Investing in Human Capital

Application Portfolio
by
Marie-Claude Nadeau

Presented to
Prof. Richard de Neufville
Michel-Alexandre Cardin
Thomas Rand-Nash

ESD.71 Engineering Systems Analysis for Design
Engineering Systems Division
Massachusetts Institute of Technology

Submitted on November 27, 2007

Executive Summary

The impact of uncertainty on a system where a car manufacturer's market share and sales are related to the quality and size of its workforce is investigated. The system is modeled by making simplified assumptions to describe the relationship between the workforce's experience level, education and training investment, workforce productivity, product quality, and total sales. Performance of the system is varied by modifying the number of workers hired and the time at which they are employed. The variability in global demand constitutes the main uncertainty factor.

The monetary value of flexibility is estimated using two variations of decision analysis: a decision tree and a binomial lattice. The base case for both methods includes a plant of fixed capacity and a fixed initial number of workers hired. The flexible plans considered constitute of a larger plants with initially smaller workforces, with the option of hiring more workers later in the project lifetime. When a decision tree is used, the fixed plan is determined to have a higher expected present value over 10 years than the flexible plan. Using a binomial lattice developed over 6 years, the opposite conclusion is found. Implications of these results, including relevance of method and the dependence of value on problem definition, are discussed.

Table of Contents

1. System Description

In a large number of industries, the quality of the workforce is a key factor in establishing a company or product's position in the market. Moreover, as products and processes grow more complex, having access to a qualified workforce becomes essential to delivering a product that is of good quality, innovative, and attractive to consumers. Many companies are now investing in hiring and training a highly skilled workforce, instead of striving to minimize labor costs. Moreover, they are doing so earlier in the process, trusting that investing in human capital ahead of the demand curve will yield higher future revenues. These trends are accompanied by forecasts of reduced availability or greater competition for this highly skilled workforce[1], leading to a possible increase in wages.

The car manufacturing world is no exception to these trends, and knowledge intensity has increased in both its product and workforce over the past decades. The industry is now facing a number of new challenges, including the adoption of alternative power trains and the incorporation of novel materials, which promise to boost product complexity while raising the need for highly skilled workers. Car manufacturers have the option of making an upfront investment in human capital or of waiting to see where the demand goes.

I'm interested in investigating the impact of uncertainty on a system where a car manufacturer's market share and sales are related to the quality and size of its workforce. The system can be modeled by making simplified assumptions to describe the relationship between the workforce's experience level (or time employed in the company), education and training investment, workforce productivity, product quality, and total sales.

Design levers

The performance of the system can be improved by changing the number of employees hired (or fired), and how far in the future these changes are made. The cost of hiring an employee includes an initial cost (to cover administration costs, interview process overhead and basic company training), as well as yearly wages.

In addition, capacity of the plant being built can be scaled, which allows the system designer to take more or less advantage of economies of scale. The capacity of the plant can be different from the capacity allowed by the current workforce productivity, but the actual production will be determined by the minimum of the two. Cost of the plant is composed of an initial investment that is scaled to capacity but takes into account

---

[1] SINGH, Mahender. (2004). A Review of Leading Opinions on the Future of Supply Chains. MIT Supply Chain 2020 Project Working Paper.foo

economies of scale, and of annual variable (operational) costs, excluding labor, which are directly proportional to actual production.

Uncertainty factors

Future demand for the product and future workers' wages are uncertain. Both are strongly related to economic conditions: strong economic growth will potentially increase demand for and the cost of skilled workers, and the demand for cars; however, a recession could reduce customer demand while decreasing the cost of skilled labor. Technical innovations may also increase the demand for new car designs, or provide a substitution product that will sharply decrease demand. Technical innovation in all fields can also cause scarcity of skilled labor and increase wages.

Future changes in market regulations may also affect both customer demand and wage levels. Stronger customer-oriented environmental regulations could decrease the demand for cars, or increase the demand for cars with alternative power trains. Industry-oriented environmental regulations could increase the need for innovative designs and strategies in all aspects of production, and increase the value of highly skilled workforce. Furthermore, new labor regulations impacting the free circulation of workers internationally could either increase or decrease the availability of skilled workers in certain regions. Labor union progression or regression, as well as new regulations regarding the treatment of workers, could change the cost of letting off employees.

