MIS775 Decision Modelling for Business Analytics

TOPIC 6: Decision Analysis: Making Decisions under Uncertainty

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MIS775 WEEK 6

MIS775 Assignment Submission Deadline

The deadline for submission is next week (Week 6)

Date: Wednesday, 9th April

Time: 8:00 PM

Assignment one support session on Monday and Thursday at 7pm

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MIS775 WEEK 6

Week 7 - Easter vacation/intra-trimester break:
Friday 18th April –Sunday 27th April Sunday (inclusive)

What's the Plan for Week 7?

- No F2F seminars or online seminars on Friday 18th April (Public Holiday)
- **Week 7 Online seminar will be on Thursday, 17th April at 7 pm**
- **Friday On-Campus Seminar groups are very welcome to attend the week 7 online seminar or any other face to face seminar**

Decision Analysis

- Decision analysis can be used when a decision maker is faced with several decision alternatives and uncertain future outcomes
- It considers all decision alternatives, future outcomes, their probabilities, and their consequences
- It identifies the best course of action (i.e. decision alternative) according to the decision criteria applied
- Decision analysis should include a risk analysis that provides probability information about favourable/unfavourable consequences that may occur

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Learning Objectives

This topic focuses on decision analysis techniques for structuring and analysing decision problems in a logical manner

Learning objectives:

- **Steps involved in decision analysis**
- **How probabilities are used in the decision making process**
- **Criteria for choosing between decision alternatives**
- **How to conduct sensitivity analysis and risk analysis**
- **How a decision maker can quantify the value of information**

Textbook reading: Chapter 9 (9.1-9.3, 9.5). Ignore references to Precision Tree software

Case 1: GymFit

- GymFit's management is considering whether to build a new fitness centre and is trying to determine what type of facility to build. Only two types are under consideration: a Fitness Centre, and a Fitness Centre with Aquatic facilities
- The following decision alternatives are available to management:
  - **Build a Fitness Centre with Aquatic facilities**
  - **Build a Fitness Centre**
  - **Build nothing (keep their business at its current size)**
- Management believes that each decision alternatives has three possible future outcomes (called **states of nature**):
  - **Strong demand**
  - **Moderate demand**
  - **Weak demand**

Case 1: GymFit

- Management also believes that:
  - **a Fitness Centre with Aquatic facilities would produce a net profit of $80k, $40k, or a net loss of $60k if demand was strong, moderate, or weak respectively**
  - **a Fitness Centre would produce net profits of $45k, $25k, or a net loss of $10k if demand was strong, moderate, or weak respectively**
  - **building nothing would result in a net profit of $10k, $5k and $0 if demand was strong, moderate and weak respectively.**
- We use this information to construct a payoff table (or matrix)

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Payoff Table

- List the payoffs (V_{ij}) for each decision alternative (d_i) and outcome (s_j) pair
  - **Positive payoffs correspond to gains/profit**
  - **Negative payoffs correspond to costs/loss**

decision alternatives

Decision alternatives (*d*)	**States of nature** Strong demand (s_1)	Moderate demand (s_2)	Weak demand (s_3)
Fitness Centre with Aquatic facilities (d_1)	80	40	-60
Fitness Centre (d_2)	45	25	-10
Do nothing (d_3)	10	5	0

Note: All payoffs shown in the table are in $'000

Consequences/ Outcomes / Pay off values

Probabilities of Outcomes

- We also need to know the likelihood (i.e. probability) of each state of nature
- These can be based on historical data and/or judgement
- In our case study, GymFit management decides to use their knowledge and experience to determine the probabilities of occurrence of the three different outcomes. Based on their research, they believe there is:
  - **a 20% chance of demand being strong**
  - **a 50% chance that demand being moderate**
  - **a 30% chance that it will be weak**
- **Which decision alternative would give GymFit the greatest net profit?**

Steps in Decision Analysis

1. Identify the decision alternatives (different strategies available to decision maker)
2. Identify the states of nature (future chance outcomes which may occur – these are not under the control of the decision maker)
3. Determine the payoff (consequence) for each combination of decision alternatives and possible outcomes
   - **Payoffs can be any appropriate measure, e.g. profit, cost, time**
4. Assess the probabilities of the states of nature
5. Develop a decision tree
6. Select decision criteria for choosing the best decision alternative
7. Apply the criteria and make your decision

