Capability Acquisition Strategy Analysis: A Real Options Approach

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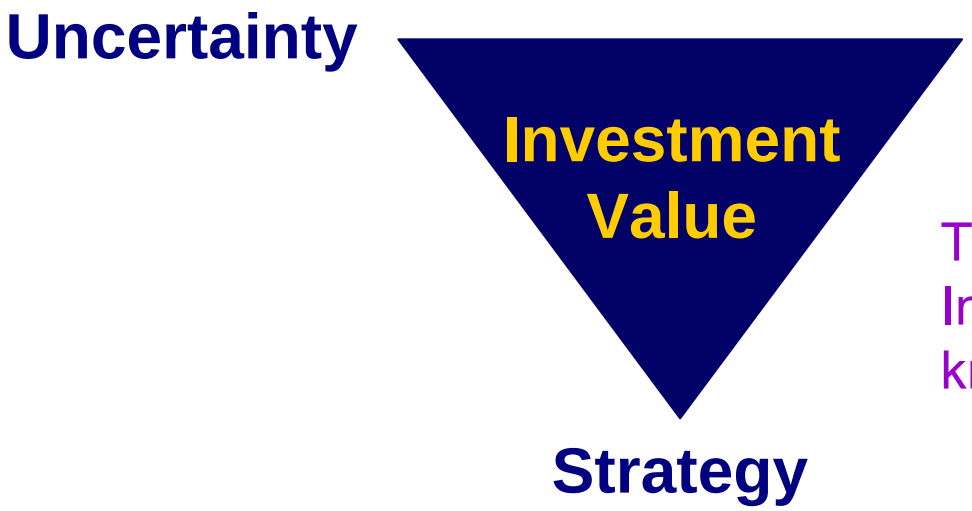
What is “Real Options”?

- An option confers a *right*, but not obligation, to take an action in the future for managing an asset.
- The Real Options methodology is a framework for valuing and planning of real assets.
- Examples of real options:
  - A stronger foundation and structure for a multistory parking garage
  - A rocket with extra fuel on each satellite to reconfigure a constellation
  - Application “hooks” built into the architecture of a software system
  - A foundation IT asset enabling future high-value applications
  - Pilot projects, feasibility studies, and prototypes can all create options

Real Options Triad



The Return on Investment can only be known *probabilistically*.

Viewing investment value through a Real Options lens:

The value of a project must be assessed not just from the technical/engineering aspect, but also on how the management would dynamically respond to uncertainties to achieve better Return on Investment.

Real Options supports strategic intuition with analytical rigor

- The traditional investment valuation tends to be
  - Optimistic: assume the project will *finish* and achieve *optimal* value
  - Simplistic: model uncertainty by an *"average scenario"*
  - Deterministic: can't handle scenario-dependent cash flows caused by *optionality*
- Through a Real Options lens, the risk and strategy context of the project is examined; potential evolution paths are accounted for. The value of an investment is assessed probabilistically.
- 4 major methods for Real Options Valuation:
  - Black-Scholes formula
  - Binomial lattice model
  - **Decision tree analysis**
  - **Monte Carlo simulation**

Real Options can offer a flexible systems engineering approach for capability acquisition

- Consider these concepts:
  - Field operationally acceptable capability earlier and make evolutionary increments over time. Considered contingency plans and exit opportunities. (Defense Acquisition Performance Assessment Report, 2006)
  - Take evolutionary steps to increase learning of a product's usefulness and consider an option to terminate a project if it is no longer beneficial. (GAO-04-744, 2004)
  - Structure major acquisitions into useful segments with a narrow scope and brief duration. (OMB Circular A-11, 2005)
- How would you assess the value of a project being shaped by these concepts?
  - We use a case study with notional data to demonstrate an analysis methodology based on a Real Options approach.

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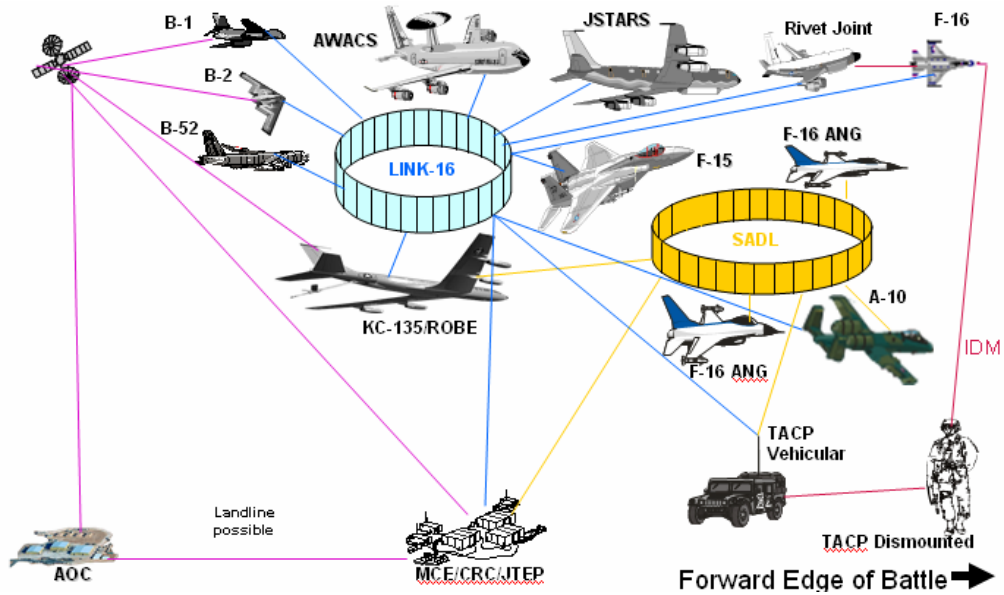
Case: Improving Tactical Data Link (TDL) systems to support the Close Air Support (CAS) mission



Two major problems in current TDL systems for CAS:

- Lack common data communication medium for all participants
- Need more effective message contents and delivery protocols

2 TDL Solutions for the CAS Mission

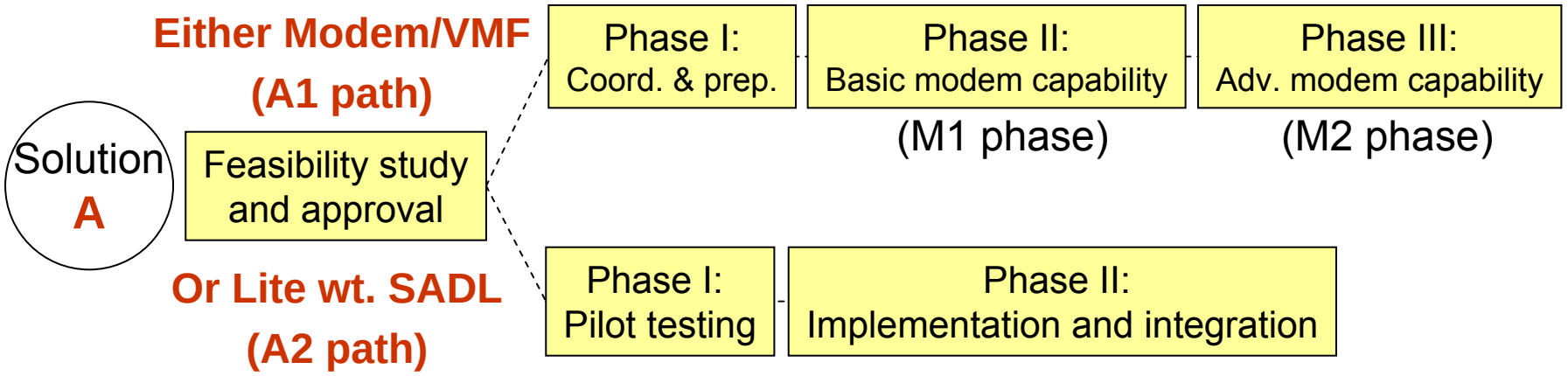
✓: existing or programmed capabilities Proposed solutions: A B

Participants / Systems	Primary CAS aircraft		Secondary CAS aircraft			Joint Terminal Attack Controller (JTAC)	CAS Gateway
	A-10	F-16 C+	F-16 CG	F/A-18	AV-8B		
Modem+AFAPD			✓			✓	
Modem+VMF	A	A		✓		✓	B
Modem+MTS					✓	✓	
Situational Awareness Data Link (SADL)	✓	✓				A	B
Link 16			✓				B

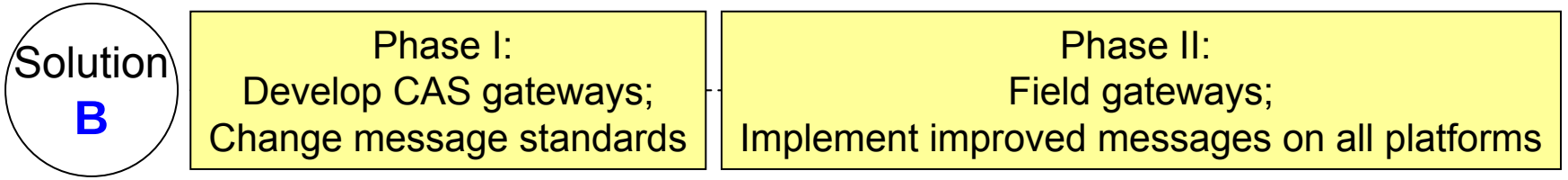
Two Solution Strategies

- Solution Strategy **A** : Equip primary CAS participants with a common data communication device
  - **A1**: Install improved data modems with VMF message format on all primary CAS aircraft.
  - **A2**: If **A1** is not feasible, provide a light-weight SADL device to each tactical air controller.
- Solution Strategy **B** : Use CAS gateways to translate and forward messages for all CAS participants
  - Develop and field CAS gateways; extend the existing TADIL-J message standard and implement on CAS aircraft.

