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A New Software Tool that Optimizes Dynamic Decision Making

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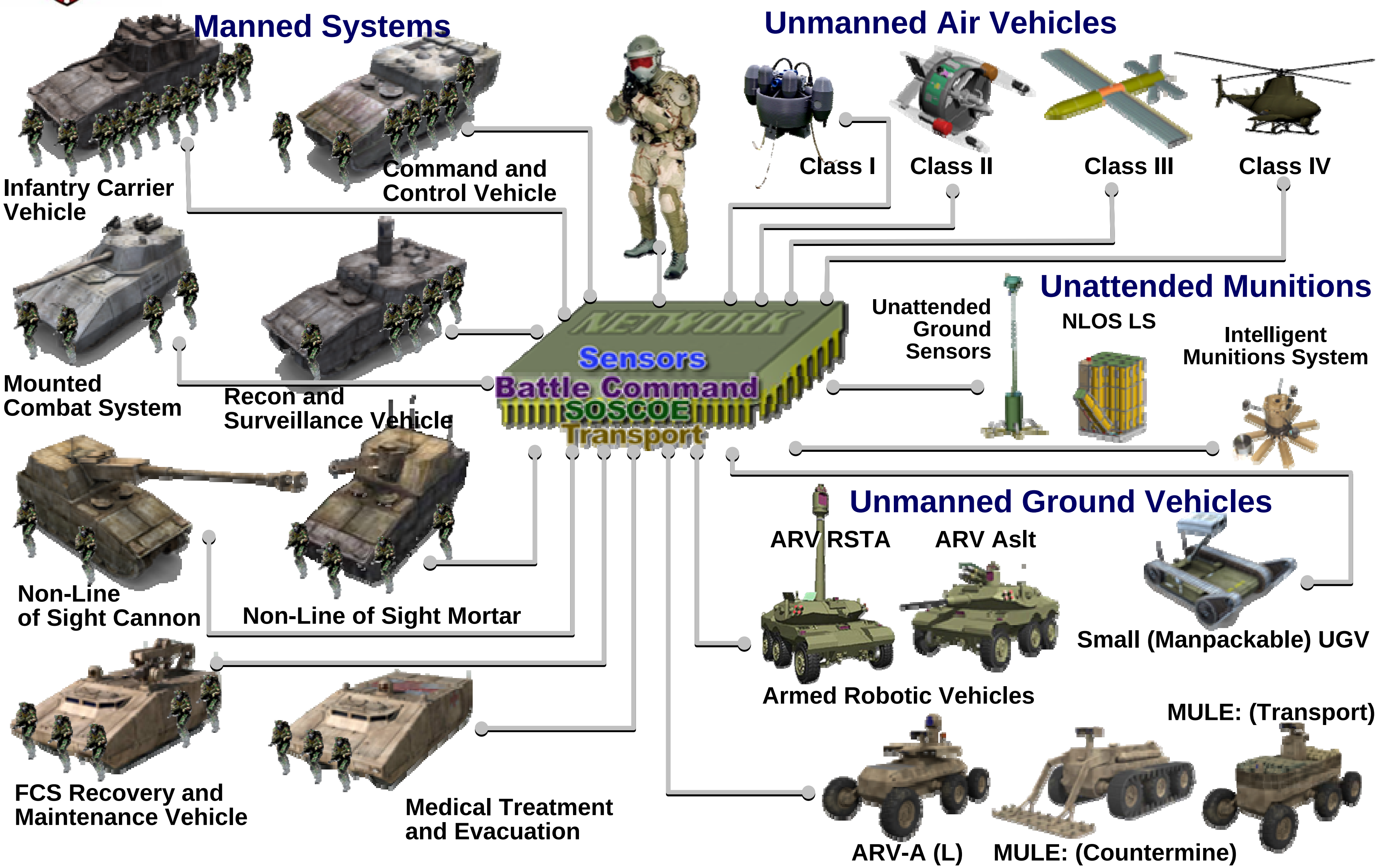
Outline

- Introduction
- Dynamic Decision Network (DDN) overview
- A simplified example
- A complex example
- Software implementation
- Software challenges and insights
- Future research

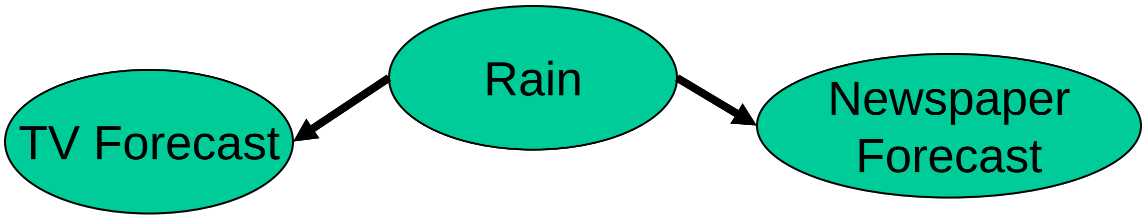
Future Combat Systems (FCS)...Soldier + Network + 18 Integrated Systems



A problem: Automate repetitive decision making

- Our approach uses DDNs
  - DDNs are a composition of Bayesian networks and influence diagrams
  - DDNs suggest a decision at each step based on
    - Deterministic information about the mission and available resources
    - Probabilistic information about the situation and environment
    - The goals and objectives we are trying to achieve
  - They can address repetitive decisions
    - Target prioritization
    - Route clearing
    - Sensor placement and maintenance
  - We are applying this approach to decision making encountered by the FCS