Other model parameters

The system is modeled using a set of intermediate parameters that relate externally determined design levers and uncertainty factors to costs and revenues. Some of these parameters are described below:

Workforce productivity is the maximum number of cars produced per employee. This is a function of the workforce's average experience level and the company's investments in training and education.

A product quality factor is determined by the number of employees, the average experience level and training investments. It will influence the company's future market share and product price.

The number of products sold is a function of market demand for this type of product, workforce productivity, number of employees, and product quality. Product quality will affect the company's share of the overall market demand, while productivity and number of employees will set the maximum sales number.

The price of the product is influenced by overall market demand, and product quality.

2. Salient Uncertainties

In the system I will be investigating, future demand for the product and future workers' wages are uncertain. Both are strongly related to economic conditions: strong economic growth will potentially increase demand for and the cost of skilled workers, and the demand for cars; however, a recession could reduce customer demand while decreasing the cost of skilled labor. Changes in oil prices may also decrease or increase the demand for cars, depending on fuel efficiency.

Technical innovations may increase the demand for new car designs, or provide a substitution product that will sharply decrease demand. Technical innovation in all fields can also cause scarcity of skilled labor and increase wages.

Future changes in market regulations may affect both customer demand and wage levels. Stronger customer-oriented environmental regulations could decrease the demand for cars, or increase the demand for cars with alternative power trains. Industry-oriented environmental regulations could increase the need for innovative designs and strategies in all aspects of production, and increase the value of highly skilled workforce. Furthermore, new labor regulations impacting the free circulation of workers internationally could either increase or decrease the availability of skilled workers in certain regions, and limit the number of cars that could be exported to regions with high demand growth. Labor union progression or regression, as well as new regulations regarding the treatment of workers, could change the cost of letting off employees.

Finally, major political events could prohibit sales in parts of the world where the demand has the most growth potential. A terrorist event involving one form of transportation or another could also shift consumer demand toward a mode of transport that is perceived as less dangerous, and thus decrease or increase the demand for cars.

Consumer demand

Worldwide car sales have increased steadily in the last seven years, going from 46.4 million units in 2000 to 55.8 million units in 2006. This increase is mainly due to strong sales growth in Asia. Figure 1 shows the progression of car sales, as well as a forecast for years 2007-2009. Yearly growth from 2000 to 2006 has varied from 0.2% to 3.9%, with an average of 1.7%.

In order to represent the variability in sales growth, it could be appropriate to model future growth according to a normal distribution centered around 1.5% or so. For every year ahead, the growth percentage relative to the previous year is randomly picked from this normal curve. Sales absolute value can start at the realistic number of 55.8 millions units sold in 2006.