Decision Tree

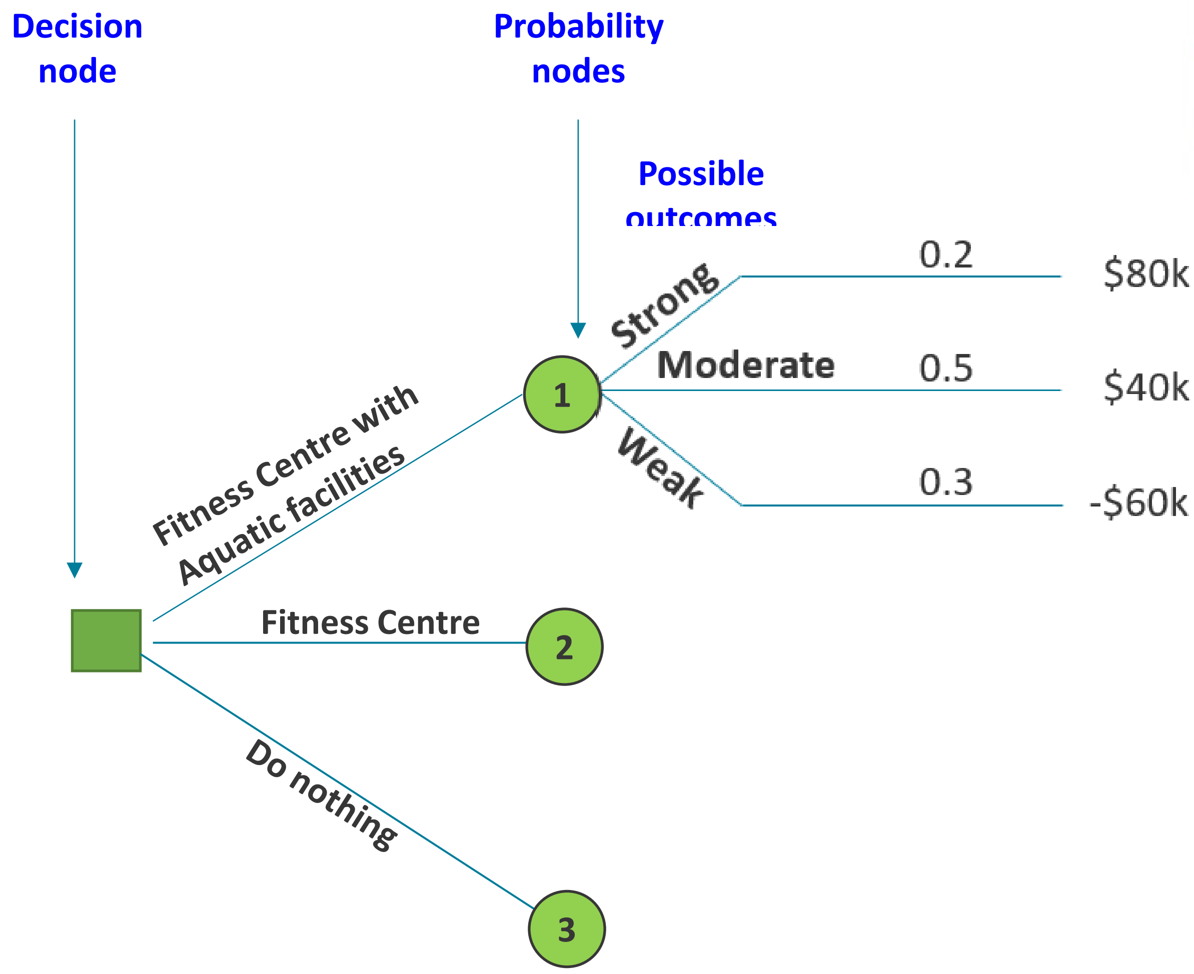
- Graphical tool for Decision Analysis problems
- Decision trees show the sequence of decision alternatives, outcomes, probabilities and payoff values, with *time flowing from* ***left to right***
  - **Usually begin with a decision node, i.e. decision maker must make a decision *before* observing the uncertain outcome**
  - **Probabilities are listed on outcome branches**

- Decision tree conventions

■ A **decision node** represents a time when the decision maker makes a decision. Decision maker must select only one alternative

● A **probability node** represents a time when the results of an uncertain outcome becomes known

Decision Tree for GymFit (Ex: First decision)



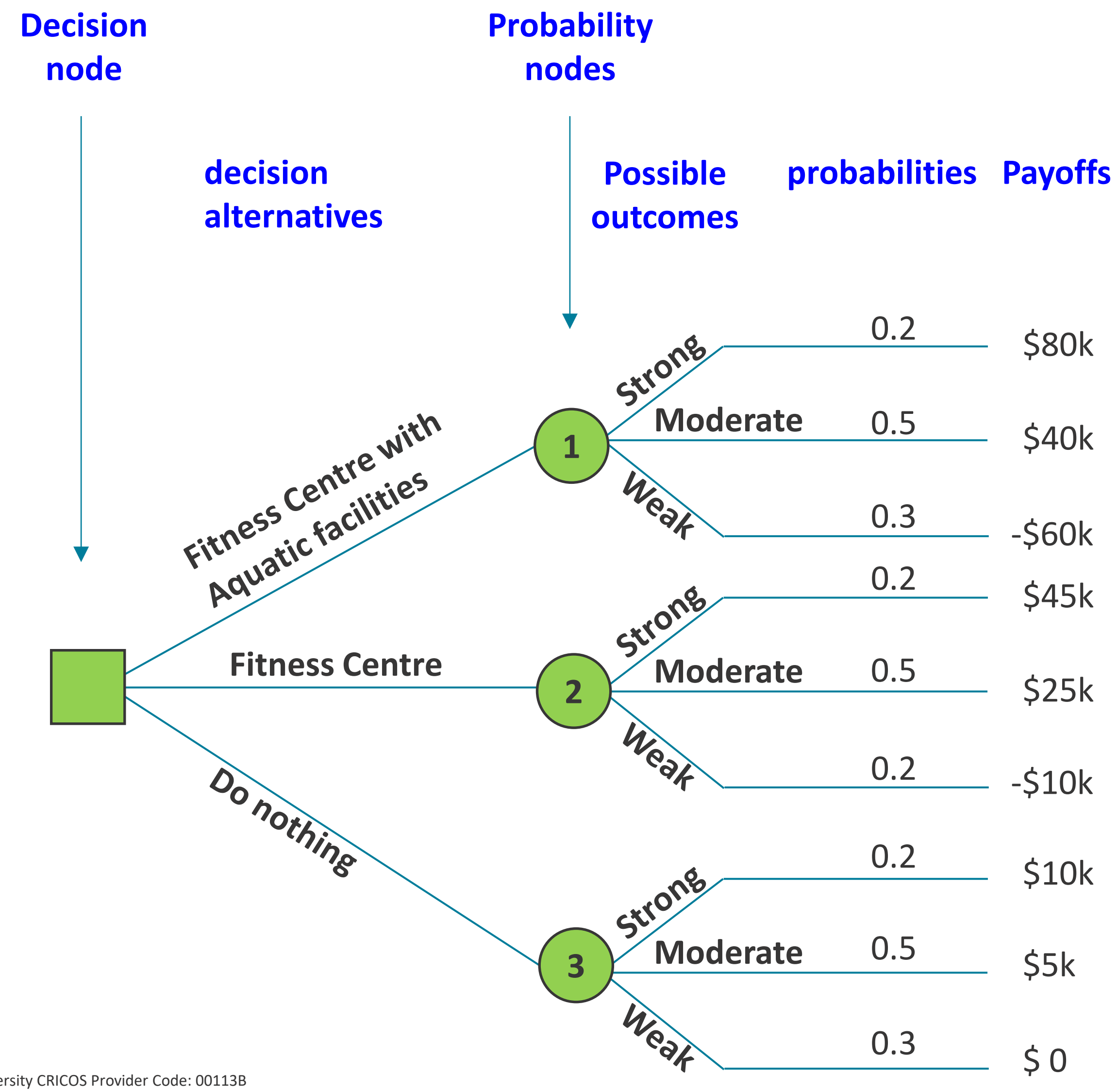
	0.2	0.5	0.3
	States of nature		
Decision alternatives (d)	Strong demand (s_1)	Moderate demand (s_2)	Weak demand (s_3)
Fitness Centre with Aquatic facilities (d_1)	80	40	-60
Fitness Centre (d_2)	45	25	-10
Do nothing (d_3)	10	5	0

