Real Options for a Computer Wholesaler Distribution Center Expansion Strategy

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Table of Contents

Abstract

In this paper, the expansion of a distribution chain of a computer wholesale company into a specific region of Peru is analyzed using real options analysis. The driving force behind the expansion of distribution centers (DC's) is that clients in the region will no longer have to assume transportation risks and costs and as a result demand will increase from the region for each DC established. A fixed design of establishing just one large DC is explained. Then it is contrasted with a flexible design that has the one time option each year to add just one other DC that will increase demand in the region by a certain percentage. The option is thus similar to a European call option that seeks to take advantage of potential upsides in uncertainty. The main uncertainty across which the designs are contrasted is demand. First, a two stage decision analysis is carried out where demand uncertainty is modeled with uniform random distributions, and the value of the option is assessed. Second, the demand is modeled by lattice analysis which uses a lognormal binomial distribution for demand, and the value of the option is calculated in this scenario. Results suggest that while real options has clear potential to exploit upsides of uncertainty in this case, the model used to describe the demand uncertainty and the values of the fixed parameters used greatly determine the value of the option. The results of the analysis in the paper reveal new areas and issues for future productive investigation of the system.

System Background

The system analyzed in this paper entails the distribution chain of a computer wholesale company in Peru in a specific region of the country in its interior, Huancayo. The system to be deployed and analyzed is establishing new distribution centers (DC's) in that region where none exists, and these new locales would in theory help increase profit from the region and grow the information technology market there as well. As it stands, the region currently gets its distribution from the central warehouse in Lima, and the costs and risks of shipment are incurred by the clients in Huancayo. However, under the system to be analyzed, the company would assume these costs and risks, but would be able to sell at a higher price in the region as well as increase demand there since potential customers would no longer have to assume the previous risks. Also, the DC's would not carry inventory, but simply be regional outposts where the pre-ordered merchandise could be picked up by the customers when the merchandise is shipped every month. This eliminates complications caused by overstock and computer depreciation.

The system analysis presented in this paper contrasts a fixed and flexible strategy of establishing DC's in the region. The fixed strategy consists of establishing one large DC in the region. Adding to the fixed strategy the option of adding a second, smaller DC that would increase demand by a certain percentage is the option in the flexible strategy.

It is important to note that the system includes only the segment of the client region in Huancayo and excludes all other regional markets. Also, the merchandise being analyzed will be looked on as computers as predetermined whole units, rather than parts, which would complicate the analysis by fragmentizing it per part and brand.

Given the nature of the system, the time frame of the analysis will be over 3 to 5 years, as it would be too uncertain to forecast demand beyond this time frame in a region that is fairly susceptible to national and market issues, as the next section addresses.

System Uncertainties

In practice, there are various factors that could affect the system. The political situation can deteriorate the market for computers in the Huancayo region, for example. Various climate issues, such as with El Nino, can complicate travel to this region which is relatively hard to access. Peru is very subject to these types of logistical disruptions, and so customers tend to lose faith in the DC approach and often prefer to buy directly from Lima, if at all. However, though important, these issues are very difficult to model and speculate as to their future. Thus, for the purposes of this system model, it is necessary to neglect side issues and concentrate on market forces. Such market forces include the effect of competition causing sales to fall, and then the profitability of having a local DC would be heavily compromised. Another relevant market force although exogenous is the overall economic situation of Peru which would influence buying power of clients and the industry as a whole. All of these market uncertainties are reflected in demand (and therefore sales).

It is clear then that the main uncertainty applying to the system is demand, and it is influenced positively and negatively by different factors. One factor that increases demand stems from the general underlying driver in having a DC in the region. The idea is that customers do not have to assume the costs and risks of transporting merchandise themselves. As a result, demand is expected to increase from year to year in the region as clients gain confidence in the established, reliable system. The particular increase in demand can vary within a certain range. However, this projected demand can also be less than a projected value due to market competition, low service levels, and economic factors among other things. Thus, the demand must be allowed to vary below the mean forecasted value within a certain range as well. While the decision analysis will model the demand uncertainty using uniform distributions, the lattice analysis will use a lognormal binomial distribution. Each distribution has its differences in assumptions to be explained later. The specific numerical models are explained in their corresponding sections.