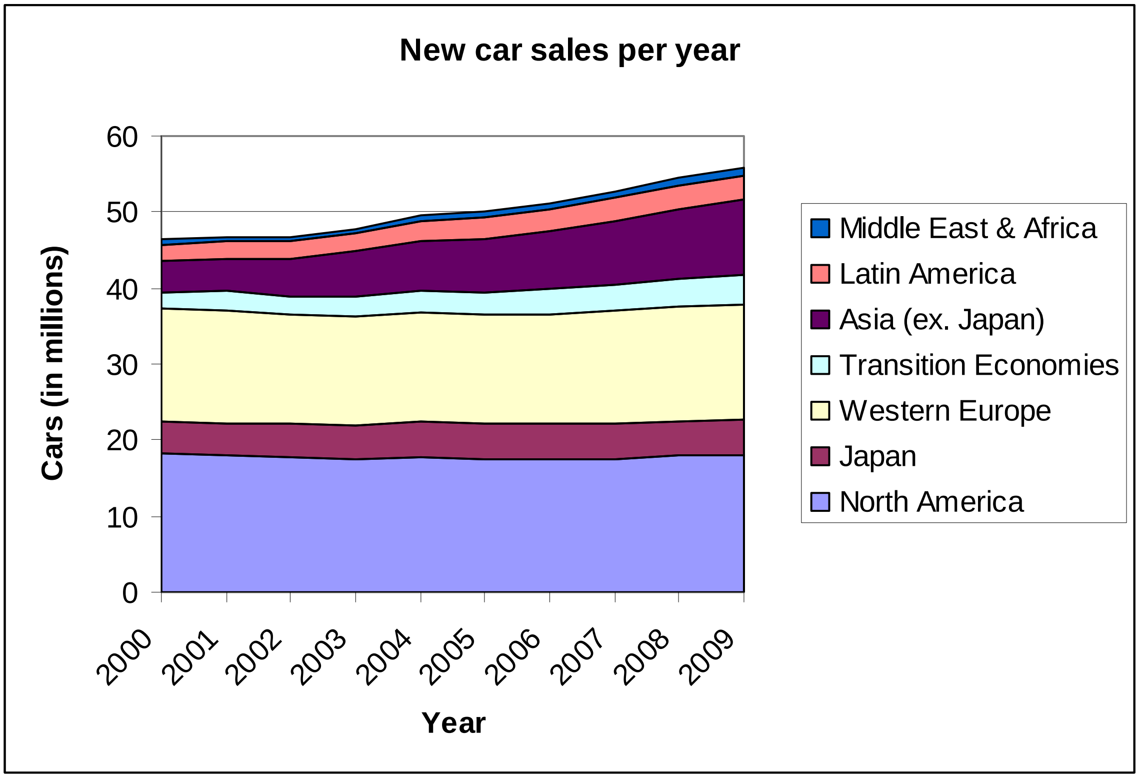

Figure 1 Worldwide annual car sales[2]

Workers' wages

As shown in Figure 2 below, workers' wages in the manufacturing industry have varied from $710 to $740 in the last 10 years, showing almost no growth overall. In fact, the compounded annual growth rate between 1997 and 2007 was 0.04%.

In order to represent the variability of wages, a similar approach to the one just presented can be used. This way, yearly wage growth can be randomly sampled from a normal distribution centered around 0.05%. The starting absolute value can be the 2007 value of $724, adjusted for additional health and pension benefits incurred to the employer.

2 The Economist Intelligence Unit Ltd. (2006). Automotive Forecast. Retrieved on October 2, 2007 from www.eiu.com.

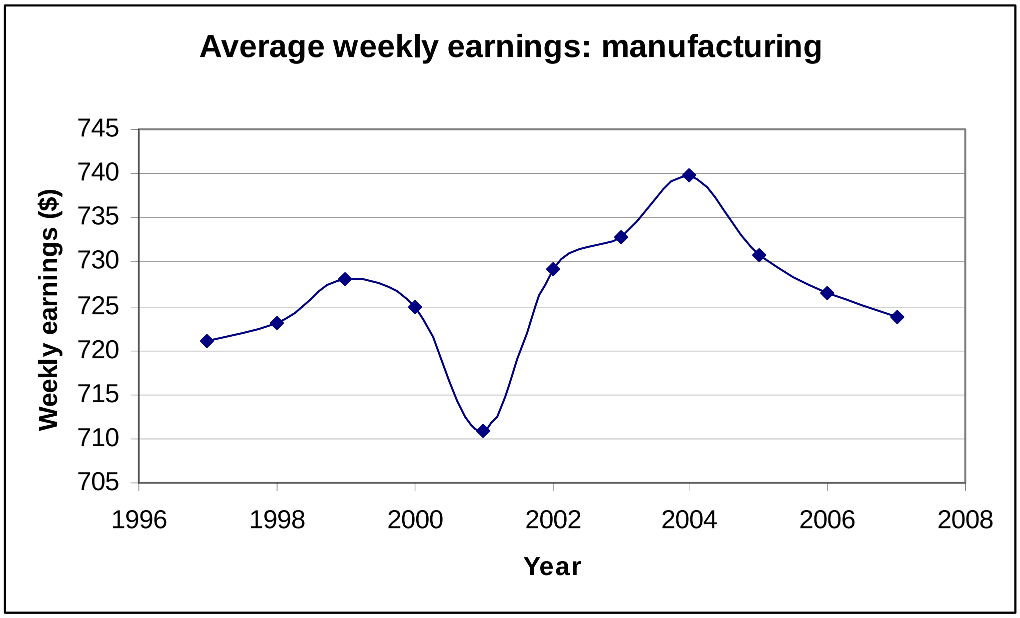

Figure 2 Annual averages of weekly earnings for manufacturing workers[3]

For the sake of simplicity, the analyses that follow will assume a fixed annual growth rate for wages and only consider explicitly the uncertainty in demand. Note however that the uncertainty in future wages could potentially be investigated using very similar analyses.