At each probability node, calculate

$$EMV(d_i) = \sum_{j=1}^{N} V_{ij} P(s_j)$$

Outcome node 1:
EMV = $80k(.2) + $40k(.5) -60k(.3) = $18k

Decision Tree for GymFit



	0.2	0.5	0.3
	States of nature		
Decision alternatives (*d*)	Strong demand (s_1)	Moderate demand (s_2)	Weak demand (s_3)
Fitness Centre with Aquatic facilities (d_1)	80	40	-60
Fitness Centre (d_2)	45	25	-10
Do nothing (d_3)	10	5	0

Decision Criteria – Expected Monetary Value

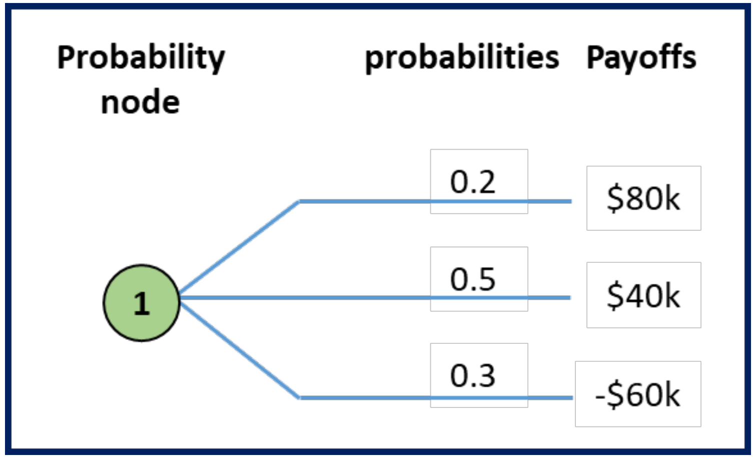
- We use the expected monetary value (EMV) approach to identify the best decision alternative
- EMVs are calculated through a "*folding back*" process, starting from the *right of the decision tree* and working back *to the left*:

1. At each probability node, calculate $EMV(d_i) = \sum_{j=1}^{N} V_{ij}P(s_j)$

   Outcome node 1: EMV = $80k(.2) + $40k(.5) -60k(.3) = $18k

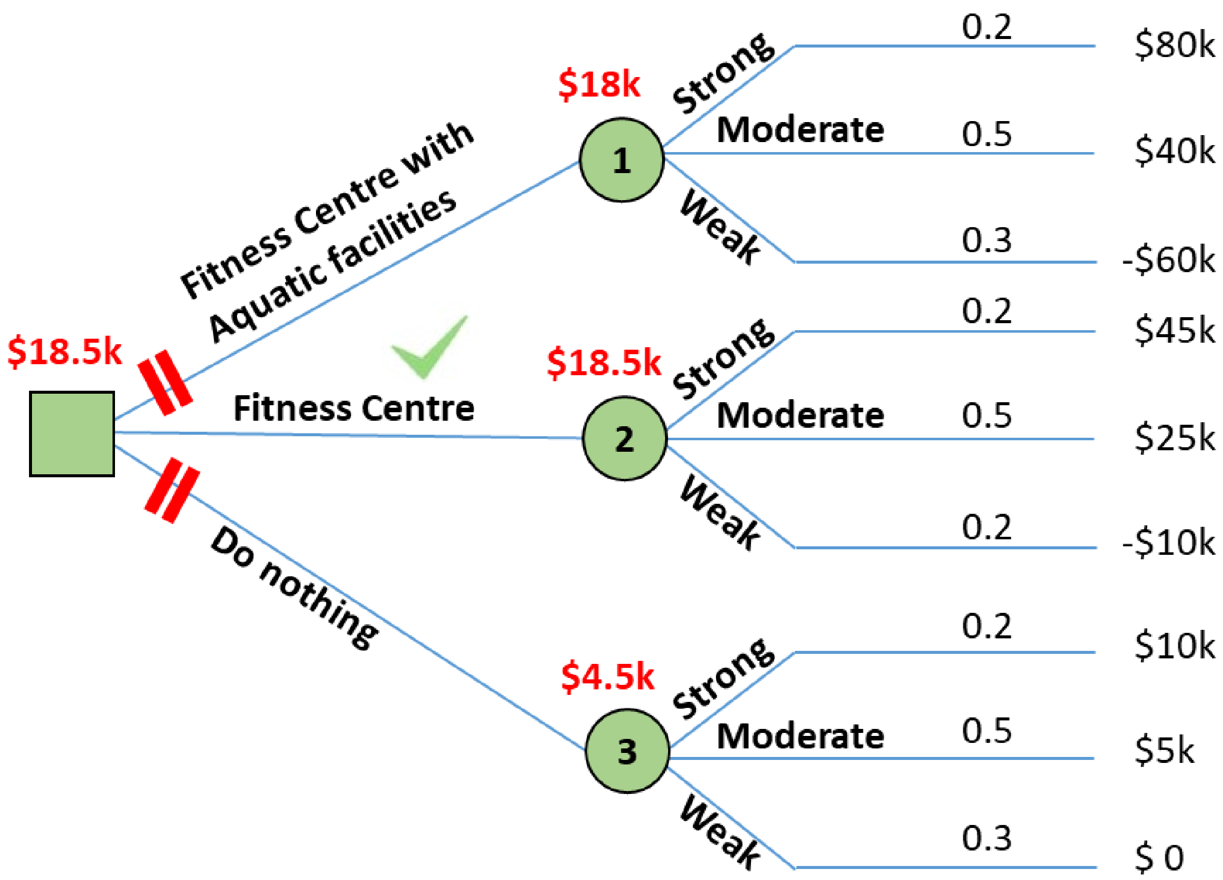
   Outcome node 2: EMV = $45k(.2) + $25k(.5) -10k(.3) = $18.5k

