Satellite Fleet for a Commercial Remote Sensing Company

Application Portfolio

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Abstract

This study considers the impacts of uncertainty and flexibility on satellite fleet design for the commercial remote sensing company GeoEye. For this company, customer demand and the regulatory environment are key uncertainties. GeoEye needs to be able to respond to unexpected changes in both of these areas. But satellites operate in space. Once they are launched, their design is fixed. Thus finding ways that GeoEye can exercise flexibility is a challenge. This analysis considers several ways that GeoEye can use flexibility by exercising real options. These options are also evaluated to see if they improve expected net revenues for GeoEye. The options considered are 1) the option to delay purchase of a satellite, 2) using a satellite with 2 kinds of sensors that can perform two different tasks, and 3) the option to reduce operational fleet size from 3 to 2 satellites. These options are evaluated using a decision tree analysis and a lattice analysis. In each case the uncertainty that is modeled is customer demand. In the decision analysis, the results show that a fixed design brings the best revenues. In the lattice analysis, there is a small financial benefit from flexibility. The results here are not conclusive because they are based on limited knowledge about the actual parameters of the market such as its growth rate. The main benefit of this work is to challenge the assumption that satellite design is fixed and does not allow flexibility.

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Introduction

This study analyses the design of a satellite fleet for a commercial Remote Sensing company. The scenario is based on the company GeoEye (www.geoeye.com), using approximations where appropriate. The system under consideration includes the set of 2 to 3 satellites that GeoEye operates at any given time to produce imagery that is sold. The various market sectors that GeoEye considers are 1) NASA and other U.S. government science agencies; 2) the U.S. Department of Defense; 3) Google, Microsoft, Yahoo! and other commercial satellite imagery users; 4) the fishing industry; 5) the agriculture industry; 6) local, state and international governments. Each potential consumer of GeoEye's data has different imagery needs. For example, urban planners in local governments need frequently updated visual imagery of cities with a spatial resolution on the order of 1 meter. Meanwhile, in the fishing industry, data which shows the changes in sea surface temperature or chlorophyll concentration is useful. The Department of Defense sometimes contracts for high spatial resolution imagery of a war zone; they have the right to restrict the use of this data for non-security purposes. NASA is interested in a variety of types of data; sometimes they work with commercial providers to create special instruments to collect scientific measurements. As a result of this variety of customer needs, it is very difficult to anticipate what the demand will be for a certain kind of data in the future.

In order to produce the various kinds of data needed by their customers, GeoEye can use three basic categories of sensors on the satellites: Panchromatic (PAN), Multispectral (MS) or Hyperspectral. Each type offers a different sensitivity to the various wavelengths of light they observe. The other major design variables of the individual satellites are listed in the table below. Various combinations of these design variables are used to create products that appeal to the different market sectors. I use data from GeoEye's current remote sensing products to understand these relationships.[1]

Table 1: This table shows the important design variables for the satellites in GeoEye's fleet.

Categories	**Design Variables**
Instruments	• Number of instruments • Types of instruments • Spatial resolution (meters) • Spectral resolution (nanometers of wavelength)
Orbit	• Orbit altitude • Revisit time
Mission	• Mission design lifetime

This study considers the satellite fleet design of the GeoEye company. The following analysis compares the various combinations of satellites and instruments that GeoEye could operate. It is assumed that GeoEye always wants to have at least 2 satellites in operation. The major area of uncertainty to be considered is demand for imagery; this

[1] Rowberg, Richard. "Commercial Remote Sensing by Satellite: Status and Issues". Congressional Research Service Report for Congress. The Library of Congress. January 8, 2002.

demand is influenced by the regulatory environment. The goal of the study is to determine how GeoEye can use flexibility of design to maintain a robust satellite fleet that is capable of supplying products that will meet the shifting demands of the future.

Modeling the Sources of Uncertainty for GeoEye

Currently, GeoEye has a 3 satellite fleet in which one satellite (OrbView-2) is just MS and two (GeoEye-1 and IKONOS) are both Pan and MS. OrbView-2 and IKONOS are in current operation and GeoEye-1 is scheduled to launch in 2008. Each satellite caters to different applications and thus different markets. It is unclear what the demand will be for each market in the future. Also, the future regulatory environment is uncertain. The commercial remote sensing industry depends heavily on the federal government for procurement of its imagery. Even though the federal government has stated a desire to promote this industry, the funding for imagery purchases is inconsistent. Also, security concerns sometimes limit how imagery is sold or used.[2] The following sections discuss how I model the two source of uncertainty – demand and regulation – in more detail.

