A Real Option and System Dynamics Simulation Framework for Resilient Multi-stage Design of Pavements Facing Uncertain Climate Change Threats

Frederick Kautz, Rajib Mallick, and Michael Radzicki

The Concept of Real Options

- Investment decision can be treated as the exercising of an option.
- Firm has option to invest.
- Need not exercise the option now — can wait for more information.
- If investment is irreversible (sunk cost), there is an opportunity cost of investing now rather than waiting.
- Opportunity cost (value of option) can be very large.
- The greater the uncertainty, the greater the value of the firm's options to invest, and the greater the incentive to keep these options open.

Adapted from Robert S. Pindyck, MIT Lectures on Real Options (2008)

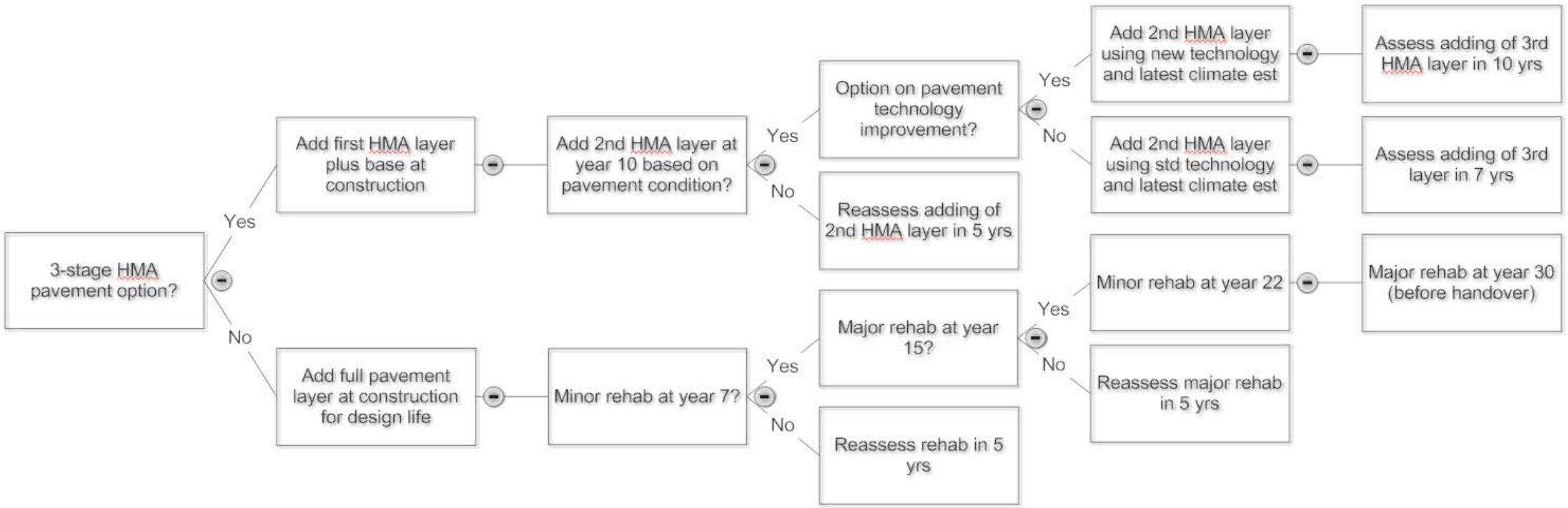
The Problem with DCF Analysis of Projects

- Assumes fixed scenario for outlays and operations. Ignores “option value.”
- Examples:
  - Option to delay project
  - Option to stop before completion
  - Option to abandon after completion
  - Option to expand a project
  - Option to switch to a newer/different technology
  - Option to temporarily stop production
- How important are these options? Often very important.

Real Options “on” *vs* “in” Infrastructure

- In infrastructure finance, many examples of Real Options “on” systems of systems
  - Option to invest (e.g., call option on technology upgrades, updated systems)
  - Option to expand (capacity call option)
  - Option to delay (forward start option)
  - Option to abandon (put option, before construction start or after)
  - Minimum Revenue Guarantee (strip of independent put options)
- Real Options “in” infrastructure systems
  - Flexibility in functionality, operations output, etc.
  - Designed-in options to accept/embed new technologies
  - Cyber-physical security systems optionality/flexibility
  - Fuel switching in energy systems
  - Process switching in water treatment/delivery infrastructure

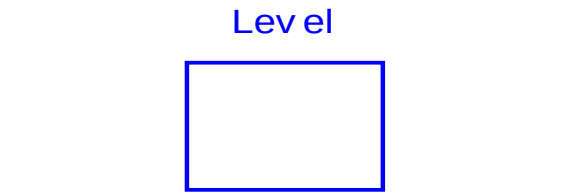
Decision Tree for Pavement Options



Solution Approach

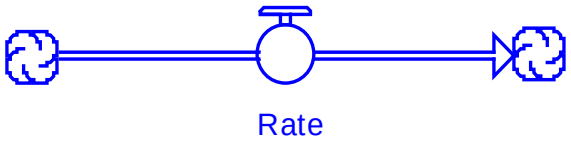
- Deconstruct the optionality and key cash flows over the total life cycle of the road project, to include phases for:
  - Design and ROW acquisition
  - Construction
  - Operations & maintenance
- Model the stock-and-flow structures for the primary cost and revenue sources in the project over its life cycle (to end of concession period and handoff).
- Include discounting of these cash flows in the stock-and-flow modeling to generate the PV of each cash flow stream in the project.
- Sum the PV of each cash flow stream during the course of the simulation (for the total life cycle) to arrive at the NPV of the project over time.
- The aggregate NPV at the end of the life cycle simulation = project NPV
- Difference in project NPV with and without option path cash flows = **option value**

Basic building blocks of System Dynamics models



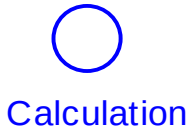
Stocks

Purpose: Stocks are accumulations. They collect/discharge whatever flows into/out of them