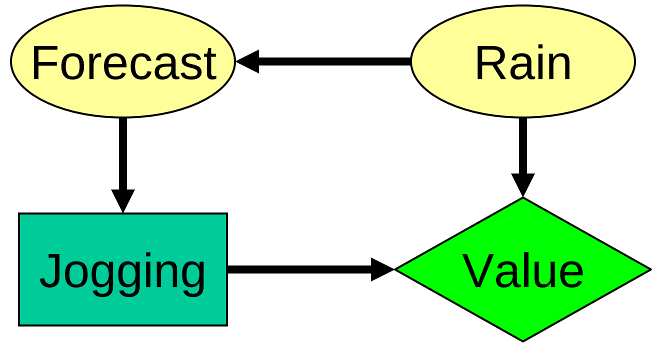
Bayesian Network



Conditional Probability Table		Newspaper forecast	
		Rain	No Rain
Will actually rain	Yes	.8	.2
	No	.25	.75

- Defined by a graph and a set of conditional probability tables
- Can compactly represent complex probabilistic relationships
- Consistently update likelihoods of variables of interest based on new and possibly conflicting evidence
- Non-intuitive computations can be done easily with an adequate software
- Network structure can be exploited to simplify probability assessments

Influence diagram



- Extends Bayesian networks to analyze decisions
- Closely related to decision trees
- Adds decision and value nodes
  - Decision nodes describe what we can do
  - Value nodes describe how much we like the possible outcomes
- We can “solve” the network to identify the best decision given our current information and values
- We can also compute the value of additional information (e.g., how much would we pay a clairvoyant to tell us if it will rain)

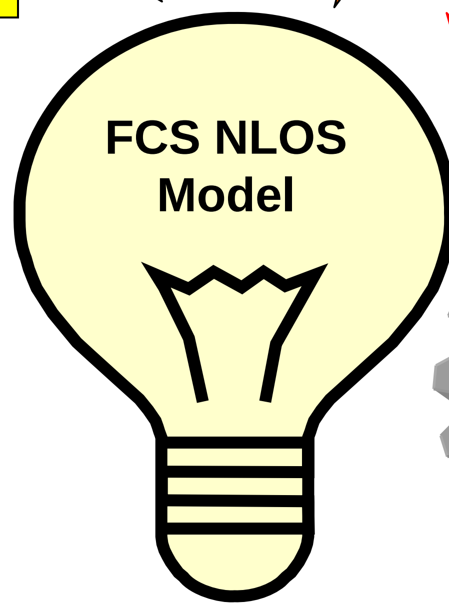
A complex example

- We modeled non-line-of-sight (NLOS) targeting for the FCS mortar system.
- The DDN models the fire mission process using current doctrine.
- The DDN streamlines the information from the tactical and strategic sources. It then incorporates the value model to reach the optimum decision.
- NLOS is one of the systems that can benefic most from the DDNs.

Modeling Process

- Old & new weapon system comparison
- Scenario development
- Proper assumptions
- Call for fire and fire planning procedure analysis

- Streamline data
- Value model development
- Chance node probability computation



Modeling Considerations

- Tactical information – provided by the observer, typically either a member of the unit requesting fires or co-located with the unit that benefits from the fire.
- Strategic information – mainly provided by the fires planning from the battalion commander and his fire support officer.
- FCS sensors provide real time tactical and strategic information.

Some assumptions

- The battalion maintains the control of the mortar battery.
- The requested targets are not priority targets.
- Final protective fires are not requested.
- All calls for fires are cleared of any maneuver control measures and restrictive fire support coordinating measures.

Scenario

A mortar platoon of a UA tactical battalion is in place to provide fire support. More than one fire mission are generated relatively at the same time, and the platoon leader has to make a decision as to which target his platoon will shoot first to maximize the probability of the mission accomplishment and other requirements.

NLOS (Mortars) configurations

Current

**Light infantry BN

4-6 tubes mortar (81mm) PLT in BN HQ

4-6 tubes mortar (60mm) in maneuver companies

**Mech infantry / tank BN

4-6 tubes mortar (120mm) PLT

**Conventional munitions. Digital and voice fire processing. manual fire control

FCS

A mortar battery composed of 2 PLTs in a maneuver BN

8 turreted tubes (120 mm) (4 per PLT) digital / automatic fire control

4 tubes (81 mm) (2 per PLT) dismounted.

smart and conventional munitions.

Other FCS common sensors and data equipment

Call for fire

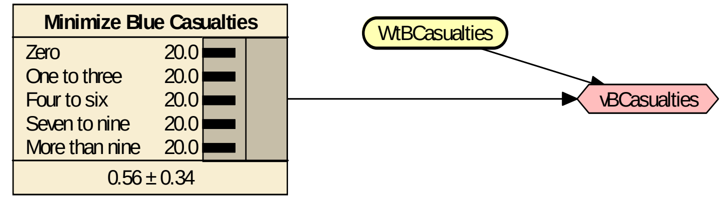
Observer identification	Target description
Warning order *Type of the mission *Size of element to fire *Method of target location	Method of engagement *Type of adjustment *Danger close *Mark *Trajectory *Ammunition (projectile and fuze)
Target location *Grid, polar, shift from a known point	Method of fire and control *Method of fire *Method of control

Fire planning

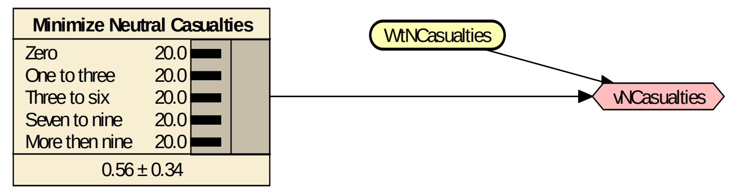
- Enemy situation
- Priority of fires
- Control of the mortar battery
- High-payoff targets
- Future plans
- Logistics of ammunition
- Special ammunition missions