[3] Bureau of Labor Statistics, U.S. Department of Labor. Employment, Hours, and Earnings from the Current Employment Statistics survey (National). Retrieved on October 2, 2007 from http://www.bls.gov/home.htm

3. Alternative Designs

Both designs considered will be modeled over a 10 year lifetime. Main variable inputs to the model (design levers) are the number of workers hired/fired, which can vary yearly. Future total demand and wages are uncertain and are assumed to also vary yearly; starting values for these uncertainty factors are the same for all designs.

The preferred design or strategy will be chosen to maximize the present value of revenue, net of labor costs.

Design 1: Fixed Workforce Strategy

The fixed workforce strategy consists of hiring a certain number of workers at year 0, and maintaining that workforce at the same level for years 1 through 10, no matter how demand evolves. The initial number of workers can be chosen to either respond to the expected value of demand in year 10, but also to its maximum or minimum level, depending on whether the goal is to be able to capture demand upturns or to minimize labor costs in case of downturns. The yearly investment in education and training also remains constant throughout the 10 years considered.

The potential advantage of this strategy is that workers hired early will have a gained maximum average experience level by year 10, allowing them produce a higher quality product, thus potentially gain a larger market share and capture a larger part of any upturn in demand.

Design 2: Flexible Workforce Strategy

The flexible workforce strategy consists of hiring a certain number of workers at year 0 to cover for the expected (or minimum/maximum) value of demand after a period shorter than 10 years. After this time period has elapsed, estimates for future demand are revised according to actual demand, and an appropriate number of workers are hired or fired in accordance with this new estimate. Investments in education and training can also be adjusted at this point.

The potential advantage of this strategy is that investments in labor are delayed until some of the uncertainty about the evolution of demand is resolved, allowing the company to be better shielded against market downturns, while also being able to adjust for possible upturns.

4. Decision Analysis

Each stage considered has a length of 5 years, but only the flexible design can be adjusted after year 0. Demand was simulated (2000 instances) using a geometric Brownian motion model to obtain probabilities for low, medium and high scenarios. The starting value for world wide demand was 55.8M units, and the average growth rate used was 1.7%, with volatility of 2%. In order to scale down the problem to approximately a single plant, only a segment of global demand is considered by dividing the total number by 100. For simplicity, the decision analysis will consider a constant yearly wage increase of 0.1% and only take into account future demand uncertainty.

The discount rate used is 10%.

At year 0, the estimates of demand for years 5 and 10 are:

Table 1

Prior probabilities of demand for year 5 ('000 units)		
Scenario	Estimated value	Probability
Low	567	0.22
Medium	607	0.43
High	801	0.35
Expected Value	667	-

Table 2

Prior probabilities of demand for year 10 ('000 units)		
Scenario	Estimated value	Probability
Low	578	0.25
Medium	660	0.39
High	1,512	0.36
Expected Value	946	-

Stage 1 Decision Node

- Fixed Strategy: Hire the number of workers needed to produce enough units in year 10 in order to cover the expected value of demand. The capacity of the plant should also be equal to this expected value. At year 10, workers will have reached 10 years of experience on average. The model assumes this means a productivity of 600 units/worker/year, and a market share of 30%. The number of workers to be hired at year 0 is then:

  946,000 * 0.3 / 600 = 473 workers

  And the capacity of the plant is:

946,000 * 0.3 = 283,800 units

- Flexible Strategy: Hire the number of workers needed to produce enough to cover the expected value of demand for the lowest year 10 scenario. However, the plant should be built to accommodate more than this capacity. As evaluated below, the expected value of segment demand in year 10 for the stage 1 low scenario is 681,000The number of workers hired is then:

  681,000 * 0.3 / 600 = 342 workers

  As will be explained below, the expected segment demand (global demand/100) for year 10 if the demand is high at year 5 is 953,000. Therefore the plant should be built with a capacity of:

  953,000 * 0.3 = 285,900 units

Both designs use a training investment of $1000/worker/year.

Stage 1 Chance node

The two chance nodes (one for each decision) representing year 5 demand in stage 1 have values and probabilities stated in Table 1.

The value (present value of revenues minus labor costs, initial investment and operational costs) of the fixed design at this point is shown in Table 3, and the value of the flexible design is shown in Table 4.