Flows

Purpose: To fill and drain stocks. The arrow indicates the direction of the flow



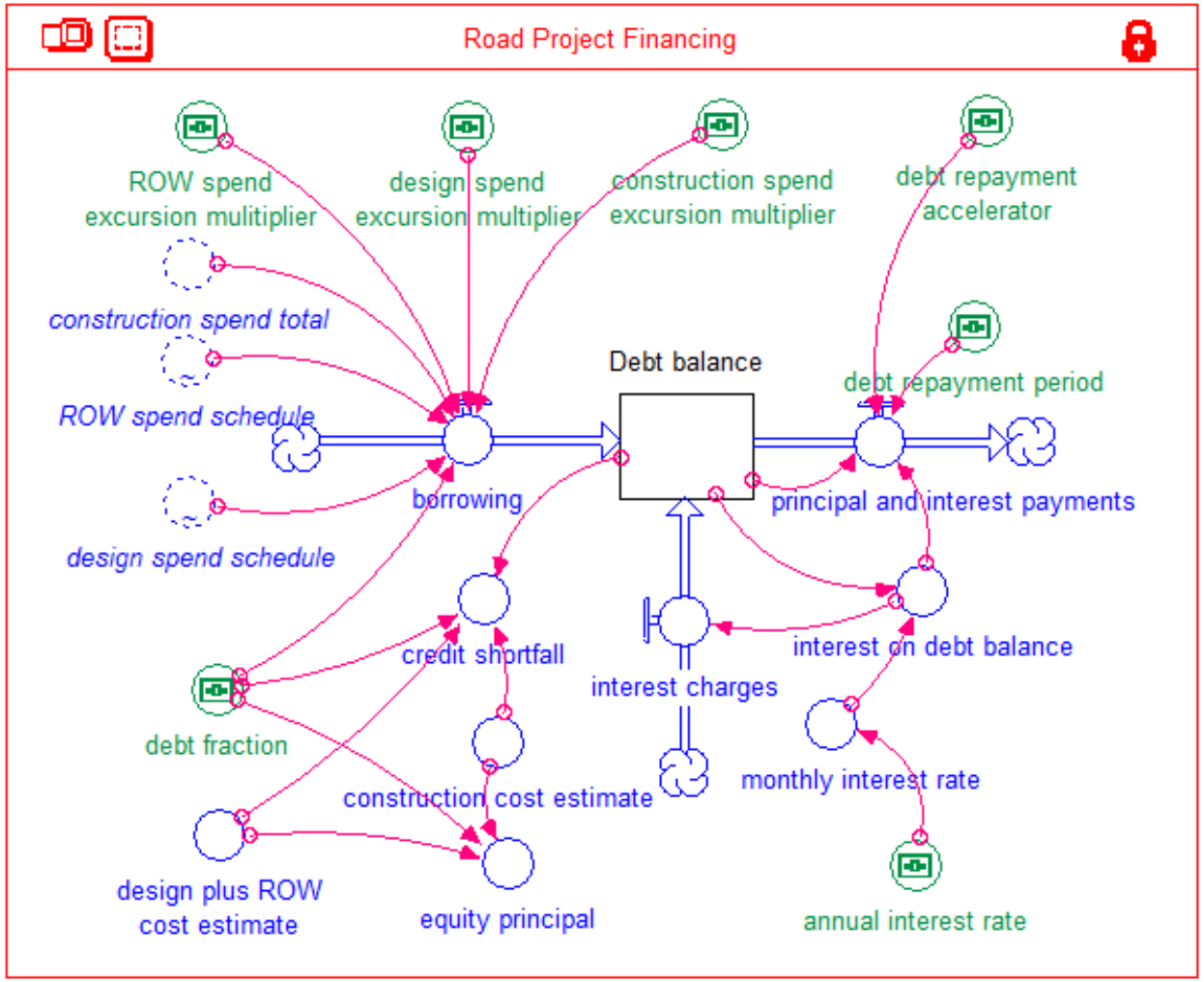
Converters

Purpose: Converts inputs to outputs - can hold values for constants, define external inputs to the model, perform algebraic calculations

