Application Portfolio

Buenaventura Port Expansion

by

Isabel Agudelo

A complete version of the application portfolio for

ESD 71 Engineering system Analysis for Design

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Abstract

This is a fictional case about a decision of capacity expansion in the Buenaventura Port in the Pacific Coast of Colombia (South America). There are many drivers of port capacity but for the purpose of this project, I selected increasing of the number port cranes as the main variable to adjust. Export container demand is the main source of uncertainty. Two types of methodology were used to analyze this project: decision analysis and lattice analysis. For the decision analysis, I made a comparison between a scenario of buying five cranes in the initial year and a scenario of buying two cranes in the first year and expand to three cranes in year five. For the lattice analysis, I maintained the same situation but the uncertainty was reduced to the demand of only one type of container. The two approaches presented a positive value of flexibility but I believe that decision analysis is a better tool for this type of project because of the level of complexity involved in the process and the number of decision variables in the real world.

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1 Engineering system description

Colombia is a country located in the northwest corner of Latin-America as presented in Figure 1. The country has coast in the Pacific and Atlantic Ocean.

Figure 1. Colombia in Latin-America

One of the major goals of Colombian government is to increase the amount of international commerce with the rest of the word. To reach this goal is very important to have the adequate logistics infrastructure related to maritime, rail, fluvial and land transportation. Colombia has limited resources to invest, so is important to make good decisions regarding this infrastructure. One of the major concerns in the maritime infrastructure is the port of Buenaventura. This port is the largest in the Colombian Pacific Coast and according to United Nations Economic Commission for Latin-America and the Caribbean (ECLAC) (2007) was the sixteenth container port in Latin-America in 2006. The port is located in Cauca Valley state in the center – west of the country. See Figure 2 and 3.

Figure 2.Cauca Valley State

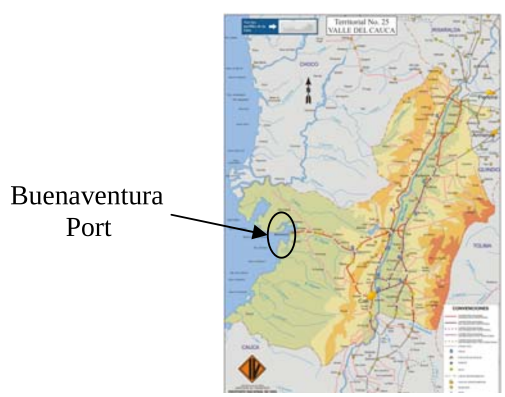


Figure 3.Port location

According to ECLAC (2007), Buenaventura moved 622.233 TEUS[1] in 2006. This is the current information about the Buenaventura port.

Drivers	Current Data
Terminal space	2000 meters
Number of terminals	14 docks
Cranes	16 container cranes

Source: http://www.sprbun.com

Source: http://www.sprbun.com

The main concern with the Buenaventura port is that Colombian economy is growing annually at rates of 6% and it was estimated that the capacity utilization of the port was 73.5% in 2005 and today this figure has passed 100%. With the expected rate of increase generated by the free trade agreements that Colombia is signing, the capacity of the port is already insufficient.

[1] According to Rowlett (2004), the Twenty-foot Equivalent Unit (TEU) is an inexact unit of cargo capacity often used to describe the capacity of container ships and container terminals. It is based on the volume of a 20-foot long shipping container, a standard-sized metal box which can be easily transferred between different modes of transportation, such as ships, trains and trucks.

The main benefit of this project is to avoid Buenaventura port of becoming a bottleneck of the export process of the country and also, to evaluate the adequate moment to make the investment given the limitation of resources of the country.

There are many factors that might affect the value of ports performance. Colombian economy (exports and imports) is always a challenge to define. Now, the economy is in good shape but is not isolated from the effects of the world situation, especially because this is project to focus mainly in exportation markets.

2 Salient Uncertainties

Economic Uncertainty: According to the United Nations **-** UNCTAD – Review of Maritime Transport (2007), the growth of the world economy with special concentration on emerging economies such as an India and China had a very important effect of world trade (8% increase), this effect was also extended to maritime transport. This situation had an important effect on the growth of the world fleet starting with 1.04 billion deadweight tons (dwt) at the beginning of 2007 to an 8.6 per cent increase. In general, the situation is positive for ports in Colombia. The growth of Asia – Pacific region represents an important opportunity for Latin-American Pacific ports like Buenaventura. This also means that competition among ports to attract shipping companies is going to be even more difficult. One positive issue is the fact that the Buenaventura port is close to the Panama Canal. The Panama Canal is the main maritime route from Asia- pacific to the US east coast.

Politics / Economics Uncertainty: There are a group of FTA (Free Trade Agreement) agreements is process. According to the Colombian Embassy in the US, "*The economic arguments in favor of the agreement are clear, as the free trade agreement (FTA) will ensure*

Colombian goods continued duty-free access to the U.S. market, and provide to U.S. exporters the same benefits". To have FTA is positive for the port because of the increase in the use of the port for imports and exports. The uncertainty comes from the political nature of the process when is not always easy to get an approval from the two governments.

Technology uncertainty: Technology advances in the maritime sector have generated the creation of bigger ships. "Panamax" ships are of the maximum dimensions that will fit through the locks of the Panama Canal. According to the Panama Canal Authority, the maximum dimensions allowed for a ship transiting the canal are: Length: 294.1 meters (965 ft), Beam (width): 32.3 meters (106 ft), Draft: 12.0 meters (39.5 ft) in tropical fresh water (the salinity and temperature of water affect its density, and hence how deeply a ship will sit in the water), Air draft: 57.91 meters (190 ft) measured from the waterline to the vessel's highest point. The uncertainty here is that new ships, the Post – Panamax are now in use. So, the question here is to take into account this situation knowing that the Panama Canal is going to start an expansion plan to allow post-panamax ships is the canal. The world ports had been adjusted to be able to receive post-panamax but there is still some doubts about the expansion.