Value model

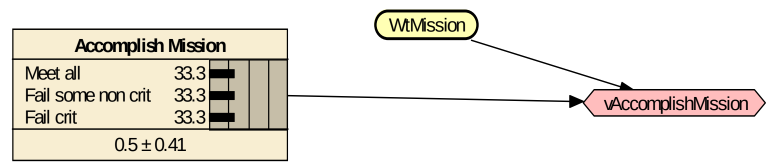
A natural measure that considers the distribution over the number of blue personnel fatalities and life threatening injuries due to either enemy action or fratricide



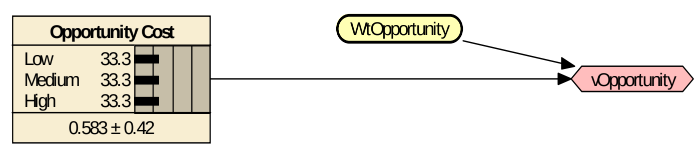
A natural measure that considers the distribution over the number of noncombatant fatalities and life threatening injuries due to blue actions

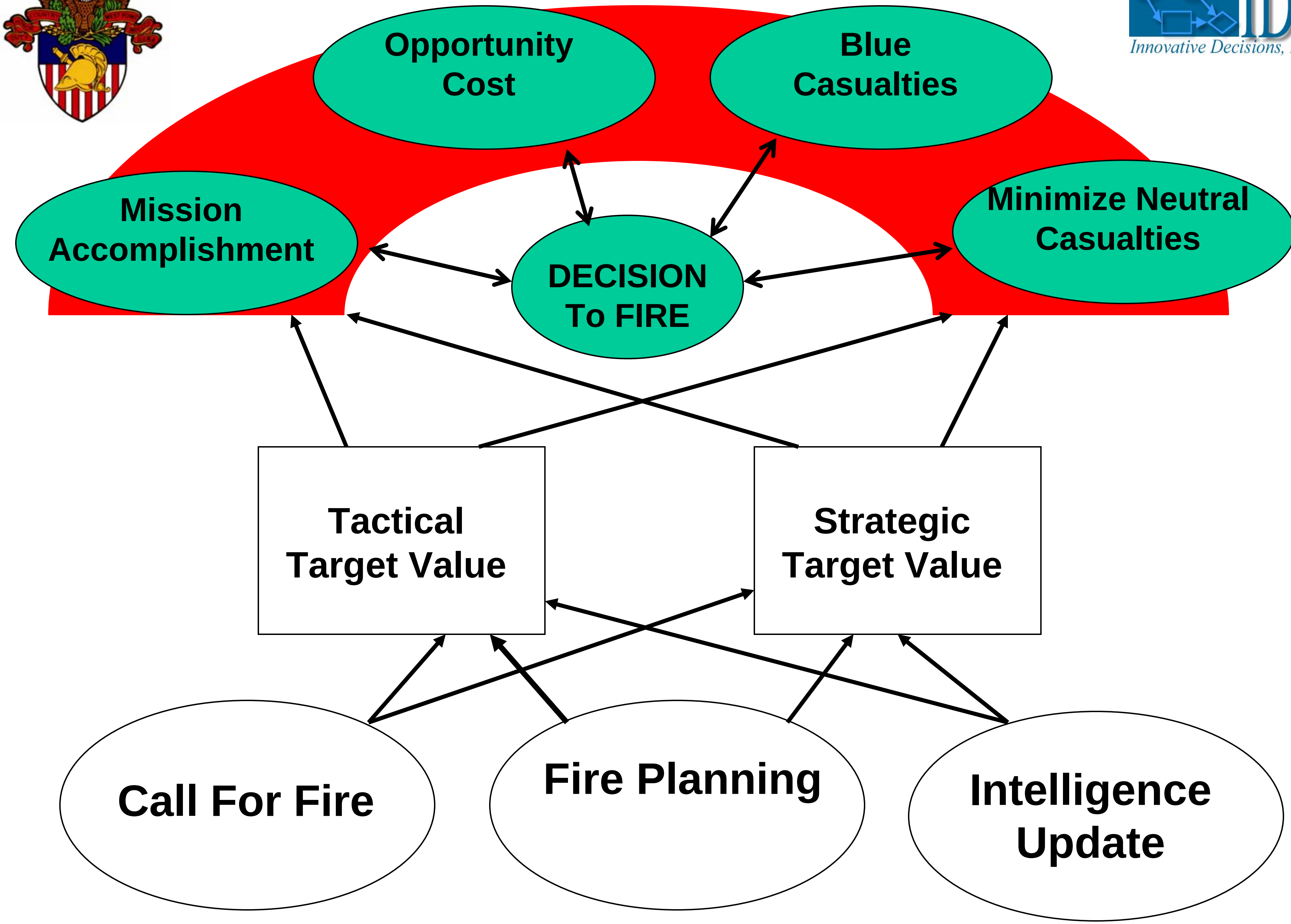


A constructed measure that evaluates the likelihood of mission success within that time period given a decision alternative that is being evaluated.