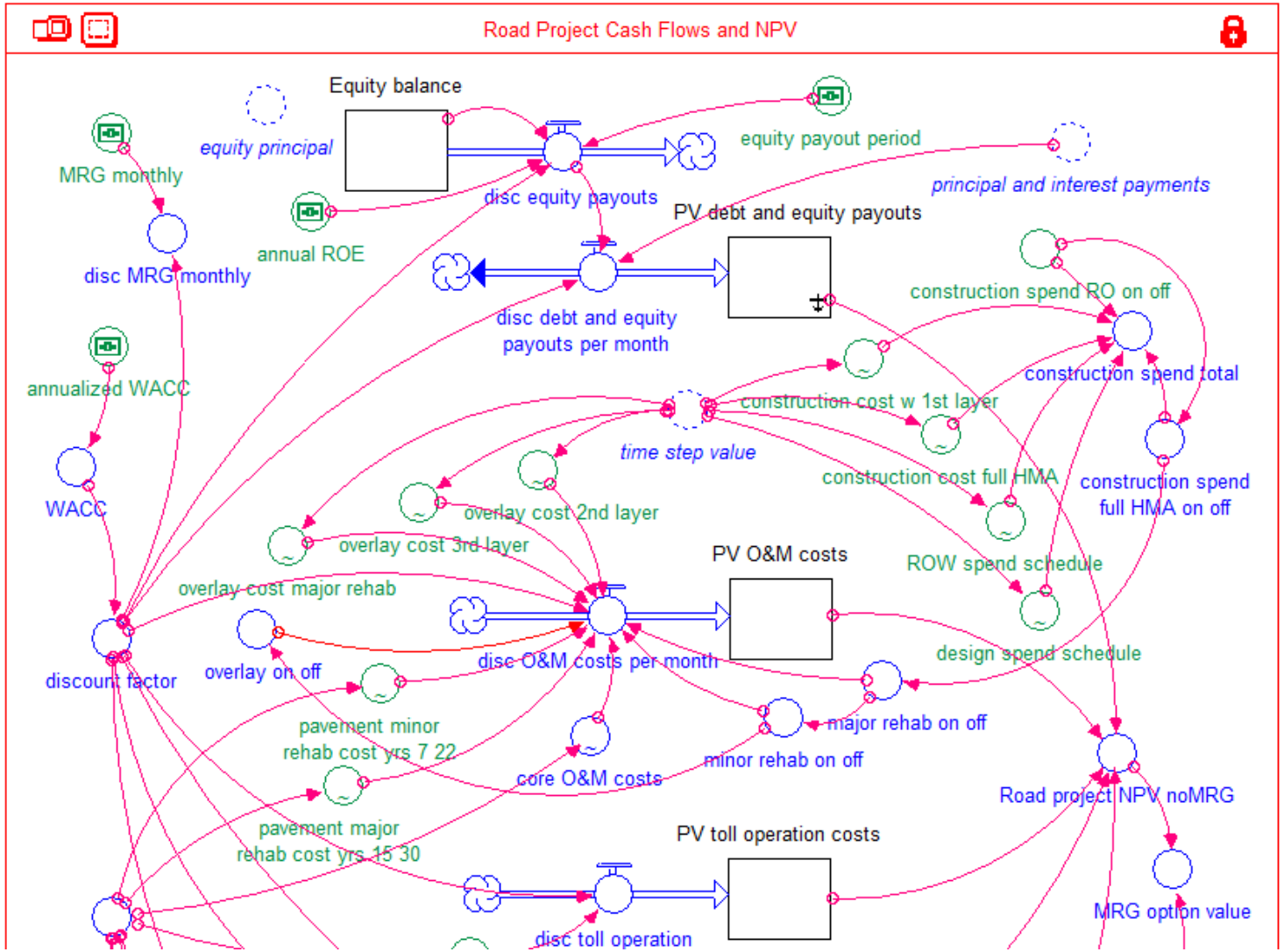
Connectors

Purpose: Connect model elements (information or material transfer)