Basic Data

Before explaining in detail the fixed and flexible strategies to be analyzed, Table 1 defines the fixed parameters that will be used in analyzing the system. As related before, the system entails the use of one large DC and the potential use of a smaller DC that will increase demand by a certain percentage.

Note on References used in this paper: Although the system described relates to a potentially very real problem, the actual data used in this paper including cost structures and demand are purely hypothetical. The values do not come from a validated source and are meant simply as a means to the end of illustrating real options analysis principles in a hypothetical application.

Table 1: Fixed parameters to be used in subsequent analysis.

Cost and Price Structure		
	Big DC	2nd DC
Cost/ unit	$400	$400
Shipping Cost /unit	$3	$3
Margin/ unit	13.5%	13.5%
Price/ unit	$454	$454
Revenue/ unit	$51	$51
Cost of Locale/ yr	$20,000	$5,000
Cost of Operating DC/ yr	$80,000	$37,500
Total Fixed Cost/ yr	$100,000	$42,500
% Demand increase	0.0%	7.5%
Discount rate	12.0%	12.0%

There are a few key implicit assumptions being made with the structure defined as above.

- The system assumes that only one homogeneous product, identified as a PC, is the unit sold as opposed to a whole collection of diverse products that would be sold in reality.
- Although the DC's are in separate locations, the shipping cost per unit is assumed to be the same for both.
- The margin at which each unit is sold is assumed constant for all customers. In practice, volume discounts and/or different customer strata make pricing more complex.
- The DC's are rented locales, which accounts for the disparity between operating and locale costs.

Each of the bulleted simplifications are made to highlight the relevant issues at the heart of the flexibility issue and not get bogged down in complex calculations.

Fixed Design

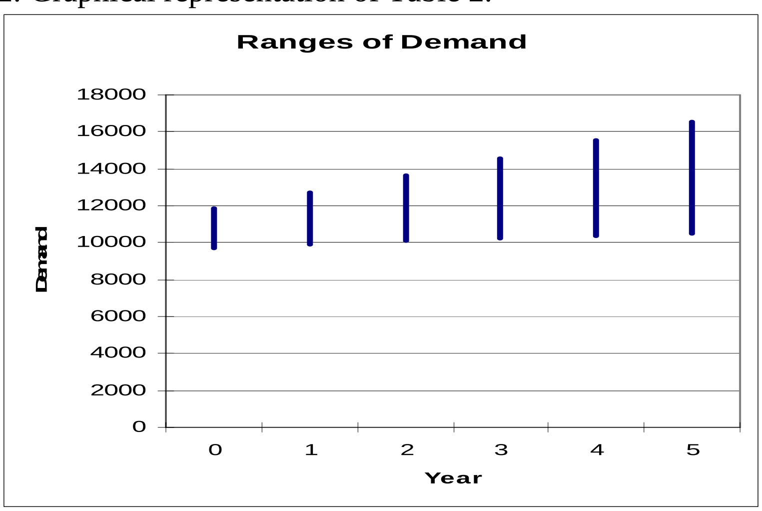
The fixed design is comprised of starting out with one large DC in year 1 to establish a solid customer base and remaining with only this DC throughout the life of the system. This large DC will be a leased or rented locale in the region, and it is assumed that no initial investment has to be made in year 0 to acquire the place. The costs of whatever modifications and investments are made in the DC are accounted for in the locale and operation costs and are distributed evenly over the lifetime of the system. This assumption is fairly good given current industry practice in the provinces of Peru outside of Lima, where rental costs are very low compared to acquiring real estate that may easily and unpredictably devalue.

At this point it is a good point to introduce the exact framework adopted for modeling demand uncertainty in decision analysis. The previous section discussed the justifications and drivers behind the demand uncertainty, and below the exact model is given. The demand for the decision analysis is modeled with a uniformly distributed random variable in each year. Note that the mean demand in each year increases, but so does the uncertainty as events farther in the future are less certain. Thus the model allows for demand to be high in one year and significantly drop in the next. That is, demand is independent from year to year. Table 2 and Figure 1 describe the model for the demand uncertainty.

Table 2: Uniformly distributed demand forecast for decision analysis.

	Year					
	0	1	2	3	4	5
Demand	10800	11340	11880	12420	12960	13500
% uncertainty	10.0%	12.5%	15.0%	17.5%	20.0%	22.5%
low end	9720	9922.5	10098	10246.5	10368	10462.5
high end	11880	12757.5	13662	14593.5	15552	16537.5

Figure 1: Graphical representation of Table 2.