Class	**Panamax**	**Panamax II**
Length	1050 ft (320.04 m)	1400 ft (426.72 m)
Width	110 ft (33.53 m)	180 ft (54.86 m)
Draft	41 ft (12.50 m)	60 ft (18.29 m)
TEU	5000	12000

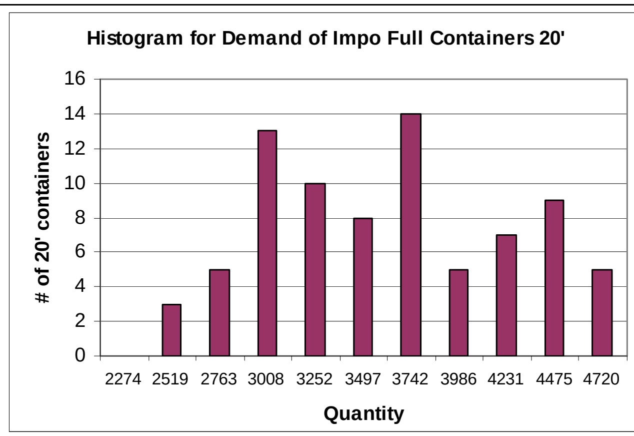
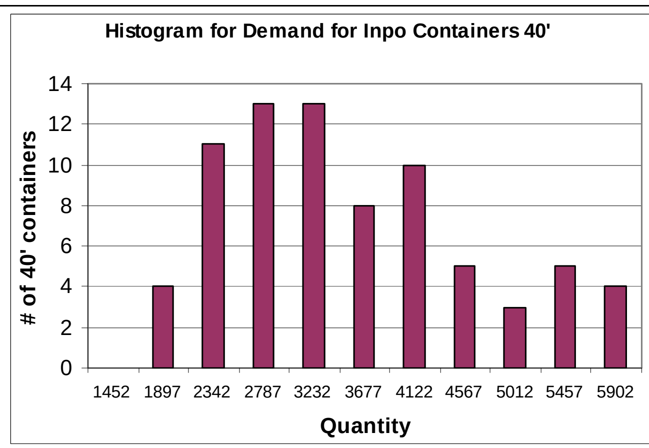
Variability in demand. The web site of the Buenaventura Port Authority has statistical information about monthly demand from January 1999 to August 2008. This is the mean, the standard deviation, the minimum, the maximum value and the coefficient of variation obtained from this information.

	Mean (1)	**StDev (2)**	**Min**	**Max**	**CV* (2)/(1)**

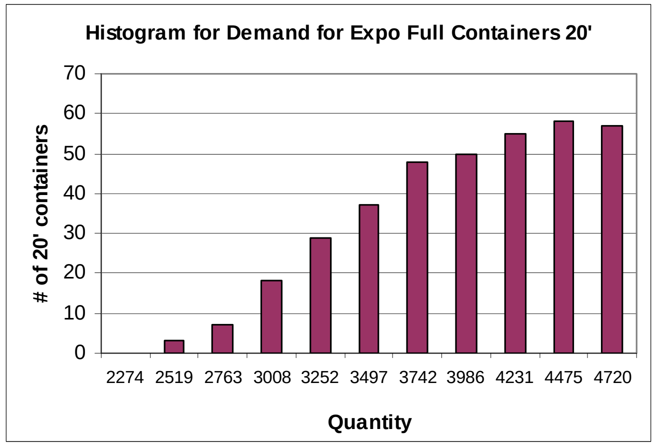
Imports					
Number of full containers 20’	4,231.2	1,274.4	2,274.0	7,166.0	0,30
Number of full containers 40’	4,880.8	2,470.3	1,452.0	10,351.0	0.51
Number of empty containers 20’	422.8	319.1	0	993.0	0.75
Number of empty containers 40’	104.5	94.7	0	489.0	0.91
Exports					
Number of full containers 20’	3,230.5	516,1	2,091.0	4,485.0	0,16
Number of full containers 40’	2,227.3	651.4	880.0	3,466.0	0.29
Number of empty containers 20’	1,651.7	824,8	567.0	4,366.0	0.5
Number of empty containers 40’	2,468.7	1,719.9	415.0	7,565.0	0.7

*Coefficient of variation

From the data I obtained the following distributions.

Import full 20’ containers	
Import full 40’ containers	

<table>
<tr><td>Expo full 20’

containers</td><td>
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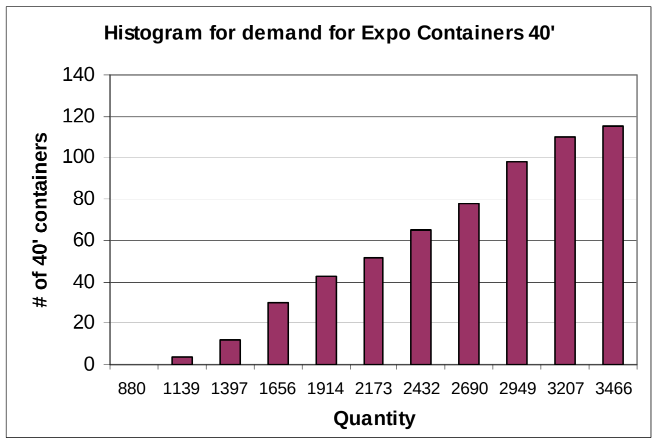
<tr><td>Expo full 40’

containers</td><td>
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To facilitate the calculations in this project I’m only going to focus in the export containers.

3 Flexibility identification

Regarding to Ocean port capacity drivers, Jackson (2005) on his paper “North American Container Port: An exploratory analysis”, made the following literature review about port capacity factors. There were a total of 25 capacity factors. This is a summary of the factors that he found.

Category	Capacity Factor
Port Infrastructure	Terminal space
	Berth space
	Land for port expansion
	Gate capacity
	Port equipment
	Terminal operator capacity
Labor	Longshore labor efficiency
	Longshore labor costs
	Longshore labor capacity
	Other port labor efficiency
	Other port labor capacity
	Other port labor costs
Waterways	Channel depth
	Channel width
	Tug and tow
	Barge, short sea feeders
	Pilotage
	Bridge clearance
	Channel congestion
Truck and Rail	Local road capacity
	Rail – local capacity
	Local dray capacity
	Rail – on-dock capacity
Technology	Gate systems
	Scheduling
	Container tracking
	Data exchange with partners

Jackson (2005) found that "Focusing on the top factors reveals that many of the capacity drivers of greatest port concern are heavily if not completely influenced by other stakeholders Looking for a variable that can be controlled by the port, I assumed that the only things that I can modify in the port are the number of cranes. The other variables are constrained.

4 2-Stage Decision Analysis of Alternative Designs

I am going to make a decision analysis comparing two alternatives one fixed and one flexible. This is the description of each alternative.