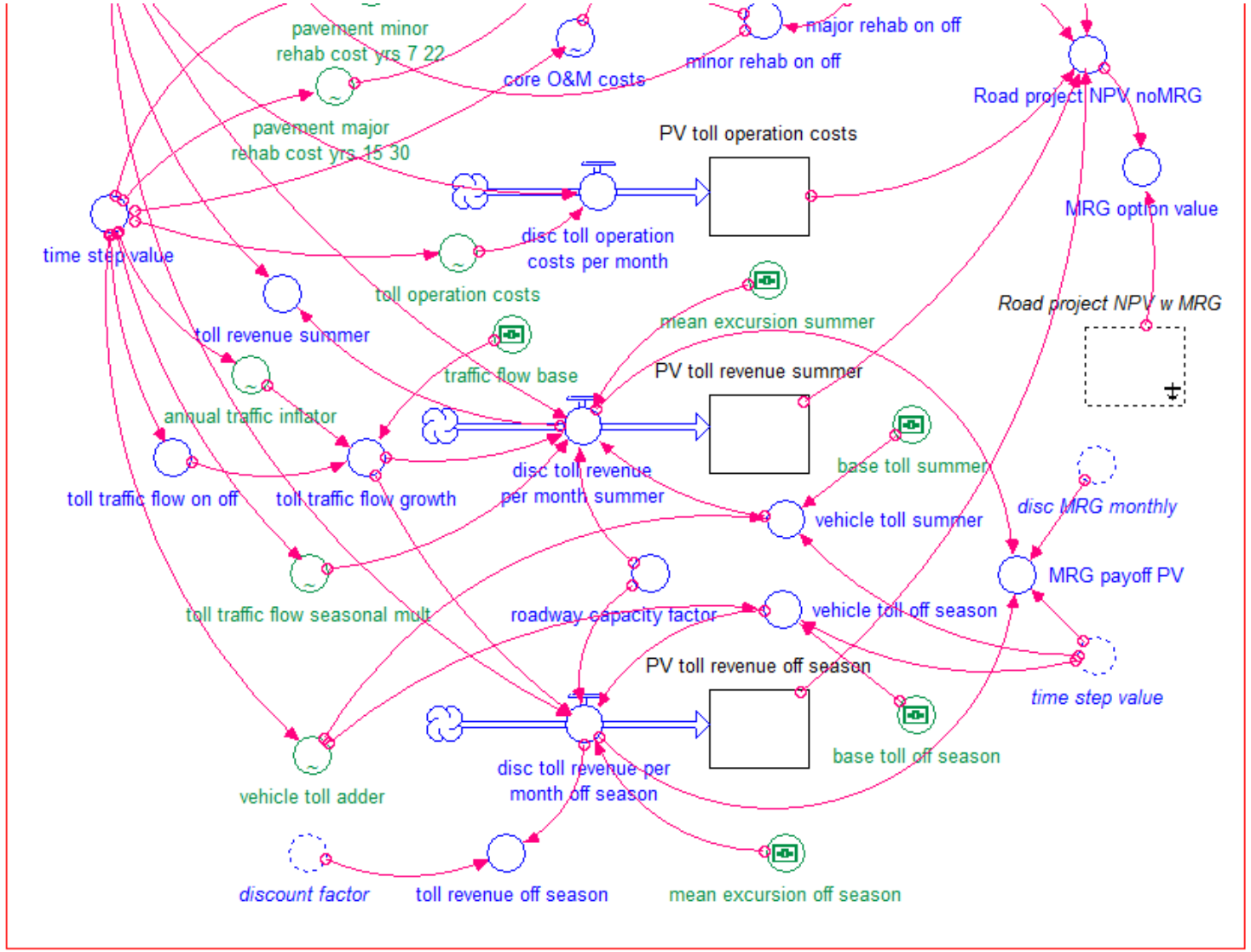
Road Project Financing



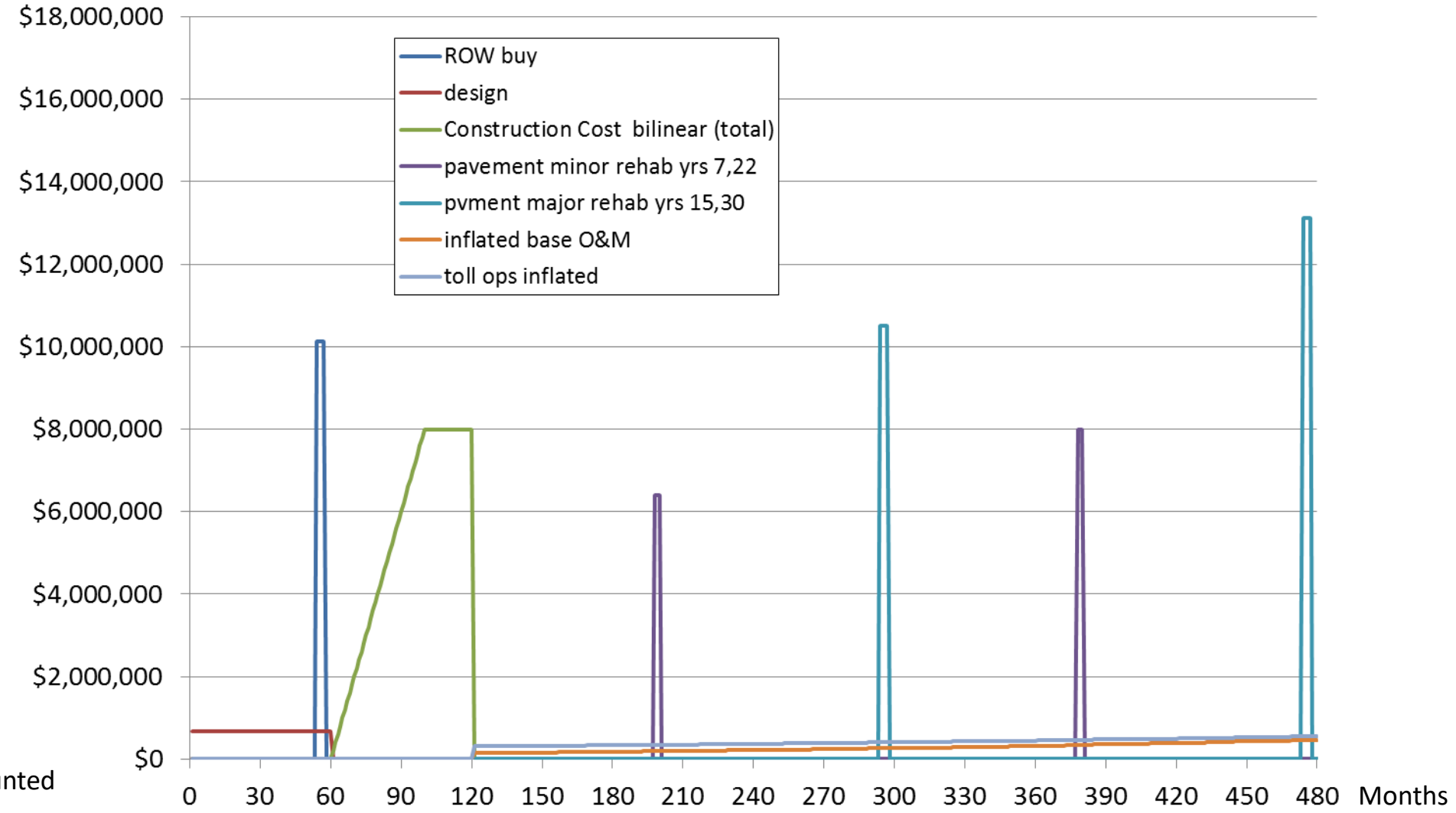
Road Project Cash Flows and NPV (1 of 2)



Road Project Cash Flows and NPV (2 of 2)

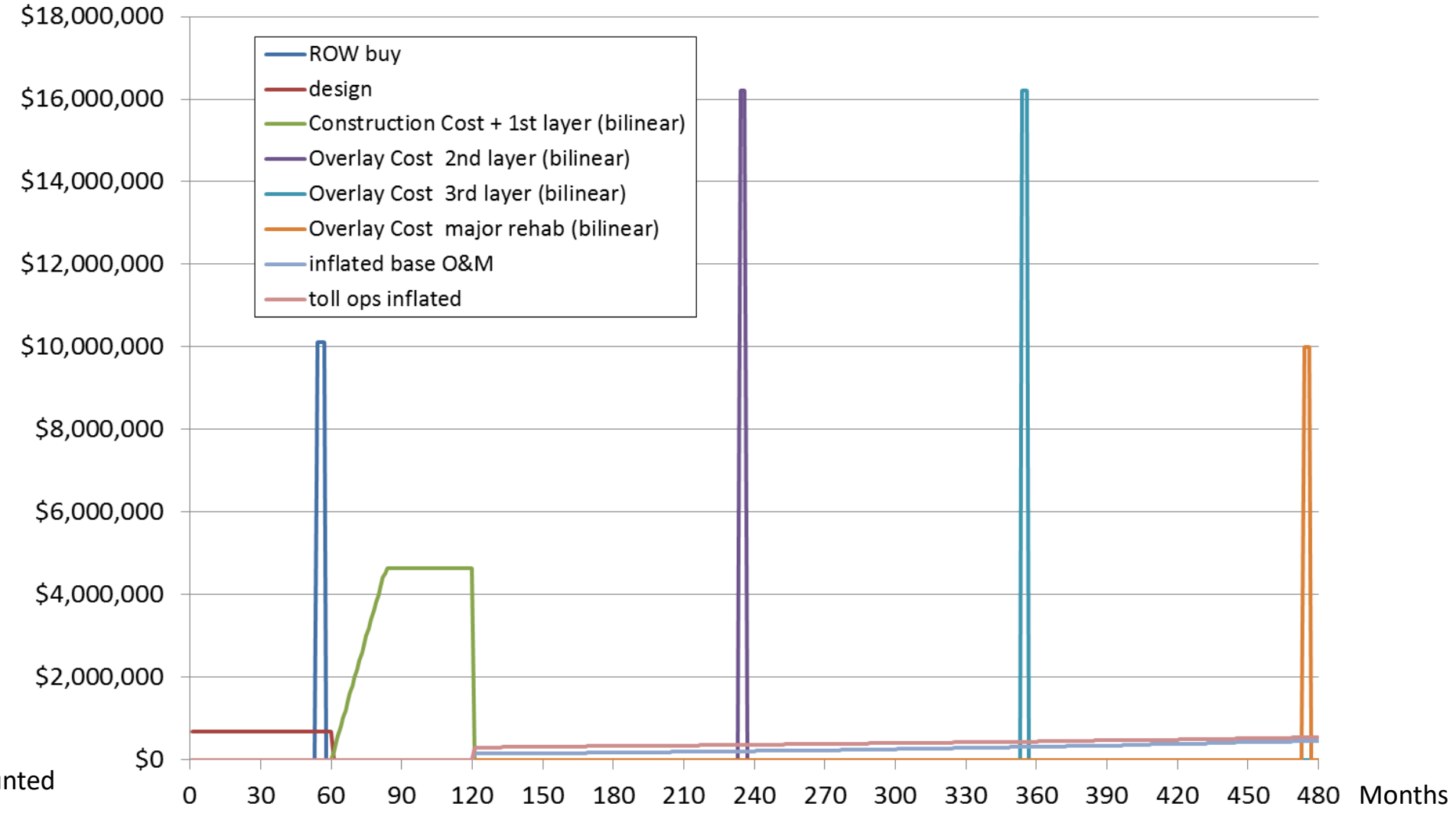


Project Costs for Full Initial Paving*



* undiscounted

Project Costs for 3-Stage Paving*



* undiscounted

Case Study Inputs

6-lane highway - conceptual estimate (new construction, urban locale)

