206	3.965	3.411	3.359	3.330	2.722	2.656	2.625	2.546	2.174	2.112	2.027	1.967	1.943	1.925	1.906	1.678	1.649	1.579	1.416	1.388	1.373	1.342	1.240	60.000

TOTAL TIME (min)

	M 14	M 15	M 16	M 17	M 18	M 19	M 20	M 21	M 22	M 23	M 24	M 25	M 26	M 27	M 28	M 29	M 30	M 31	M 32	M 33	M 34	M 35	M 36	M 37	M 38	
PTE ARANDA		182.942	47.584	133.018	25.196		85.736	139.416	19.686	118.407			72.963		58.298	51.964	62.896	70.489								1.068.594
FONTIBON_2																										0
SOACHA_2	81.926																									81.926
CAJICA_2																										0
CALLE_80						194.779					104.359	53.859		29.499					44.533	28.430	67.953	77.044	72.084	40.260	40.915	753.714
0																										0
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Figure 5 Worksheet solution where the transportation problem is solved

Conclusions:

Even though this model is not perfect and is based on some assumptions that are not completely accurate in the real world (such as the assumption that theoretical time curves are the same during whole day, or that the location of the market will follow a patter based on the historical location of the dispatches), this kind of approach give us very valuable information that can be crucial on a decision making process (just the raw picture of the location of the market on a map where you can point the locations of your factories is too good to see if we are located where we should be).

As long as the information systems in the companies keep getting stronger with more reliable information that reflects the real conditions of every single unit of the business as an individual entity (specially the costs of every single plant independently, that are one of the main inputs for this kind of problems), we will be able to apply more sophisticated models, like the ones that we saw on lecture 18 of the curse about integer linear programs (ILP), which can tell you the final answer without you having to propose some solutions for the model.

Also, because of the restriction of the number of variables that the software can handle, it should be important to analyze the possibility of migrate to a more powerful package that will give us the flexibility to work with more variables and more constraints that will be crucial for ILP models.