<u>Fixed system:</u> Increase the capacity by buying 5 container cranes in year one. This will increase the capacity by 280 in 20' container and 120 in 40'containers per crane per year. No

more cranes will be added to the system. It is assumed that is no salvage value for the cranes. The new cranes will add capacity to the current capacity of the port.

Flexible system: There are two possible options of flexibility. In year one, buying 2 container cranes and in year 5 buy another 3 containers cranes if demand can support the purchasing. Again, an additional crane will increase the capacity 280 in 20' container and 120 in 40'containers per crane per year. It is assumed that is no salvage value for the cranes.

Basic Data: These are the basic assumptions for the model. The numbers are fictional.

Table 1. Assumptions for the model

Issue	20' Container	40' Container
Price (dollar per container)	$140	$200
Current capacity	40,000	20,000
Additional capacity per crane added (containers per year)	2800	1200
Current port expenses (thousand per year)	$300	
Additional cost per crane added (thousand per year)	$56	
Investment per crane (Thousand dollars). No salvage value.	$700	
Discount rate	5%	

Demand projections: According to the Colombian government, the signature of Free Trade Agreements in the next following years is going to generate a major increase in the exports of the country. According to the National Planning Department, the FTA with the US might generate 6.44% increase in exports and 11.92% increase in imports. There is a major discussion around this point and there is no consensus about it. For the purpose of the exercise, I will assume the results in Table 2 for the forecast growth in containers per year for a high (15%), medium (7%) and low situation (2%) during a period of 10 years.

Table 2. Annual demand projections for 20' and 40' export containers

Year	1	2	3	4	5	6	7	8	9	10
HIGH DEMAND										
Forecasted Demand Cont 20'	38.892	44.726	51.435	59.150	68.022	78.226	89.960	103.453	118.972	136.817
Forecasted Demand Cont 40'	27.060	31.119	35.787	41.155	47.328	54.427	62.591	71.980	82.777	95.194
MEDIUM DEMAND										
Forecasted Demand Cont 20'	38.892	41.614	44.527	47.644	50.979	54.548	58.366	62.452	66.824	71.501
Forecasted Demand Cont 40'	27.060	28.954	30.981	33.150	35.470	37.953	40.610	43.452	46.494	49.749
LOW DEMAND										
Forecasted Demand Cont 20'	38.892	39.670	40.463	41.273	42.098	42.940	43.799	44.675	45.568	46.480
Forecasted Demand Cont 40'	27.060	27.601	28.153	28.716	29.291	29.876	30.474	31.083	31.705	32.339

Decision Tree: I defined random probabilities for the three forecast scenarios presented in Table 3.

Table 3. Probability of random scenarios

Type of Forecast	Probability
High	25%
Medium	25%
Low	50%

Note: These probabilities are estimated by the author.

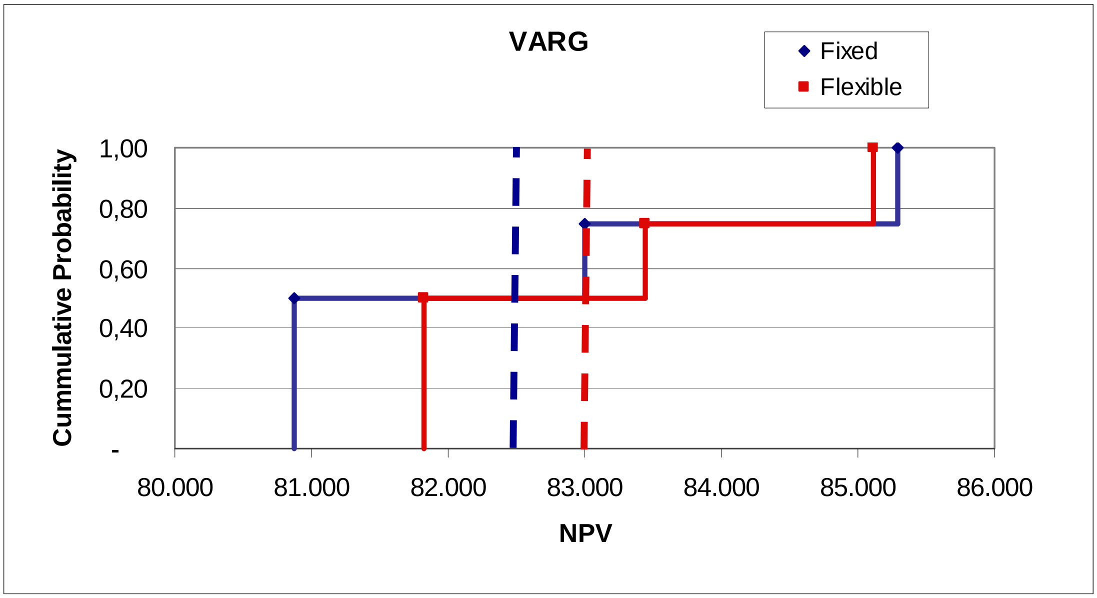
I believe that the high and medium scenarios are less likely to occur than the low scenario, thus I assigned lower probabilities numbers. The main reason for my belief is the uncertainty of the signature of the FTA (Free Trade Agreement) with the US especially with the election of the new US president. According to the Wall Street Journal in his online edition in April 2008 "*Sen. Barack Obama promised to stand firm in his opposition to the Colombia Free Trade Agreement on Wednesday–days after President Bush asked Congress to quickly pass the trade deal–in a speech to rally the union vote at the Pennsylvania AFL-CIO's annual convention*".[2] On the other hand, "*John McCain Will Push To Ratify The Colombia Free Trade Agreement. American exporters now pay an extra $3.5 million in tariffs each day because we don't have a completed trade agreement with Colombia*"[3]. Then, I calculated the

[2] http://blogs.wsj.com/washwire/2008/04/02/obama-vows-opposition-to-colombia-trade-deal/
[3] http://www.johnmccain.com/Informing/News/PressReleases/read.aspx?guid=8ecb028a-dd2e-47f1-965a-bbb422acb454

NPV for each branch based the basic data in Table 1 and the demand of Table 2. There are 27 possible branches in the decision tree and the result is in Figure 4.

Best strategy: Based on the assumptions made, the best strategy is the flexible strategy that generates an expected value of 83 million dollars. The best strategy is the acquisition of two cranes in year one and if demand increases to a high level expand to the additional 3 cranes. If demand is medium or low, is better to maintain the 2 cranes and not expand. In this situation, flexibility proves to be better that the fixed option of the investment in five container cranes in year 1. In this case, flexibility has a value of 536,000 dollars.