   Outcome node 3: EMV= $10k(.2) + $5k(.5) + 0 = $4.5k



2. At each decision node, take the *maximum* of EMVs to identify the *optimal* decision

Completed Decision Tree for GymFit



Outcome node 1: EMV = $80k(.2) + $40k(.5) -60k(.3) = $18k

Outcome node 2: EMV = $45k(.2) + $25k(.5) -10k(.3) = $18.5k

Outcome node 3: EMV= $10k(.2) + $5k(.5) + 0 = $4.5k

The best decision is to build a Fitness Centre for an expected net profit of $18.5k

Sensitivity Analysis

- Recommended decision is sensitive to the estimated probabilities
  - **Does the decision continue to be 'best' if one or more probabilities change?**
- Sensitivity analysis can be used to determine how changes to the following inputs affect the recommended decision alternative:
  - **Probabilities for the states of nature**
  - **Payoff values**
- If a small change in the value of one of the inputs causes a change in the recommended decision alternative, extra effort and care should be taken in estimating the input value
- It is therefore important to accompany decision analysis with a sensitivity analysis

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Sensitivity Analysis: States of Nature Probabilities

- One approach to sensitivity analysis is to select different values for the probabilities of the states of nature and the payoffs and then re-solve the decision analysis problem
- If the recommended decision alternative changes, we know the solution is sensitive to changes

The initial probabilities of states of nature are $P(s_1) = 0.2$, $P(s_2) = 0.5$ and $P(s_3) = 0.3$
$EV(d_1) = \$80k(.2) + \$40k(.5) - \$60k(.3) = \$18k$
$EV(d_2) = \$45k(.2) + \$25k(.5) - \$10k(.3)$ **$= \$18.5k$**
$EV(d_3) = \$10k(.2) + \$5k(.5) + 0 = \$4.5k$

By changing the probabilities of states of nature to $P(s_1) = 0.3$, $P(s_2) = 0.5$ and $P(s_3) = 0.2$
$EV(d_1) = \$80k(.3) + \$40k(.5) - \$60k(.2) =$ **$\$32k$**
$EV(d_2) = \$45k(.3) + \$25k(.5) - \$10k(.2) = \$24k$
$EV(d_3) = \$10k(.3) + \$5k(.5) + 0 = \$5.5k$

- **Explain the results:**
  - If probability of strong demand is low (0.2), then build Fitness Centre for expected net profit of $18.5k
  - But if that probability is 0.3, then build Fitness Centre with Aquatic facilities for expected net profit of $32k
- **Drawback:**
  - The drawback of this approach is the numerous calculations required to evaluate the effect of several possible changes in the state of nature probabilities

Sensitivity Analysis: Payoff Values

- Sensitivity analysis calculations can also be undertaken for the payoffs

The initial probabilities of states of nature are $P(s_1) = 0.2$, $P(s_2) = 0.5$ and $P(s_3) = 0.3$
$EV(d_1) = \$80k(.2) + \$40k(.5) - \$60k(.3) = \$18k$
$EV(d_2) = \boxed{\$45k(.2)} + \$25k(.5) - \$10k(.3) =$ **\$18.5k**
$EV(d_3) = \$10k(.2) + \$5k(.5) + 0 = \$4.5k$

Decision alternative d_2 will remain the optimal decision alternative as long as $EV(d_2) \geq \$18k$, the expected value of the *second best decision alternative*

- Assuming that the payoffs for d_2 stay at the original values of \$25k and -\$10k when demand is moderate and weak respectively, the decision alternative will remain optimal provided $EV(d_2)$ = 0.2R + 0.5(25) + 0.3(-10) ≥ 18 → **R ≥ \$42.5**
- The calculation shows that decision alternative d_2 will remain optimal as long as the payoff for d_2 is at least \$42.5k when demand is strong

Risk Profile for GymFit

- The risk profile for a decision alternative shows the possible payoffs along with their associated probabilities
- It helps the decision maker understand the difference between the expected payoff (18.5K) and the payoffs which might actually occur
- Sometimes a review of the risk profile may cause the decision maker to choose another decision alternative even though its expected value is not as good

Decisions (d)	States of nature		
	s1	s2	s3
d1	80	40	-60
d2	45	25	-10
d3	10	5	0

Risk Profile of the best decision

Outcome	Profit	Probability
Strong demand	$45k	20%
Moderate demand	$25k	50%
Weak demand	**-$10k**	**30%**
	Total	100%

Outcome node 2:
EMV = $45k(.2) + $25k(.5) -10k(.3) = $18.5k

Should GymFit buy Information?

- A marketing research company approached Gymfit management with a business proposal to make the right decision regarding building of the new facilities at a cost of $20,000.
- According to their proposal, the analysis will tell GymFit with certainty whether the demand for new facilities including Fitness Centre with or without Aquatic facilities will be strong, moderate, or weak
  - **What should management do?**
  - **Does this information prevent management from making an expensive mistake?**
  - **Is the new information worth $20,000?**
  - **If not, how much should management be willing to spend on perfect information?**

Expected Value of Perfect Information (EVPI)

- Perfect Information is almost never available in practice at any price. But finding its value places an upper bound on what to pay for any information on which state of nature will occur
- EVPI = EV *with* PI – EV *without* PI
- **EV *with* PI** is the expected value (or payoff) with perfect information about which state of nature will occur
  - **The decision maker will choose the decision alternative that maximises the payoff**
  - **Chances of each state of nature are then used to find the expected value**
- **EV *without* PI** is the expected value without perfect information about which state of nature will occur

EVPI for GymFit

- To calculate EV *with* PI we first identify the best (maximum) payoff for each state of nature

	States of nature		
Decision alternatives	Strong demand s_1 (0.2)	Moderate demand s_2 (0.5)	Weak demand s_3(0.3)
Fitness Centre with Aquatic facilities (d_1)	**80**	**40**	-60
Fitness Centre (d_2)	45	25	-10
Do nothing (d_3)	10	5	**0**

