BIO-IMAGING DEVELOPMENT STRATEGIES

In 2004, the company Bio-Imaging, Incorporated was formed by James Bates, Scott Tillman, and Michael Ford, in order to develop, produce, and market a new and potentially extremely beneficial tool in medical diagnosis. Scott Tillman and James Bates were each recent graduates from Massachusetts Institute of Technology (MIT), and Michael Ford was a professor of neurology at Massachusetts General Hospital (MGH). As part of his graduate studies at MIT, Scott had developed a new technique and a software package to process MRI (magnetic resonance imaging) scans of brains of patients using a personal computer. The software, using state of the art computer graphics, would construct a three-dimensional picture of a patient's brain and could be used to find the exact location of a brain lesion or a brain tumor, estimate its volume and shape, and even locate the centers in the brain that would be affected by the tumor. Scott's work was an extension of earlier two-dimensional image processing work developed by James, which had been used extensively in Michael Ford's medical group at MGH for analyzing the effects of lesions on patients' speech difficulties.

Over the last few years, this software program had been used to make relatively accurate measurements and diagnoses of brain lesions and tumors.

Although not yet fully tested, Scott's more advanced three-dimensional software program promised to be much more accurate than other methods in diagnosing le-sions. While a variety of other scientists around the world had developed their own MRI imaging software, Scott's new three-dimensional program was very different and far superior to any other existing software for MRI image processing.

At James' recommendation, the three gentlemen formed Bio-Imaging, Incorporated with the goal of developing and producing a commercial software package that hospitals and doctors could use. Shortly thereafter, they were approached by the Medtech Corporation, a large medical imaging and software company. Medtech offered them $150,000 to buy the software package in its then-current form, together with the rights to develop and market the software worldwide. The other two partners authorized lames (who was the "businessman" of the partnership) to decide whether or not to accept the Medtech offer. If they rejected the offer, their plan was to continue their own development of the software package in the next six months.

This would entail an investment of approximately $200,000, which James felt could be financed through the partners' personal savings.

If Bio-Imaging were successful in their effort to make the three-dimensional prototype program fully operational, they would face two alternative development strategies.

One alternative would be to apply after six months time for a $300,000 Small Business Innovative Research (SBIR) grant from the National Institutes of Health (NIH). The SBIR money would then be used to further develop and market their product. The other alternative would be to seek further capital for the project from a venture capital firm. In fact, Michael had had several discussions with the venture capital firm Nugrowth De-velopment. Nugrowth Development had proposed that if Bio-Imaging were successful in producing a three-dimensional prototype program, Nugrowth would then offer $1,000,000 to Bio-Imaging to finance and market the software package in exchange for 80% of future profits after the three-dimensional prototype program became fully oper-ational. (Because NIH regulations do not allow a company to receive an NIH grant and also receive money from a venture capital firm, Bio-Imaging would not be able to receive funding from both sources.)

James knew that there was substantial uncertainty concerning the likelihood of receiving the SBIR grant. He also knew that there was substantial uncertainty about how successful Bio-Imaging might be in marketing their product. He felt, however, that if they were to accept the Nugrowth Development offer, the profitability of the product would probably then be higher than if they were to market the product themselves.

If Bio-Imaging was not successful in making the three-dimensional prototype program fully operational, James felt that they could still apply for an SBIR grant with the two-dimensional software program. He realized that in this case, they would be less likely to be awarded the SBIR grant. Furthermore, clinical tests would be needed to fine-tune the two-dimensional program prior to applying for the grant.

James estimated that the cost of these additional tests would be around $100,000.

The decision problem faced by Bio-Imaging was whether to accept the offer from Medtech or to continue the research and development of the three-dimensional software package. If they were successful in producing a three-dimensional prototype, they would have to decide either to apply for the SBIR grant or to accept the offer from Nugrowth. If they were not successful in producing a three-dimensional prototype, they would have to decide either to further invest in the two-dimensional product and apply for an SBIR grant, or to abandon the project altogether. In the midst of all of this, James also won dered whether the cost of the Nugrowth offer (80% of future profits) might be too high relative to the benefits ($1,000,000 in much-needed capital). Clearly James needed to think hard about the decisions Bio- Imaging was facing.

Data Estimates of Revenues and Probabilities

Given the intense competition in the market for medical imaging technology, James knew that there was substantial uncertainty surrounding the potential revenues of Bio-Imaging over the next three years. James tried to estimate these revenues under a variety of possible scenarios. Table 1.2 shows James' data estimates of revenues under three scenarios ("high profit," "medium profit," and "low profit") in the event that the three-dimensional prototype were to become operational and if they were to receive the SBIR grant. Under the "high profit" scenario the program would presumably be very successful in the marketplace, yielding total revenues of $3,000,000.