Total roadway length	20	miles (divided highway)
Number of traffic lanes (toll)	6	3 lanes each way, 2-way toll
PPP term (concession period)	30	yrs
Design & ROW prop buy (yrs)	5	yrs
Construction (yrs)	5	yrs
Base toll rate ($/vehicle)	$2.00	car
	$1.50	car (off-season/off-peak)
	$5.00	each additional axle
Pavement layer breakdown	0.55	base layer
	0.45	HMA (3 layers of 0.15 each)
	$48,600,000	HMA cost per layer (3 total)

Developmet cost breakdown

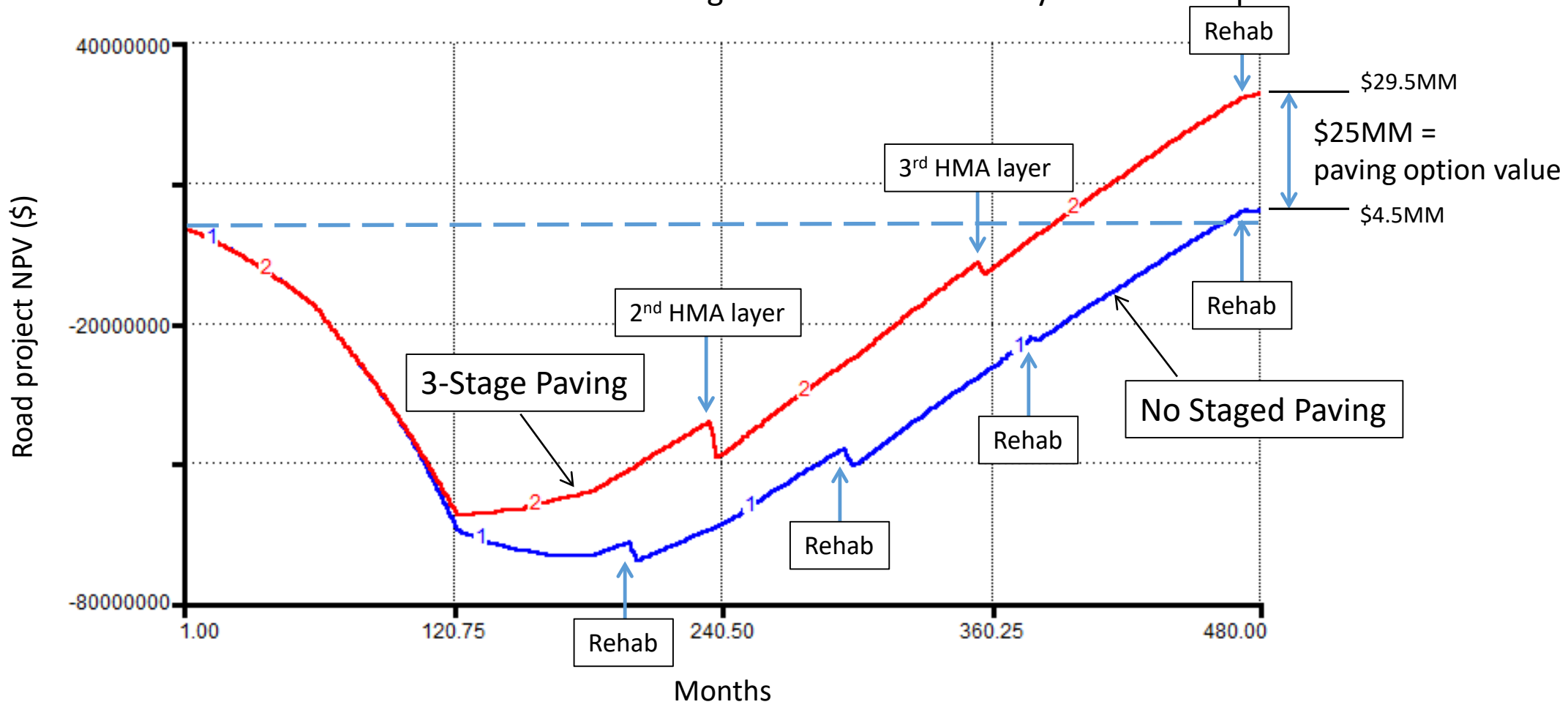
$	2,700,000	construction cost per lane-mile (urban areas)	
$	324,000,000	total roadway construction spend	80%
$	40,500,000	cost of ROW land acquistion per mile	10%
$	40,500,000	design & engineering	10%
$	**405,000,000**	total development cost	

Maintenance/rehab and operations

$	10,000	annual base maintenace per lane-mile
$	250,000	major rehab/ thick overlay per lane-mile
$	125,000	minor rehab/ thin overlay per lane-mile
	7, 22	years for minor rehab (full HMA to start)
	15, 30	years for *major* rehab (full HMA to start)
	1.25	cost inflator for pavement rehab
$	250,000	base toll operation cost per month (2017 $)