Demand

Demand is modeled based on the various market sectors that purchase data from GeoEye. In actuality, GeoEye has a very wide spectrum of customers from government and the private sector. These customers buy images through contracts (which allow them to control what the satellite views) as well as through the purchase of value-added imagery products. This situation is simplified for this analysis by focusing solely on demand for contract-based image taking, not on the sale of archived imagery or value-added image products. The goal is to consider whether the company has enough image-taking capacity to meet the demand for contracts. Assume a simple mapping between the type of customer and the predominant kind of data they need. This is summarized in the chart below.

Table 2: This table summaries the simple mapping between the type of customer and the main satellite applications they demand.

Customer	Main Application	Satellite(s)	Nominal Percentage of Demand
U.S. Department of Defense/Military	High Spatial Resolution Color Photographs	IKONOS/GeoEye-1	40
International	High Spatial Resolution Color Photographs	IKONOS/GeoEye-1	46
Other Gov't	Scientific Imagery at lower spatial resolution	OrbView-2	5

[2] Rowberg, Richard. "Commercial Remote Sensing by Satellite: Status and Issues". Congressional Research Service Report for Congress. The Library of Congress. January 8, 2002.

Microsoft/Yahoo/Google, etc	High Spatial Resolution Color Photographs	IKONOS/GeoEye-1	3
Commercial Fishing	Scientific Imagery at lower spatial resolution	OrbView-2	3
Other	High Spatial Resolution Color Photographs	IKONOS/GeoEye-1	3

The nominal percentage of demand is a number estimated based a review of several sources of information about GeoEye. This nominal situation roughly approximates the current breakdown of customer demand. The GeoEye website provides information about their portfolio of customers. The U.S. military is a major contributor to the demand through contracts for security-related, high-resolution imagery.[3] The report of GeoEye to the Securities and Exchange Commission for their stockholders can be accessed from the company website. This report reveals that international customers are a large part of the overall demand, totaling 46% in 2006.[4] GeoEye also has long-term contracts with Microsoft and Yahoo! for high spatial resolution imagery.[5] Another service that GeoEye offers is to the commercial fishing industry. Their SeaStar Fishery Information Service offers "customized fish-finding and data services" to help fishing companies maximize their catch.[6] Using this information, I constructed a summary of GeoEye's customer base.

Note that a key part of GeoEye's strategy is determining what products each customer type purchases. As can be seen in the table above, the majority of the customers primarily want the services of IKONOS or GeoEye-1. In general, the composition of GeoEye's customer base could change as well as the actual level of demand. In the analyses that follow, it assumed that the composition remains constant, but the overall level of demand changes.

In order to understand the actual amount of revenue that GeoEye makes from these customers, I reviewed the financial summaries from their SEC documentation. GeoEye published a financial report showing its revenues, expenses and profits since 2002, when the company started. There were several major changes since then that make it hard to find a consistent trend. The company went through bankruptcy in 2002-2003, so the profits were quite low. In 2006 they acquired another company and its satellite assets, thus profits rose quickly. A chart showing a summary of the record is below. I will

[3] GeoEye Website, Corporate Overview. http://www.geoeye.com/corporate/default.htm Accessed October 4, 2007.
[4] Report of GeoEye to SEC. http://www.sec.gov/Archives/edgar/data/1040570/000095013307001119/w31787e10vk.htm#101 Accessed October 4, 2007.
[5] GeoEye Website, Corporate Overview. http://www.geoeye.com/corporate/default.htm Accessed October 4, 2007.
[6] SeaStar Fishing Information Service. http://www.geoeye.com/products/seastar/seastarFisheries.htm Accessed October 4, 2007.

assume in my analysis that the company will stay structured in its current state, without buying or selling any major elements of the company.

Table 3: Summary of GeoEye Cash Flows

Year	*2006*	*2005*	*2004*	*2003*	*2002*
Revenue (thousands)	151168	40702	31020	9219	15552
Expenses (thousands)	82837	38116	33754	10697	10498
Profit (thousands)	68331	2586	-2734	-1478	5054

Regulatory Environment

Four potential regulatory issues could strongly affect GeoEye. These are outlined in the table below. Although these situations are not directly modeled in this analysis, they represent forces that could cause a change in demand for GeoEye's products. The four scenarios are as follows.

Table 4: This table summarizes the potential regulatory shifts and their effect on the commercial remote sensing industry.