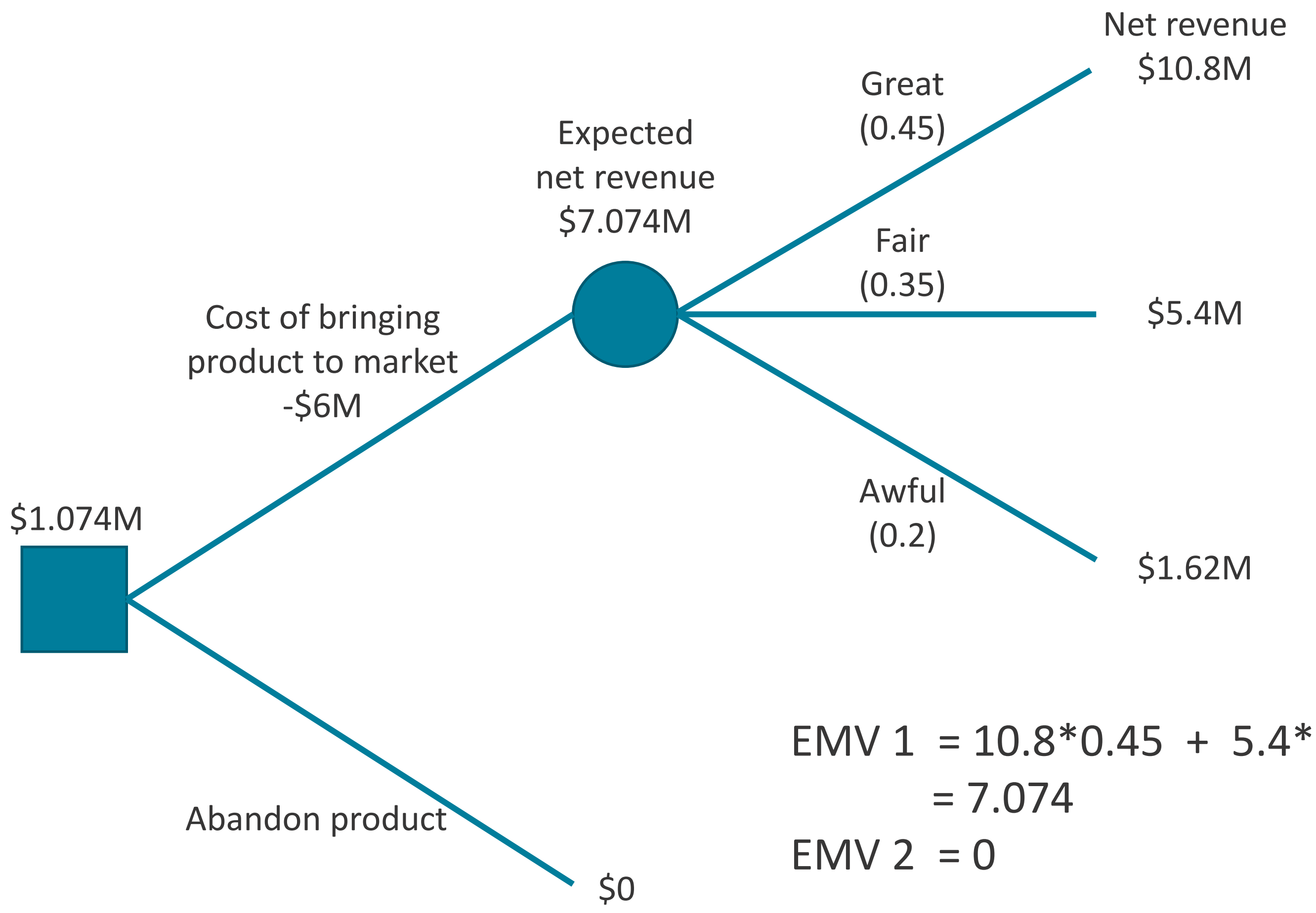
- EV *with* PI = 80×0.2 + 40×0.5 + 0×0.3 = 16 + 20 + 0 = $36,000
- EV *without* PI = $18,500 (already calculated using the decision tree)
- Therefore the EVPI = $36,000 - $18,500 = $17,500
- **Therefore management should not pay more than $17,500 for *any* information about the state of nature**

Case 2: Acme's New Product Decision*

- Acme Company is trying to decide whether to market a new product
- They are currently part way through developing the product. If they decide to continue development they will incur a fixed cost of $6 million
- If the product is marketed its unit margin will be $18
- Possible outcomes are 'great', 'fair', 'awful' with estimated sales volumes (in 1,000s) 600, 300, 90 and probabilities 0.45, 0.35, 0.2 resp.
- **Should Acme proceed with development?**

*Example from section 9.3 of textbook

Decision Tree for Acme



- If they decide to continue development they will incur a fixed cost of **$6 million**
- If the product is marketed its unit margin will be **$18**
- Possible outcomes are 'great', 'fair', 'awful' with estimated sales volumes (in 1,000s) 600, 300, 90 and probabilities 0.45, 0.35, 0.2 resp.

Great = 18*600*1000 = 10800K = 10.8M
Fair = 300*18*1000=5.4M
Awful = 90*18*1000=1.62M