Table 3

Value of fixed design after stage 1			
Scenario	Total demand ('000)	Probability	Value ($M)
Low	567	0.22	60.1
Medium	607	0.43	91.9
High	801	0.35	246.4
Expected Value	-	-	139.0

Table 4

Value of flexible design after stage 1			
Scenario	Total demand ('000)	Probability	Value ($M)
Low	567	0.22	93.9
Medium	607	0.43	125.7
High	801	0.35	236.4
Expected Value	-	-	157.4

Stage 2

After actual demand in year 5 is known, demand estimates and probabilities for year 10 can be adjusted. Table 5 reflects these revised estimates:

Table 5

Revised demand estimates for stage 2 (in '000 units)			
Stage 1 Scenario	Stage 2 Scenario	Estimated demand	Probability
Low	Low	576	0.23
	Medium	617	0.40
	High	821	0.37
	Expected Value	683	-
Medium	Low	618	0.27
	Medium	660	0.39
	High	883	0.34
	Expected Value	724	-
High	Low	819	0.34
	Medium	871	0.25
	High	1115	0.41
	Expected Value	953	-

The number of workers for the fixed design remains the same for each case, and the total present value of this design for each outcome is shown in Table 6.

Table 6

Total present value of fixed design after stage 2			
Stage 1	Stage 2	Probability	Value ($M)
Low (p = 0.22)	Low	0.23	955.6
	Medium	0.40	995.8
	High	0.37	1,196.0
	Expected Value	-	1,060.6
Medium (p = 0.43)	Low	0.27	1,055.2
	Medium	0.39	1,096.4
	High	0.34	1,315.2
	Expected Value	-	1,159.7
High (p = 0.35)	Low	0.34	1,535.7
	Medium	0.25	1,586.7
	High	0.41	1,724.4
	Expected Value	-	1,625.8

After stage 1, the flexible design can be adjusted according to the actual demand scenario outcome. To cover the expected demand, the number of workers hired in year 5 for each scenario is the following (note that productivity becomes 600 and market share, 30%):

- Low: 683,000 * 0.3 / 600 – 342 = 0
- Medium : 724,000 * 0.3 / 600 – 342 = 20
- High : 953,000 * 0.3 / 600 – 342 = 135

The expected value for each chance is shown in Table 7.

Table 7

Total present value of flexible design after stage 2 if hiring			
Stage 1	Stage 2	Probability	Value ($M)
Low (p = 0.22)	Low	0.23	986.3
	Medium	0.40	1,026.5
	High	0.37	1,144.1
	Expected Value	-	1,060.7
Medium (p = 0.43)	Low	0.27	1,053.6
	Medium	0.39	1,094.2
	High	0.34	1,216.3
	Expected Value	-	1,124.8
High (p = 0.35)	Low	0.34	1,356.0
	Medium	0.25	1,403.4
	High	0.41	1,547.1
	Expected Value	-	1,446.2

Decision Analysis Results

The expected values for each strategy are therefore:

- Fixed plan: $1,301M
- Flexible plan: $1,223M

The best strategy in this case is therefore to go with the **fixed plan** and hire all the workers in year 0. This mainly because having a large workforce from the start allows them to gain experience and, overall, to capture the potentially large rise in demand that may occur in subsequent years.

An approximation of the Value at Risk and Gain graph for the present case is shown below. From that graph, we can see that the flexible option minimizes the downside risk, but also the upside.