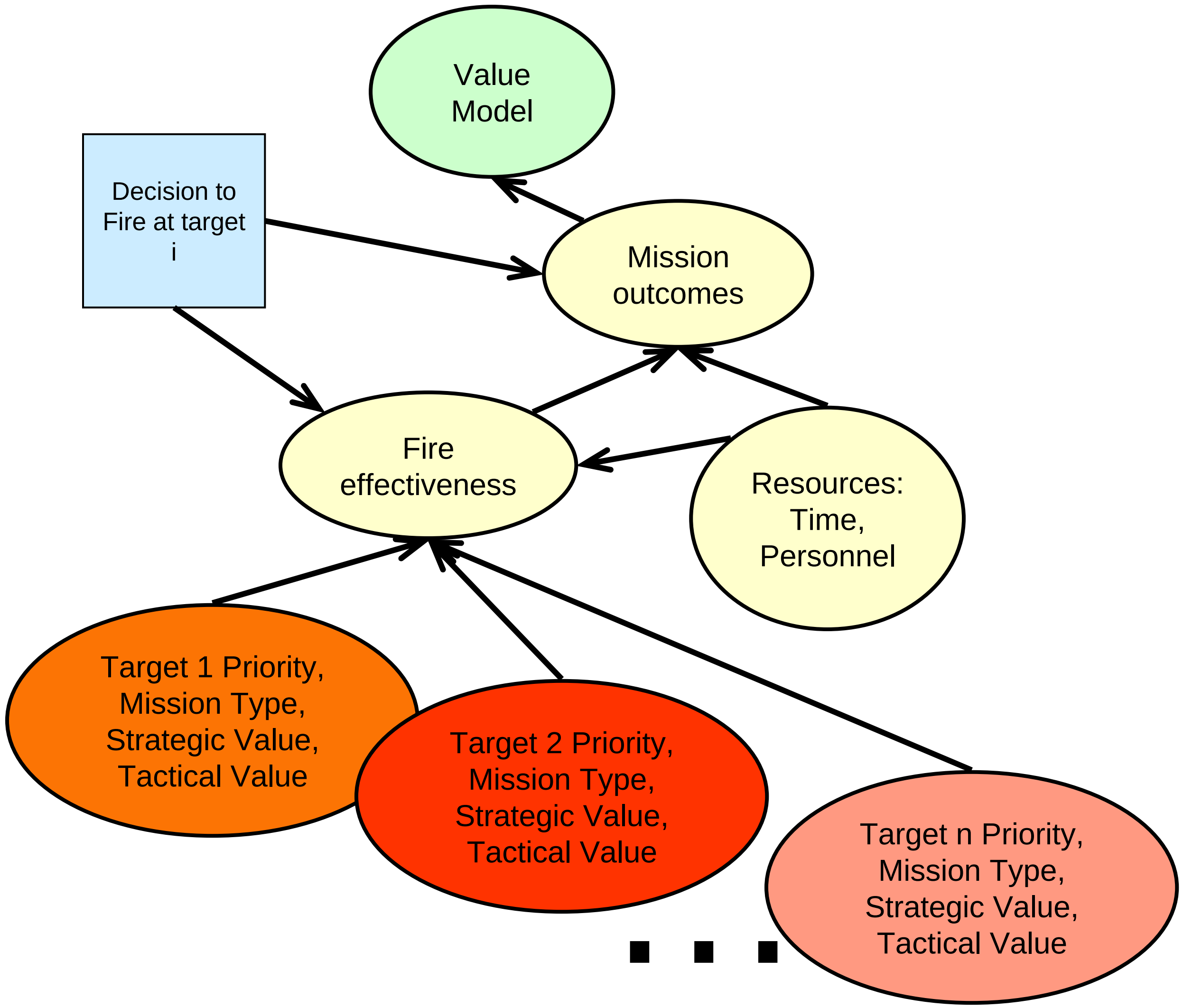


A constructed measure that evaluates the potential impact of a given decision on potential for success of future actions inside the time horizon of the DDN.