Flexible Design

The flexible design uses the same assumptions as the fixed design in terms of demand uncertainty for decision analysis. As before, the idea is that adding a DC will increase proximity to potential smaller clients and lure them into the market by increasing visibility and reducing their transportation risks.

The difference between the two designs is the option available starting in the second year after the large DC has grown the regional market in the first year. This option is to build a second smaller, lower cost DC that will automatically increase the demand, whatever it may be, by a certain percentage. The demand is taken from the model presented in the fixed case, except it is multiplied by a factor (1.075 is the hypothetical value in this case). The potential drawback to the option is the added yearly cost of having the locale and operating it. Of course, this option seeks to take opportunity of potential high demand in the subsequent years. Because the option embedded seeks to take advantage of an upside and can be exercised only at one time and at fixed intervals (i.e. at the end of a year), it is similar to a European call option.

Note that the value of the option (and hence of the flexible design) depends directly on the percentage increase of demand parameter which is set at 7.5%. While in reality this parameter would also vary, here the focus will be on the effect of the parameter and not on its accuracy. This is an extension of the simplifying assumptions being made to identify and analyze the most important parts of a very complex real system.

Finally, it is assumed that once the option is exercised it is permanent until the end of the system life. That is, once the second DC is established it cannot be closed. The reason for this important requirement is the necessary condition of path independency for the lattice valuation that is to come. This condition restricts the option as a call option that takes advantage of upside potential. Thus the flexible strategy to be analyzed does not have the added complexity of having also a put option to close the small DC to avoid losses. While this is would be a more important and interesting case to analyze in reality, for the sake of coherence between the decision analysis and lattice valuation it will not be analyzed in this paper.

Two-Stage Decision Analysis

The decision analysis to be used in this section compares the fixed and flexible strategies and decides on the basis of expected NPV which strategy is best over a period of the years 1 and 2. The method of analysis requires that the chance outcomes be divided into different strata: high, medium, and low demand. Each of these levels of chance must have a probability associated to it in both stages. After all the possible paths are enumerated over two periods, a NPV must be associated to each path. The analysis using a decision tree then consists of taking expected values at chance nodes and choosing higher value expected outcomes at decision nodes. The end result is an expected NPV and a clear depiction of the best strategy to follow over two periods.

Since the outcomes of chance in years 1 and 2 are uniformly distributed random variables, it makes sense to divide the levels of demand into the high, medium, and low levels according to Table 3.

Table 3: Definition of high, medium, and low demands for years 1 and 2.

Probabilities for Stages 1 & 2		
H1	0.25	>11340*1.0625
L1	0.25	<11340*.9375
M1	0.50	else
H2	0.25	>11880*1.075
L2	0.25	<11880*.925
M2	0.50	else

The factors are computed according to the percent uncertainty in each year. For example, in the first year there is a 12.5% uncertainty and so the 75^{th} percentile in the uniformly distributed range is: 11340*(1+(.125/2))=11340*1.0625. It follows that above this value lie the high demand outcomes by defining the proportions between high, medium, and low demand levels to be 1:2:1.