In the "medium profit" scenario, James estimated the revenues to be $500,000, while in the "low profit" scenario, he estimated that there would be no revenues. James assigned his estimated probabilities of these three scenarios to be 20%, 40%, and 40% for the "high profit," "medium profit," and "low profit" scenarios, respectively.

Table 1.3 shows James' data estimates of revenues of Bio-Imaging in the event that the three-dimensional prototype were to become operational and if they were to accept the financing offer from Nugrowth Development. Given the higher resources that would be available to them ($1,000,000 of capital), James estimated that under the "high profit" scenario the program would yield total revenues of $10,000,000. In the "medium profit" scenario, James estimated the revenues to be $3,000,000; while in the "low profit" scenario, he estimated that there would be no revenues. As before, James assigned his estimated probabilities of the three scenarios to be 20%, 40%, and 40% for the "high profit," "medium profit," and "low profit" scenarios, respectively.

Table 1.4 shows James' data estimates of revenues of Bio-Imaging in the event that the three-dimensional prototype were not successful and if they were to receive the SBIR grant for the two-dimensional software program. In this case James considered only two scenarios: "high profit" and "low profit." Note that the revenue estimates are quite low. Under the "high profit" scenario the program would yield total revenues of $1,500,000. In the "low profit" scenario, James estimated that there would be no revenues. James assigned his estimated probabilities of the scenarios to be 25% and 75% for the "high profit" and the "low profit" scenarios, respectively.

James also gave serious thought and analysis to various other uncertainties facing

Bio-Imaging. After consulting with Scott, he assigned a 60% likelihood that they would be successful in producing an operational version of the three-dimensional software pro-gram. Moreover, after consulting with Michael Ford, James also estimated that the like lihood of winning the SBIR grant after successful completion of the three-dimensional software program to be 70%. However, they estimated that the likelihood of winning the SIR grant with only the two-dimensional software program would be only 20%.

Scenario

High Profit

Medium Profit

Low Profit

Probability

20%

40%

40%

Total Revenues

$3,000,000

$500,000

$O

Scenario

High Profit

Medium Profit

Low Profit

Probability

20%

40%

40%

Total Revenues

$10,000,000

$3,000,000

SO

Scenario

High Profit

Low Profit

Probability

25%

75%

Total Revenues

$1,500,000

SO

Construction of the Decision Tree

Let us now construct a decision tree for analyzing the decisions faced by Bio-Imag-ing. The first decision that must be made is whether Bio-Imaging should accept the offer from Medtech or instead continue with the research and development of the three-dimensional software program. This decision is represented by a decision node with two branches emanating from it, as shown in Figure 1.12. (The label "A" is placed on the decision node so that we can conveniently refer to it later.)

If Bio-Imaging were to accept the offer from Medtech, there would be nothing left to decide. If instead they were to continue with the research and development of the three-dimensional software program, they would find out after six months whether or not they would succeed in making it operational. This event is represented by an event node labeled "B" in Figure 1.13.

If Bio-Imaging were successful in developing the program, they would then face the decision whether to apply for an SBIR grant or to instead accept the offer from Nugrowth Development. This decision is represented as node C in Figure 1.14. If they were to apply for an SBIR grant, they would then either win the grant or not.

This event is represented as node E in Figure 1.14. If they were to win the grant, they would then complete the development of the three-dimensional software product and market the product accordingly. The revenues that they would then receive would be in accordance with James' estimates given in Table 1.2. The event node G in Figure 1.14 represents James' estimate of the uncertainty regarding these revenues.

If, however, Bio-Imaging were to lose the grant, the offer from Nugrowth would then not be available either, due to the inherent delays in the grant decision process at NIH. In this case, Bio-Imaging would not have the resources to continue, and would have to abandon the project altogether. This possibility is represented in the lower branch emanating from node E in Figure 1.14.

On the other hand, if Bio-Imaging were to accept the offer from Nugrowth De-velopment, they would then face the revenue possibilities in accordance with lames' estimates given in Table 1.3. The event node H in Figure 1.14 represents James' estimate of the uncertainty regarding these revenues.