Regulatory Scenario	**Consequence for Commercial Remote Sensing Industry**
Favorable federal policy or legislation toward commercial remote sensing industry	Increase in US military and government demand for imagery
War or defense crisis that precipitates more fed gov't use of satellite imagery	Increase in US military demand for imagery
Negative government policy that reduces priority of federal support for commercial remote sensing industry	Decrease in US military and government demand for imagery
Change in status of NASA Landsat Data Continuity Mission	NASA and the US Geological Survey have an interest in ensuring that the data continuity of the Landsat series of missions is not broken. There is currently a design in place for a new mission in the Landsat series, but if it has problems, this could increase the demand for commercial, scientific data.[7]

[7] Landsat Data Continuity Mission http://ldcm.nasa.gov/ Accessed October 4, 2007.

The U.S. commercial satellite remote sensing industry is small. There are only 2 to 4 major firms. Any sudden regulatory shift would dramatically affect all the companies. Thus it is reasonable to assume that GeoEye would be directly affected by regulation as an individual company.

Alternative Satellite Designs

In the next section we use a decision tree analysis to study how GeoEye may use flexibility in their design to respond to uncertainty. To facilitate the discussion of the decision tree analysis, we here define several alternative satellite designs that will be compared. GeoEye uses 2 major types of satellites. I call them Category A and Category B. The two categories differ in technical specifications and purpose. Category A satellites have high spatial resolution, low orbital altitude, infrequent revisit times, and narrow swath width. With these characteristics they are best suited to produce high quality images such as would be appropriate for national security. Category B satellites have low spatial resolution, high orbital altitude, frequent revisit times, and wide swath width. The main application for B satellites is for scientific observation of natural phenomena.

In terms of the current GeoEye fleet, IKONOS and GeoEye-1 are Category A satellites. OrvView-2 is a Category B satellite. Note then that Category A satellites provides the majority of the revenue for GeoEye. They serve a larger percentage of the market and have a higher charge per operating hour.

I define a third, Hybrid, category of satellites that GeoEye does not use. This satellite is capable of functioning as either a category A or B satellite. It has the high quality sensors of an A satellite and it carries extra fuel to allow it to reconfigure its orbit from a B orbit to an A orbit. As will be seen below, the hybrid satellite is used to provide flexibility in one of the architecture options. The table that follows provides more detail regarding the difference in technical specification between the three categories. The architecture or system concept options I analyzed are for different combinations of these satellite categories. I assume that GeoEye wants to keep 2 to 3 satellites in orbit at all times, but part of their strategy is choosing what kinds of satellite to fly.

Table 5: The information in this table is adapted from data on the GeoEye website. www.geoeye.com

Design Variables	Category A	Category B	Hybrid
Number of Instruments	2	1	2
Type(s) of Instruments	Panchromatic and Mulitspectral Sensors	Panchromatic	Panchromatic and Mulitspectral Sensors
Spatial Resolution	1 meter (high spatial resolution)	1 kilometer (low spatial resolution)	1 meter and 1 kilometer
Orbit Altitude	650 kilometers (low altitude)	705 km (high altitude)	capable of either 684 or 705 km

Revisit Time	Every 3 Days (infrequent)	Daily (frequent)	capable of daily or every 3 days
Mission Design Lifetime	10	10	10
Cost per observation hour	$10,000	$8000	$8000 when acting as B, $10,000 when acting as A
Cost of Satellite	$500 Million	$350 Million	$550 Million

Decision Analysis

One way to analyze the consequences of using different satellite designs is through Decision Analysis. In this analysis, the key uncertainty is the demand for GeoEye imagery. It is assumed that this demand is influenced by the regulatory scenario, though this is not shown explicitly. Here a decision tree is used to assign probabilities to various possible demand outcomes that GeoEye could face. Next, the best decisions are modeled in response to these demand levels. Finally, the model produces expected values for the GeoEye's profits. This process is repeated for several alternative fleet architectures. For this decision analysis, the activity of GeoEye over a 10 year total period is considered. Each stage is 5 years long. The expected value of GeoEye's profits for three architectures is compared, as described below.