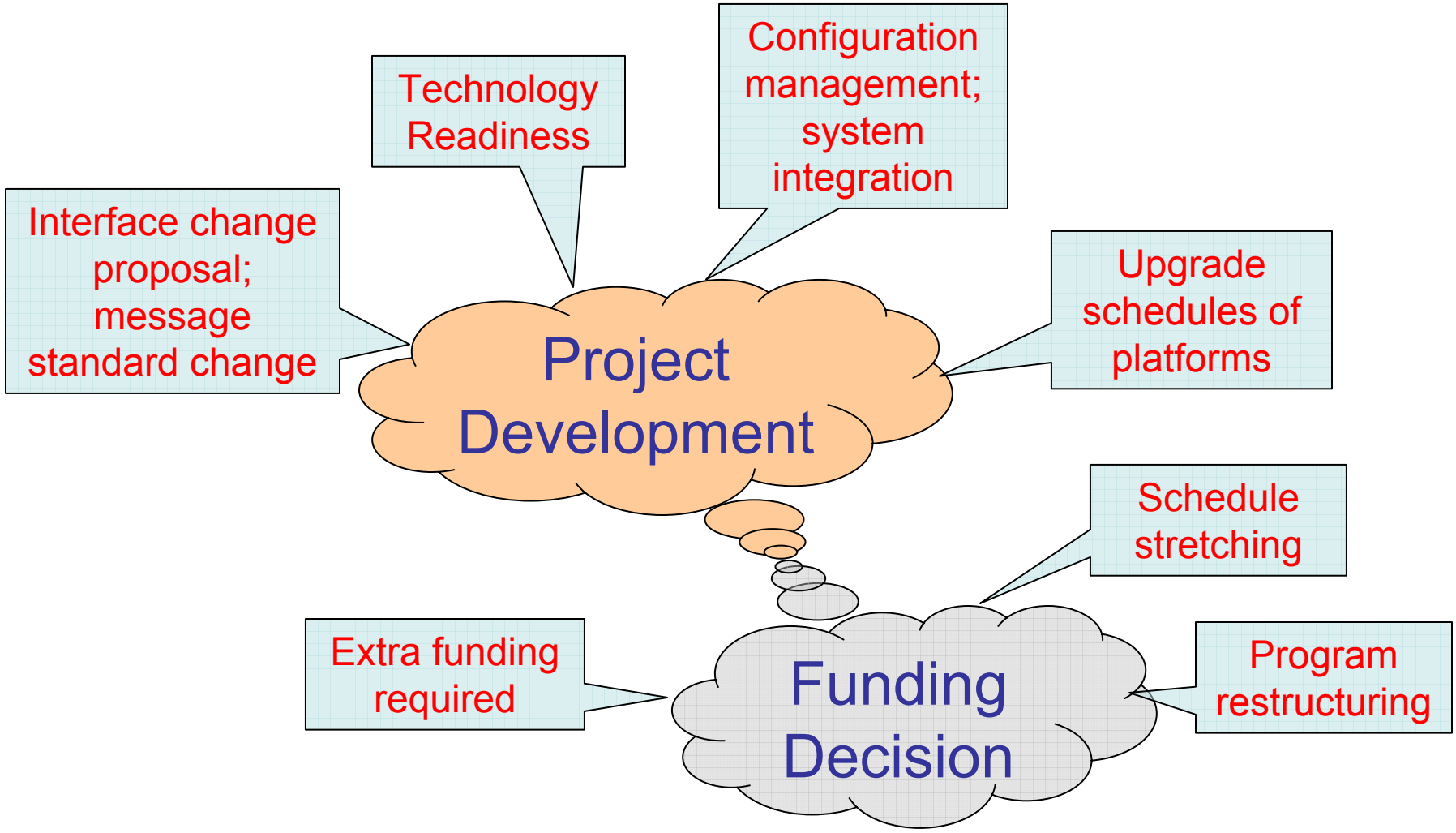
Staged Development and Implementation



Gateways + TADIL-J extension



Uncertainties in TDL Capability Acquisition



Which solution should be chosen?

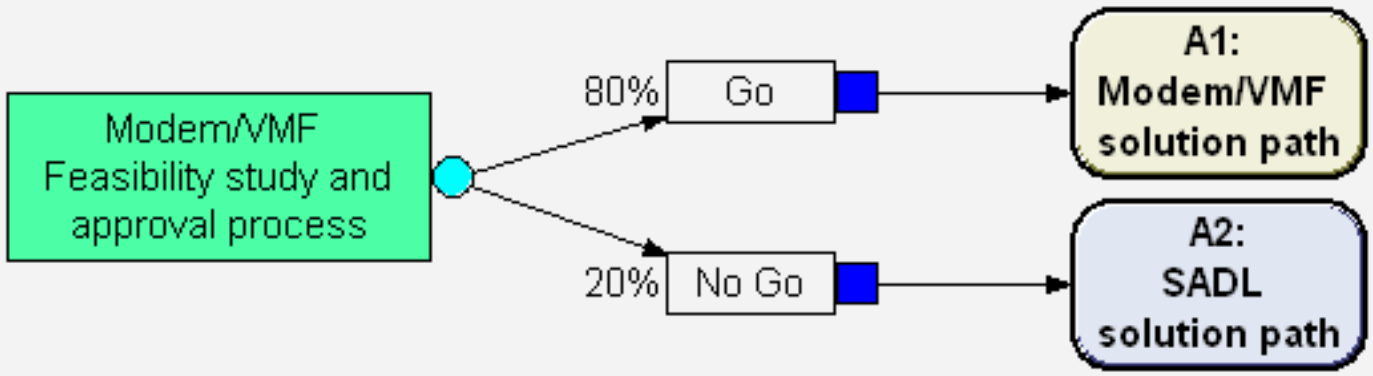
- Conventional approach: trade off benefit, cost, and schedule; use sensitivity analysis or scenario analysis to understand the impact of uncertainties.
- The conventional approach ignores possible actions that could be taken by the manager to dynamically respond to uncertainties.
- **Our remedy:**
  - Use **Decision Tree** to model the interplays between technical development and management actions.
  - Use **Monte Carlo simulation** to compute scenario-dependent benefit, cost, and schedule.

Starting off a Decision Tree for Solution A

Solution Strategy A - either Modem/VMF or SADL

A1: Modem/VMF
M1 - Provide standalone capabilities for primary CAS aircraft pilots to receive digital 9-Line briefing
M2 - Digitally integrate the 9-Line briefing with the aircraft Operational Flight Program (OFP)

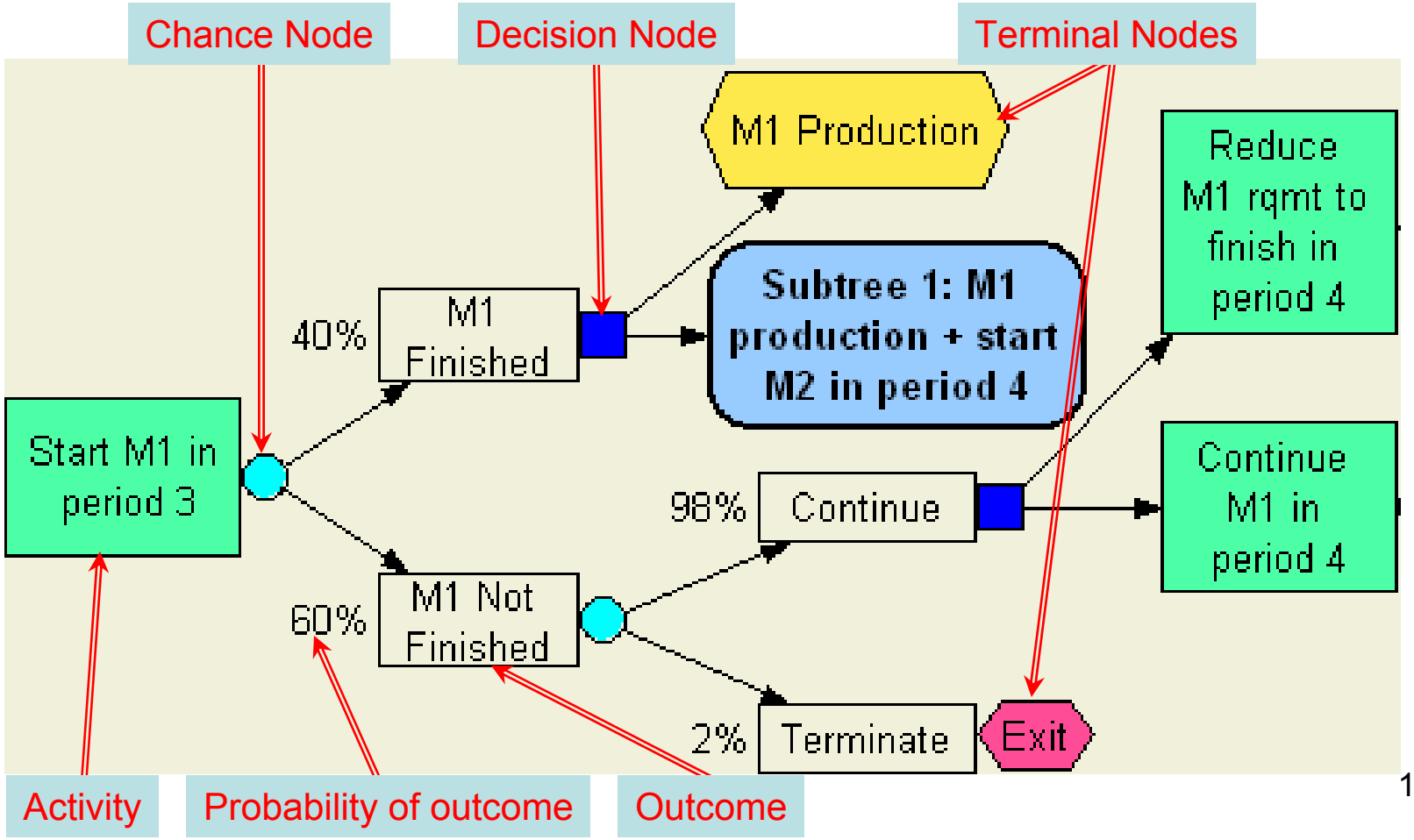
A2: SADL
Develop and field light-weight SADL to JTAC with suitable TACP system interface to enable direct connectivity to SADL aircraft.



(Analytica screen shot)

Anatomy of a Decision Tree

Each solution strategy is modeled as a decision tree containing a series of chance nodes and decision nodes. Each path of the tree ends at a terminal node.



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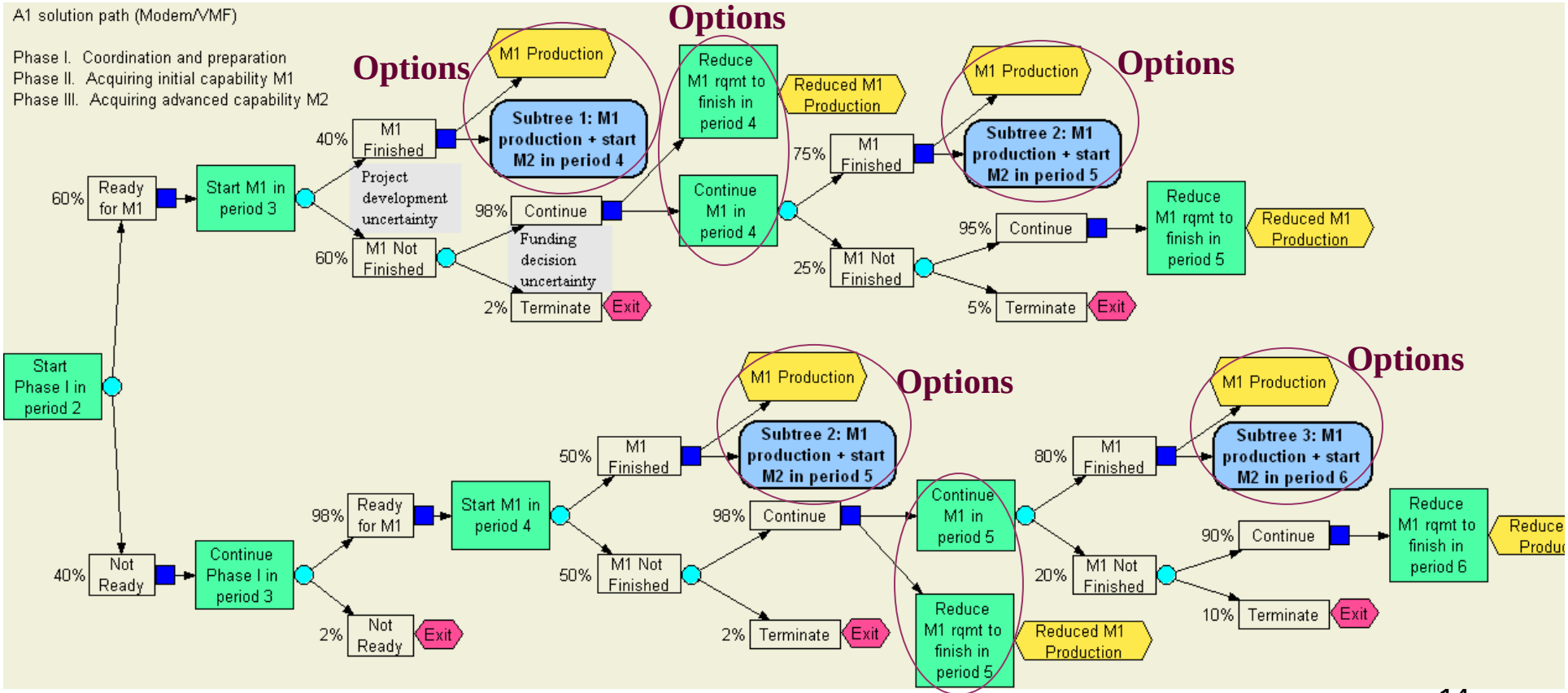
Decision Tree for the A1 (Modem/VMF) Branch