VARG Curve and Multiple Criteria: The Value at Risk (VARG) curve of the project is presented here. This VARG is made using the expected values of the second chance nodes. As you can see from the graph, the flexibility option reduces the variability and increased the mean net present value of the project.



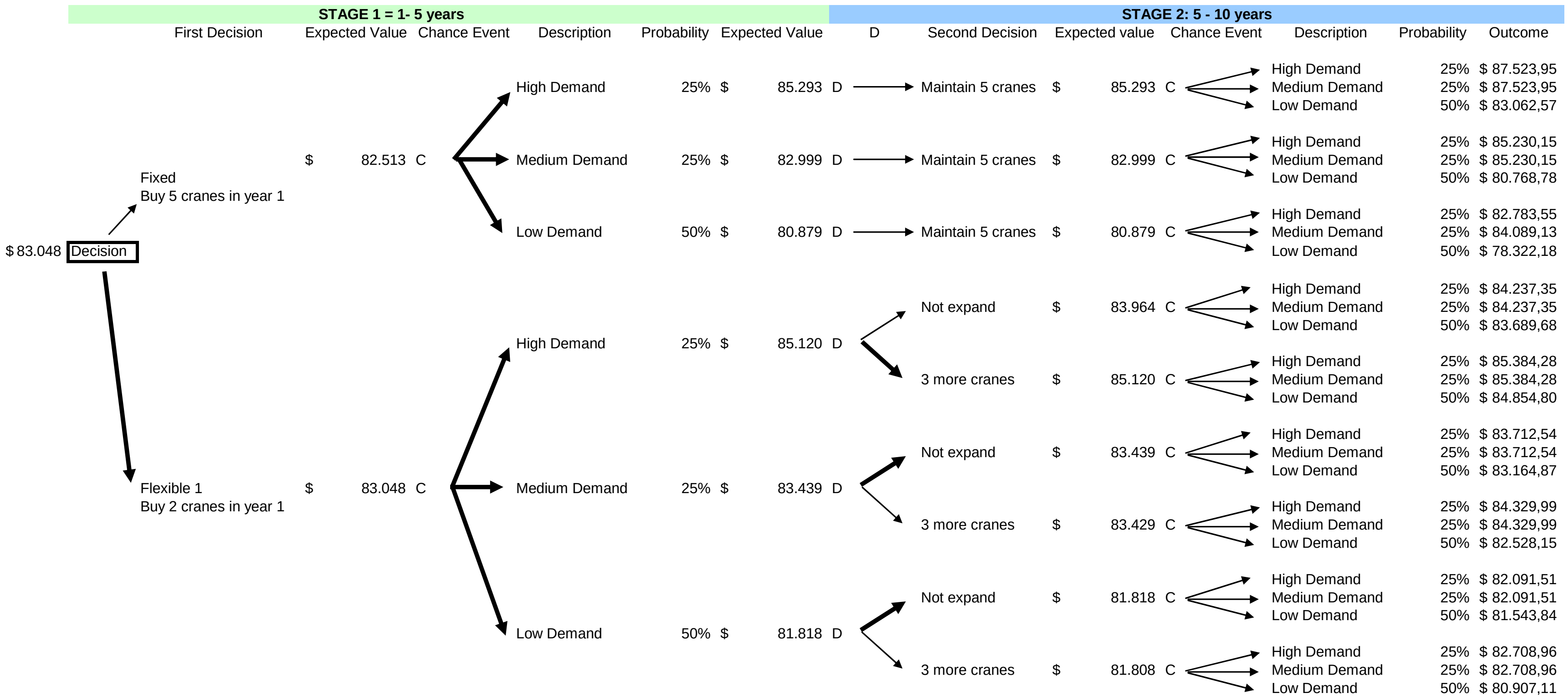


Figure 4. Decision tree

5 Lattice Analysis of Evolution of a major uncertainty

For the Lattice analysis, I'm going to assume that the demand for the containers in the port is going to follow a binomial distribution starting from year 0. There are two types of demand in the port, the one related to 20' containers and the one related to 40' containers. I'm only going to analyze the demand for 20' containers as a source of uncertainty. It is also assumed that demand growths exponentially and depend of the demand of the previous year. To get an approximation of the parameters of the model, I made a "Best to fit analysis" to find the values of the exponential growth per year (v) and the standard deviation (σ) for monthly demand export containers of 20'. In this case the v value is 2.34% per year and the value of σ is 52.66% per year.

With this information I calculated the value of u, d and p using the following formulas:

$$v_{year} = 0.5266$$
$$\sigma_{year} = 0.0234$$
$$\Delta t = 1 year$$
$$u = \ell^{\sigma\Delta t} = 1.69$$
$$d = 1/u = 0.59$$
$$p = 0,5 + 0,5 \times (v/\sigma) \times \sqrt{\Delta t} = 0.52$$
$$Value\ to\ start = 34200$$

With this information I calculated the Outcome Lattice and the Probability Lattice.

Table 4. Outcome Lattice

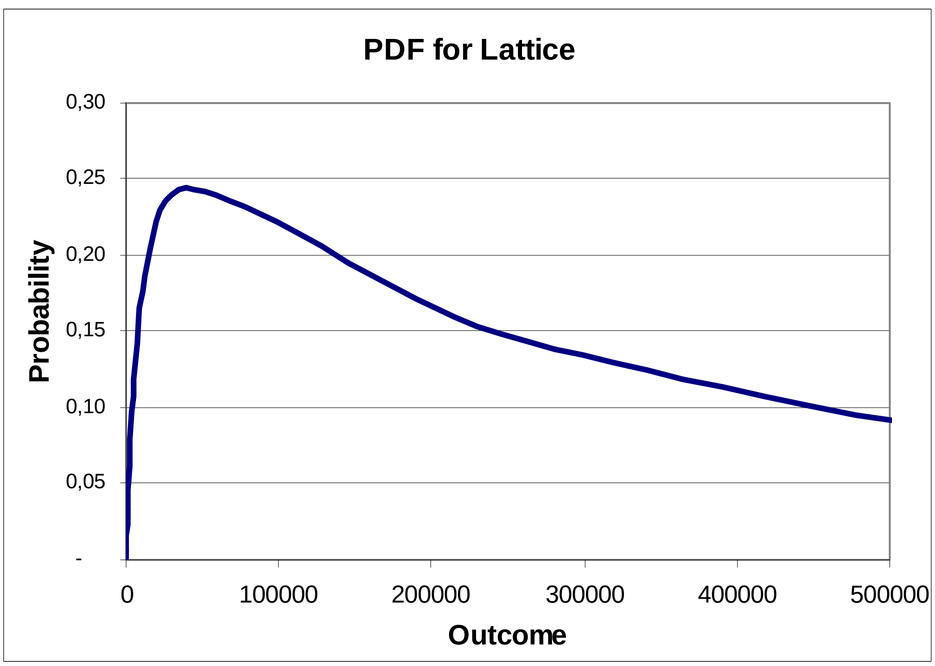
OUTCOME LATTICE										
0	1	2	3	4	5	6	7	8	9	10
34200	57904	98038	165989	281037	475827	805627	1364016	2309429	3910118	6620259
	20199	34200	57904	98038	165989	281037	475827	805627	1364016	2309429
		11930	20199	34200	57904	98038	165989	281037	475827	805627
			7046	11930	20199	34200	57904	98038	165989	281037
				4162	7046	11930	20199	34200	57904	98038
					2458	4162	7046	11930	20199	34200
						1452	2458	4162	7046	11930
							857	1452	2458	4162