1. **Architecture 1: Fixed design.** Launch 3 satellites at time zero. Two satellites are in Category A and one is Category B, as defined in the table above.
2. **Architecture 2: Delayed design.** Launch 2 satellites at time zero, one from category A and one from category B. Wait to observe demand and decide whether to launch a third satellite at year 5. The third satellite would be from Category A because it has a higher charge per imaging hour and serves a higher percentage of the market.
3. **Architecture 3: Hybrid Design.** Launch 3 satellites at time zero. Two are category A, because this category has had more demand traditionally. The third is initially configured to work in Category B but has flexibility that would allow it to be changed to category A. In order to change it, one must change the orbit to a lower altitude and have high spatial resolution sensors on-board. Thus, the cost of the flexibility is the cost of including extra fuel for the orbital change and the increased cost of high quality sensors.

Table 6: This Table summarizes the three possible architectures that were compared in the decision analysis.

Architecture	Strategy	# Satellites	Cost Schedule, paid by GeoEye
1 (Fixed)	Launch 2 A sats and one B sat at year zero	3	Pay $500M for each A sat and $350M for B sat. Total is $1350M
2 (Delay)	Launch 1 A sat and	2 or 3	Pay $850M in year 0

	1 B sat at year 0. At year 5 decide whether to launch additional A sat or no sat.		and possibly pay $500M in year 5.
3 (Flex)	Launch 2 A sat and 1 hybrid sat in B format. Decide whether to change hybrid to A at year 5.	3	Pay $1550M in year 0.

A 2-stage decision analysis is modeled over a 10 year period. It starts with a decision node allowing three branches for Architectures 1, 2 or 3. Next, for each branch a chance node appears showing the level of demand for satellite imaging time in hours. In the second period, the decision nodes are appropriate for each architecture. Architecture 1 is fixed; no decisions are made. Architecture 2 allows a decision about whether or not to launch a third satellite. Architecture 3 allows a decision about whether to change the hybrid satellite from a B to an A category satellite. After each of these decisions, another chance node for demand appears. The model calculates the expected values for each outcome and compares the values of each decision. The final result is that **Architecture 1 is the best strategy**. It provides an expected value of $812.4 Million for the ten years. Meanwhile Architecture 2 had an expected value of $575.6M and Architecture 3 earned only $390.4M. Note that operating costs were not taken into account, only capital investments for launching satellites. The methods and assumptions are discussed more below and the following table summarizes the results.

Table 7: This table summarizes the results of the Decision Analysis. Architecture 1, the fixed plan, had the best results.

Architecture	E[NPV] ($M)	Max NPV ($M)	Min NPV ($M)	CAPEX ($M)
1 (Fixed)	$812	$868	$234	-1350
2 (Delay)	$576	$576	$576	-850
3 (Flex)	$390	$747	$34	-1550

Assumptions

Independent Variable: The independent variable modeled in the chance node is the customer demand for satellite imaging time in hours. This variable could take a value of “High”, “Medium” or “Low”. “High” customer demand is defined as 24 hours per day for 3 satellites or 72 total hours per day. “Medium” demand means 60 hours per day of observing time (spread among 3 satellites). “Low” demand is 48 hours per day, which can be covered by 2 satellites. The other important independent variable is Regulatory Status for the commercial remote sensing industry, but it is not included explicitly in this analysis. It is assumed that the regulatory environment affects demand. The demand levels were implied from past performance of GeoEye based on the data shown above.

Assessing probabilities: The model uses uniform probabilities for each level of customer demand for satellite imaging time. This is based on informed judgment. There is not a long history of data to consider for the demand of satellite-based remote sensing, but there is a growing acknowledgement of the value of the product. The market is heavily dependent on government procurement. Meanwhile, the government also produces satellite imagery of its own. There is legislation that explicitly commits the government to support the commercial satellite imagery industry, but the posture could change as administrations change. Since the model considers 5 year periods, which roughly correspond to potential changes of political priorities, we assume that it is equally likely that the government will be supportive, neutral or uninterested in buying commercial remote sensing data. In the neutral case, demand would stay more or less the same. In the uninterested case, the demand would decrease. Thus, the probability is modeled as 1/3 for High, Medium and Low Demand. Demand could also be influenced by the actions of the few competitors in the U.S. and international remote sensing markets.

Stages: One stage in this decision tree represents 5 years. This is based on the lifetime of satellites. The design life of the satellites in the fleet is approximately 10 years. After 5 years, the state of the fleet should be re-evaluated.