If Bio-Imaging were not successful in making the three-dimensional product op-erational, there would then be only two alternative choices of action: Abandon the project, or do more work to enhance the two-dimensional software product and then apply for an SBIR grant with the two-dimensional product. These two alternatives are represented at decision node D in Figure 1.15. If Bio-Imaging were to apply for the SBIR grant in this case, they would either win the grant or not. This event is represented as event node F in Figure 1.15. If they were to apply for the SBIR grant and were to win it, they would then complete the development of the two-dimensional software product and market it accordingly. The revenues they would then receive would be in accordance with James' estimates given in Table 1.4. The event node I in Figure 1.15 represents James' estimate of the uncertainty regarding these revenues. Finally, if they were to lose the SBIR grant for the two-dimensional product, they would have to abandon the project, as represented by the lower branch emanating from node F of

Figure 1.15.

At this point, we have represented a description of the decision problem faced by Bio-Imaging in the decision tree of Figure 1.15. Notice that Figure 1.15 represents all of the decisions and all of the relevant uncertainties in the problem, and portrays the logical unfolding of decisions and uncertain events that Bio-Imaging is facing.

Assigning Probabilities in the Decision Tree

The next task in the decision analysis process is to assign probabilities to all of the uncertain events. For the problem at hand, this task is quite straightforward. For event node B, we place the probability that Bio-Imaging will succeed in producing an operational version of the three-dimensional software under the upper branch emanating from the node. This probability was estimated by James to be 0.60, and so we place this probability under the branch as shown in Figure 1.16. The probability that Bio- Imaging would not be successful in producing a three-dimensional prototype software program is therefore 0.40, and so we place this probability under the lower branch emanating from node B.

For event node E, we place the probability that Bio-Imaging would win the SBIR grant (if they were to succeed at producing an operational version of the three-dimensional software), which lames had estimated to be 0.70, under the upper branch emanating from node E. We place the probability of 0.30, which is the proba bility that Bio-Imaging would not win the SBIR grant under this scenario, under the lower branch emanating from node E.

For event node F, we have a similar situation. We place the probability that Bio-Imaging would win the SBIR grant (if they were not to succeed at producing an operational version of the three-dimensional software), which James had estimated to be 0.20, under the upper branch emanating from node F. We place the probability of 0.80, which is the probability that Bio-Imaging would not win the SBIR grant under this scenario, under the lower branch emanating from node F.

Finally, we assign the various probabilities of high, medium, and /or low profit scenarios to the various branches emanating from nodes G, H, and I, according to James' estimates of these scenarios as given in Table 1.2, Table 1.3, and Table 1.4.

Valuing the Final Branches

The remaining step in constructing the decision tree is to assign numerical values to the final branches of the tree. For the Bio-Imaging decision problem, this means computing the net profit corresponding to each final branch of the tree. For the branch corresponding to accepting the offer from Medtech, the computation is trivial: Bio-Imaging would receive $150,000 in net profit if they were to accept the offer from Medtech. This is shown in the lower branch emanating from node A, in Figure 1.17.

For all other final branches of the tree, the computation is not quite so easy.

Let us consider first the branches emanating from node G. The net profit is the total revenues minus the relevant costs. For these branches, the total revenues are given in Table 1.2. The relevant costs are the costs of research and development of the operational three-dimensional software (which was estimated by James to be $200,000). The SBIR grant money would be used to cover all final development and marketing costs, and so would not figure into the net profit computation. Therefore, by way of example, the net profit under the "high profit" scenario branch emanating from node G is computed as:

$2,800,000 = $3,000,000 - $200,000.

The other two net profit computations for the branches emanating from node G are computed in a similar manner. These numbers are then placed next to their respective branches, as shown in Figure 1.17.

Next consider the lower branch emanating from node E, which corresponds to succeeding at making an operational version of the three-dimensional software, applying for the SBIR grant, and losing the competition for the grant. In this case, the revenues would be zero, as Bio-Imaging would abandon the project, but the costs would still be the $200,000 in development costs for the operational version of the three-dimensional software. Therefore the net profit would be - $200,000, as shown in Figure 1.17.

Next consider the three final branches emanating from node H. At node H, Bio-Imaging would have decided to accept the offer from Nugrowth Development, and so Bio-Imaging would only receive 20% of the total revenues. Under the "high profit" scenario, for example, the total revenues would be $10,000,000 (see Table 1.3). There-fore, the net profits to Bio-Imaging would be:

$1,800,000 = 0.20 × $10,000,000 - $200,000.

The other two net profit computations for the branches emanating from node H are computed in a similar manner. These numbers are then placed next to their respective branches, as shown in Figure 1.17.

Next consider the two final branches emanating from node I. At node I, Bio-Imaging would have been unsuccessful at producing an operational version of the three-dimensional product (at a cost of $200,000), but would have decided to go ahead and further refine the two-dimensional product (at a cost of $100,000). Under the "high profit" scenario, for example, the total revenues would be $1,500,000, see Table 1.4. Therefore, the net profits to Bio-Imaging would be:

$1,200,000 = $1,500,000 - $200,000 - $100,000.