								506	857	1452
									299	506
										177

Table 5. Probability Lattice

PROBABILITY LATTICE										
0	1	2	3	4	5	6	7	8	9	10
1,00	0,52	0,27	0,14	0,07	0,04	0,02	0,01	0,01	0,00	0,00
	0,48	0,50	0,39	0,27	0,18	0,11	0,07	0,04	0,02	0,01
		0,23	0,36	0,37	0,33	0,25	0,19	0,13	0,09	0,06
			0,11	0,23	0,30	0,31	0,28	0,24	0,19	0,14
				0,05	0,14	0,21	0,26	0,27	0,25	0,22
					0,02	0,08	0,14	0,20	0,23	0,24
						0,01	0,04	0,09	0,14	0,19
							0,01	0,02	0,06	0,10
								0,00	0,01	0,03
									0,00	0,01
										0,00

Then, I calculated the PDF (Probability Distribution Function) of this for the outcome over 10 years.



Based on the outcome lattice demand in Table 4, I created a lattice analysis for the project for 10 years. In this case, the fixed strategy is to buy 5 cranes in year 1 and continue with the same number of cranes for 10 years. The flexible strategy is buying 2 cranes in year 1 and 3 cranes in year 5 if demand is sufficient.

Calculations for the fixed strategy (5 cranes for 10 years)

Lattice demand in Table 4 is used to calculate the expected NPV of each node for the fixed strategy. The parameters to calculate the cash flows are the same of Table 1 (Decision Analysis) with one difference; the annual cost was reduced from 300,000 dollars to 186,000 dollars based on 20' containers share of capacity.

The Cash Flow (CF) of a node is calculated as the minimum amount between the capacity and the demand multiplied by the revenue per container minus the fixed cost per year. In year 1, the investment in five cranes is included as well as the increment of capacity for a total of 54,000 (40,000 + 5 x 2800) containers per year that remains constant during 10 years. In the rest of the years, there is an additional variable cost represented by the variable cost of the five cranes. Table 6 presents the calculated cash flows.

CASH FLOW FIXED LATTICE - 5 cranes in year 1										
0	1	2	3	4	5	6	7	8	9	10
4.601.967	3.874.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000
	-858.088	4.321.967	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000
		1.204.247	2.361.912	4.321.967	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000	7.094.000
			520.497	1.204.247	2.361.912	4.321.967	7.094.000	7.094.000	7.094.000	7.094.000
				116.654	520.497	1.204.247	2.361.912	4.321.967	7.094.000	7.094.000
					-121.868	116.654	520.497	1.204.247	2.361.912	4.321.967
						-262.746	-121.868	116.654	520.497	1.204.247
							-345.952	-262.746	-121.868	116.654
								-395.096	-345.952	-262.746
									-424.122	-395.096
										-441.266

Then I multiplied the cash flows with the correspondent probabilities in Table 5 to obtain the weighted cash flows.

Table 7. Weighted Cash Flows

CASH FLOW * PROBABILITY LATTICE

0	1	2	3	4	5	6	7	8	9	10
4487967	1963372	1903202	993801	518937	270975	141496	73885	38581	20146	10520
	-464489	2099846	2728202	1899459	1239809	776874	473273	282435	165915	96263
		248923	804000	1571787	2269030	1777241	1299239	904571	607298	396393
			44347	248434	668682	1307247	1981497	1655496	1296684	967277
				138	55325	232449	583946	1141591	1779840	1548975
					-5875	207	57977	216525	524518	1025412
						-4484	-10261	241	57863	202593
							-2616	-8950	-13167	258
								-1383	-5874	-12562
									-699	-3452
										-345

Then, I calculated the sum of the undiscounted and discounted weighted cash flows. The expected value of the fixed strategy (5 cranes) during the first 6 years is 24.5 million dollars and for 10 years is 36.3 million dollars.

Table 8. Sum of the undiscounted and discounted weighted cash flows.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
E [Cash Flow]	4601967	1612883	4365971	4684350	4352755	4611946	4345029	4570941	4343107	4546524	4345332
PV(E[Cash Flow])	4601967	1536079	3960064	4046518	3581022	3613581	3242328	3248483	2939586	2930730	2667657
ENPV over 6 years	**24581559**										
ENPV over 10 years	36368014										

I also calculated the Expected NPN (Cash Flow) with the folding back process of the Lattice.

Table 9. ENPV (Cash Flow) Fixed Strategy

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
ENPV (Cash Flow)	36368014	43065174	48100198	46442557	42675983	37753207	32248973	26412722	20284658	13850190	7094000
FIXED STRATEGY		22742269	33556293	39356201	39829767	36932565	32130089	26412722	20284658	13850190	7094000
Fixed: 5 cranes in year 1			15189969	21232141	27368225	31574954	30456687	26151480	20284658	13850190	7094000
Dynamic programming				7530240	11558129	16137591	20512317	22759749	19710593	13850190	7094000
Approach					2772728	5116826	7855311	10705416	12884777	12588713	7094000
(check next year)						244876	1515846	2916400	4253825	5059282	4321967
							-850628	-112415	616258	1172464	1204247
								-1168995	-652680	-183424	116654
									-1095340	-656415	-262746
										-821415	-395096
											-441266

To calculate the information on each node, I started in year 10 with the information from Table 6 (Cash flow lattice). From year 9 to 1, I calculated a weighted average based on the results of the next year bringing to the current year with the discount factor and then adding the present cash flow. This is an example for the first node of year 9: Node = (p * $CF_{fixedyear10Node1}$ + (1-p) * $CF_{fixedyear10Node2}$) / (1+r) + $CF_{fixedyear9}$. This is a numerical example for the first node of year 9: 13,850,190 = (0.52*7,094,000 + 0.48*7,094,000) / (1+0.05) + 7,094,000. The final result in year 0 is the same result that I obtained in Table 8.