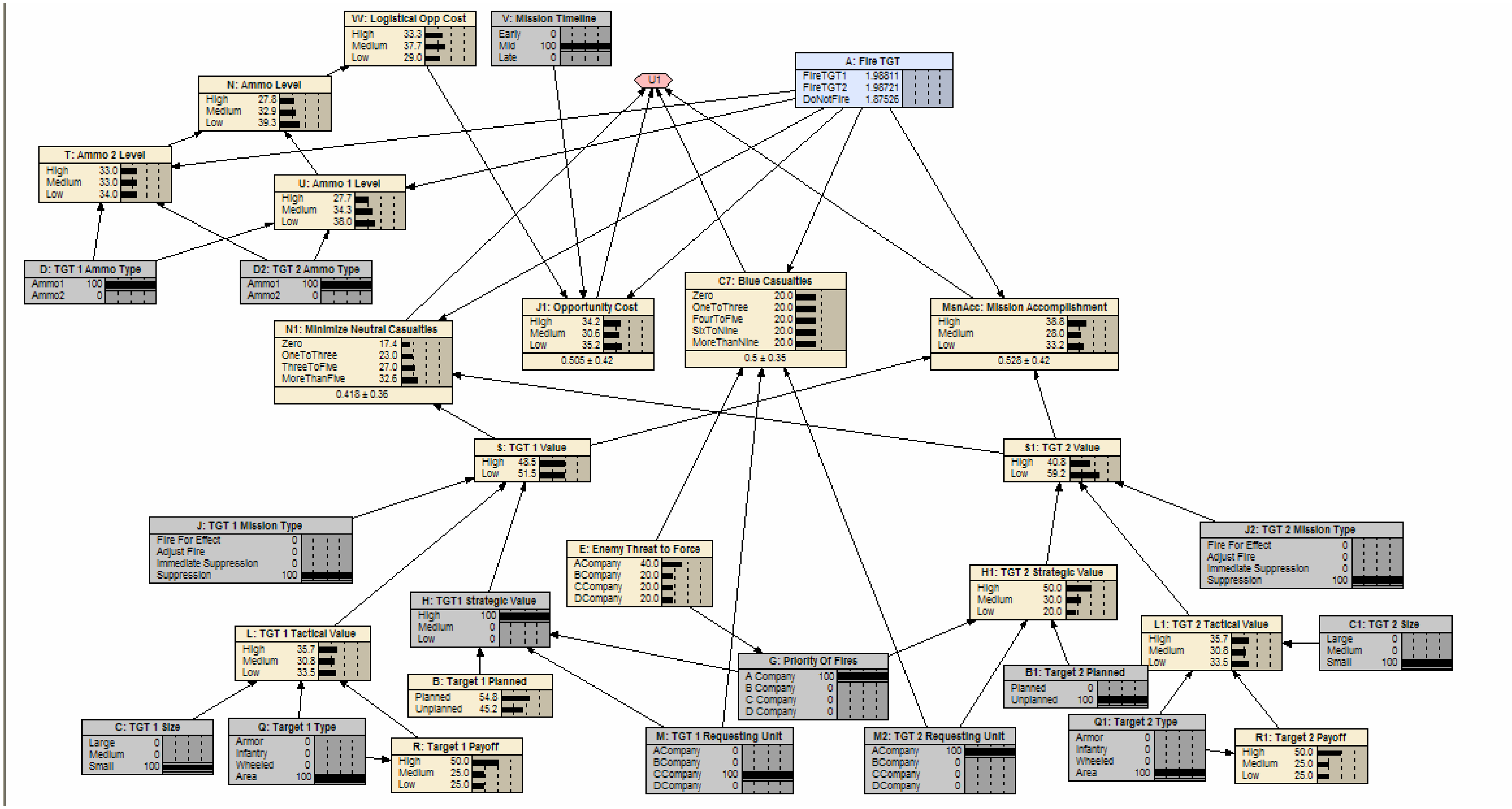



Opportunity Cost
Blue Casualties
Mission Accomplishment
DECISION To FIRE
Minimize Neutral Casualties
Tactical Target Value
Strategic Target Value
Call For Fire
Fire Planning
Intelligence Update

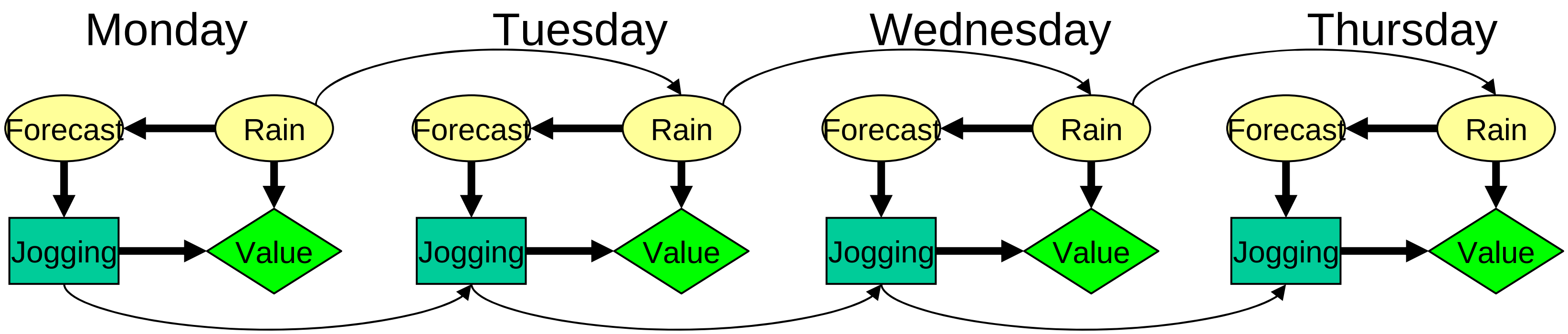
NLOS Targeting Model



NLOS single step influence diagram for two targets



Dynamic Decision Networks extend influence diagrams to decisions that repeat over time



- Extend influence diagrams to handle repetitive decisions over time
- Values and decisions remain constant
- The situation changes over time
  - Resources are used
  - The mission progresses towards completion
  - Information is gathered
- We want to find the best decision in the current time period given the current situation, what's happened in the past and what may happen in the future