The other net profit computation for the "low profit" scenario branch emanating from node I is computed in a similar manner. These numbers are then placed next to their respective branches, as shown in Figure 1.17.

Finally, we compute the net profits for the lower branches of nodes D and F. Using the logic herein, the net profit for the lower branch of node D is - $200,000 and the net profit for the lower branch of node F is - $300,000. These numbers are shown in Figure 1.17.

At this point, the description of the decision tree is complete. The next step is to solve the decision tree.

Solving for the Optimal Decision Strategy

We now proceed to solve for the optimal decision strategy by folding back the tree. Recall that this entails computing the EMV (expected monetary value) of all event nodes, and computing the EMV of all decision nodes by choosing that decision with the best EMV at the node. Let us start with node H of the tree. At this node, one of the three scenarios ("high profit," "medium profit" and "low profit") would transpire. We compute the EMV of this node by weighting the three outcomes emanating from the node by their corresponding probabilities. Therefore the EMV of node H is computed as:

0.20 ($1,800,000) + 0.40 ($400,000) + 0.40 (- $200,000) = $440,000.

We then write the EMV number $440,000 above node H, as shown in Figure 1.18.

Similarly we compute the EMV of node G as follows:

0.20 ($2,800,000) + 0.40 ($300,000) + 0.40 (- $200,000) = $600,000, and so we write the EMV number $600,000 above node G, as shown in Figure 1.18.

The EMV of node E is then computed as:

0.70 ($600,000) + 0.30 (- $200,000) = $360,000,

and so we write the EMV number $360,000 above node E, as shown in Figure 1.18.

Node C corresponds to deciding whether to apply for an SBIR grant, or to accept the offer from Nugrowth Development. The EMV of the SBIR option (node E) is $360,000, while the EMV of the Nugrowth offer is $440,000. The option with the highest EMV is to accept the offer from the Nugrowth Development. Therefore, we assign the EMV of node C to be the higher of the two EMV values, i.e., $440,000, and we cross off the branch corresponding to applying for the SBIR grant, as shown in Figure 1.18.

The EMV of node I is computed as:

0.25 ($1,200,000) + 0.75 (- $300,000) = $75,000,

and so we write the EMV number $75,000 above node I, as shown in Figure 1.18.

The EMV of node Fis

0.2 ($75,000) + 0.8 (- $300,000) = - $225,000,

and so we write the EMV number - $225,000 above node F, as shown in Figure 1.18.

At node D, the choice with the highest EMV is to abandon the project, since this alternative has a higher EMV (- $200,000) compared to that of applying for an SBIR grant with the two-dimensional program (- $225,000). Therefore, we assign the EMV of node D to be the higher of the two EMV values, i.e., - $200,000, and we cross off the branch corresponding to applying for the SBIR grant, as shown in Figure 1.18.

The EMV of node B is computed as

0.6 ($440,000) + 0.4 (- $200,000) = $184,000,

which we write above node B in Figure 1.18.

Finally, at node A, the option with the highest EMV is to continue the development of the software. Therefore, we assign the EMV of node A to be the higher of the two EMV values of the branches emanating from the node, i.e., $184,000, and we cross off the branch corresponding to accepting the offer from Medtech, as shown in Figure 1.18.

We have now solved the decision tree, and can summarize the optimal decision strategy for Bio-Imaging as follows:

Bio-Imaging Optimal Decision Strategy:

* ﻿﻿Bio-Imaging should continue the development of the three-dimensional software program and should reject the offer from Medtech.
* ﻿﻿If the development effort succeeds, Bio-Imaging should accept the offer from Nugrowth Development.
* ﻿﻿If the development effort fails, Bio-Imaging should abandon the project alto-gether.

﻿﻿The EMV of this optimal decision strategy is $184,000.

Sensitivity Analysis

Given the subjective nature of many of the data values used in the Bio-Imaging decision tree, it would be unwise to adopt the optimal decision strategy derived herein without a thorough examination of the effects of key data assumptions and key data values on the optimal decision strategy. Recall that sensitivity analysis is the process of testing and evaluating how the solution to a decision tree behaves in the presence of changes in the data. The data estimates that James had developed in support of the construction of the decision tree were developed carefully, of course. Nevertheless, many of the data values, particularly the values of many of the probabilities, are inherently difficult or even impossible to specify with precision, and so should be subjected to sensitivity analysis. Here we briefly show how this might be done.