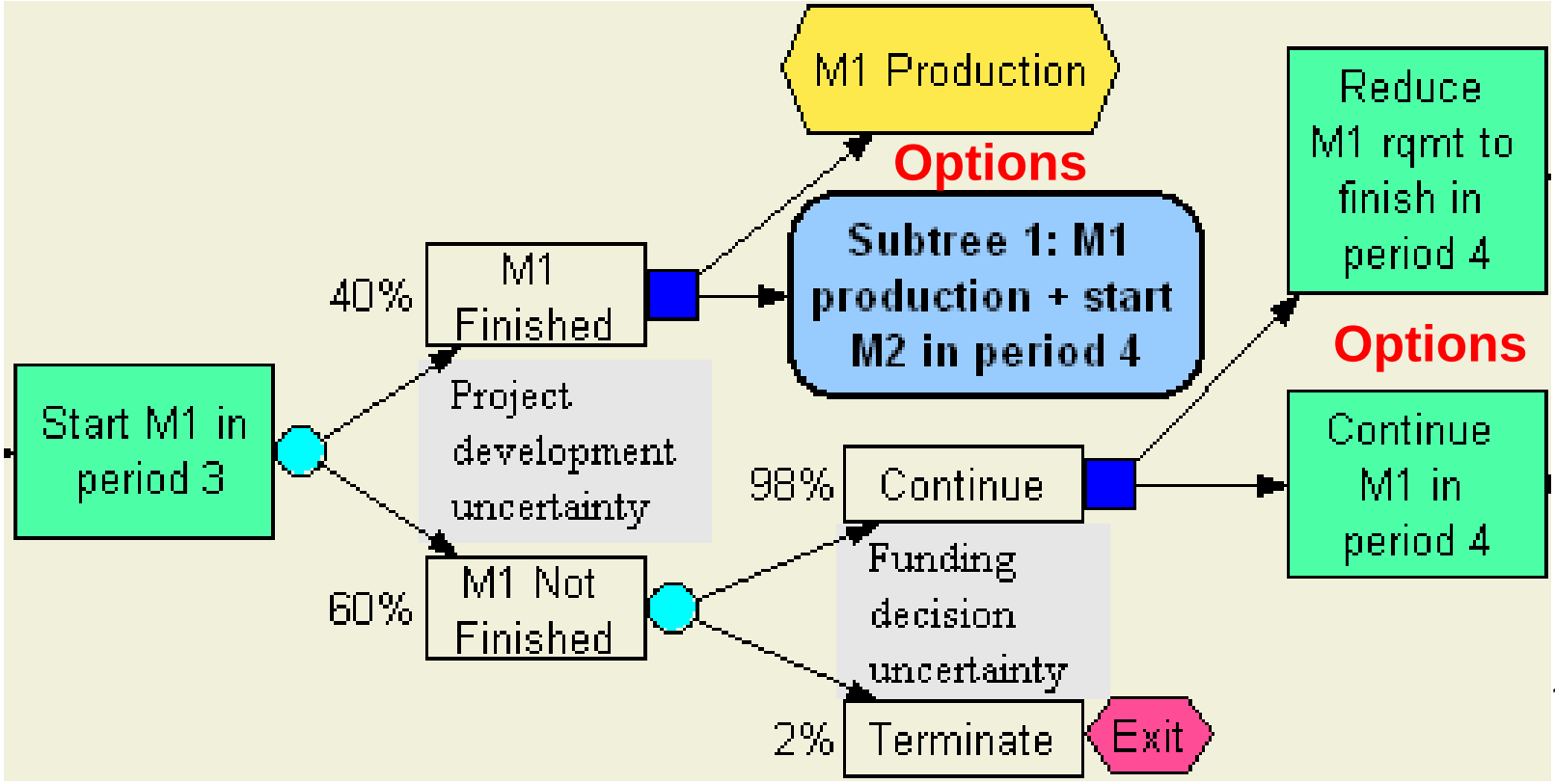
This decision tree is organized around two kinds of uncertainties considered in tandem. Each outcome is followed by one or more decision options.



(Analytica screen shot)

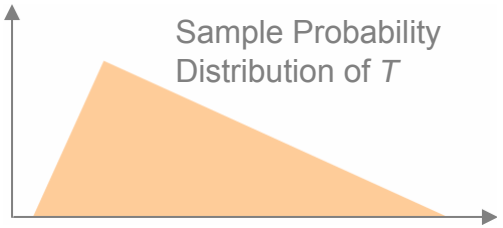
The Core Module of the A1 Decision Tree

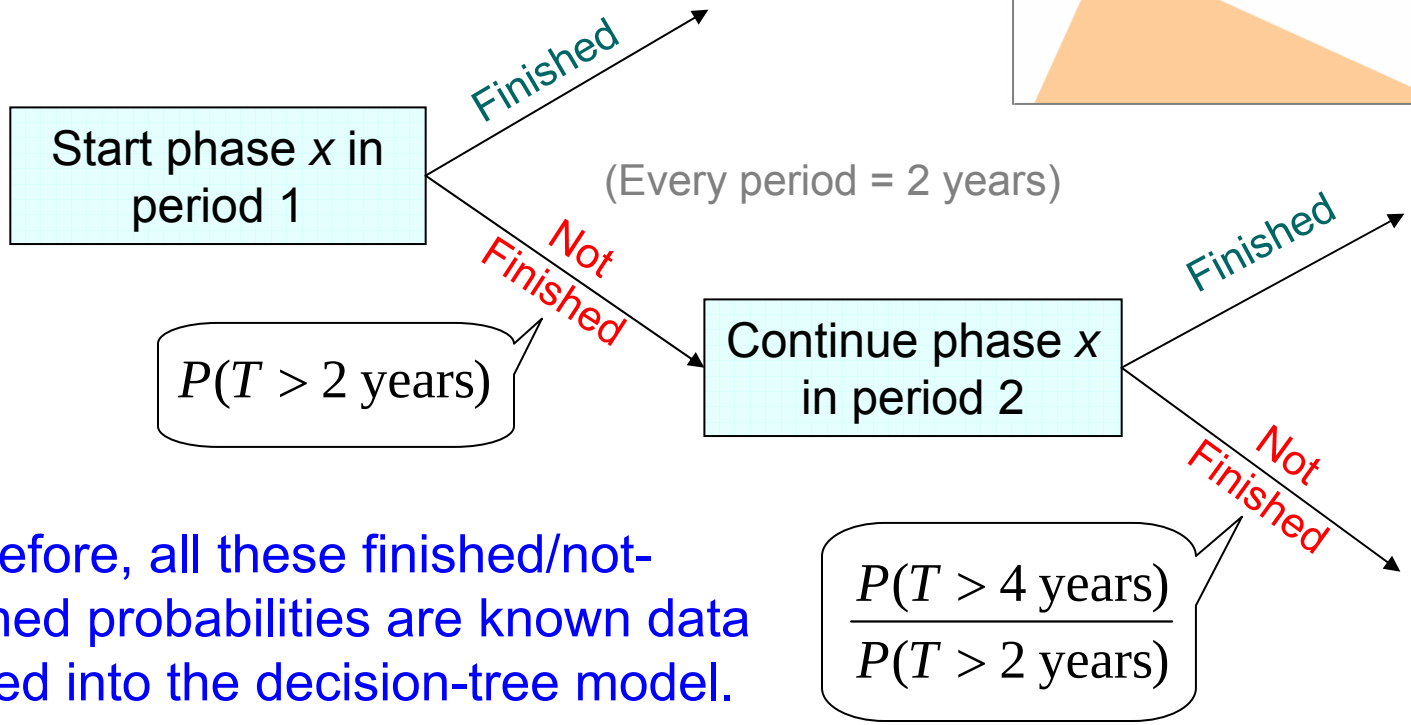
- Each phase may span across multiple time periods.
- Progress status and outlook are reviewed after each period.
- The manager will decide which option to take; the project could embark on a different course of action.



Progress status probabilities can be *easily* derived from the probability of duration time

Duration time *T* of each phase has a probability distribution. Every project planning must have estimated this distribution.



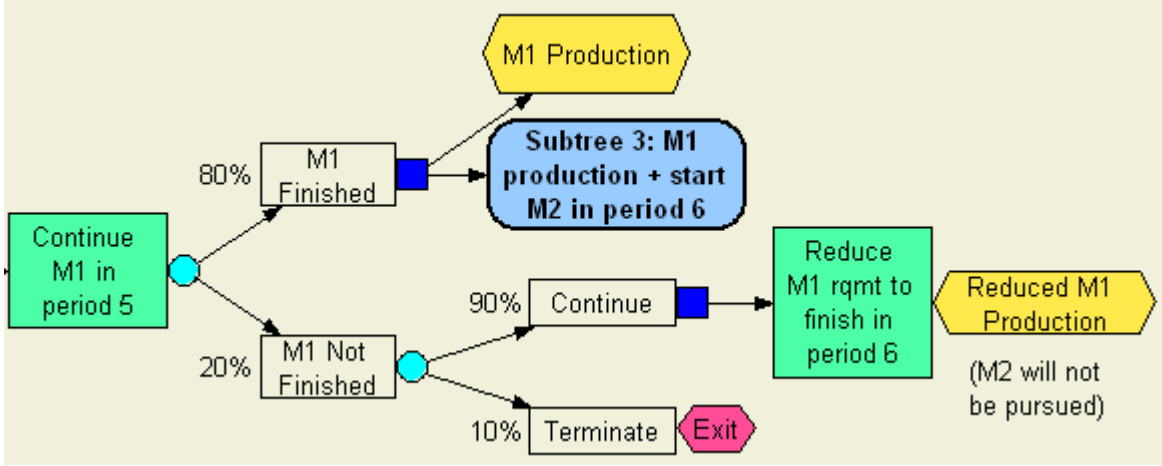


Therefore, all these finished/not-finished probabilities are known data to feed into the decision-tree model.

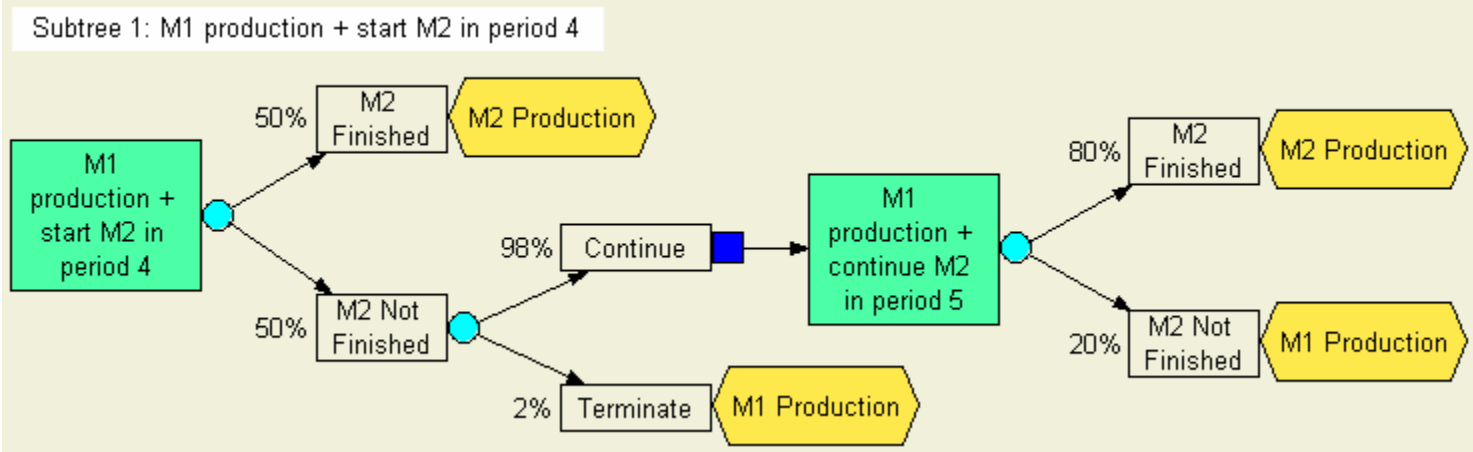
No guesswork is needed !