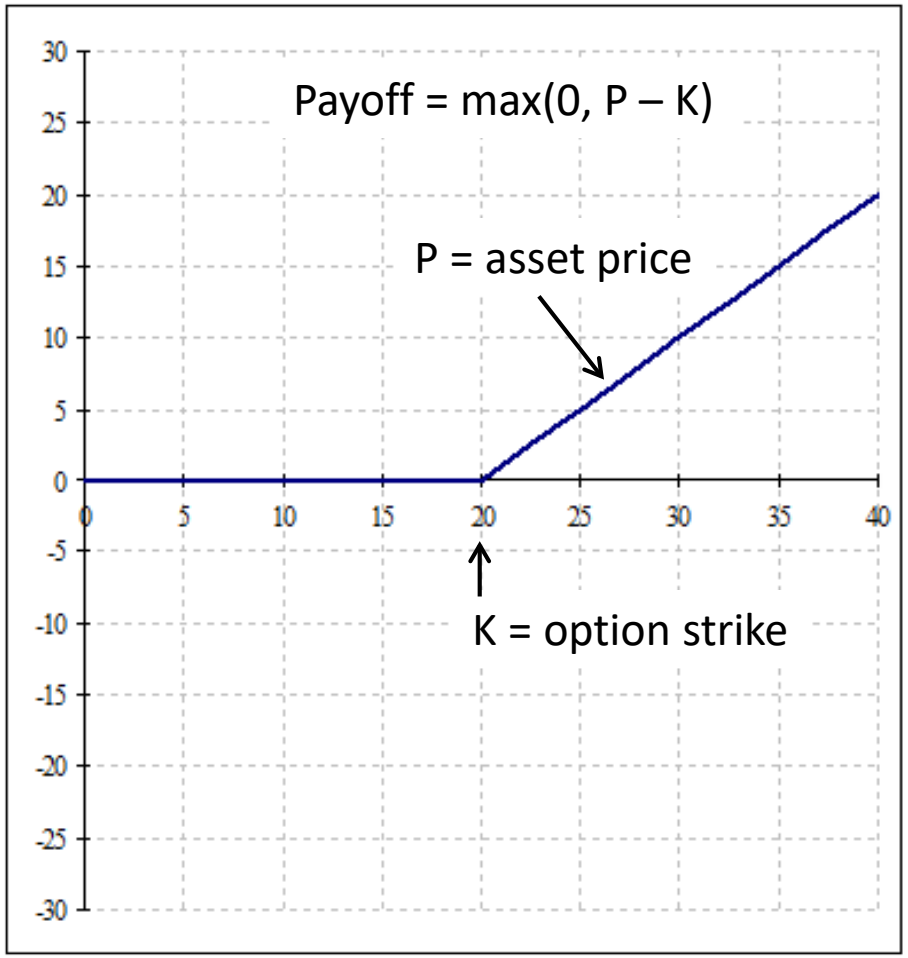
Road Project NPV w/ Staged Paving Option

Cumulative discounted net cash flows over design + construction + 30-yr concession period