Calculations for the flexible strategy (2 cranes in year 1 and 3 cranes in year 5)

There are five steps in this analysis. The first two steps are based on the strategy of maintaining 2 cranes fixed for 10 year. The following two steps are based on starting with 2 cranes and expand to 3 cranes in year five. The final step is the comparison of the two options to decide if the expansion to 3 cranes in year 5 is adequate or not.

<u>First step: Cash Flow of MAINTAINING 2 CRANES FOR 10 YEARS</u>: This is the undiscounted cash flow generated by maintaining 2 cranes during 10 years. See results in Table 10.

Table 10. Cash Flow of MAINTAINING 2 CRANES FOR 10 YEARS Not dynamic programming approach (check current year).

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Cash Flow	4601967	4798000	6086000	6086000	6086000	6086000	6086000	6086000	6086000	6086000	6086000
FLEXIBLE STRATEGY		1241912	4489967	6086000	6086000	6086000	6086000	6086000	6086000	6086000	6086000
Flexible: 2 cranes in year 1			1372247	2529912	4489967	6086000	6086000	6086000	6086000	6086000	6086000
NOT dynamic programming				688497	1372247	2529912	4489967	6086000	6086000	6086000	6086000
approach					284654	688497	1372247	2529912	4489967	6086000	6086000
(check current year)						46132	284654	688497	1372247	2529912	4489967
							-94746	46132	284654	688497	1372247
								-177952	-94746	46132	284654
									-227096	-177952	-94746
										-256122	-227096
											-273266

The information on each node is the undiscounted cash flow of each year taking into account the capacity expansion. The formula for each node is the following: Node = Minimum (demand; extended capacity) * revenue per container - fixed cost - (variable cost per crane)*(2 cranes per year). This is an example for the first node of year 10. The capacity on this year is 45,600 (2 cranes x 2800 containers per crane + 40,000). Then, 6,086,000 = MIN

(805,627: 45,600)*140- 186,000 – 56,000*2. Note: Investment in 2 cranes is taking into account in year 1.

Second step: ENPV (Cash Flow) MAINTAINING 2 CRANES FOR 10 YEARS Dynamic programming approach (check next year). I also calculated the Expected NPN (Cash Flow) with the folding back process of the Lattice. See results in Table 11.

Table 11. ENPV (Cash Flow MAINTAINING 2 CRANES FOR 10 YEARS Dynamic programming approach (check next year).

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
ENPV (Cash Flow)	35395321	40003423	42028728	40150759	36704000	32404046	27666655	22659688	17402372	11882190	6086000
FLEXIBLE STRATEGY		23950736	31432764	35105216	34745124	31870075	27598206	22659688	17402372	11882190	6086000
Flexible: 2 cranes in year 1			15551481	20842137	25798475	28149071	26499634	22509275	17402372	11882190	6086000
Dynamic programming				8381674	12047379	16062810	19523444	20259591	17071847	11882190	6086000
Approach					3739884	5904477	8402462	10895440	12489481	11155879	6086000
(check next year)						1140228	2279565	3541906	4734206	5387282	4489967
							-86909	513091	1096639	1500464	1372247
								-543489	-172299	144576	284654
									-614959	-328415	-94746
										-493415	-227096
											-273266

This is the process that I followed to calculate the information in each node. In year 10, I put the cash flows of the last column of Table 10. From year 9 to 1, I calculated a weighted average based on the results of the next year bringing to the current year with the discount factor and then adding the flexible present cash flow from Table 10. This is the formula that I used, Node = (p * $CF_{flexibleyear10Node1}$ + (1-p) * $CF_{flexibleyear10Node2}$) / (1+r) + $CF_{flexibleyear9}$. This is a numerical example for the first node of year 9: 11,882,190 = (0.52*6,084,000 + 0.48*6,084,000) / (1.05) + 6,084,000.

Third step: Cash Flow of STARTING WITH 2 CRANES IN YEAR 1 AND EXPAND TO 3 CRANES IN YEAR 5. This is the undiscounted cash flow of this strategy. See results in Table 12.

Table 12. Cash Flow of 2 CRANES IN YEAR 1 AND 3 CRANES IN YEAR 5. Not dynamic programming approach (check current year).

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Cash Flow	4601967	4798000	6086000	6086000	6086000	7262000	7094000	7094000	7094000	7094000	7094000
FLEXIBLE STRATEGY		1241912	4489967	6086000	6086000	7262000	7094000	7094000	7094000	7094000	7094000
Flexible: 2 cranes in year 1			1372247	2529912	4489967	7262000	7094000	7094000	7094000	7094000	7094000
3 cranes in year 5				688497	1372247	2529912	4321967	7094000	7094000	7094000	7094000
NOT dynamic programming					284654	688497	1204247	2361912	4321967	7094000	7094000
Approach						46132	116654	520497	1204247	2361912	4321967
(check current year)							-262746	-121868	116654	520497	1204247
								-345952	-262746	-121868	116654
									-395096	-345952	-262746
										-424122	-395096
											-441266

The information on each node is the undiscounted cash flow of each year taking into account the capacity expansion. The formula for each node is the following: Node = Minimum (demand; extended capacity) * revenue per container - fixed cost - (variable cost per crane)*(# cranes available per year). This is an example for the first node of year 10. The capacity on this year is 54,000 (5 cranes x 2800 containers per crane + 40,000). Then, 7,094,000 = MIN (805,627: 54,000)*140- 186,000 – 56,000*5. Note: Investment in 2 cranes is taking into account in year 1 and investment in 3 cranes is taking into account in year 5.

Fourth step: ENPV (Cash Flow) of 2 CRANES IN YEAR 1 AND 3 CRANES IN YEAR 5 Dynamic programming approach (check next year).

Table 13. ENPV (Cash Flow of 2 CRANES IN YEAR 1 AND 3 CRANES IN YEAR 5 Dynamic programming approach (check next year).