Exit Criteria for the A1 Solution

- The entire effort should not take more than 6 periods.
- M1 development should not take more than 3 periods. Can wrap up the M1 effort with reduced requirements (Plan B).



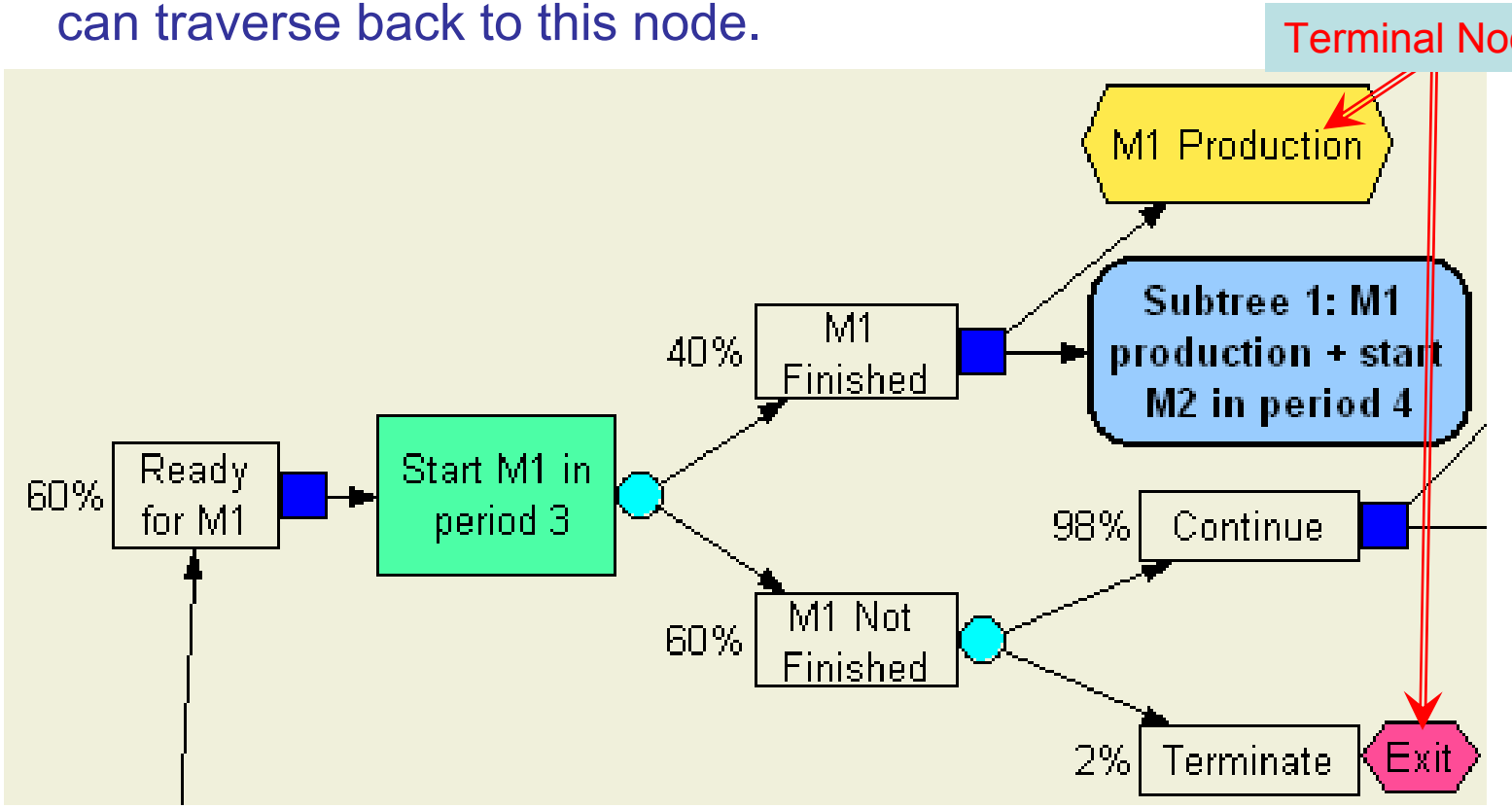
- M2 development should not take more than 2 periods.



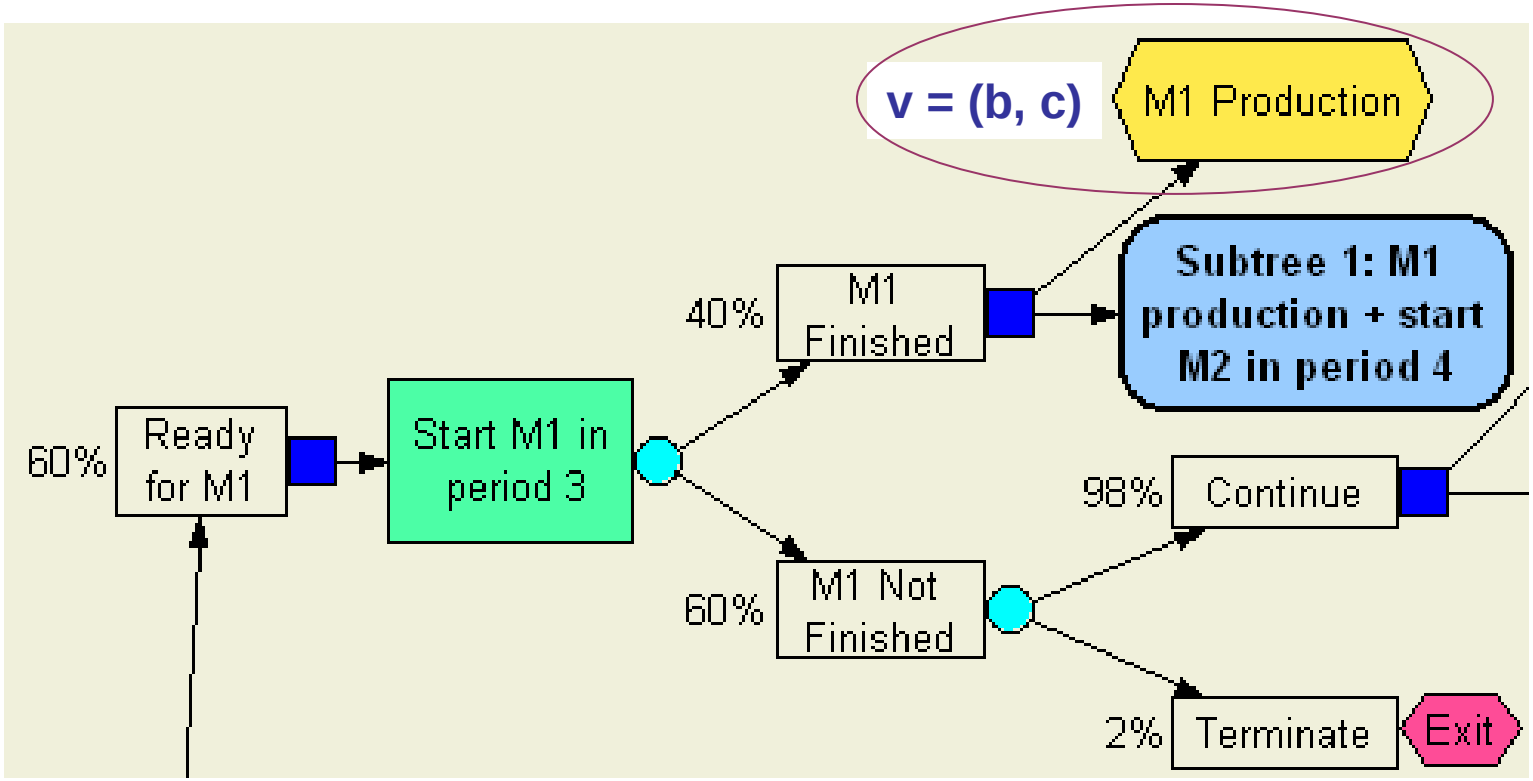
Decision Tree Valuation

A decision tree is evaluated starting from terminal nodes back to the root.

Each node keeps a **value vector (b, c)**, which represents the **benefit** and **cost** rolled back from all terminal nodes that can traverse back to this node.



Valuation at a Production Node



Let m denotes the length of the planning horizon, and the project takes n years to reach a **Production node**, then the value vector at this node is:

$$\left(b = \sum_{i=0}^{m-n-1} \frac{\text{product benefit per year}}{(1+\text{benefit discount rate})^i} \;,\quad c = \sum_{i=0}^{m-n-1} \frac{\text{O \& M cost per year}}{(1+\text{cost discount rate})^i} \right)$$

Discount Rates

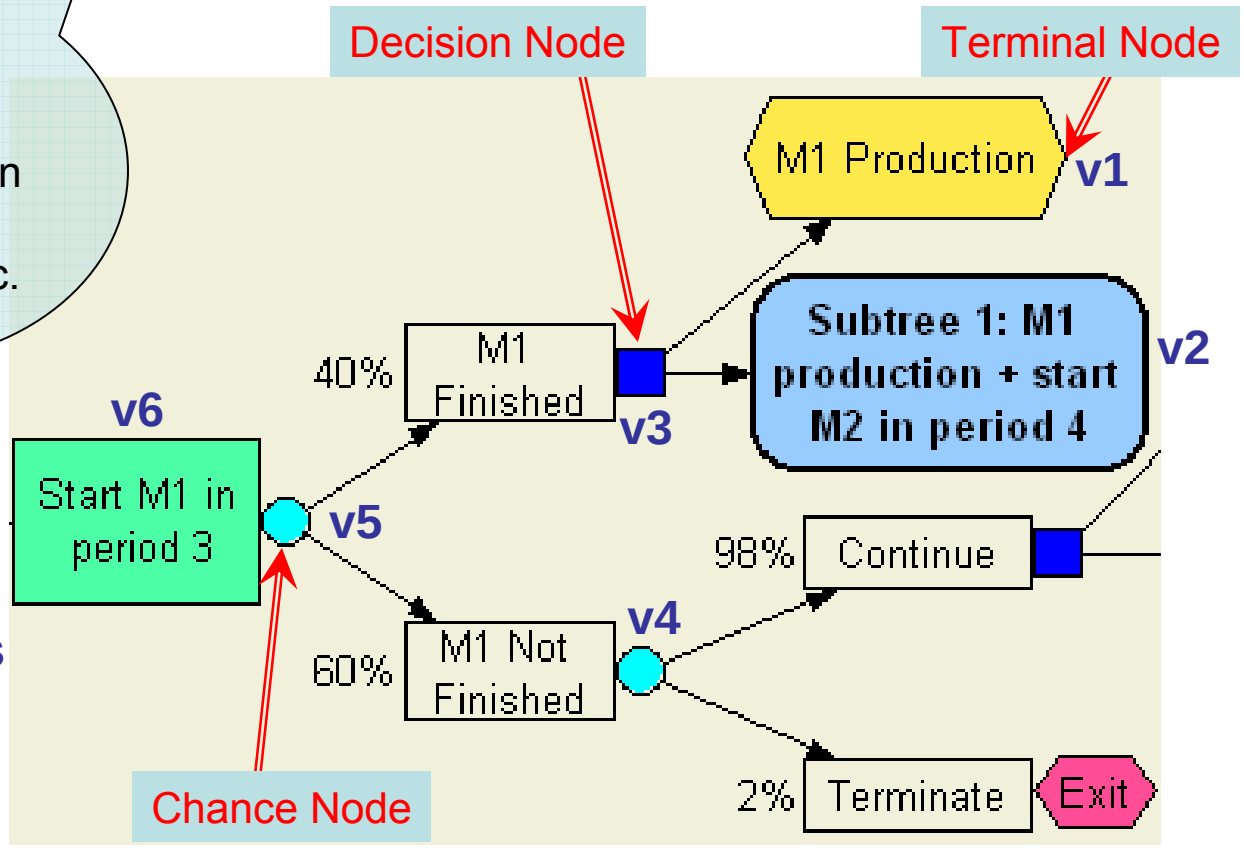
- **Cost discount rate**: a measure of the time value of money for investments and expenses.
- **Benefit discount rate**: to express the urgent need for a timely solution or to penalize a delay in delivering required capabilities. (OMB Circular A-4 has an example.)
- With the use of discount rates, time preference is embedded in the decision rule – an alternative branch will be chosen if it has a higher ratio of discounted benefit / discounted cost.
  - *Performance, affordability, and timeliness are all molded into a single metric for solution comparison*.