Outcomes

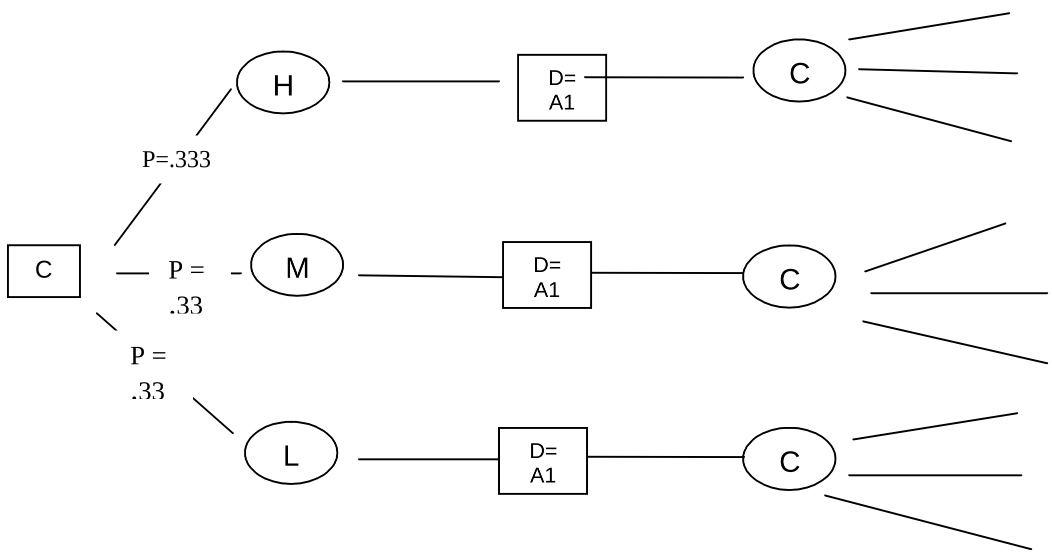
The model assumes that each satellite operates 24 hours a day for 330 days of the year for the 10 years. The above sections show the financial performance and profits of GeoEye over the last few years. This data was used to imply a reasonable cost per imaging hour given this operating schedule. The following prices are assumed for the GeoEye services. Category A satellites provide high spatial resolution imagery of the quality desired for defense purposes. The price per hour of observation for this class is $10,000. In Category B the satellites produce lower spatial imagery that is more useful for scientific purposes, in part because this category also returns to view the same location more often. The price per hour of observation here is $8000. Category B is cheaper because the instruments that provide lower spatial resolution data are less expensive. Another reason is that Category A satellites need two kinds of instruments while B satellites need just one. There is also one hybrid design in the 2nd flexible architecture. It will have the same instruments as a category A satellite as well as extra fuel. In my model, however, when the satellite operates as a B satellite, the cost per observation hour will be the normal B cost, $8000. When it operates as an A satellite, the cost will be $10,000 per hour.

In order to calculate the outcome of a given path on the decision tree, consider the number of hours demanded that were actually filled (some times demand is higher than the satellite capacity). Next, multiply these hours spent imaging times the appropriate rate per imaging hour. This is the price paid by customers per day. Multiply again to get the price paid over 5 years. It is assumed that customers buy services with 5 year contracts.

After summing the total revenues, minus satellite costs, for each period, one can find the expected value at each chance node. At this point, the tree can be pruned to eliminate decisions that are clearly inferior. For example, in Architecture 2, launching a third satellite at year 5 is always less profitable than launching no satellite, so that option is eliminated. In Architecture 3, it is more profitable to change the 3rd satellite from a B to an A satellite, so that branch is kept. Next, calculate the expected value of the each architecture. As stated above, Architecture 1 has the highest expected value.