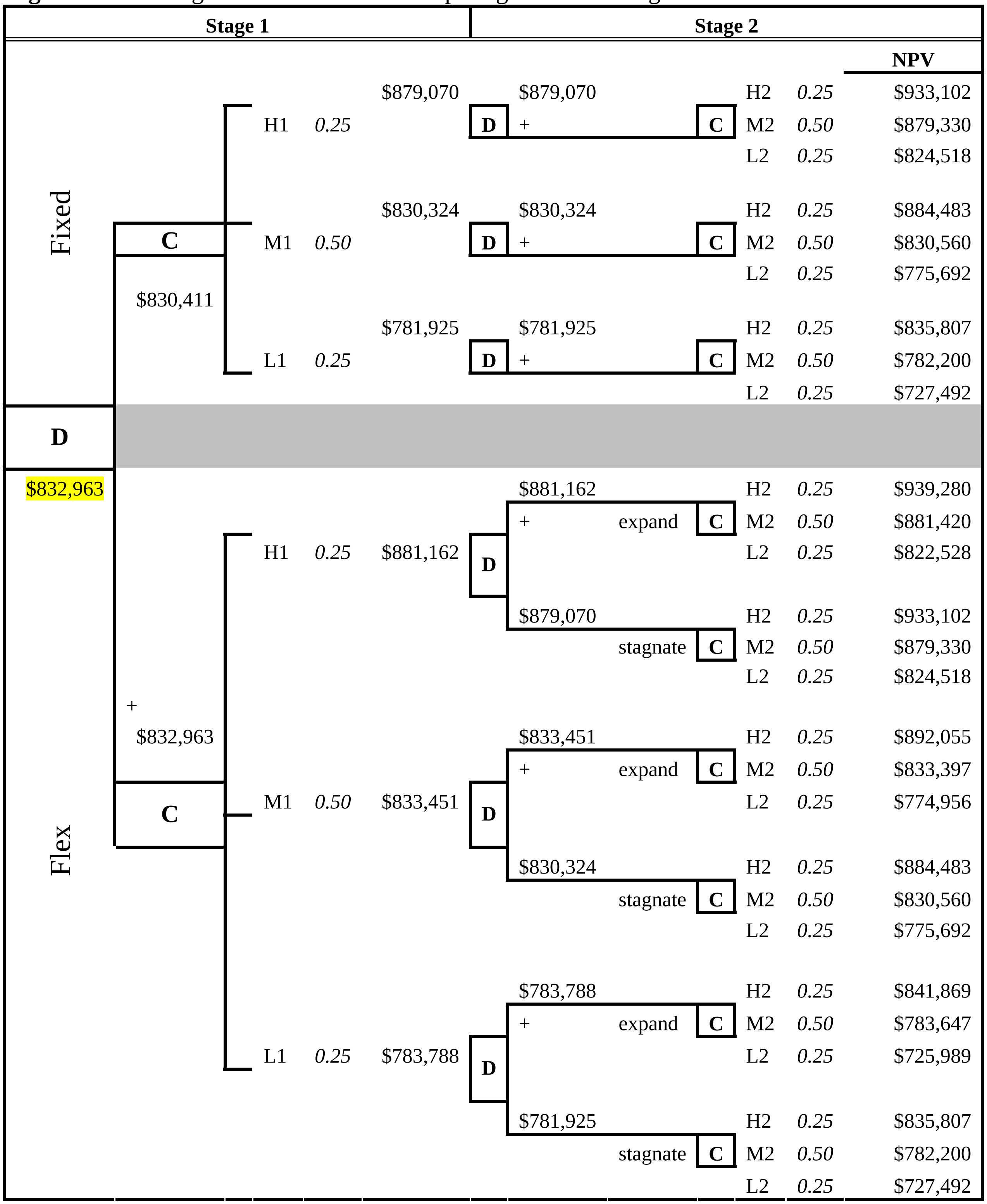
The next issue to consider is how to get the expected NPV at the end of a path over two years. To do this, a simulation of 1000 runs was carried out for each possible path in both strategies by isolating the demand levels appropriately in each case. Note that there are 27 possible paths over two periods, but that half of the values in the flexible branch result in the same NPV's as the fixed branch where the second decision in the flexible branch is not to expand. Table 4 shows an example simulation for how the scenario of high demand in years 1 and 2 in the fixed case is calculated in Excel.

Table 4: Example calculation of one branch of the Decision Tree in Fixed Case. Demand is high in both years. Resulting NPV is simulated 1,000 times to get value in Tree.

FIXED	Year 1	Year 2	
			NPV@12%
Demand	12602	12993	
	=11340*RAND()*0.0625+11340*1.0625	=11880*RAND()*0.075+11880*1.075	
Revenue	$515,061	$593,975	$933,117
	=12600*(R-C-S)-O-L	=12991*(R-C-S)-O	

Where: R=Price/unit ; C=Cost/unit; S=Shipping Cost/unit;
O=Operating Cost Big DC/year; L=Locale Cost Big DC/year