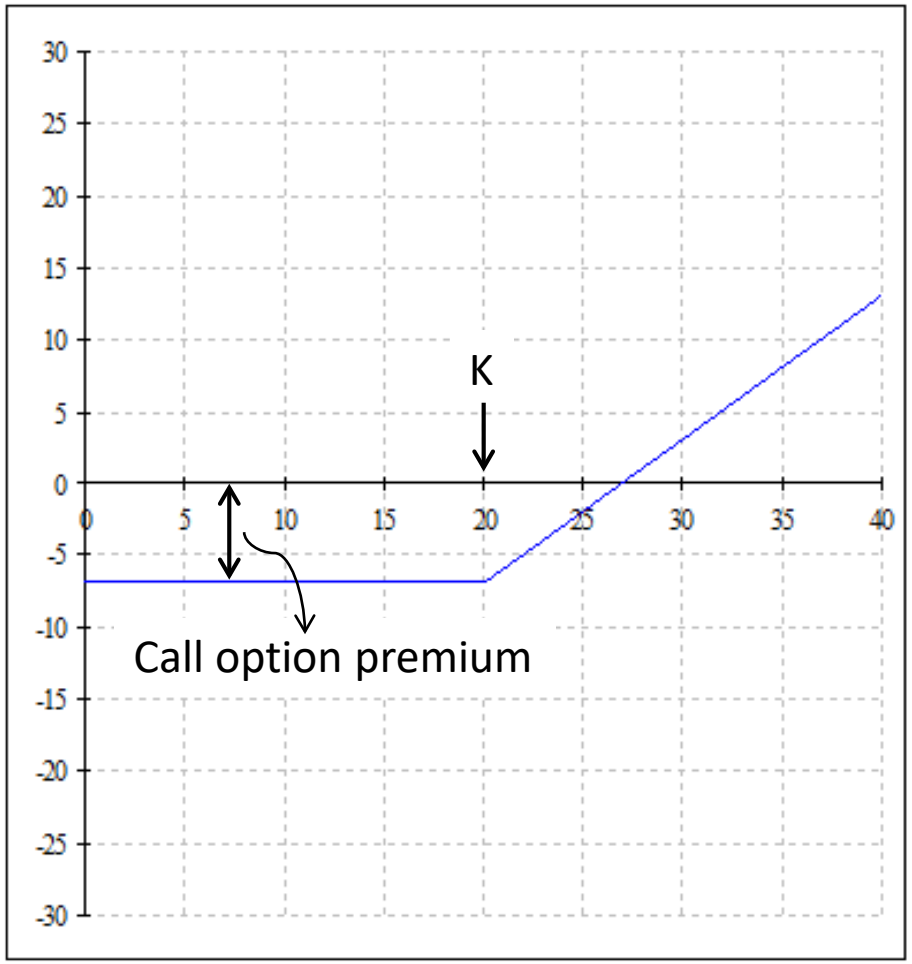


Option Payoffs*

Call Option payoff



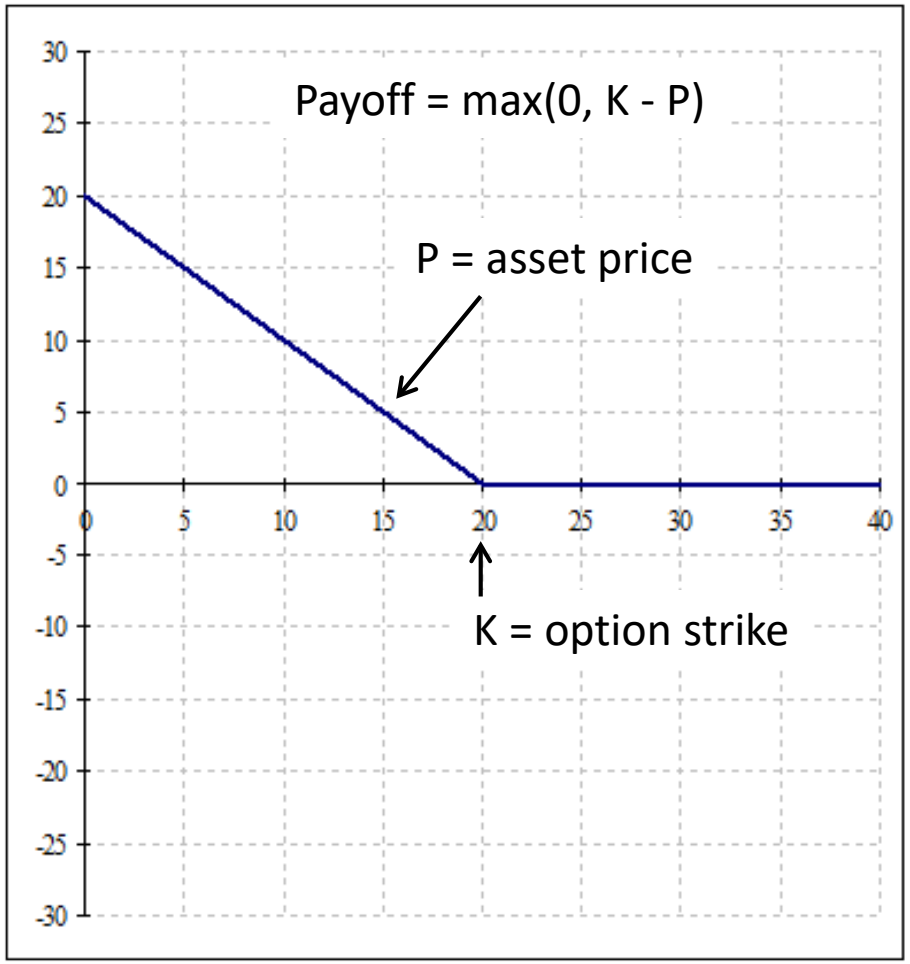
Call Option profit



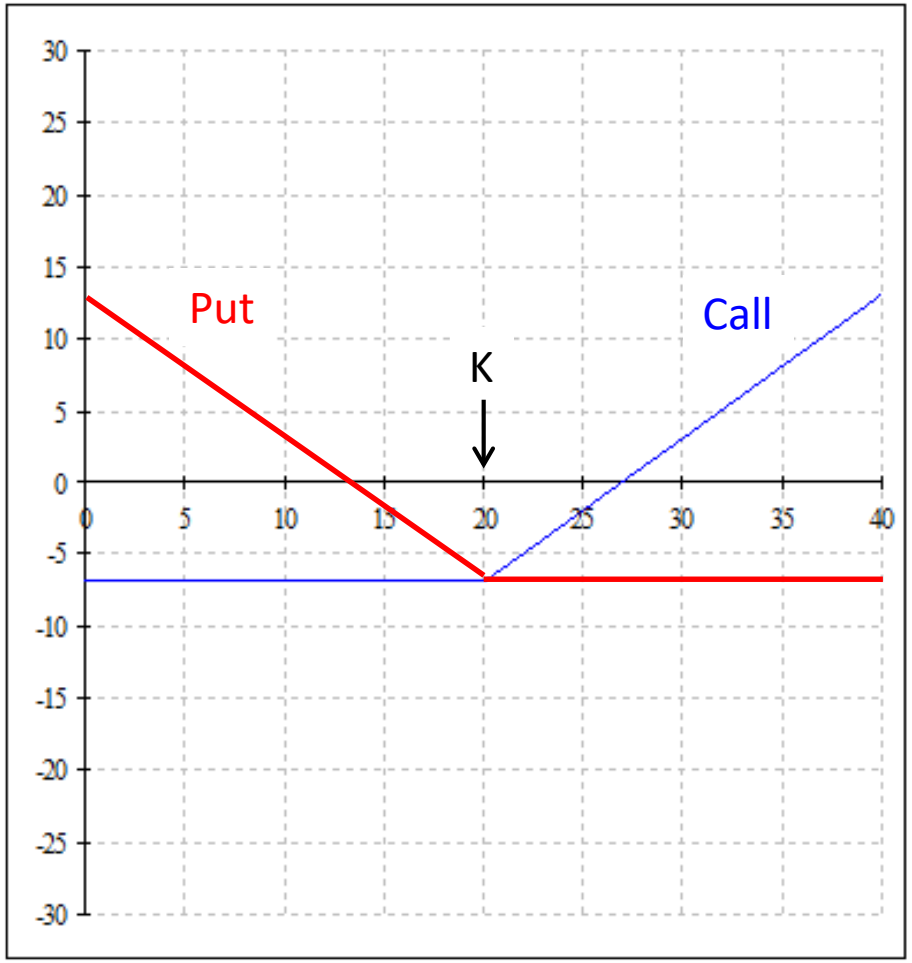
* At option maturity

Option Payoffs

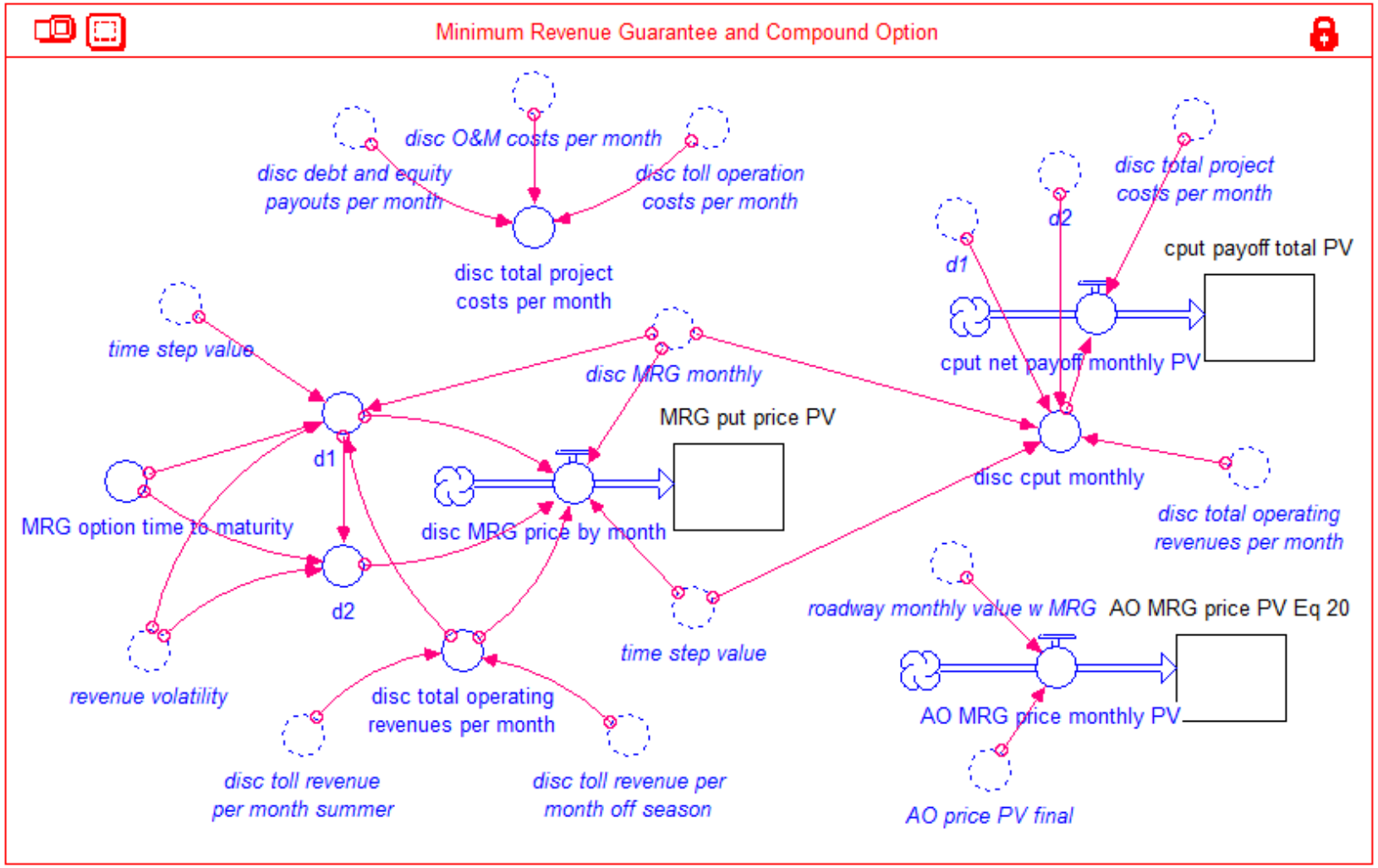