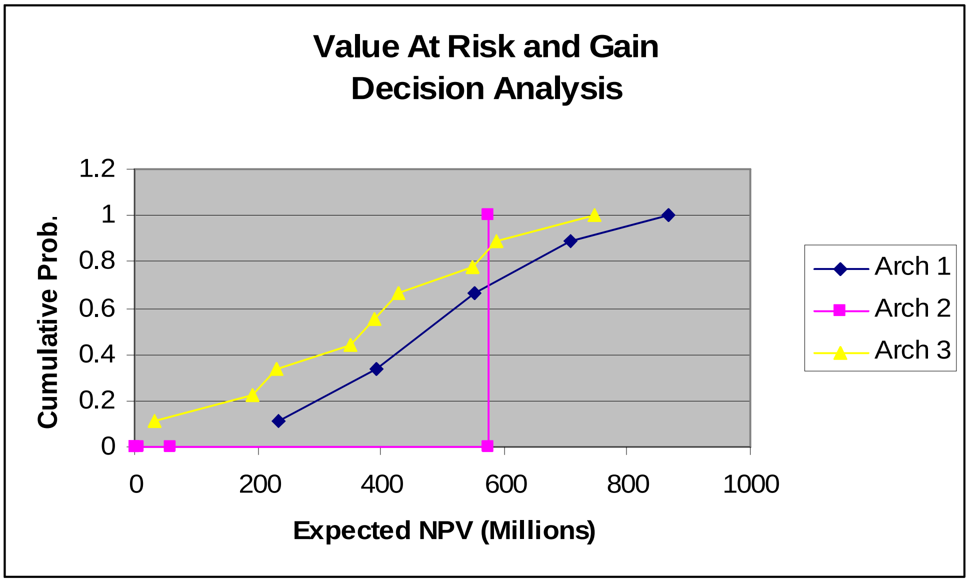
The results of the decision analysis make sense. Architecture 2, in which you delay in launching the third satellite, is less desirable because you spend 5 years in which money is only earned from 2 satellites rather than 3. The results are not discounted so there is no benefit in present value from waiting until year 5 to pay for the third satellite. In Architecture 3, there is a high cost for the flexibility of the hybrid satellite. This high cost detracts from the benefits of the flexibility. Architecture 1 allows you to make a lot of money and always satisfy demand over 10 years. The one drawback of architecture 1 is that it requires a huge capital investment at year zero.

Below I include a notional drawing showing the decision tree just for Architecture 1. The probabilities of High, Medium or Low demand are shown for period 1. Identical probabilities would be assigned to all the final branches of period 2.



1: This figure is a notional drawing of the section of the decision tree for ARCHITECTURE 1.

The figure below shows the Value at Risk and Gain curve for the three architecture options. This provides yet another way to compare the three cash flows. The X-axis shows expected Net Present Value (NPV) and the Y-axis shows the Cumulative Probability for each NPV. The shape of the curve for architecture 2 is interesting. In this architecture, the capacity is only for 48 hours per day of observation and the demand never goes below 48 hours per day. Thus it is guaranteed, according to the model, that the revenue will be constant near $600 M. This architecture reduces risk. Architecture 1 however is better if a manager wants to get a higher updside potential. Architecture 3 is less desirable because it is the most risky in terms of possible loss and it does not have the highest possible gains.



Lattice Analysis

Another method for evaluating design options is through Lattice Analysis with dynamic programming. A lattice method is similar to a decision tree in that it creates various possible paths with some probabilities. A lattice may be used, for example, to describe a series of potential values for an important uncertainty such as demand. At each stage, it is assumed that the value of the variable will either increase or decrease by a given factor. The lattice is recombinant in this case; that is, the states recombine and the total number of possible states is thus manageable, even over many time periods. This is because we can assume path independence of the quantities modeled in the lattice. After the lattice provides the progress of the variable in question, we use a dynamic programming approach to optimize management decisions in response to the uncertain outcomes. In this study a lattice analysis is performed for GeoEye to find the value of an option to reduce the satellite fleet from 3 satellites to 2. This is a change from the method used above; rather than study how GeoEye can change its satellite design, we study how strategic use of flexibility in management can increase net revenues. The details of the model and results are explained below.

Modeling Demand

The variable of interest is demand. In the decision tree analysis, it was assumed that demand would change suddenly, possibly due to a regulatory shift. The lattice method is more useful for modeling a gradual change in demand, which is more common within a period of regulatory stability. Here demand is measured in dollars rather than hours. Instead of considering how much satellite capacity is filled, the analysis simply considers overall profits to make fleet management decisions.

In order to model the changes in demand, the model needs a starting value, an average growth rate, a volatility value and the length of a time step. The overall world demand for commercial satellite imaging is assumed to start at $1.5 Billion in year 0. This is based on reviews of various estimates for the world remote sensing market. Market analysis estimates that the overall annual growth of the satellite remote sensing industry is about 4%.[8] A value of 10% is assumed for the volatility (sigma). Thus, demand is modeled to grow with an average rate (v) of 4% and a volatility of 10%. GeoEye does not receive all of the world demand. We assume they receive $0.15 Billion (or $150 Million) in gross revenue based on their recent financial performance as described above. I assume that the growth of GeoEye's demand follows the same patterns as the world market, since there are only a few firms.

Using these inputs into the model, we are able to develop possible values of demand over several periods. The model finds an upside factor (u) of 1.105 and a downside factor (d) of .904. This means that when demand goes up, it increases by a factor of 1.105. When it goes down, it factor is .904. The probability of the demand going up (p) is .7. This can be found using the standard equations given below. The time interval (delta t) used was 1 year.