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
ENPV (Cash Flow)	38828178	44362905	47420635	46531700	43827983	40021207	32248973	26412722	20284658	13850190	7094000
FLEXIBLE STRATEGY		26730183	35120181	39980509	40981767	39200565	32130089	26412722	20284658	13850190	7094000
Flexible: 2 cranes in year 1			17629534	23617284	29696225	33842954	30456687	26151480	20284658	13850190	7094000
3 cranes in year 5				9915383	13886129	18405591	20512317	22759749	19710593	13850190	7094000
Dynamic programming					5100728	7384826	7855311	10705416	12884777	12588713	7094000

approach						2512876	1515846	2916400	4253825	5059282	4321967
(check next year)							-850628	-112415	616258	1172464	1204247
								-1168995	-652680	-183424	116654
									-1095340	-656415	-262746
										-821415	-395096
											-441266

This is the process that I followed to calculate the information in each node. In year 10, I put the cash flows of the last column of Table 12. From year 9 to 1, I calculated a weighted average based on the results of the next year bringing to the current year with the discount factor and then adding the flexible present cash flow from Table 12. This is the formula that I used, Node = $(p * CF_{flexibleyear10Node1} + (1-p) * CF_{flexibleyear10Node2}) / (1+r) + CF_{flexibleyear9}$. This is a numerical example for the first node of year 9: 13,850,190 = (0.52*7,094,000 + 0.48*7,094,000) / (1.05) + 7,094,000.

Fifth step. ENPV (Cash Flow) WITH FLEXIBILITY TO EXPAND Dynamic programming approach (check next year).

Table 14. ENPV (Cash Flow) WITH FLEXIBILITY TO EXPAND (checking next year).

	Foldback					If	Foldback 2 cranes year 1				
ENPV (Cash Flow)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Dynamic programming	36764076	41965205	44701531	43560272	40707983	36745207	27666655	22659688	17402372	11882190	6086000
approach		24814653	32822817	37252620	37861767	35924565	27598206	22659688	17402372	11882190	6086000
(check next year)			15930834	21550004	27111391	30566954	26499634	22509275	17402372	11882190	6086000
(check next year)				8441718	12168116	16305591	19523444	20259591	17071847	11882190	6086000
					3739884	5904477	8402462	10895440	12489481	11155879	6086000
						1140228	2279565	3541906	4734206	5387282	4489967
							-86909	513091	1096639	1500464	1372247
								-543489	-172299	144576	284654
									-614959	-328415	-94746
										-493415	-227096
											-273266

This is the process that I followed:

- From year 10 to 6, I put the same results of Table 11. These are the results of the folding back process of maintaining 2 cranes fixed for 10 years.

- In year 5, I made a comparison between the results in column 6 (“2 cranes for 10 years”) with the results in year 6 of Table 13 (“2 cranes in year 1 + 3 cranes in year 5”). I brought to present value both results and added the correspondent cash flows of the “2 cranes for 10 year”. Then I compare the two results, if “2 cranes in year 1 + 3 cranes in year 5” is bigger than “2 cranes for 10 years” then expansion is better and vice versa. This is an example for the first node of year 5:
  - For “2 cranes for 10 years” = (0.52*27,666,655+0.48*27,598,206) / 1.05 + 6,086,000 = 32,403,904
  - For “2 cranes in year 1 + 3 cranes in year 5” = (0.52*32,248,973+0.48*32,130,089) / 1,05 + 6,086,000 = 36,744,960
  - So, in this case, “2 cranes in year 1 + 3 cranes in year 5” is better.
- From year 4 to 1, I continue the folding back from the results in column 5.

This table indicated the years when is adequate to execute the option of purchasing the 3 cranes in year 5.

Table 15. Summary of decisions

	0	1	2	3	4	5
WITH EXPAND OPTION in year 5	NO	NO	NO	NO	NO	YES
Dynamic programming		NO	NO	NO	NO	YES
approach			NO	NO	NO	YES
(check next year)				NO	NO	YES
					NO	NO
						NO

In summary and based on the assumptions I made, the call option of purchasing 3 cranes in year 5 is positive when demand is higher.

I did two calculations, the value of the call option and the value of flexibility. The value of the call option is 1.3 million and it was calculated as the difference of the lattice from “2 cranes for 10 years” and “2 cranes in year 1 + 3 cranes in year 5”.

ENPV - 2 cranes in year 1	35.395.321
ENPV - 2 in year 1 and 3 in year 5	36.764.076
Value of (call) option to expand	1.368.755

The value of flexibility is 396,062 dollars and it was calculated as the difference between the fixed alternative of buying 5 cranes in year 1 with “2 in year 1 and 3 in year 5”.

ENPV (fixed) - 5 cranes in year 1	36.368.014
ENPV (flexible) - 2 in year 1 and 3 in year 5	36.764.076
Value of flecibility	396.062

VARG for the Lattice

I calculated the VARG for five years of the project comparing “2 cranes for 10 years” with “2 cranes in year 1 + 3 cranes in year 5”.

To calculate the VARG is necessary to find the paths and its probabilities in the two options. In the case of the “2 cranes for 10 years”, is necessary to calculate the present values of the cash flows from Table 10.

Table 16. Fixed PV Cash Flow

Table 16	**0**	**1**	**2**	**3**	**4**	**5**	**6**
PV Cash Flow:	4601967	4569524	5520181	5257316	5006967	4768540	4541467
2 cranes in year 1		1182774	4072532	5257316	5006967	4768540	4541467
			1244669	2185434	3693907	4768540	4541467
				594749	1128951	1982253	3350483
					234185	539455	1023992
						36146	212413
							-70701

Then you calculate the probabilities and the NPV of each path.

Table 17. Enumeration of paths without closing option (NPV Possibilities)

EPV	P	P(PATH)	ENUMERATION OF PATHS WITHOUT CLOSING OPTION					
694.626	0,020	0,020	34265962					
3.697.270	0,111	0,019	34265962	34265962	34265962	34265962	32818313	29431563
7.877.997	0,255	0,017	34265962	34265962	34265962	34265962	34265962	32952902
7.793.169	0,311	0,016	33074978	33074978	31761918	28975630	31627329	30314269
3.636.000	0,213	0,014	26649140	25201491	22129609	19564653	18121855	21814741
891.628	0,078	0,013	17310276	13923526	11095662	9504978	8610212	8106903
93.119	0,012	0,012	7823789					
24.683.809	1,000							

For the “2 cranes in year 1 + 3 cranes in year 5, I calculated the present values of the year before of the cash flows with the expanded port.