Decision Tree Valuation (cont.)

$$\sum_{i=0}^{m-n-1} \frac{v}{(1+r)^i}$$

Decision rule: choose the branch having the best benefit/cost ratio

Can also include constraints on budget, schedule, etc.



v6 = Value of this activity + v5 discounted back one period

Simulation:
x = Bernoulli(40%)
v5 = *x* * **v3** + (*1-x*) * **v4**

Comparing Benefit and Cost of Solutions A and B

input data are notional

Their values can only be known *probabilistically*.

Benefit	A	B
Min	0	0
Median	771	871
Mean	**747**	**867**
Max	880	1122
Std. Dev.	138	223

Cost ($M)	A	B
Min	5.7	9.7
Median	21.1	31.1
Mean	**21.0**	**31.0**
Max	22.0	32.6
Std. Dev.	2.0	2.7

No clear winner.

B may get better benefit but at higher cost.

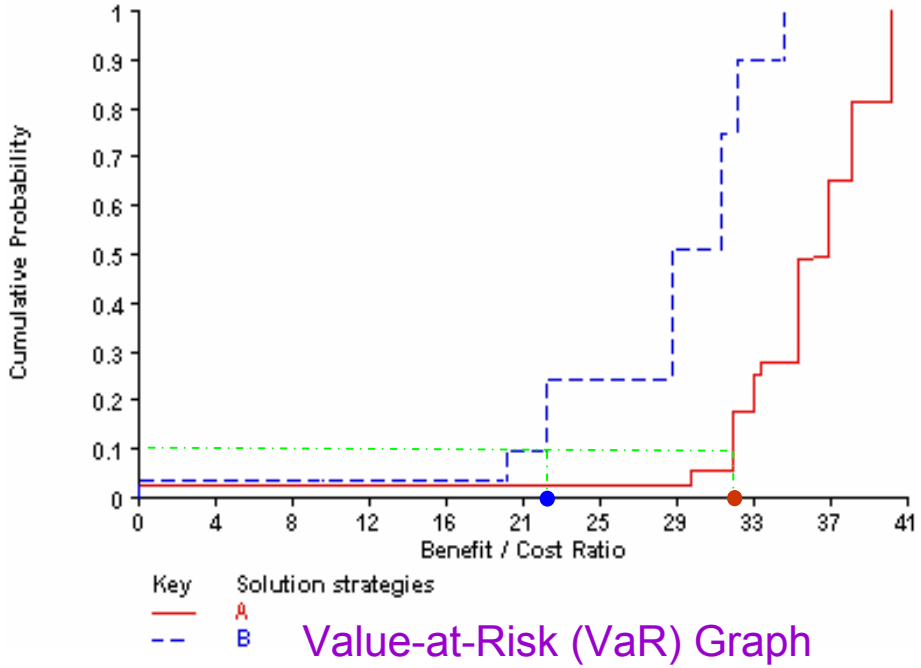
Comparing Solutions A and B based on Benefit / Cost Ratio

input data are notional

Return on Investment (ROI)

Benefit / Cost ratio	A	B
Min	0	0
Median	37	28
Mean	**35**	**28**
Max	40	34
Std. Dev.	7	7

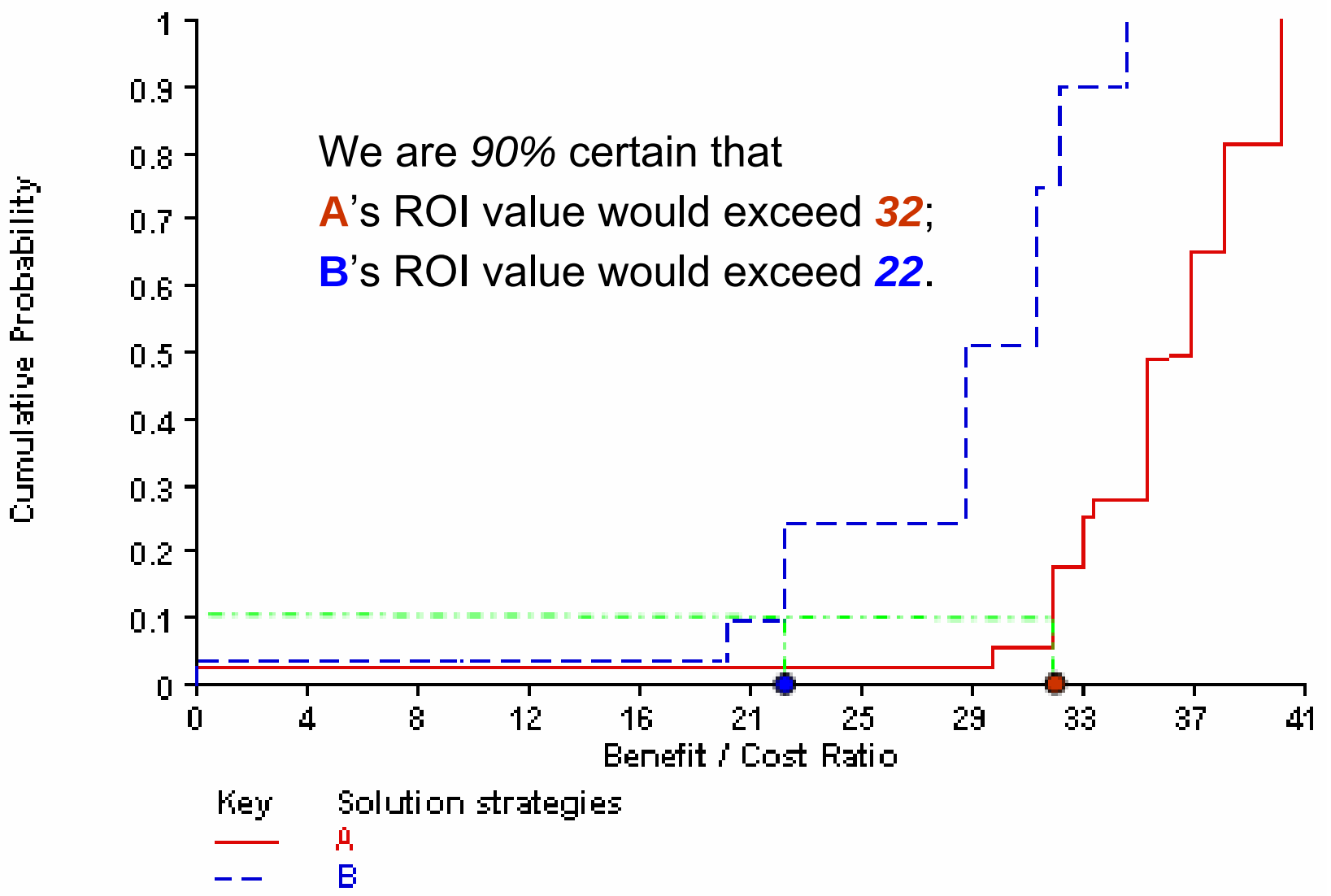
We are *90%* certain that
A's ROI value would exceed ***32***;
B's ROI value would exceed ***22***.



Value-at-Risk (VaR) Graph
a.k.a. Risk Profile

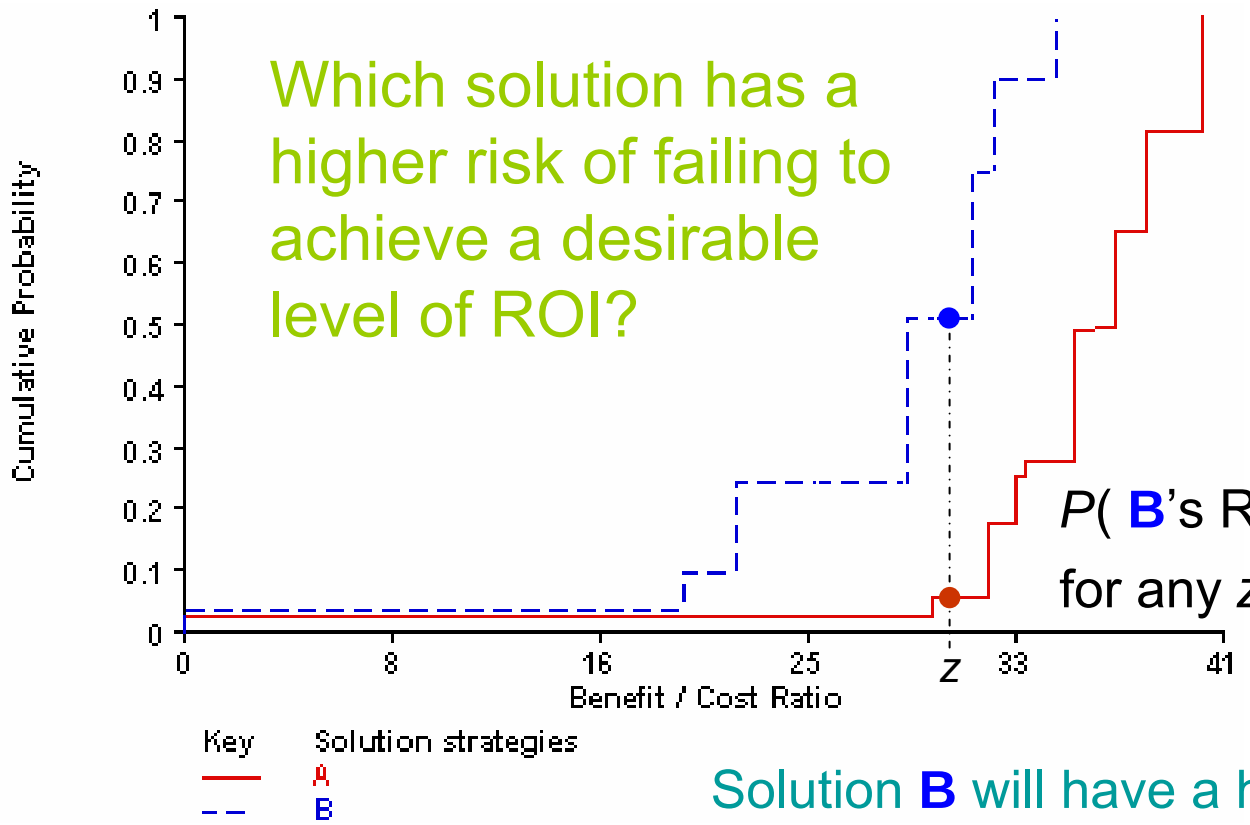
Conclusion: With all potential outcomes considered,
A is probabilistically better than **B** for Return on Investment.