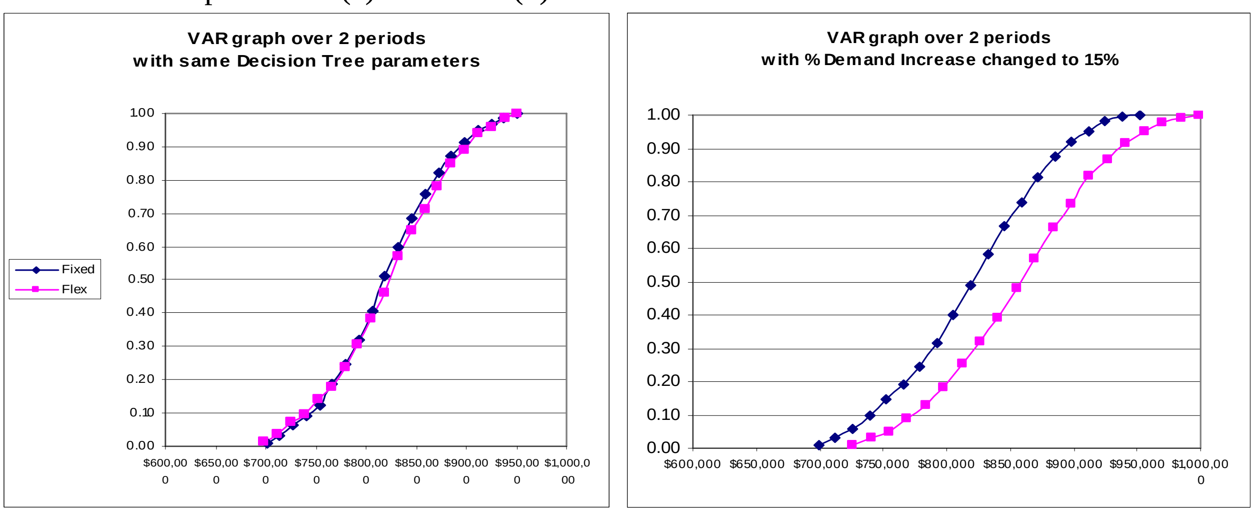
Figure 2: Two Stage Decision Tree for comparing the two strategies.



Results indicate that over two periods, the flexible strategy is slightly better than the fixed strategy that does not have the option to expand in the second year. Also, the optimal strategy revealed by the decision analysis is to choose the flexible plan in the first year and to add the smaller DC in the second year under all conditions. However, the very low percentage gain of the flexible strategy over the fixed strategy, about .4%, indicates that the two strategies are almost identical over two periods. This is a direct consequence of the parameters in the cost and pricing structure.

To illustrate how the value of the option is sensitive to these parameters, the following value-at-risk (VAR) graphs are provided (Figure 3). The optimal strategy to expand in the second year in the flexible case is used as derived from results. The first graph shows the situation analyzed in the decision tree. It is clear that the two strategies look almost identical with the flexible strategy shifted to the right by a narrow margin. However, with just the percent demand increase parameter doubled to 15%, the flexible strategy of expanding in the second year has a much higher expected value as is evidenced by the shifted curve of the flexible strategy. Similar effects are obtained by lowering the costs of the second DC. By extension, a lower percent demand increase parameter and higher costs for the second DC would make the flexible strategy less valuable.

Figure 3: Value-at-risk graphs for fixed versus flexible strategies using % demand increase parameter (a) 7.5% and (b) 15%.



(a) (b)

As a final comment to the preceding decision analysis, the fact that the option is a one time option with no possibility of closing the second DC does not matter over two periods since the option can be exercised beginning only in the second year. If the analysis were extended to three periods or more, it would then become an important issue because the option to close the small DC after it has been added in the second year would be neglected.

Lattice Analysis of Uncertainty

To use lattice analysis to analyze the system the main assumption that must be modified from the preceding decision analysis is the demand uncertainty model. Where previously demand was assumed to be uniformly distributed over certain ranges at each year, now the demand is modeled by a binomial distribution which spans out from year 0. Also, the demand in a year now depends on the demand in the previous year, and there the binomial lattice assumes an exponential demand increase. For this analysis it will be assumed that demand grows from year to year at a rate of 5% and that the initial demand for PC's is 10,800 units in year 0. Also, a volatility of 10% is assumed.
Thus, the following binomial lattice calculations apply:

$$\sigma = 10\%$$

$$v = 5\%$$

$$\Delta t = 1 \text{ year}$$

$$u = e^{\sigma\sqrt{\Delta t}} = 1.10517$$

$$d = \frac{1}{u} = 0.90484$$

$$p = .5 + .5\left(\frac{v}{\sigma}\right)\sqrt{\Delta t} = 0.75$$

Tables 5 and 6 are the probability and outcome lattices, and Figure 4 is the PDF for the outcome lattice over 5 years.