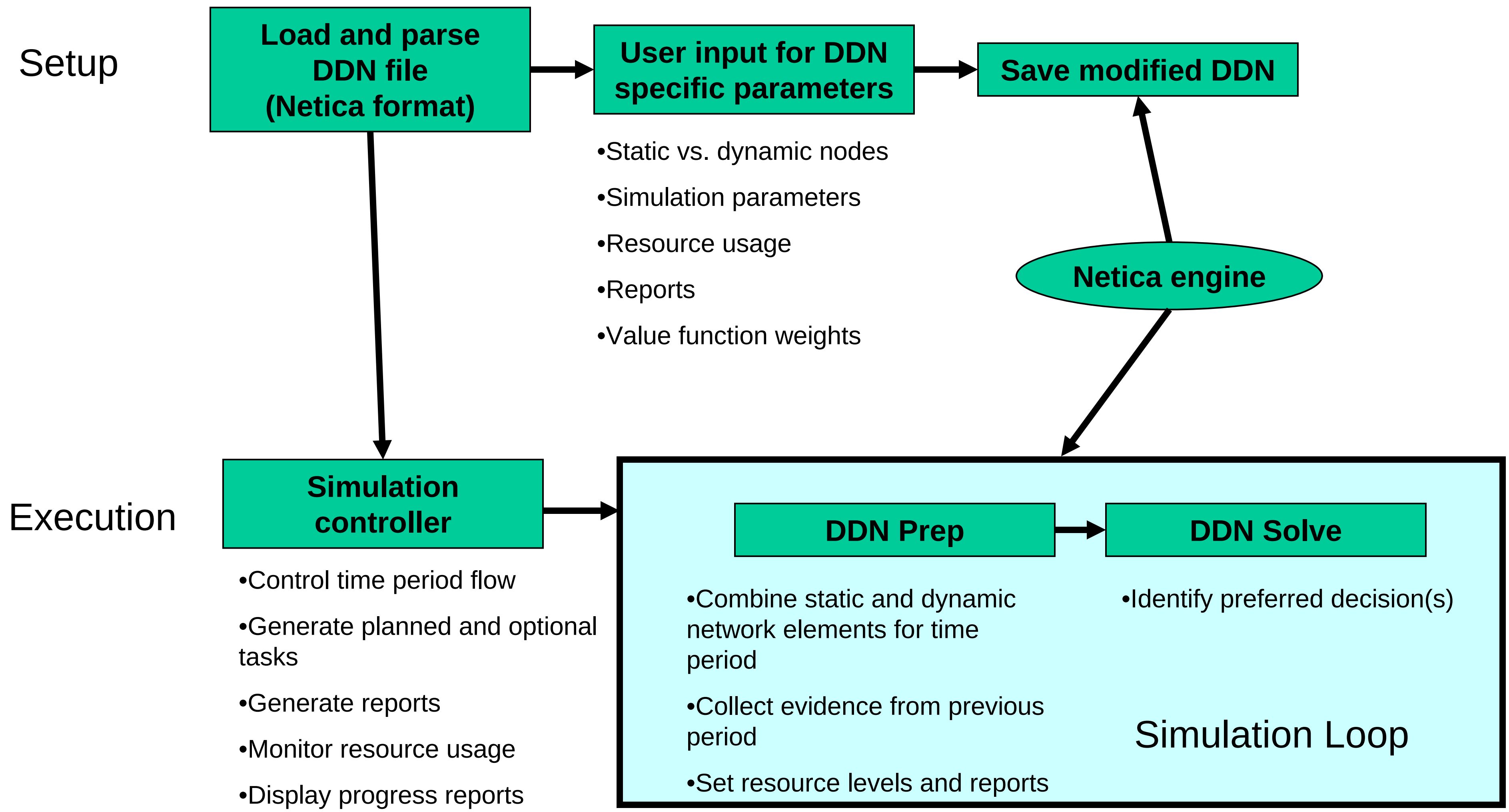
Two approaches to optimizing dynamic decisions

- The hard way (dynamic programming)
  - Solve everything at once by building a model that includes all time periods
  - Work backwards from the last time period to see what we should do now
  - Problem: the possibilities multiply exponentially
    - “the curse of dimensionality”
- The somewhat easier way (leapfrog or myopic approach)
  - Make our best decision now, using a value function that takes the possible consequences of our actions into account
  - This is the DDN approach we are using

We've implemented software to create and test DDNs

- A C++ wrapper controls an API to a COTS ID/BN package called Netica.
- Netica API allows manipulation and solution of Influence Diagrams
  - A COTS application for creating and solving influence diagrams
  - .dll library used: does not require Netica application to be running
  - Setup information stored as user variables in Netica file
- C++ allows speed, object orientation and fine control
  - MS Visual studio .NET
  - Microsoft Foundation Classes
- The software creates DDNs for each time period under control of a Monte-Carlo simulation

Simplified Software Block Diagram



The unique features of DDNs present programming challenges

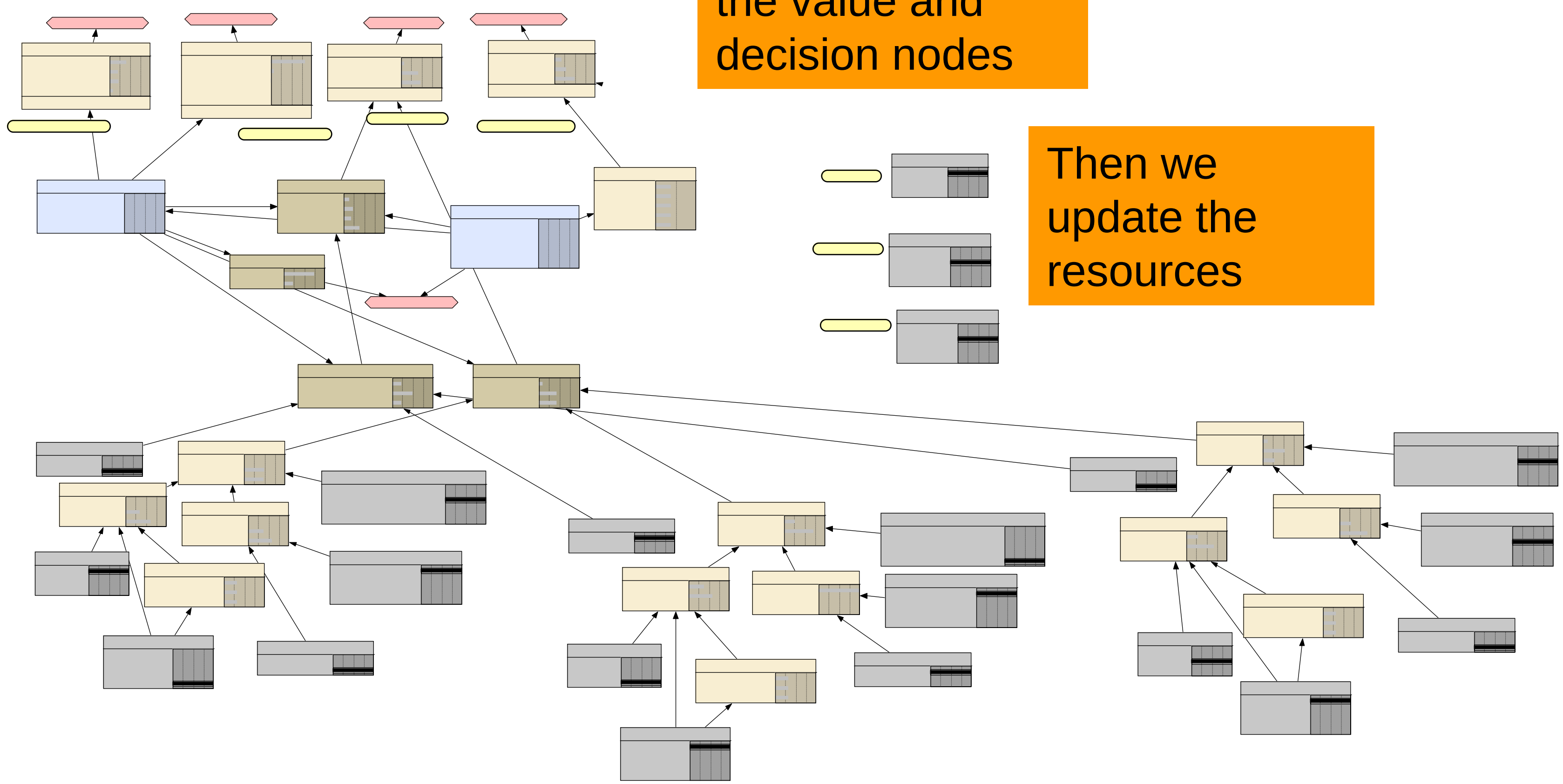
- Stepping through time
- Tracking multiple targets/tasks
- Tracking resource usage
- Incorporating values
- Receiving reports
- Dealing with asymmetries
- Interacting with analysts and decision makers