EMV 1 = 10.8*0.45 + 5.4*0.35 + 1.62*0.2
= 7.074
EMV 2 = 0

Decision is to market and the net profit =1.074M

New Product Decisions with Technological Uncertainty*

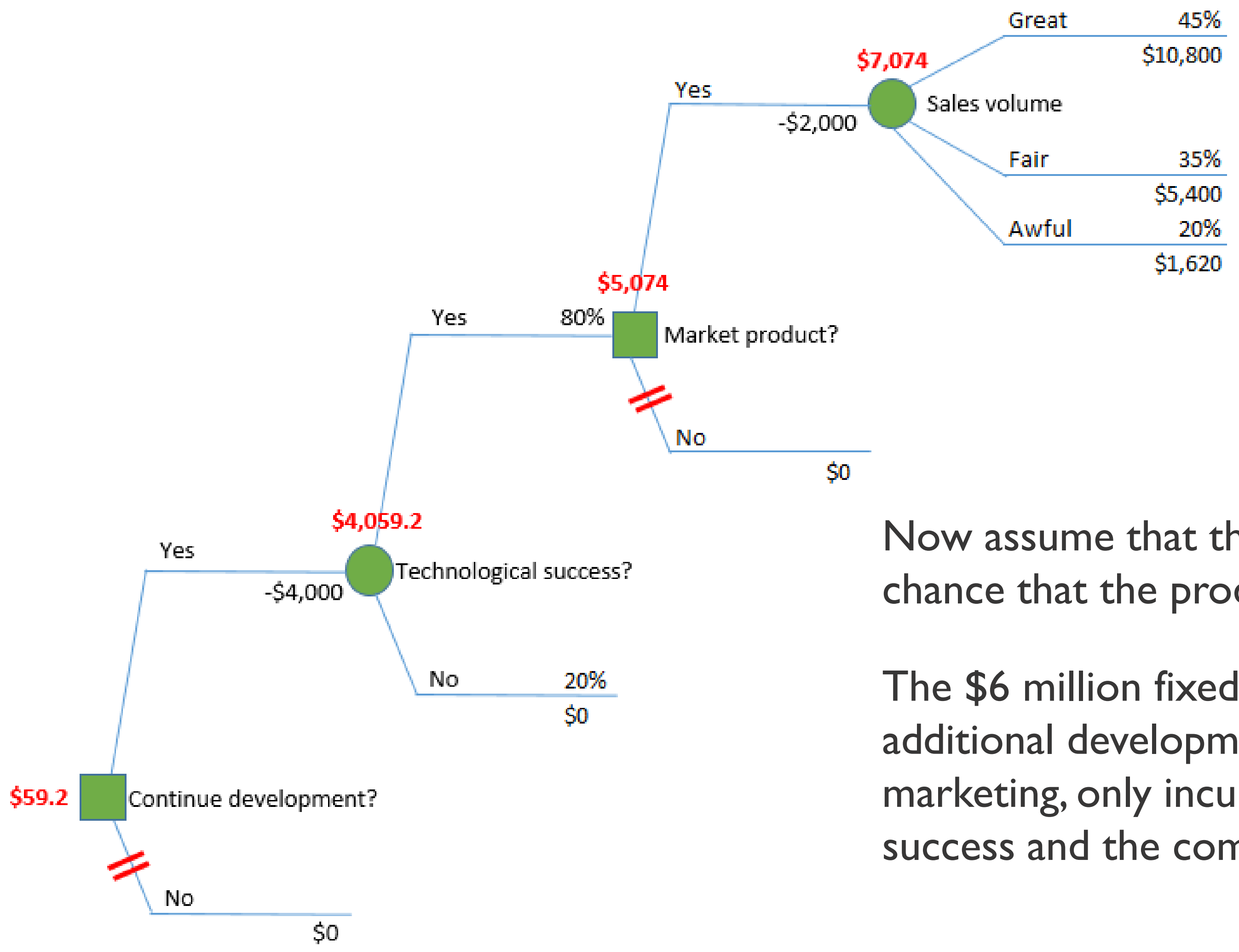
- As before, Acme are currently part way through developing the product. Now assume that the company considers there to be a 20% chance that the product will fail for technological reasons
- The $6 million fixed cost has two components - $4 million for additional development costs and $2 million for fixed costs of marketing, only incurred if the product is a technological success and the company decides to market it
- **Should Acme proceed with development?**

*Example from section 9.4 of textbook

Multistage Decision Problems

- This is an example of a **two-stage decision problem** involving a sequence of decision alternatives and outcomes
- It begins with the decision maker implementing their initial decision. This is followed by an outcome
- Depending on the initial decision and the outcome that occurs after it, the decision maker implements their next decision
- The final payoff is a function of the sequence of decisions made and the outcomes that occurred at each stage of the decision problem
- **Risk profile:** Probability of each payoff can be found by multiplying the probabilities for the branches from the outcome nodes in the sequence

Acme's Two-stage Decision Problem



Great = 18*600*1000 = 10800K=10.8M
Fair = 300*18*1000=5400K = 5.4M
Awful = 90*18*1000=1602M =1.62M

Now assume that the company considers there to be a 20% chance that the product will fail for technological reasons

The $6 million fixed cost has two components - $4 million for additional development costs and $2 million for fixed costs of marketing, only incurred if the product is a technological success and the company decides to market it

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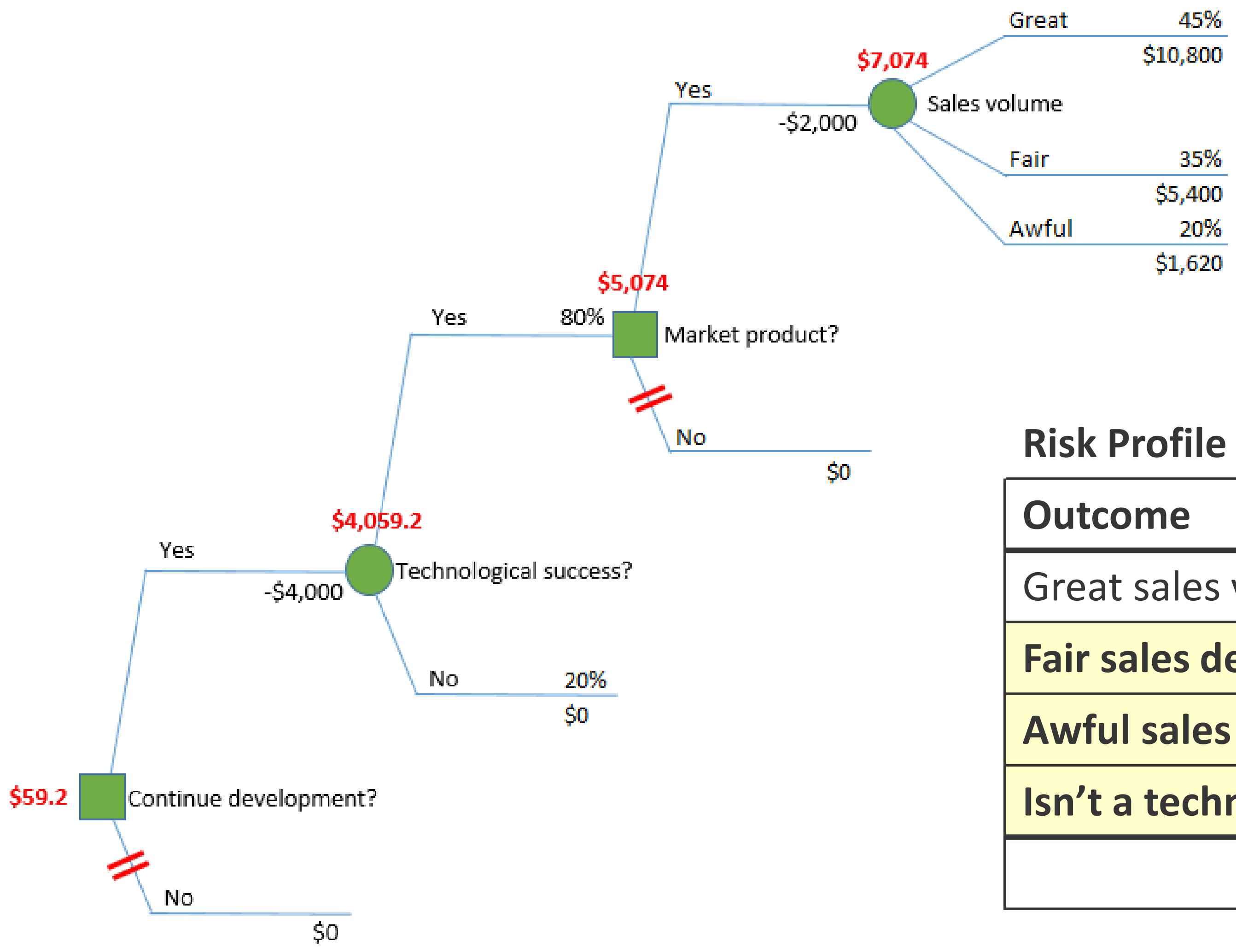
Acme's Two-stage Decision Problem