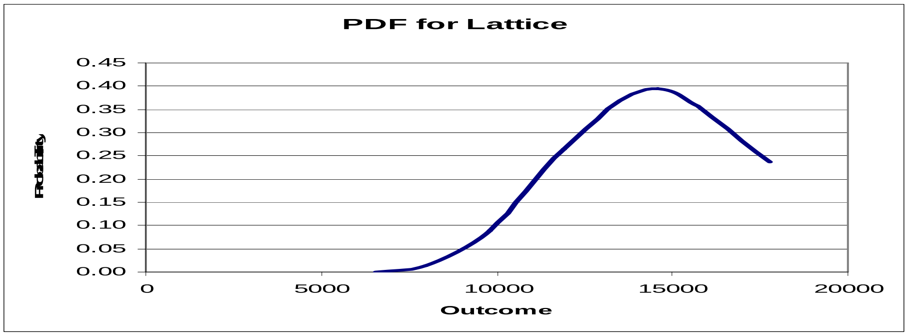
Table 5.

PROBABILITY LATTICE					
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
1.00	0.75	0.56	0.42	0.32	0.24
	0.25	0.38	0.42	0.42	0.40
		0.06	0.14	0.21	0.26
			0.02	0.05	0.09
				0.00	0.01
					0.00

Table 6.

OUTCOME LATTICE					
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
10800	11936	13191	14578	16112	17806
	9772	10800	11936	13191	14578
		8842	9772	10800	11936
			8001	8842	9772
				7239	8001
					6551

Figure 4: PDF for outcome lattice over 5 years.



Lattice Valuation of Option

In this section the value of the option over 5 years is calculated using the lattice developed for demand. The methodology consists of calculating the expected NPV's for the fixed strategy and for the flexible strategy. Their difference is the option value.

To obtain the expected NPV for the fixed strategy, the demand from each year at each node is used to develop the revenue lattice for the fixed strategy (Table 7a). Then each revenue in this lattice is multiplied by its corresponding probability from the probability lattice to produce a lattice of the revenue contributions to expected value for the fixed strategy (Table 7b). Summing the columns and discounting for each year at the 12% discount rate, the expected revenue for the fixed strategy of staying with one large DC is obtained (Table 7c).

Table 7: (a) Net Revenue at each node: Fixed Strategy; (b) Net Revenue Contributions to E[value]: Fixed Strategy; (c) Sums columns of 5b to get E[value] for Fixed strategy.

Table 7a.	**Net Revenue at each node: Fixed Strategy**				
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
$0	$508,728	$572,749	$643,502	$721,697	$808,116
	$398,384	$450,800	$508,728	$572,749	$643,502
		$350,957	$398,384	$450,800	$508,728
			$308,043	$350,957	$398,384
				$269,212	$308,043
					$234,077

Table 7b. Net Revenue Contributions to E[value]: Fixed Strategy					
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
$0	$381,546	$322,171	$271,478	$228,349	$191,770
	$99,596	$169,050	$214,620	$241,628	$254,510
		$21,935	$56,023	$95,091	$134,137
			$4,813	$16,451	$35,014
				$1,052	$4,512
					$229

Table 7c. Sums columns of 5b to get E[value] for Fixed strategy.

Undiscounted	$0	$481,142	$513,156	$546,933	$582,571	$620,172
Discounted	$0	$429,591	$409,085	$389,296	$370,234	$351,902
E[value]	$1,950,109					

For calculating the net revenues in Table 7a, the same structure for costs of locale, PC's, and profit margin were used as in the two-stage decision analysis for the sake of coherence. For example, for the high value of demand in year 1, the formula used is: Demand*$(\text{Revenue})_{\text{per unit}}$- $(\text{Total Cost})_{\text{1stDC}}$= $508,728. In Table 7b, this value is multiplied by the corresponding probability from the probability lattice: $508,7280*0.75= $381,546. The results for each node are used as described earlier to arrive at the expected NPV of the fixed strategy in Table 7c.

The expected NPV value for the flexible case involves comparing two scenarios at each node, having just one large DC or adding to the system a second smaller DC that will increase the demand by 7.5%. It is assumed the addition of the second smaller DC is permanent for simplicity and to fit the binomial lattice framework.

The algorithm used to work back to the NPV of the flexible case is as follows.