Stepping through time

- A new network is constructed for each time period

1. We start with the value and decision nodes

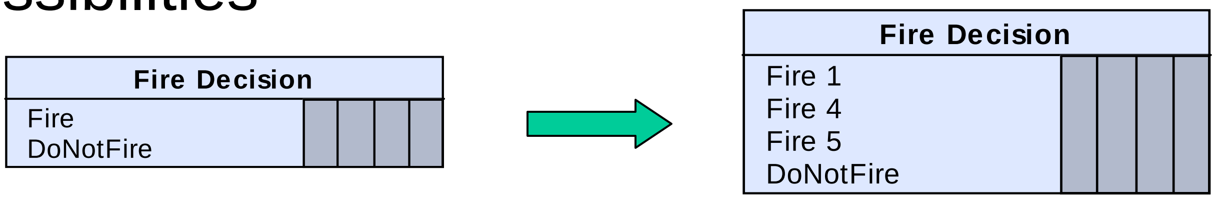
Then we update the resources



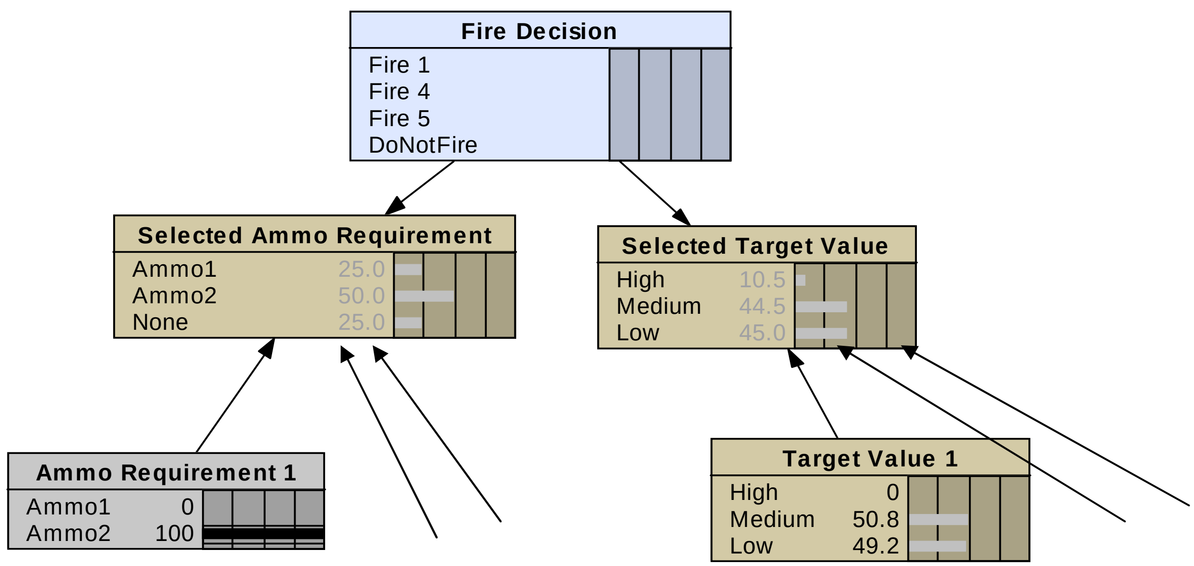
Finally we add the targets and receive reports about them

Tracking multiple targets/tasks

- Decision nodes must be updated to reflect the possibilities

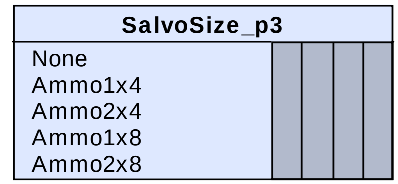


- Connector nodes aggregate information about the targets/tasks in coordination with the decision