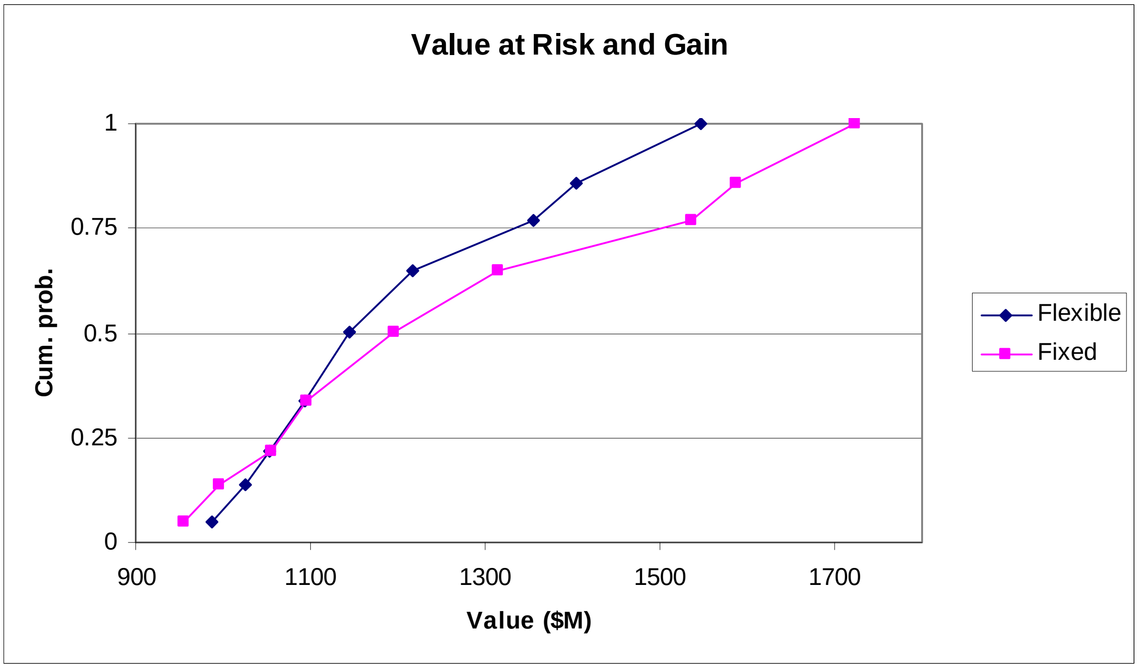

Figure 3 Value at risk and gain (VAR) graph for fixed and flexible cases, obtained through decision analysis

5. Lattice Analysis

In order to describe the evolution of global demand for cars using a binomial lattice, I used the following values:

- Demand at time zero: 55.8 millions
- Growth rate: r = 1.7%
- Volatility = 5%

These give parameter values:

Table 8 Lattice parameter values

u	1.0512711
d	0.9512294
p	0.67
p Start	1
Value Start	55.8

The probability lattice is therefore:

Table 9 Probability lattice

1.00	0.67	0.45	0.30	0.20	0.14	0.09
	0.33	0.44	0.44	0.40	0.33	0.27
		0.11	0.22	0.29	0.33	0.33
			0.04	0.10	0.16	0.22
				0.01	0.04	0.08
					0.00	0.02
						0.00

And the outcome lattice is:

Table 10 Worldwide demand outcome lattice

55.80	58.66	61.67	64.83	68.15	71.65	75.32
	53.08	55.80	58.66	61.67	64.83	68.15
		50.49	53.08	55.80	58.66	61.67
			48.03	50.49	53.08	55.80
				45.69	48.03	50.49
					43.46	45.69
						41.34