1. Start at year 4 looking towards the two possible scenarios in year 5 and choose the alternative with the highest expected value. For example, from the perspective of the highest possible demand in year 4, staying with one DC has an expected value: 0.75*$808,116+0.25*$643,502=$766,963. Note that these two net revenue values are obtained from Table 7a. Adding a second DC would yield an expected value: 0.75*$833,724+0.25*$656,765=$789,484. Note that these two net revenue values are not calculated above but are calculated for each node from the formula: Net Revenue=Demand*1.075*$(\text{Revenue})_{\text{per unit}}$-$(\text{Total Cost})_{\text{1stDC}}$-$(\text{Total Cost})_{\text{2ndDC}}$. Thus from the perspective of the being at the highest possible demand in year 4, one should exercise the option to open the second DC. Repeat the process for each node in year 4.
2. For each node in year 4, calculate the present value as seen from that node in that year. Staying with the same example in the highest node of year 4, the formula for the present value is in Excel: $721,697+NPV(.12, $789,484)= $1,426,594. Note that the discounted expected value of the highest scenario in year 5 is added to the net revenue of the fixed scenario node in year 4. This same procedure is done for each node in year 4 and the results are inputted into the present value net revenue lattice for the flexible case (Table 8).
3. For each node in year 3, the expected net revenue for two scenarios are again compared. For example, from the perspective of the highest demand in year 3, the first scenario looking into year 4 is the one shown explicitly in Table 8. The expected value of the scenario is: 0.75*$1,426,721+0.25*$1,134,762=$1,351,647. Note that this scenario assumes that the option is applied starting only in year 5. This expected value must then be compared to the scenario where the option is exercised starting in year 4. Expected value in this case is: 0.75*$1,445,721+0.25*$1,134,762=$1,367,981. Note that the revenues in the latter scenarios are not shown explicitly in the lattices but have to be calculated for each node. For example, to get the high value in year 4 the formula is:

$740,824 +NPV(.12, $789,484)= $1,445,721. The $740,824 value is simply the value of the net revenue in year 4 applying the option in that year. Since the second scenario gives a higher expected NPV, it is used to fill in the node in Table 8 by the formula: $643,502+NPV(.12, $1,367,981)=$1,864,914. This procedure is repeated to fill in the year 3 column in Table 8.

4. The same procedure as explained in step 3 is used to finish filling in the values back to year 0, which gives the PV of having the flexible option. The one further constraint is that the flexible and fixed options are the same in year 1 since it is assumed only the large DC is used in year 1.

The above algorithm results in the following present value net revenue lattice for the flexible strategy (Table 8). Also, based on which scenario was better at each node looking into the future, a strategy lattice for the flexible case is constructed. Table 9 indicates whether at the end of that year the option for next year should be exercised. Also note that the decision in year 0 is automatically not to exercise the option since it is assumed that the system will have only the one large DC in year 1.

Table 8:		**PV Net Revenue: Flexible Strategy**			
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
$1,970,457	$2,335,524	$2,158,187	$1,864,914	$1,426,594	
	$1,821,074	$1,686,806	$1,465,080	$1,126,806	
		$1,313,232	$1,141,816	$881,361	
			$885,546	$686,492	
				$527,740	

Table 9:	**Exercise Option? Exercise one time option when yellow**				
Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
NO	YES	YES	YES	YES	
	NO	YES	YES	YES	
		NO	NO	YES	
			NO	NO	
				NO	

With the above analysis, the value of the having the option to add a second smaller DC that will increase demand by 7.5% can be calculated as in Table 10.

Table 10: Calculation of option value for lattice valuation.

E[NPV] for Flexible Strategy	$1,970,457
E[NPV] for Fixed Strategy	$1,950,109
Value of Option	$20,348

The results of Table 9 also make sense qualitatively. If the demand is high, then the 7.5% increase in demand makes up for the extra cost and even provides a profit above the cost. However, if demand is low, then the 7.5% increase in demand cannot make up for the extra cost in exercising the option each year. As in the decision analysis, all other things held equal, a higher value for the percent increase in demand parameter increases the value of the option. This is shown by the following table.

Table 11: Effect of % Demand increase parameter on option value.