Value-at-Risk Graph Magnified



Another Look at the Value-at-Risk Graph

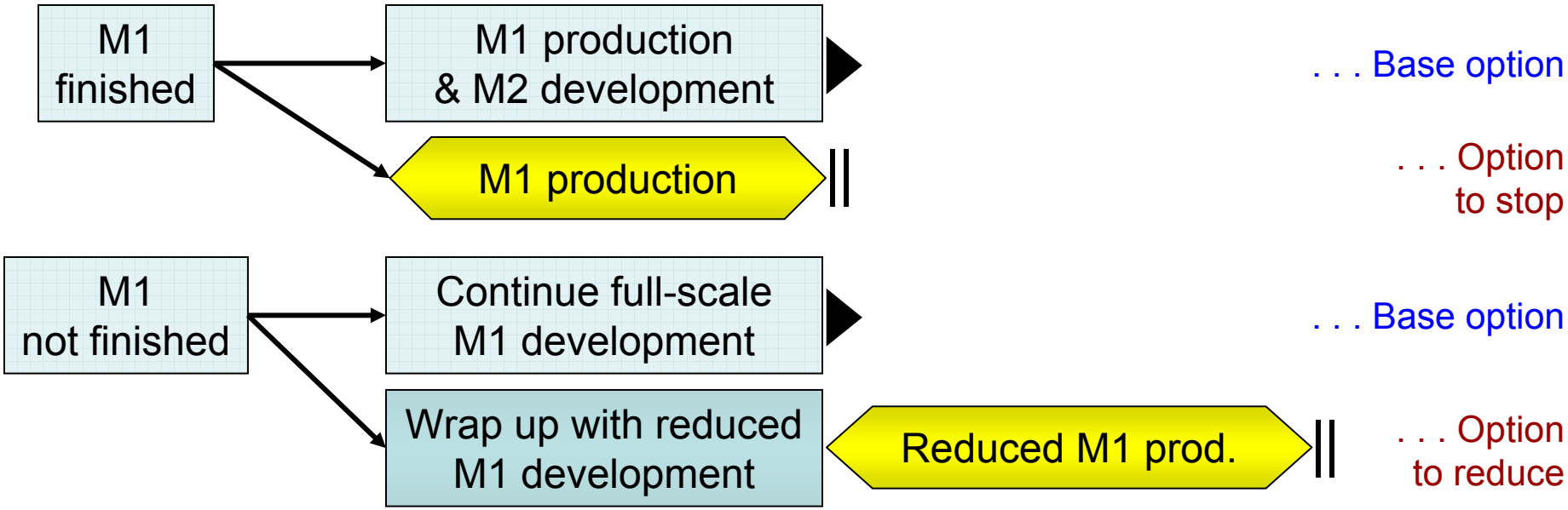
Uncertainties in project development and funding decision have been translated into **Risk in ROI**.



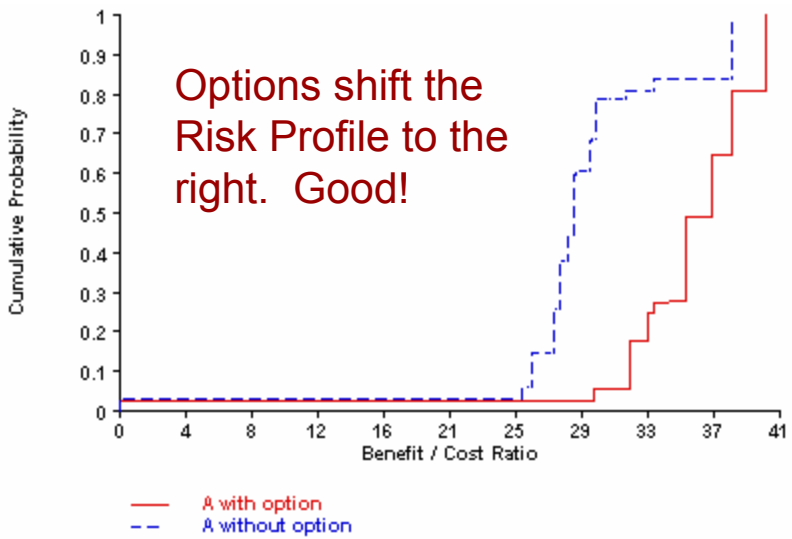
$P($ **B**'s ROI $\le z$ $) >$ $P($ **A**'s ROI $\le z$ $)$ for any $z > 0$

Solution **B** will have a higher probability of failing to achieve *any* desirable level of ROI. Hence, Solution **A** is better.

Options can enhance Solution A's ROI



ROI	A without options	A with options
Min	0	0
Median	28	37
Mean	**29**	**35**
Max	38	40
Std. Dev.	7	7



Possible Outcomes of Solution A

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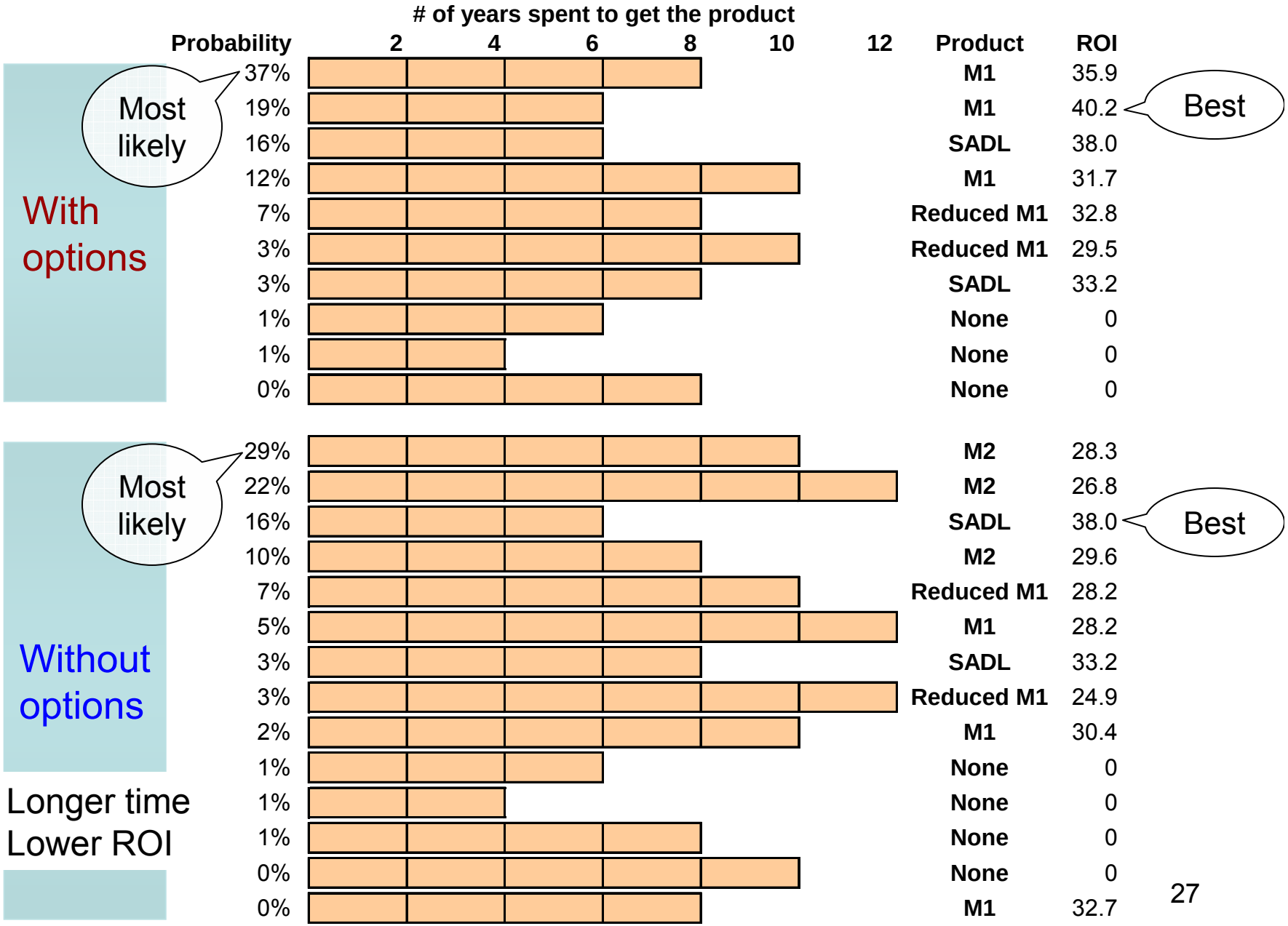
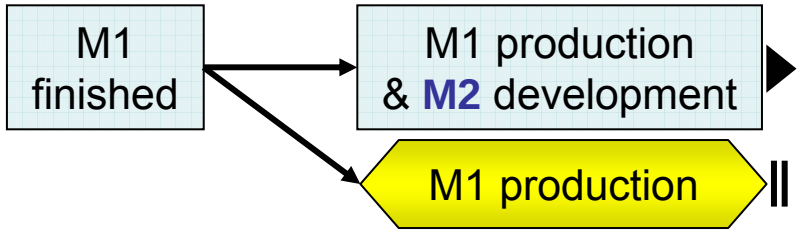


- Longer time
- Lower ROI

Strategy Analysis for the "M2 option"



Under what conditions would the "M2 option" become attractive?

M2 starting inv.

	68	69	70
$8M	M1	M1	M1	M1
$7M	M1	M1	M1	M1
$6M	M1	M1	M1	M1
$5M	M1	M1	M1	M1
$4M	M1	M1	M1	M1
$3M	M1	M1	M1	M1
$2M	M1	M1	M1	M1
$1M	M1	M1	M2	M2
	M1	M1	M2	M2

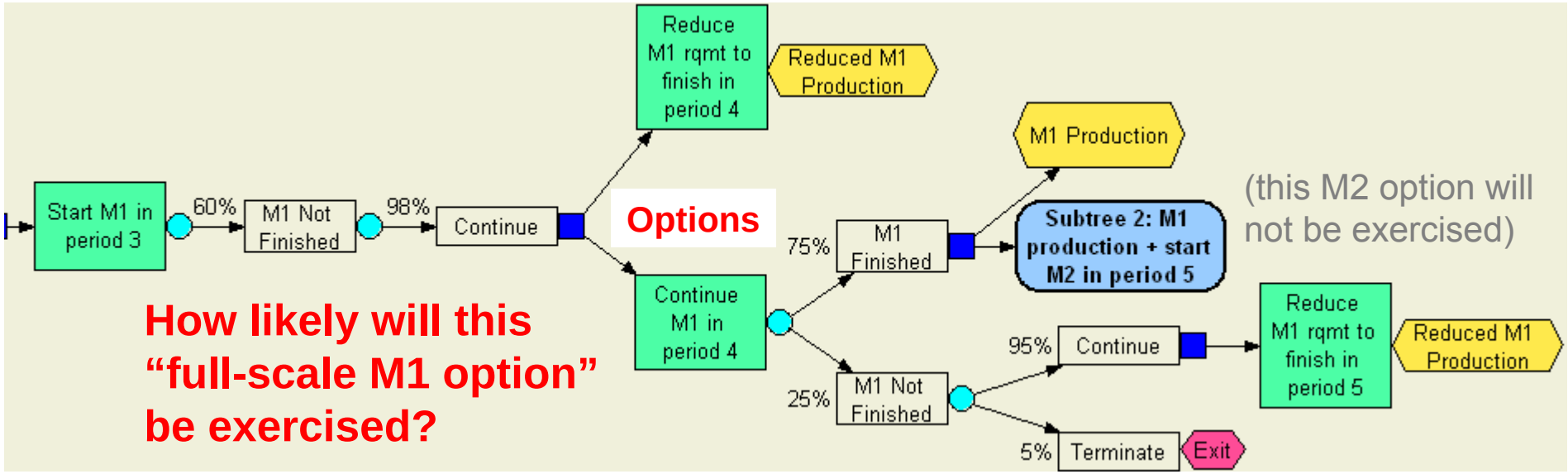
M2 annual benefit value

strategy map derived from sensitivity analysis

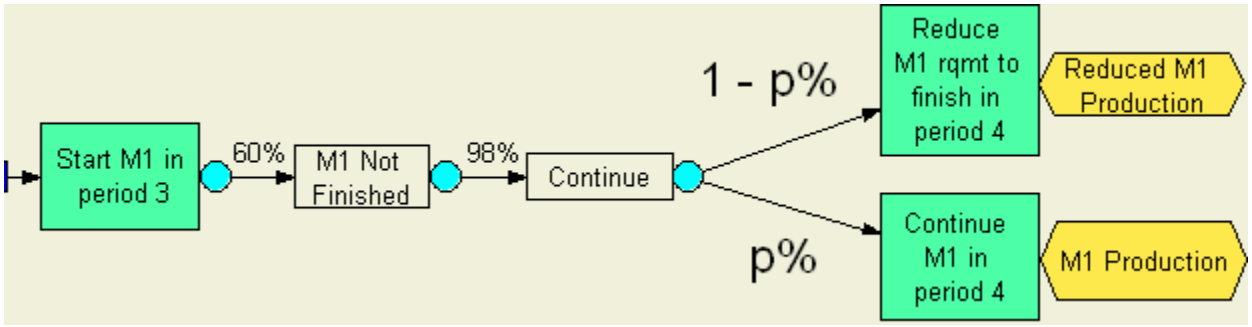
- Most critical factor: M2 starting investment
- ( ): current estimates of M2 starting investment and yearly benefit
- **Green zone**: favorable conditions for taking the M2 option

  Based on the given data, the M2 option is unlikely to be exercised.