Revised probability

Great = 0.45 * **0.8** =0.36 =36%

Fair = 0.35* **0.8** =0.28 =28%

Awful = 0.2* **0.8** = 0.16 =16%



Revised profit

Great = 10.8 - 6 =4.8 M

Fair = 5.4 - 6 = -0.6M

Awful = 1.62 - 6 = -4.38M

Not success =-4M

Risk Profile of the best decisions

Outcome	Profit	Probability
Great sales volume	$4.8M	36%
Fair sales demand	**-$0.60M**	**28%**
Awful sales demand	**-$4.38M**	**16%**
Isn't a technological success	**-$4.00M**	**20%**
	Total	100%

Should Acme Buy Information?

- Suppose Acme continued with development, and technological failure is now no longer a possibility. That leaves one decision - should Acme market the product?
- If it decides to launch the new product, marketing will cost $2 million. We follow the textbook and keep the model simple by assuming only two possible market outcomes, good or bad, with respective sales volumes of 600,000 and 100,000 units. Acme has assessed the probabilities of good and bad market outcomes as 0.4 and 0.6, respectively.
- Before making a decision, Acme could commission a research survey to predict the outcome, for $150,000. Acme believes that the prediction accuracy will be as given in the table
- What should Acme do to maximise its EMV?

Actual outcome	Survey result		
	Positive	Negative	Volume
Good (0.4)	0.8	0.2	600,000
Bad(0.6)	0.3	0.7	100,000

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Should Acme Buy Information?

- The probabilities of good and bad market outcomes (0.4 and 0.6, respectively) are known as **prior probabilities**

- The probabilities in the table are **conditional probabilities**
  E.g. 1 $P(Positive|Good) = 0.8$
  E.g. 2 $P(Negative|Bad) = 0.7$

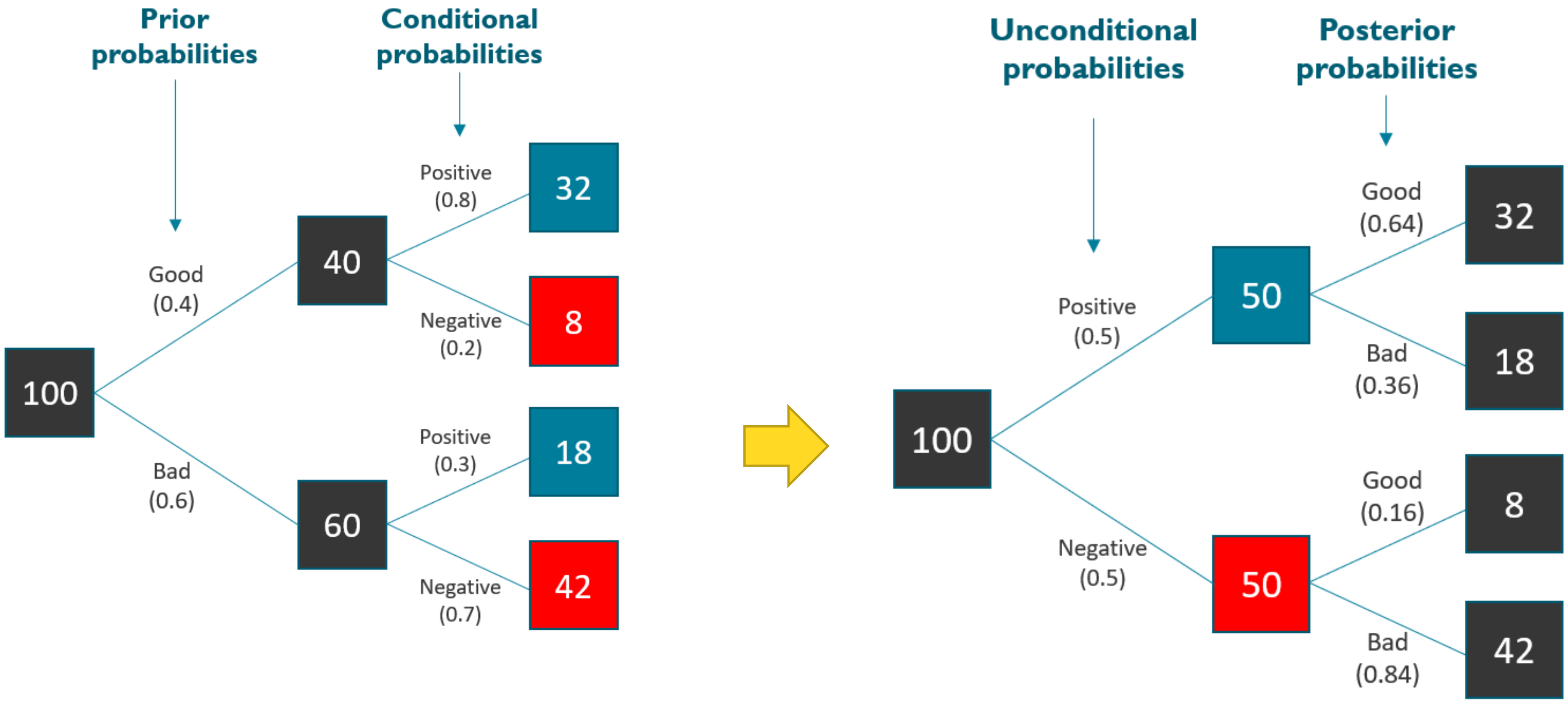
Actual outcome	Survey result		
	Positive	Negative	total
Good	0.8	0.2	1
Bad	0.3	0.7	1