Table 8: This table shows the equations used to develop the lattice model of demand.

p	0.7	$0.5 + 0.5\,(v/\sigma)\,(\Delta t)^{0.5}$
u	1.105	$e\ \exp[\,(\sigma)\,(\Delta t)^{0.5}]$
d	0.904	1/u

Cost Assumptions

Several assumptions are made regarding cost for GeoEye. Assume a start up cost that is paid in year 0 in order to launch 3 satellites. Two are high resolution satellites that each cost $500 Million; one is lower resolution satellite that costs $350 Million. These are the same costs assumed in the decision analysis. The model also assumes an operating cost for each satellite of $10 Million per satellite each year. The third aspect is the cost of fleet maintenance. The model assumes that it costs $.1 Billion (or $100 M) annually to maintain a fleet of 3 satellites. This cost is spread over each year in order to make the calculations easier. But it is based on the idea that every 5 years, GeoEye needs to spend $500 Million to replace one of their satellites due to aging of the equipment. To summarize, a capital investment of $1.15 Billion is paid in year 0 to cover the cost of 3

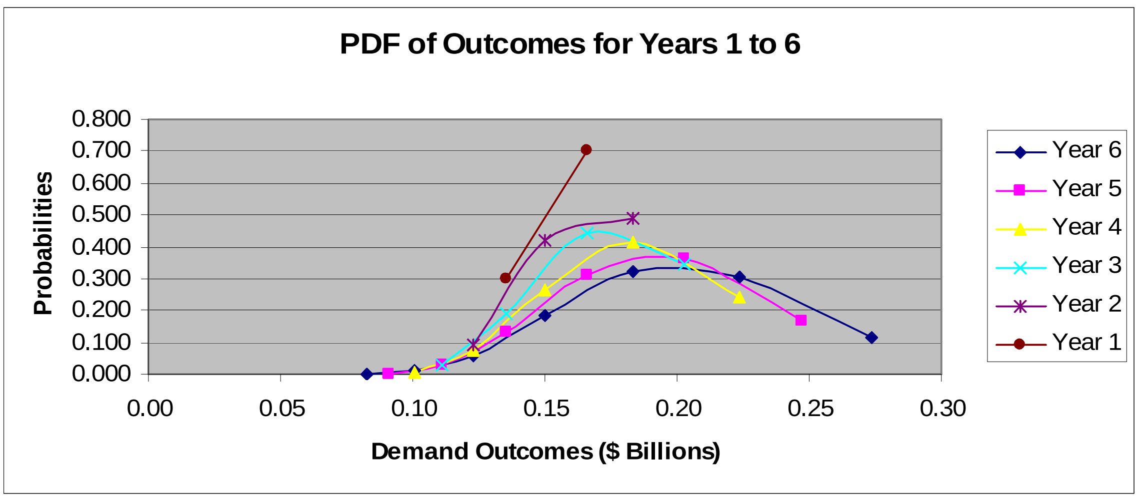
[8] http://media.digitalglobe.com/index.php?s=primer&item=13 Accessed November 9, 2007.

satellites. Each year, the net revenues are found by taking the demand and subtracting the operating cost and the cost of fleet maintenance.

The option modeled in this analysis is the right to reduce the satellite fleet size from 3 to 2 satellites in case it becomes unprofitable to operate 3. If the option is exercised, the company will not pay to replace the 3rd satellite. Thus their operating costs will decrease. For example, in year 5 if the expected revenue is less than the fleet maintenance cost, the company will choose to reduce the fleet size. Thus in year 6, they pay the cost of operating 2 satellites and they cover two/thirds of the demand they can cover with three satellites. The operating and maintenance costs decrease, but so does the revenue.

Results

A lattice analysis is performed over 6 years using the assumptions outlined above. The chart below shows the PDF of the Demand Outcomes for years 1 to 6.



Using these results the net revenues and probability weighted revenues of the company over the 6 years are found, assuming no flexibility. The expected Net Present Value of the plan was **$ -0.97 Billion**.

I next implemented the plan with the option to reduce the fleet to 2 satellites. In this case, there were 2 cases in which the option to reduce the fleet was exercised. The value of the option was $.0011 Billion or $ 1.1 Million. As the starting value for demand decreases, the value of the option increases. For example, when demand starts at $.14 Billion, the value of the option is $2.3 M. If demand goes down from $.15 to $.10 Billion, the value of the option increases to $104.7 Million. We thus see that the increase in the value of the option is very non-linear with changes in demand. A small change in demand can lead to a large change in the value of flexibility.