Strategy Analysis for the "full-scale M1 option"



It can be proved that the above decision tree can be transformed into:



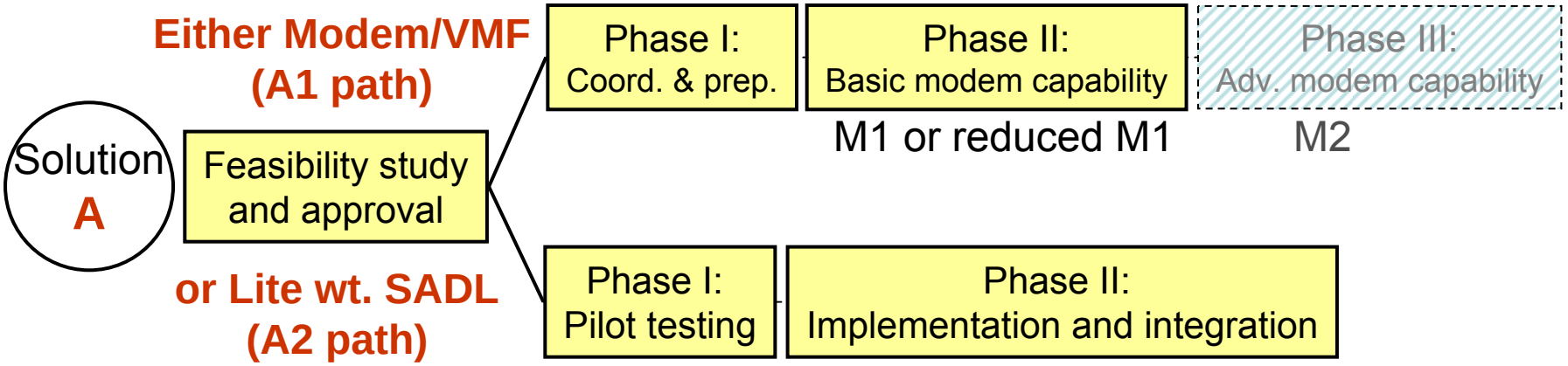
If the upper branch is more cost effective, then p% = 0%; otherwise, p% = probability of completing M1 in period 4.

Based on the given data, the lower branch is more cost effective, so there is a 75% chance that the "full-scale M1 option" will be exercised in period 4.

Further Sensitivity Analyses on Discount Rates and Planning Horizon

- **A** is increasingly better than **B** when the cost discount rate increases.
- **A**'s advantage over **B** gets diminished as the benefit discount rate increases
  - When benefit discount rate ≥ 19%, **B** becomes the preferred solution.
  - The benefit discount rate models "time preference" or urgency for a solution. If you want a solution so "bad", **B** might be a better choice.
- **A** is increasingly better than **B** for longer planning horizon. If it's shorter than 16 years, there is no clear winner.

A solution selected, a strategy suggested



Gateways + TADIL-J extension

***Strategy*:**

- If the A1 path is feasible to go, just develop the basic capability M1.
- May need to consider reduced M1 development (as Plan B).
- After each period, reassess the strategy with most current data.

Real Options Thinking for the TDL-CAS Case

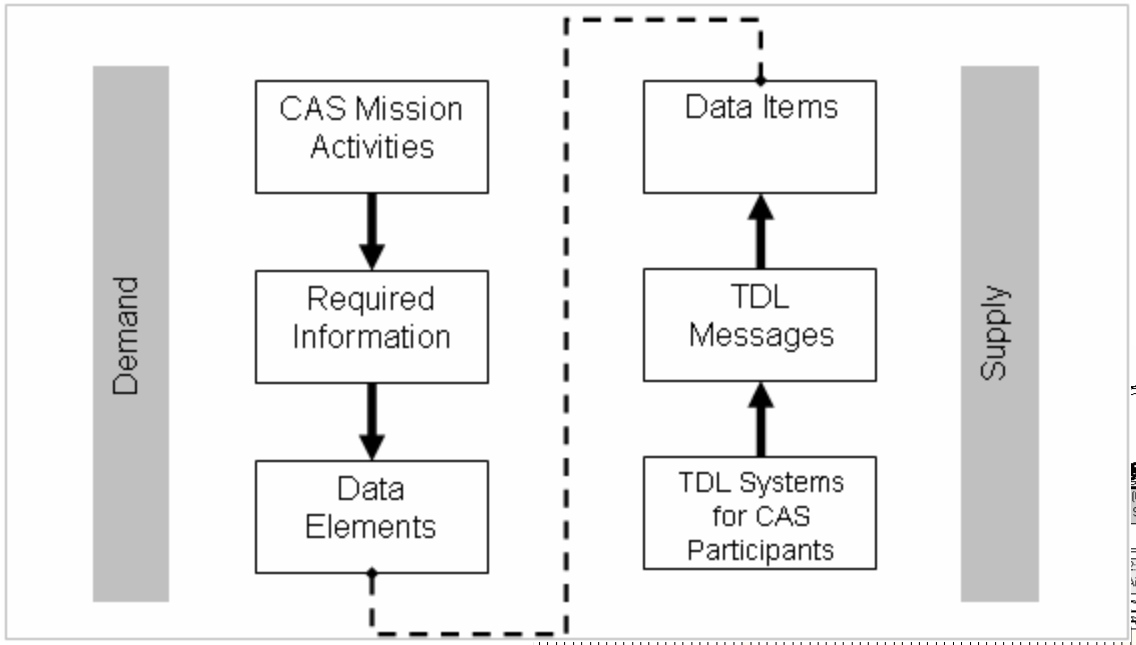
- **Uncertainty:**
  - Convoluted schedule risk in system and platform upgrade
  - Technology readiness
  - Funding
- **Flexibility:**
  - Deliver operationally acceptable capability in near term
  - Prepare to acquire capability incrementally
  - Consider contingency plans and exit opportunities
- **Strategy:**
  - Field initial capability and give up further development
  - Reduce requirements and wrap up effort after n years

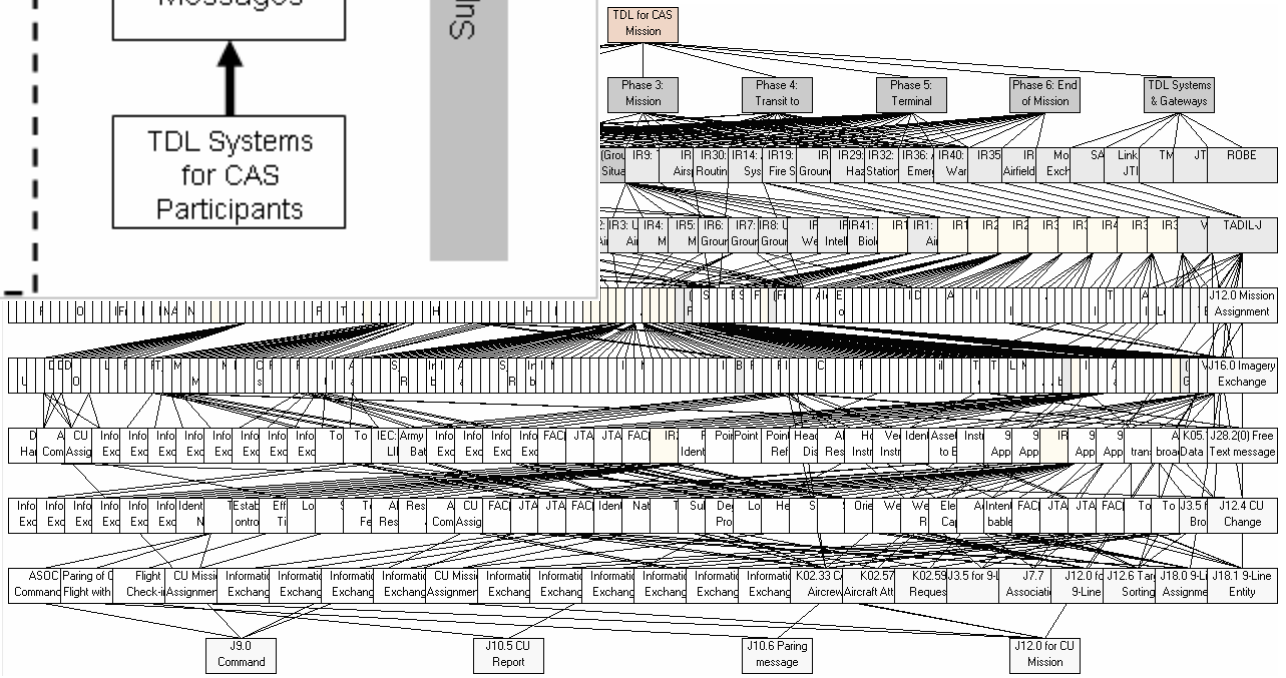
Conclusion

- Managerial flexibility can make significant difference in investment value of capability acquisition programs.
- Decision-tree analysis and Monte Carlo simulation are useful tools:
  - **Decision trees** can model flexible systems engineering concepts. The Decision Maker will be well informed of decision consequences. The decision tree should be a live one with refreshed data every period to provide updated advice.
  - **Monte Carlo simulation** with risk profile analysis enables probabilistic evaluation of Return on Investment.