Put Option payoff



Put Option profit

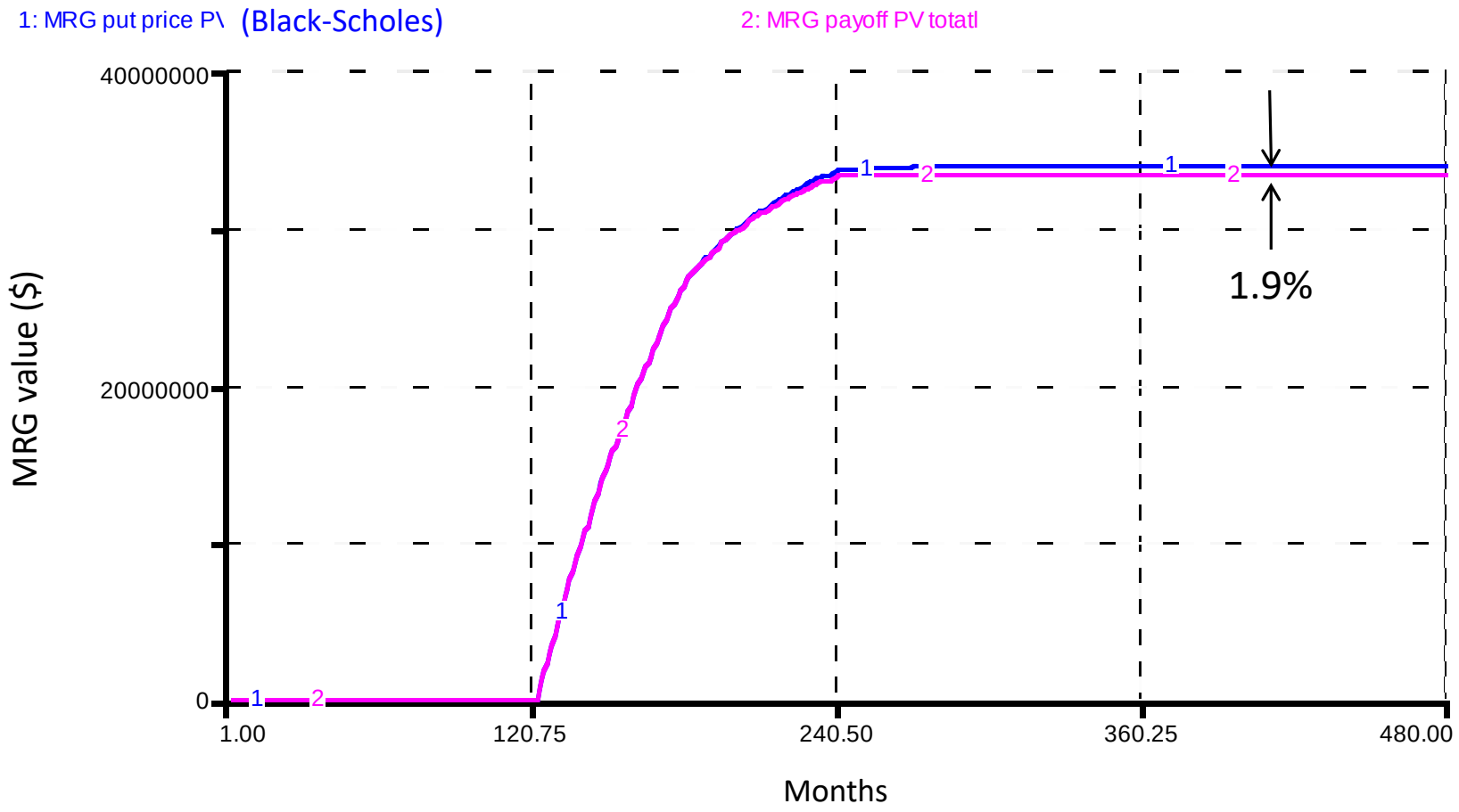


Minimum Revenue Guarantee Option



Direct vs Indirect Valuation of Real Options

Monthly Minimum Revenue Guarantee of $4,000,000 (strike for strip of monthly Put options)



Thank you!