- If Acme buys this information, then the prior probabilities can be updated based on these conditional probabilities
- The updated probabilities are known as **posterior probabilities**

Should Acme Buy Information?

Actual outcome	Survey result		
	Positive	Negative	total
Good	0.8	0.2	1
Bad	0.3	0.7	1

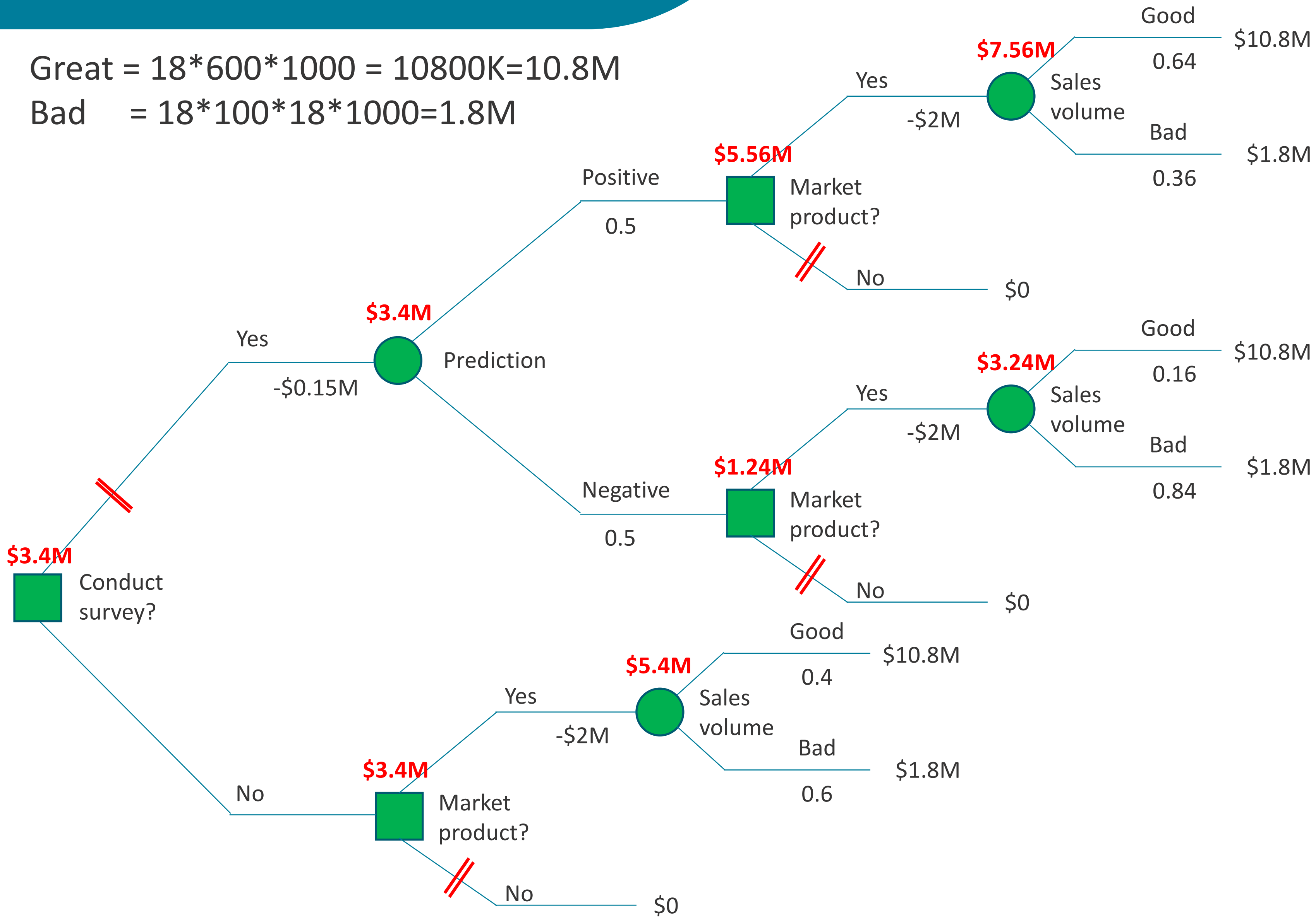
- The easiest way to calculate posterior probabilities, without using a formula, is to consider frequencies, and imagine 100 or 1,000 new products:



Completed Decision Tree for Acme

- Survey is too expensive for the level of accuracy it provides so, according to EMV, Acme shouldn't commission the survey
- If they did decide to commission the survey, then according to EMV, they should marketing the product, irrespective of the survey result, for an EMV of $3.25M

Great = 18*600*1000 = 10800K=10.8M
Bad = 18*100*18*1000=1.8M



Summary

- Decision Analysis is a structured approach to decision making that can help us make good decisions, but it can't guarantee good outcomes
- It is one of three approaches used in developing solutions for stochastic decision models and risk analysis:
  - **Approach 1. Decision analysis**
  - **Approach 2. Scenario analysis uses a range of values of input variables (Topic 7)**
  - **Approach 3. Simulation modelling (Topics 8-9)**