Backup Slides

Solution benefit is estimated from a multi-attribute value analysis





(developed using **PALMA**)

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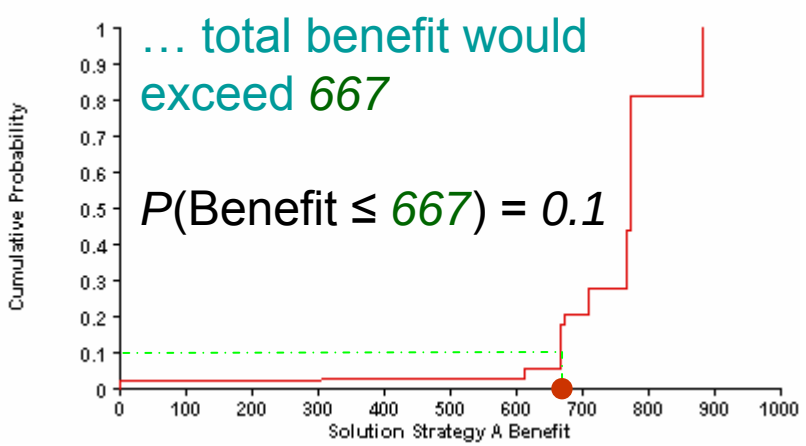
Probabilistic Evaluation of Solution A

input data are notional

We are *90%* certain that **A**'s…

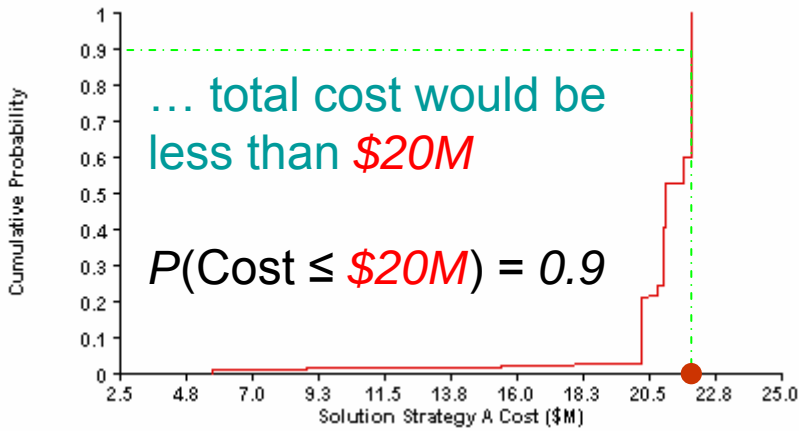
Benefit

Min	0
Median	771
Mean	747
Max	880
Std. Dev.	138



Cost

Min	5.7
Median	21.1
Mean	21.0
Max	22.0
Std. Dev.	2.0



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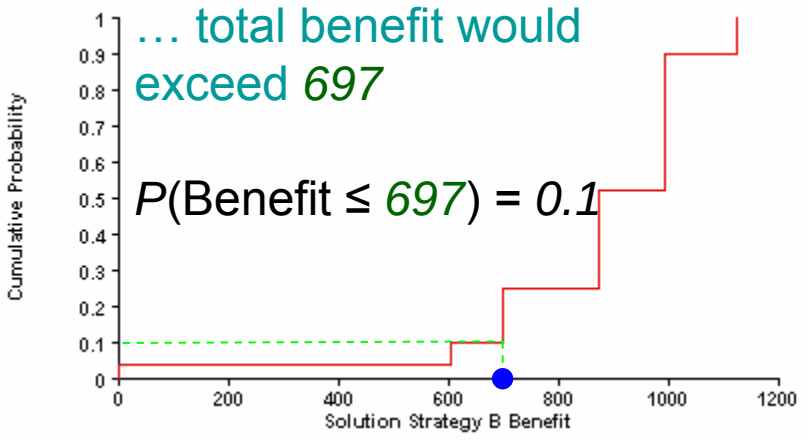
Probabilistic Evaluation of Solution B

input data are notional

We are *90%* certain that **B**'s…

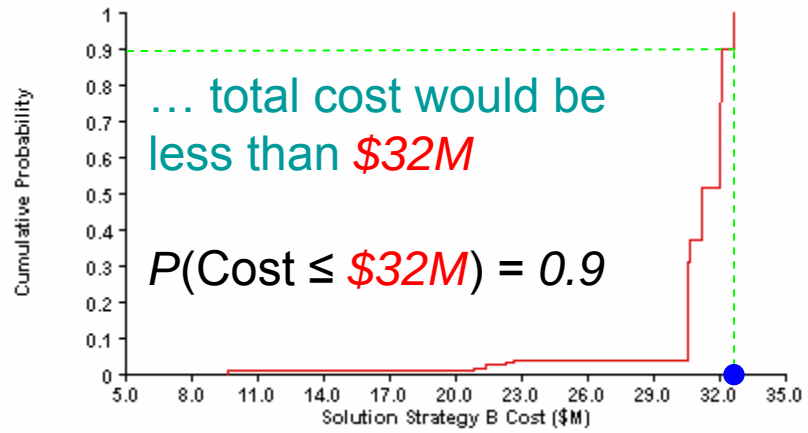
Benefit

Min	0
Median	871
Mean	867
Max	1122
Std. Dev.	223

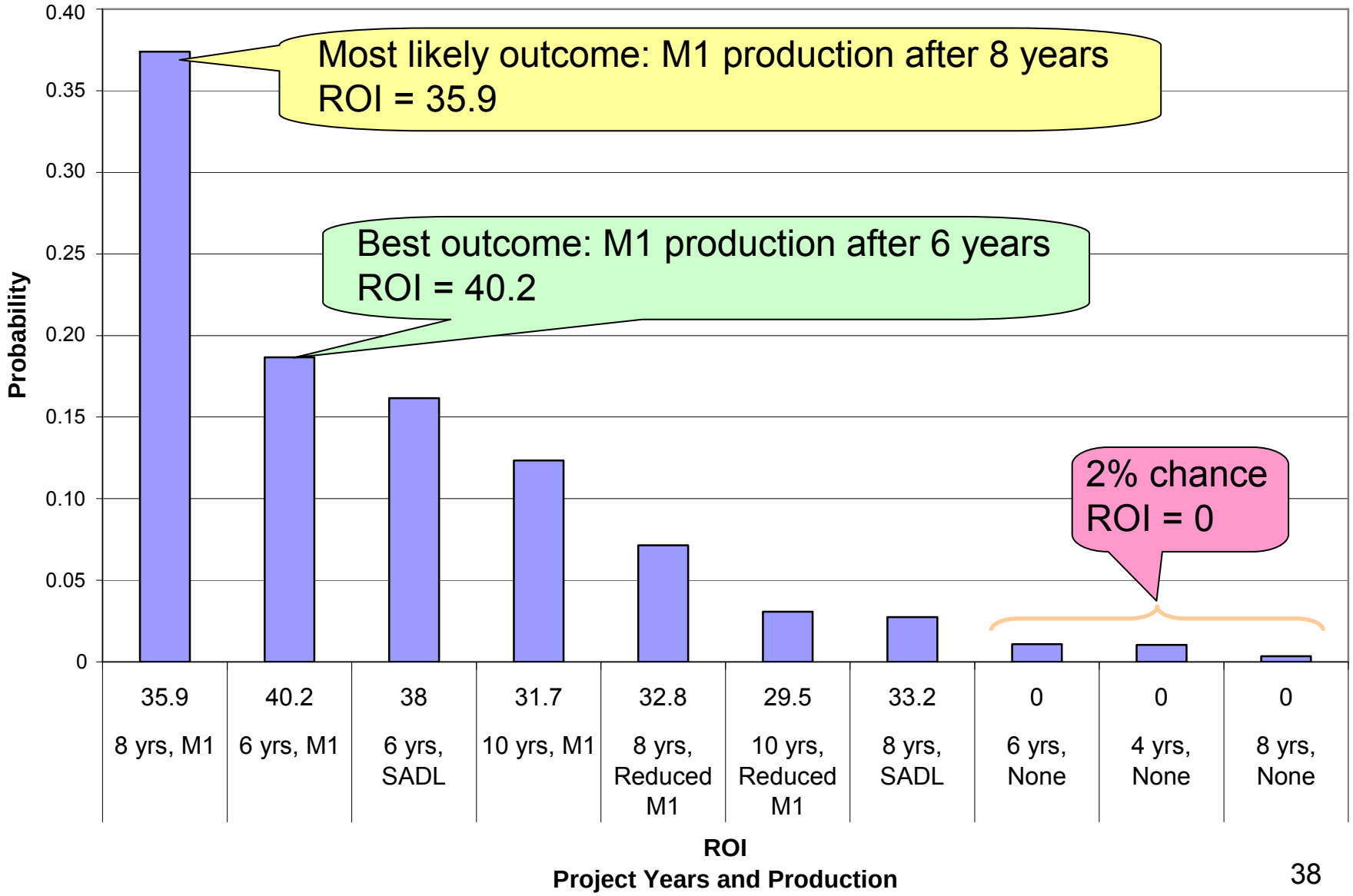


Cost

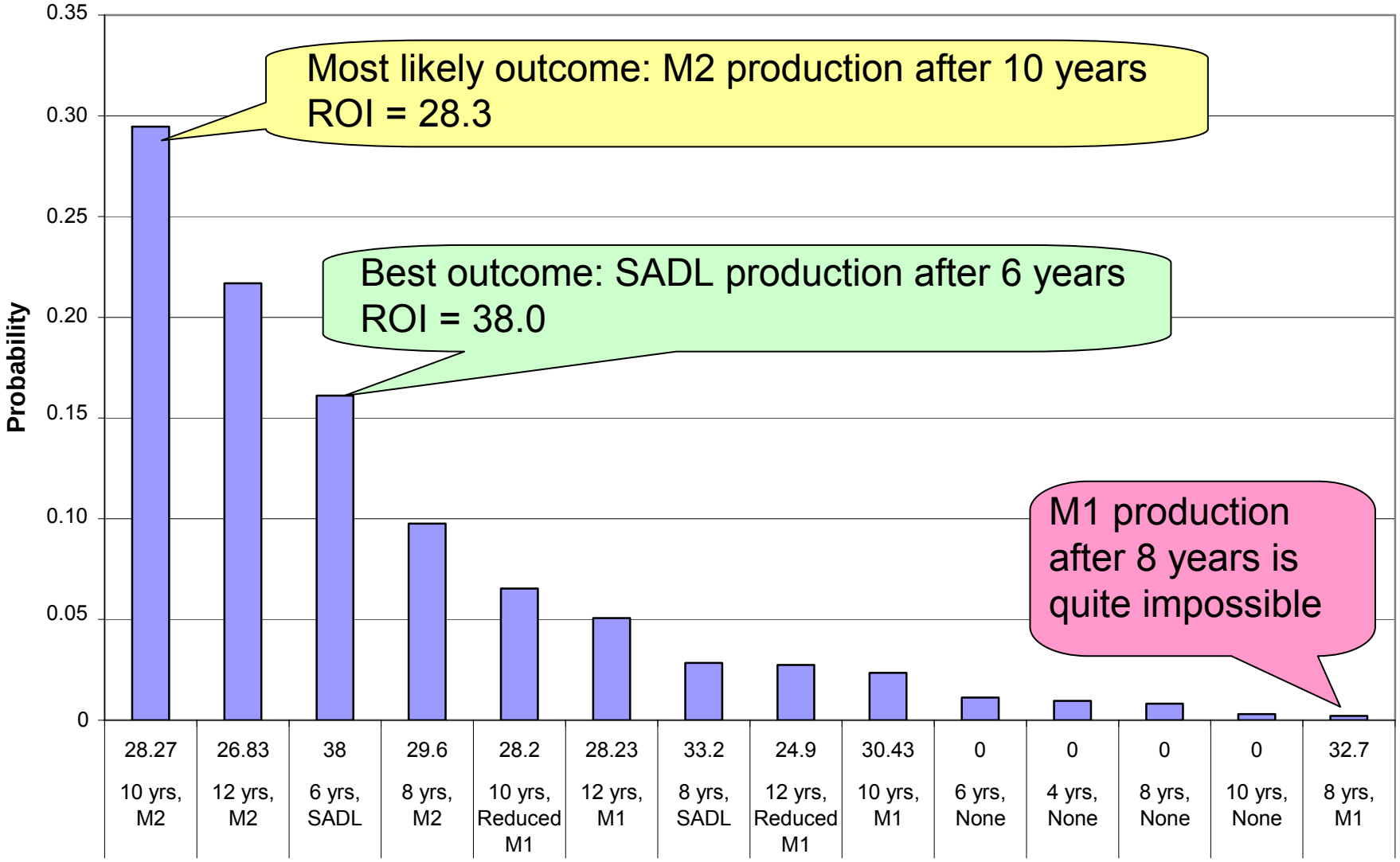
Min	9.7
Median	31.1
Mean	31.0
Max	32.6
Std. Dev.	2.7



Possible Outcomes of Solution A with Options



Possible Outcomes of Solution A without Options



This analytic approach can be applied to projects with similar characteristics

- There exist significant uncertainties in project development and funding decisions.
- There is time-to-market pressure, but the product development process will be long and has multiple phases with uncertain duration in each.
- An initial useful capability can be defined and it can enable the development of more advanced capabilities.
- The project is not destined to acquire a “100%” solution; contingency plans and exit strategies are allowed and encouraged.