Notice also that the expected NPV (with or without options) is negative assuming a starting demand value of $0.15 Billion. If this starting demand is increased to $0.36

Billion, the company will start to see an expected NPV that is positive without or without options.

The final lattices are shown below. The top lattice shows the expected Net Present Value of the revenue, given that the management of the system was optimized through dynamic programming. The second lattice shows in which scenarios the option to reduce the fleet from 3 to 2 satellites was exercised. Thus we see that if the expected net revenue in year 6 is very low, the option will be exercised in two scenarios of year 5. A "yes" in the box implies that the option was exercised while a "no" means that option was not exercised. The management strategy was determined using dynamic programming.

Table 9: This table shows the final results of the lattice analysis. The option to reduce the fleet was exercised in two cases.

PV(Net Revenue)	-0.97	0.24	0.28	0.29	0.28	0.23	0.14
WITH OPTIONS		0.09	0.13	0.16	0.16	0.15	0.09
(check next year)			0.02	0.05	0.07	0.07	0.05
				-0.01	0.01	0.02	0.02
					-0.01	0.03	-0.01
						0.00	-0.03
							-0.05

Reduce Fleet	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
WITH OPTIONS		**NO**	**NO**	**NO**	**NO**	**NO**
(check next year)			**NO**	**NO**	**NO**	**NO**
				NO	**NO**	**NO**
					NO	YES
						YES

Value of option =	0.9721	Billion	NPV with option
-	0.9732	Billion	NPV w/o option
	0.0011	Billion	

Conclusions

The purpose of this analysis is to understand how acknowledgement of uncertainty and consideration of options can help a company like GeoEye to better manage its satellite fleet. Some of the challenges of the analysis come from the fact that the satellite imagery industry is relatively young and has only a few firms. Thus it is difficult to obtain large amounts of data that allow for finding trends in variables such as demand.

In reflecting on the results of these analyses, there are three important conclusions. First, note that there are various reasons to question the results of the decision analysis. This tool was used here to represent discrete states of demand. This is not always an appropriate way of viewing demand, however. The decision tree tool is best suited to model variables that change suddenly from one state to another. The regulatory environment could cause demand to change like that for remote sensing companies. Some examples of events that could cause such a change are a new presidential administration, an outbreak of war or a natural disaster. The methods used in the decision tree model should be applied to explicitly study the effects of changes in regulation. In the decision analysis above, the fixed architecture had the best expected value. This is partly because it was assumed that the flexible architectures either paid large amounts for satellites or spent years forgoing benefits by delaying launch. The five year delay assumed in architecture 2 was also somewhat artificial and could be re-considered in a realistic management situation. It may be that delay is actually valuable, but not for 5 years. Also, it was artificial to assume that the company pays for all the satellites up front. In reality, satellites are procured in a more ad-hock manner and sometimes accompany advanced purchases for imaging time. There are times when a customer such as the Department of Defense helps to pay for a satellite. It would be helpful to consider this analysis with a more accurate costing for the flexible architecture. This could change the results. Finally, note that operating expenses were not accounted for in the decision analysis but they were in the lattice analysis. This explains the vast different between the expected NPV in the two studies. If these aspects of the situation could be more accurately modeled by a practitioner from GeoEye, I think the flexible cases would be more attractive. Note, however, that in this work the gross revenue was comparable in both the decision and lattice analyses.

The second reflection is that the lattice method was a more adequate way to represent demand as it would change in dollars. The option had a small positive value and this value increased dramatically with small decreases in revenue. Because it was so difficult to find accurate data about the market as an outside, I certainly do not think that the results from this model give conclusive numbers. For a real business situation, having the option to forgo a planned satellite purchase if the market is bad could be very useful. The model was limited here as well because it was assumed that payment is made each year toward future satellites. This was easy to model but unlike the actual situation.

Third, one interesting element to the GeoEye case that could be explored further is the make up of its customer base. Neither decision analysis nor lattice analysis were very effective tools for modeling potential changes in the types of customers GeoEye serves. For example, at the present, the majority of the customers want satellite services in category A, but this may not always be true. A discounted cash flow analysis with simulation may be a good way to compare potential changes in customer base.

The methods used in this study provide an outline for considering the situation of a company like GeoEye. The results do not provide conclusive answers, but they do provide firm managers a way to evaluate options that are not usually considered in the satellite industry.