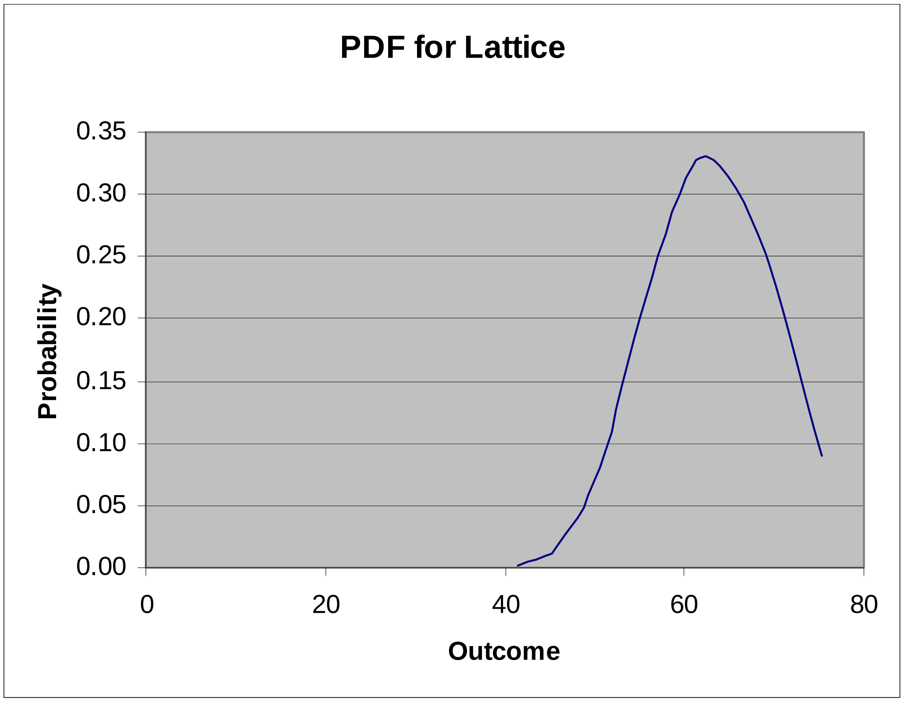

Figure 4 Probability distribution function for lattice

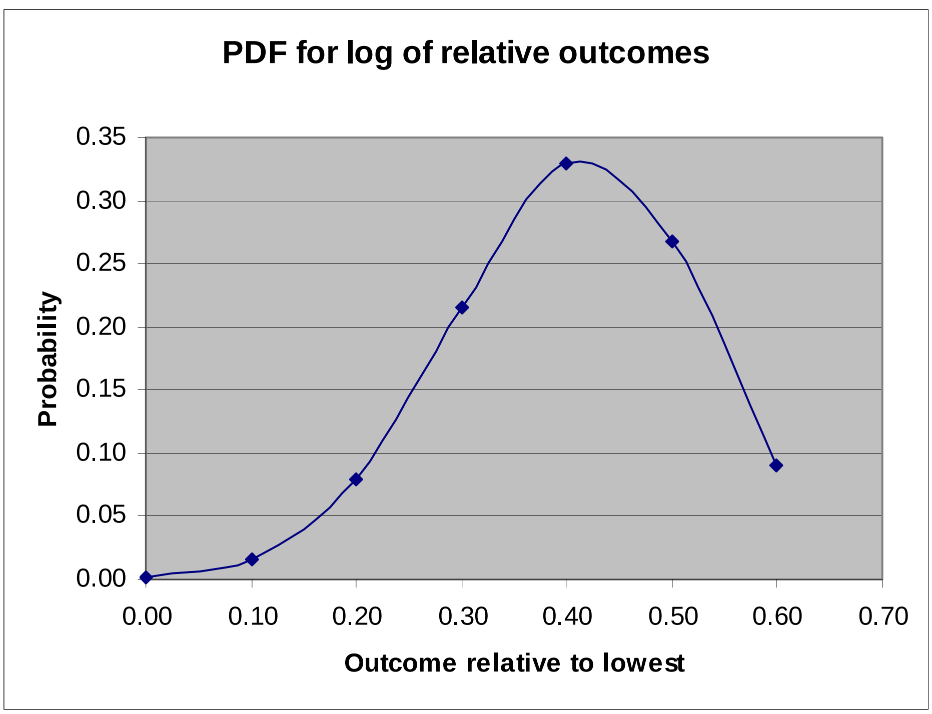

Figure 5 Probability distribution function for log of relative outcomes

6. Decision Analysis Using Lattice

In order to scale the problem to the size of demand for a single plant, I divided the initial demand value from AP5 by a factor of 30. The new outcome lattice is shown in Table 11:

Table 11 Scaled-down outcome lattice

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Outcomes:	1860.00	1955.36	2055.62	2161.01	2271.81	2388.29	2510.74
		1769.29	1860.00	1955.36	2055.62	2161.01	2271.81
			1683.00	1769.29	1860.00	1955.36	2055.62
				1600.92	1683.00	1769.29	1860.00
					1522.84	1600.92	1683.00
						1448.57	1522.84
							1377.92

The fixed case considered here is to build a plant with a capacity of 300,000 units, and hire 575 employees at year 0. Initial investment for the plant is calculated using the equation investment = k*(capacity)^(economies of scale factor), where k = $48,000 and the EOS factor is 0.75. Variable costs for the plant (excluding labour) are $400/unit.

For this fixed case, the lattice of net revenues is shown in Table 12.

Table 12 Lattice of annual net revenues, expected values and net present value over 6 years

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Net revenue ($M)	-618.74	480.96	537.00	593.04	649.08	705.12	756.29
		450.79	520.43	593.04	649.08	705.12	756.29
			468.66	565.75	649.08	705.12	756.29
				509.66	632.70	705.12	756.29
					570.24	705.12	756.29
						647.18	756.29
							737.59
EV ($M)	-618.74	471.01	522.23	584.07	646.57	704.90	756.26
NPV ($M)	1986.06						

We can see from that lattice that the revenues are capacity limited in at least a few cases for years 3 to 6. The expected values for each years are calculated with the probability lattice, and the net present value for this case is $1986M over the 6 years.

Next, we consider a flexible case (with option). For this situation, the same number of employees (575) is hired in the beginning, and so production is still initially limited. However, the initial plant capacity is 450,000, which gives the option of later hiring more employees to increase production. This increases the absolute initial investment, but benefits from further economies of scale. The option in this case is to hire another 300 employees at anytime during the 6 years (and keep them) if demand justifies it.