Table 18. PV CASH FLOW 2 CRANES IN YEAR 1 AND 3 CRANES IN YEAR 5

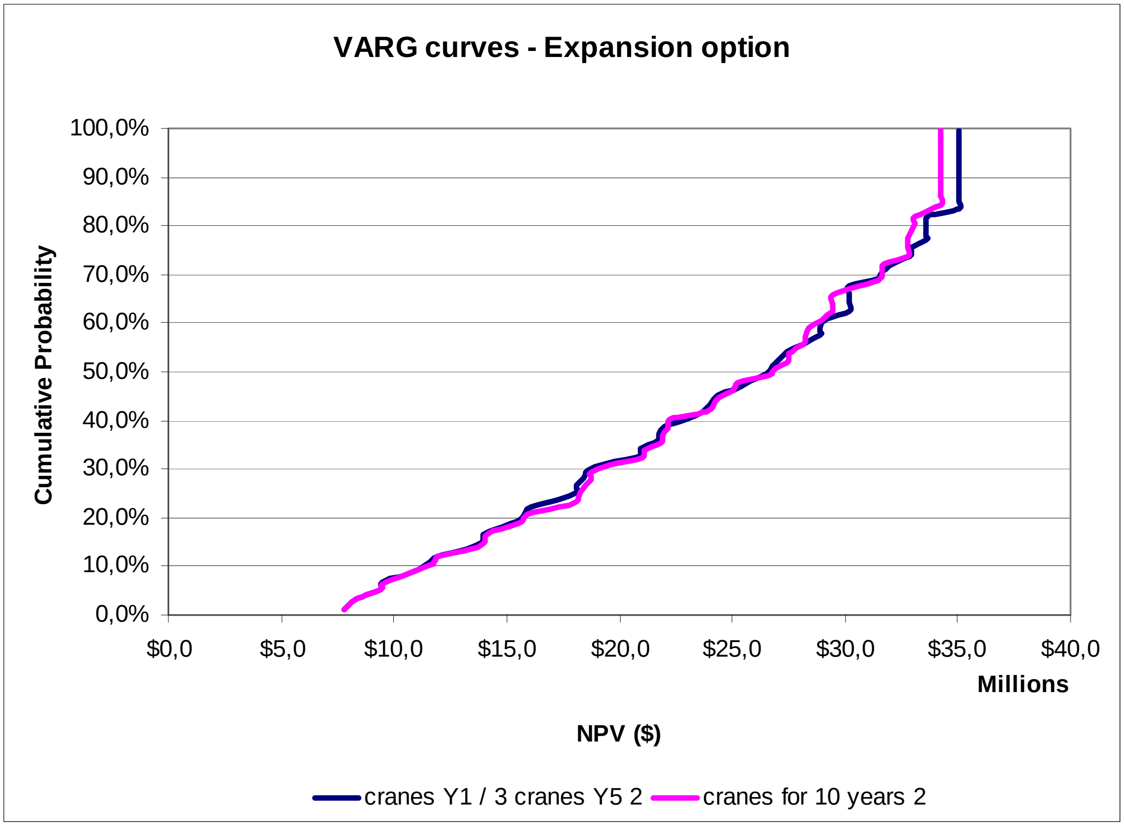
Table 18	0	1	2	3	4	5	6
2 in year 1 and 3 in year 5	4601967	4569524	5520181	5257316	5006967	7335372	5293652
		1182774	4072532	5257316	5006967	7335372	5293652
			1244669	2185434	3693907	7335372	5293652
				594749	1128951	3627658	3225118
					234185	2184860	898628
						1681551	87049
							-196065

Then you calculate the probabilities and the NPV of each path. In the calculation of the NPV is important to take into account the results in Table 15 because if the option is NO you have to use the present values of Table 16, if the option is YES you have to use the present values on Table 18.

Table 19. ENUMERATION OF PATHS (NPV POSSIBILITIES)

EPV	**P**	**P(PATH)**	**ENUMERATION OF PATHS (NPV POSSIBILITIES)**					
709.874	0,020	0,020	35018147					
3.780.988	0,111	0,019	35018147	35018147	35018147	35018147	33570499	30183749
8.069.518	0,255	0,017	35018147	35018147	35018147	35018147	35018147	33705087
7.754.223	0,311	0,016	32949614	32949614	31636554	28850266	31501965	30188905
3.618.181	0,213	0,014	26523775	25076127	22004244	19439289	18121855	21689377
891.628	0,078	0,013	17310276	13923526	11095662	9504978	8610212	8106903
93.119	0,012	0,012	7823789					
$ 24.917.531	**1,00**							

Then you calculate the cumulative probability and the result is the VARG.



In this case flexibility also proved to be a better option extending the right tale of the chart increasing the expected NPV.

6 Conclusion

This is the summary of results from decision analysis:

	CAPEX t=0	Mean ENPV	Min ENPV	Max ENPV
Fixed Buy 5 cranes from year 0	3.5 million	82.513	80.879	85.293
Flexible Buy 2 cranes in year 1 and 3 additional cranes in year 5	3.04 million	83.048	81.818	85.120

In the case of the lattice analysis, the value of flexibility is 396,062 dollars. These results are not comparable. The inputs were different; bur both proved that flexibility has value.

In general, I believe that for the case of a port expansion is better the decision analysis approach. The main reason for this is that the lattice analysis is not flexible enough to support several uncertainties at the same time; for example, the demand of the rest of the containers types or the price of the services if that is the case. I also believe that in a real project regarding port expansion decision analysis is the best way to do it.

In this process I've learned the value of flexibility. My main take away is that flexibility decision is not a random act. This is an aspect that requires analysis and awareness from the decision makers to take into account from the beginning o the process.

In my case was really interesting to compare the approach to uncertainty of this class to the approach of 15.770 Logistics System where time series was the answer. This class opened my mind to a different way of dealing with uncertainties.

Related to the structure of the course, I believe that the methodology of the course of classes and recitations is very valuable. I also think that the VARG curve is very valuable and is easy to understand from a managerial perspective. This might be a good way to introduce decision makers to this way of thinking.

The Excel course at the beginning of the semester is very important for the course. It is important to maintain but it could be interesting to extend it to two weeks maybe to cover functions in detail.