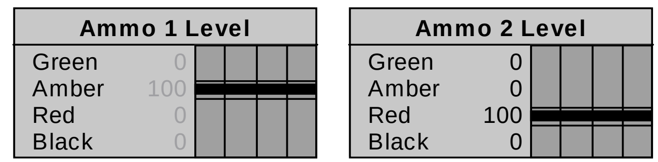


Tracking resource usage

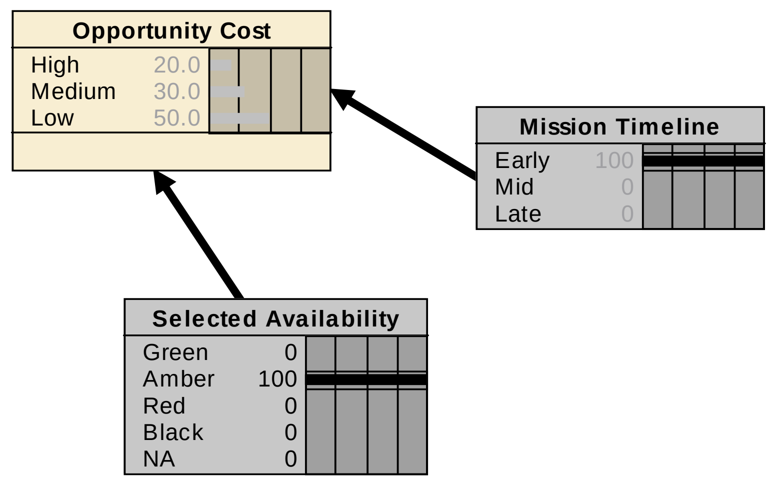
- Decisions at a time period may use up resources



- The simulation model tracks resource usage and updates resource nodes for later time periods using a stoplight scale



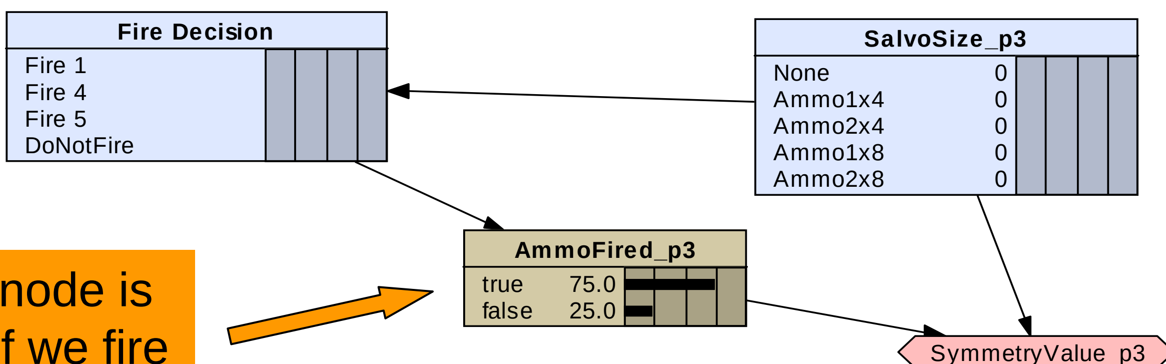
- Decisions with insufficient resources are not allowed. The opportunity cost of using resources is part of the value function



Dealing with asymmetries

- Problem: How to coordinate fire/don't fire decision with salvo size decision
  - Salvo size must be zero if fire decision is "no fire"
  - Netica makes does not allow one decision to affect the possible states of another
  - If we combine the decisions, multiple targets make the possibilities unmanageable
- Solution: add an ammo fired node and a "symmetry enforcing" value node

The value node penalizes impossible combinations



This node is true if we fire at a target

SalvoSize_p3	AmmoFired_p3	SymmetryValue...
None	true	-1000
None	false	0
Ammo1x4	true	0
Ammo1x4	false	-1000
Ammo2x4	true	0
Ammo2x4	false	-1000
Ammo1x8	true	0
Ammo1x8	false	-1000
Ammo2x8	true	0
Ammo2x8	false	-1000

Receiving reports

- Situational information is obtained in the model through report nodes
- The simulation controller generates values for all active report nodes in the model
  - The sampled values are based on the current estimates of the probabilities of the possible states
- Reports can depend on actions taken in previous steps
  - Don’t get a sensor report in step i unless the sensor is turned on in step i-1
- The model can use value of information computations to estimate the future costs and benefits of turning on a sensor

Interacting with analysts and decision makers

- The least developed but most important part of the software
- Analysts need to be able to build models without worrying about special software requirements
  - The software allows many extensions to standard Netica models, but they must be easy to implement to be useful
- Decision makers need to quickly understand the DDN results
  - They need to understand why the model recommended the decisions it did and when it is appropriate to override those decisions

We plan to do additional work on the software implementation

- Separate the simulation from the DDN processing and move to a backplane
- Integrate with simulation system developed by C2ORE group at Ft. Monmouth
- Evaluate the software on large/complex DDNs and optimize its performance
- Enhance the user interface to allow greater control and customization of DDNs
- Develop more sophisticated, user friendly and informative output displays
- Allow more user control over the simulation, including allowing recommended decisions to be changed
- Develop a tool to aid the creation of DDNs in Netica
- Refine and test the method for selecting which sensors to activate in a given time period, based on value of information calculations

Review

- Introduction
- DDN Overview
- A Simplified Example
- A More complex example
- Software implementation
- Software challenges and insights
- Planned new work