To see if demand would justify the hiring of more employees, we look at the net revenue lattice for the case of a 450,000 unit plant, with 875 employees:

Table 13 Lattice of net revenues – 450,000 plant and 875 employees

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Net revenue ($M)	-837.42	488.37	565.32	683.91	849.99	1070.03	1133.91
		438.48	508.10	615.40	765.68	964.77	1133.91
			456.33	553.41	689.38	869.53	1099.64
				497.33	620.35	783.35	991.56
					557.89	705.37	893.77
						634.82	805.28
							725.22
EV ($M)	-837.42	471.91	528.15	618.19	743.83	906.92	1066.99
NPV ($M)	2165.99						

By comparing both net revenue lattices, we can see the cases where hiring additional workers would be justified:

Table 14 Lattice of options and decisions: is hiring justified?

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
		YES	YES	YES	YES	YES	YES
		NO	NO	YES	YES	YES	YES
			NO	NO	YES	YES	YES
				NO	NO	YES	YES
					NO	YES	YES
						NO	YES
							NO

The net revenue lattice for the case with option is shown in Table 15.

Table 15 Net revenue lattice for case with hiring option

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Net revenue ($M)	-837.42	488.37	565.32	683.91	849.99	1070.03	1133.91
		450.79	520.43	615.40	765.68	964.77	1133.91
			468.66	565.75	689.38	869.53	1099.64
				509.66	632.70	783.35	991.56
					570.24	705.37	893.77
						647.18	805.28
							737.59
EV ($M)	-837.42	475.97	534.94	621.34	745.16	906.97	1067.00
NPV ($M)	2178.61						

If we compare it to the 300,000 fixed case, the value of flexibility here is :

2,178 – 1,986 = $192M.

When compared to a fixed case with capacity of 450,000 and 875 workers initially, the value of flexibility is:

2,178 – 2,166 = $12M.

7. Discussion

The analyses above show that the value of flexibility is not absolute. It varies strongly with the method used to evaluate it: in the case of decision analysis, the fixed case had the greater expected value; and when a lattice was used, the flexible approach was favoured. However, each type of analysis may relevant to different objectives. For example, decision analysis could be more appropriate to options on the building of the plant itself, since this kind of decision is not made every single year and fewer stages would need to be considered for the analysis to be relevant. On the other hand, a binomial lattice appears more useful when considering the option of hiring additional workers. This decision can be made quickly, occurs at least once per year, and is relatively dependent on short-term variations in demand.

The value of an option itself is also dependent on the set objective. For example, in section 4, decision analysis is used, and the expected value for the flexible scenario is found to be lower than for the fixed scenario. However, if the objective had been a "maximin", that is, to maximize the minimum value, the flexible case would have been preferable.

Moreover, value of an option depends strongly on how the scenarios are defined, both in terms of outcomes for uncertain variables, and in terms of how the option is exercised. If I had chosen to group the outcomes of my simulation in a different manner for the chances in section 4, the result would likely have been different. The binomial lattice considers a wide range of possibilities, but does not consider sudden changes in the conditions of the problem – and such changes do occur, as we often observe. In addition, the choice of the initial and option parameters have a great impact on its value, and sometimes a bad choice can give unrepresentative results. To ensure that the option is evaluated to its full value, many different scenarios could be considered; but this directly multiplies the complexity of the problem. In addition, the value of flexibility will vary depending on the fixed case to which it is compared, just like in the lattice analysis above. And some options may be simply irrelevant depending on the definition of the problem: in the problem considered above, there is no probability that global demand will decrease in the next 10 years. This may be unrepresentative of reality, but in this context, an option to close a plant – a "put" option – would likely have no value.

Both valuation methods have the flaw of being dependent on parameters which are likely to be determined somewhat arbitrarily, such as the discount rate, and the time span considered. The discount rate chosen here was 10%. It is likely that a higher rate would have tipped the balance toward the flexible case in the decision analysis method: the cash flows for the first few years where higher in the flexible scenario, as displayed in Table 3 and Table 4. Likewise, the fact that the project lifetime considered in the lattice method was shorter (6 years) probably contributed to favouring flexibility.

Finally, the analyses above show that this type of problem can scale very rapidly, and even the introduction of one more uncertainty factor would have made it very complex.