% Demand Increase Parameter	**Value of Option**
2.5%	$0
5.0%	$152
7.5%	$20,348
10.0%	$63,914
12.5%	$108,707
15.0%	$153,500

In the lattice analysis, the rate of growth (v) and the volatility (σ) also change the value of the option. To show the quantitative effects of different v and σ combinations, the following data table (Table 12) is provided assuming the original fixed cost and profit structure. It is assumed that v is always less than or equal to σ.

Table 12: Value of Option for different v and σ combinations in Lattice Analysis.

Value of Option		v						
		0.0%	2.5%	5.0%	7.5%	10.0%	12.5%	15.0%
σ	5.0%	$1,866	$7,939	$17,465				
	10.0%	$5,537	$11,907	$20,348	$30,736	$42,469		
	15.0%	$10,147	$16,835	$25,109	$35,030	$46,406	$59,009	$72,771
	20.0%	$15,510	$22,646	$31,112	$40,941	$52,296	$64,855	$78,599
	25.0%	$21,751	$29,427	$38,282	$48,345	$59,887	$72,658	$86,609
	30.0%	$29,033	$37,314	$46,705	$57,244	$69,157	$82,360	$96,742
	35.0%	$37,499	$46,481	$56,542	$67,722	$80,216	$94,052	$109,074
	40.0%	$47,348	$57,142	$68,007	$79,987	$93,271	$107,929	$123,796
	45.0%	$58,825	$69,554	$81,368	$94,315	$108,601	$124,279	$141,203
	50.0%	$72,221	$84,031	$96,956	$111,050	$126,567	$143,477	$161,683

Table 12 indicates that as the growth rate and/or the volatility increases, so does the value of the option. The results make sense qualitatively, given that in general flexible strategies increase in value in scenarios of greater uncertainty.

Conclusion

The development and analysis of the system studied in this paper has shown that real options analysis has great promise not just in the system of expanding DC's in Huancayo, but also in any system where expansion in the midst of uncertainty can lead to better returns at an added cost. It is also clear that both decision analysis and lattice evaluation can be very powerful tools if used appropriately under the correct circumstances.

In developing the paper a few lessons have been learned concerning when flexible designs are most useful. First, the results support the notion that the value of an option in a flexible strategy tends to increase with increasing uncertainty. This is evidenced by Table 12 which shows that as volatility increases, so does the option value. A similar result is obtained when increasing the ranges of uncertainty in the decision analysis although those results are not explicitly shown in the paper. Second, for flexibility to be worthwhile, the right option must be applied to the particular scenario. For instance, this paper presupposes that the option of adding a second DC is the best to take advantage of potential demand increases. However, what is not discussed in the paper is all of the brainstorming about different options such as simply providing shipping insurance from Lima that could be used to the same end. It turned out that when analyzing this other option initially, it would not be as desirable since it would take too much of the profit.

Other more specific lessons relating to the expansion of DC's in Huancayo have also been learned and can serve as starting points for future analysis. First, more detailed data must be analyzed to pin down the true nature of demand behavior in the region since the accuracy of the entire analysis depends on how well the demand uncertainty is modeled. For example, the decision analysis assumed that demand patterns are independent from year to year while the lattice model assumed that they were not. Second, since the lattice valuation does not allow for path dependency, the flexible strategy of adding and removing DC's was not analyzed. Pure decision analysis would have to be applied in this case, which would consist of a lengthy process of developing a rather large decision tree over the system life. Third, a further complexity to be resolved would be the stratification of customer types. Finally, since the industry in question comprises a wide variety of products, some sort of framework would have to be developed to account for product diversity.

And so, as a whole, doing the application portfolio is a necessary exercise to truly understand real options analysis. In modeling and analyzing any system there are many side issues and problems discovered along the way which may seem to be trivial at first but that in reality have a deep connection to the issues at heart. Thus, the opportunity to develop this application portfolio in the context of class material has helped me gain a better and sincere appreciation for the very valuable tools that this kind of analysis has to offer.

References

Although the system described relates to a potentially very real problem, the actual data used in this paper including cost structures and demand are purely hypothetical. The values do not come from a validated source and are meant simply as a means to the end of illustrating real options analysis principles in a hypothetical application.

To develop the binomial lattice for the demand uncertainty, the following Excel spreadsheet was taken from the internet and used as an initial tool:

"Binomial Lattice.xls".
From: http://ardent.mit.edu/real_options/Common_course_materials/spreadsheets.html
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