One of the probability numbers used in the decision tree model is the probability of winning an SBIR grant with the three-dimensional prototype software. Let us denote this probability by g. James' original estimate of the value of g was g = 0.70. Because the "true" value of g is also impossible to know, it would be wise to test how sensitive the optimal decision strategy is to changes in the value of g. If we were to construct a spreadsheet model of the decision tree, we would find that the optimal decision strategy remains unaltered for all values of q less than q = 0.80. Above q = 0.80,

the optimal decision strategy changes by having Bio-Imaging reject the offer from Nu-growth in favor of applying for the SBIR grant with the three-dimensional prototype.

If James were quite confident that the true value of g were less than 0.80, he would then be further encouraged to adopt the optimal decision strategy from the decision tree solution. If he were not so confident, he would then be wise to investigate ways to improve his estimate of the value of g.

Another probability number used in the decision tree model is the probability that Bio-Imaging would successfully develop the three-dimensional prototype. Let

us denote this probability by p. James' original estimate of the value of p was p = 0.60.

Because the "true" value of p is also impossible to know, it would be wise to test how sensitive the optimal decision strategy is to changes in the value of p. This can also be done by constructing a spreadsheet version of the decision tree, and then testing a variety of different values of p and observing how the optimal decision strategy changes relative to the value of p. Exercise 1.3 treats this and other sensitivity analysis questions that arise in the Bio-Imaging decision tree.

Decision Analysis Suggests Some Different Alternatives

Note from Figure 1.18 that the EMV of the optimal decision strategy, which is $184,000, is not that much higher than the EMV of accepting the offer from Medtech, which is $150,000. Furthermore, the optimal decision strategy, as outlined above, entails substantially more risk. To see this, observe that under the optimal decision strategy, it is possible that Bio-Imaging would realize net profits of $1,800,000, but they might also realize a loss of - $200,000. If they were instead to accept the offer from Medtech, they would realize a guaranteed net profit of $150,000. Because the two EMV values of the two different strategies are so close, it might be a good idea to explore negotiating with Medtech to see if they would raise their offer above

$150,000.

In order to prepare for such negotiations, it would be wise to study the product development decision from the perspective of Medtech. With all of the data that has been developed for the decision tree analysis, it is relatively easy to conduct this analysis. Let us presume that Medtech would invest $1,000,000 in the project (which is the same amount that Nugrowth would have invested). And to be consistent, let us assume that the possible total revenues that Medtech might realize would be the same as those that were estimated for the case of Bio-Imaging accepting financing from Nugrowth, and with the same probabilities (as specified in Table 1.3). If we further assume, to be safe, that Medtech would face the same probability of successful development of the three-dimensional software program, then Medtech's net profits from this project can be represented as in Figure 1.19. In the figure, for example, the net profit of the "high profit" outcome is computed as:

$8,850,000 = $10,000,000 - $1,000,000 - $150,000,

where the $10,000,000 would be the total revenue, the $1,000,000 would be their investment cost, and the $150,000 would be their offer to Bio-Imaging to receive the rights to develop the product.

The EMV of the node labeled "T" of the tree in Figure 1.19 is computed as:

0.20 ($8,850,000) + 0.40 ($1,850,000) + 0.40 (- $1,150,000) = $2,050,000, and the EMV of the node labeled "S" of the tree in Figure 1.19 is computed as:

0.60 ($2,050,000) + 0.40 (- $1,150,000) = $770,000.

Therefore, it appears that Medtech might still realize a very large EMV after paying Bio-Imaging $150,000 for the rights to develop the software. This suggests that Bio-Imaging might be able to negotiate a much higher offer from Medtech for the rights to develop their three-dimensional imaging software.

One other strategy that Bio-Imaging might look into is to perform the clinical trials to fine-tune the two-dimensional software and apply for an SBIR grant with the two-dimensional software, without attempting to develop the three-dimensional software at all. Bio-Imaging would incur the cost of the clinical trials, which James had estimated to be $100,000, but would save the $200,000 in costs of further development of the three-dimensional software. In order to ascertain whether or not this might be a worthwhile strategy, we can draw the decision tree corresponding to this strategy, as shown in Figure 1.20.

The decision tree in Figure 1.20 uses all of the data estimates developed by James for his analysis. As shown in Figure 1.20, the EMV of this alternative strategy is - $25,000, and so it is not wise to pursue this strategy.

As the previous two analyses indicate, decision trees and the decision analysis framework can be of great value not only in computing optimal decision strategies, but in suggesting and evaluating alternative strategies.