27th annual INCOSE international symposium
Adelaide, Australia
July 15 - 20, 2017

ENGINEERS AUSTRALIA SESA

Modeling and Analyzing the Emergency Management Mission as an Executable Model

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Abstract

- Successful execution of the Emergency Management (EM) mission space requires Critical Infrastructure (CI) sector participation to enable the accomplishment of the EM mission
- A methodology is provided to describe, organize, and evaluate the interdependencies of the various EM missions and their respective CI sectors
- An illustrative example with an executable model of the EM mission space is provided to graphically display the CI sectors' contributions to the EM mission functions, as well as calculating the mission accomplishment percentage
- The model is extended to consider disturbances to one or more CI sectors, recalculating the resultant mission performance
- Due to the nature of these interdependencies, decision makers may consider varying the allocation of resources to the CI sectors in order to evaluate the impact of EM mission accomplishment based on their decisions

Needs / Motivation

- The Emergency Management (EM) responders require the use of selected Critical Infrastructure (CI) sectors in order to accomplish their missions
- However, when some of these CI sectors are degraded, there is no quantified methodology to show how degraded the EM missions will become
- By developing a methodology to describe the functionality and then convert to an executable model, we may evaluate how well the performance may result in the modification of the CI sector resources

Literature Review

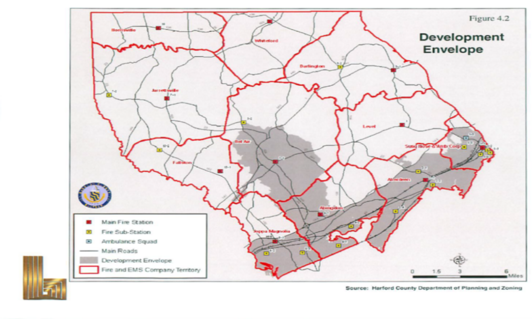
- The research is motivated by the creation of the CI sectors, which are described by the Department of Homeland Security (DHS, 2014) and the need to strengthen and secure the nation’s Critical Infrastructure resources (Presidential Policy Directive (PPD) 21, 2013)
- CI systems becoming more interlinked and dependent on each other, (Balducelli et al.), which can increase the potential risk of degradation and disruption (via intentional attack, natural disaster, or accident)
- Recent work focuses on the analysis of the network structure, and the impacts of the network when it is disturbed (Fiedrich et al. (2000) and Dunn et al. (2013))
- Wang et al. (2009) use workflows to describe the sequential and parallel steps to graphically display the relevant actions and decision flows that EM responders and managers would encounter, which we may extend this concept to evaluating how well and where does the EM mission flow get stressed

Methodology Overview

- Define the EM mission scope and identify EM mission functions
- Identify and quantify the CI sector contributions to the EM mission functions
- Convert the EM mission functions into an executable model
- Observe and interpret the results

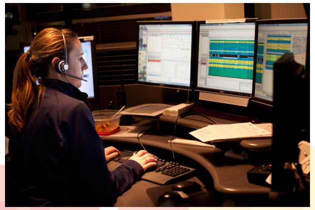
Emergency Management Mission and Functions

- For the purpose of this presentation, the EM mission scope is defined as:
- A county that is part urban and part rural
- EM responders must address the entire county space
- They must perform a variety of missions to include: fire and rescue, hazardous materials handling, and emergency management, to name a few
- A top-level functional description of their mission is provided below, and further decomposed in the next slide



EM Responder Functions

1. Monitor Situation → **2. Select Response Units** → **3. Transit to Incident** → **4. Respond to Incident** → **5. Redeploy to Base**

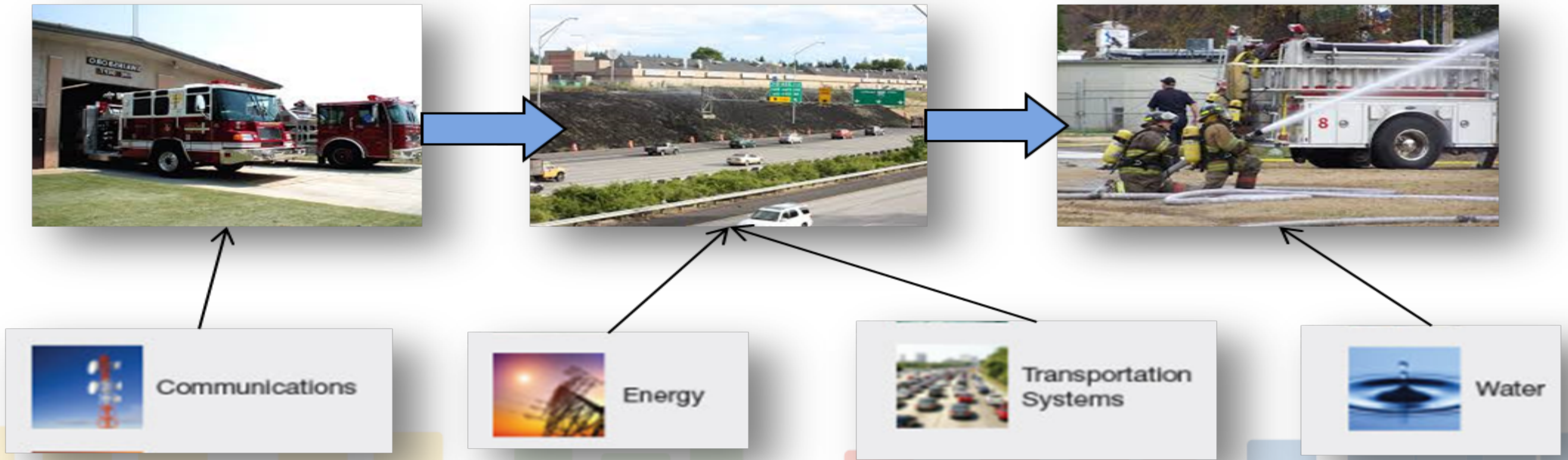


Emergency Management Mission Functions

Top level function	#	EM mission functions:		#	Interfaces between functions (transitions):
1.0 Monitoring the county	1.1	Monitor sensors		1a	Determine active or passive alarm initiation
	1.2	Passively sense environment		1b	Determine alarm threshold
	1.3	Determine if action meets threshold for action		1c	Send alarm
	1.4	Actively initiate alarm		1c	Send alarm
	1.5	Send incident report		1d	Send request for responders
2.0 Select the responder units	2.1	Query available units in vicinity		2a	Determine available / unavailability of responders
	2.2	Receive available units reply		2b	Signal sent from available responder
	2.3	Receive unavailable units reply			End of mission thread, results in unsuccessful mission completion
	2.4	Select closest unit to dispatch		2c	Send assignment to responder
	2.5	Receive acknowledgement		2d	Assignment confirmation message
3.0 Transit to the incident	3.1	Transit to site and receive enroute updates		3a	Status message and use of transportation
	3.2	Arrive on site		3b	Reporting on site message
4.0 Respond to the incident	4.1	Setup equipment and connect to CI resources		4a	Determine availability / unavailability of CI resources
	4.2	Use successful CI resources		4b	Use of resources and status of incident
	4.3	Do not use unsuccessful CI resources			End of mission thread, results in unsuccessful mission completion
	4.4	Respond to incident		4c	Incident resolution message
5.0 Redeploy to the base	5.1	Pack up equipment and disconnect from CI resources		5a	Departure of site message
	5.2	Transit to base and report on status		5b	Status message and use of transportation
	5.3	Return to base			End of mission thread, results in successful mission completion

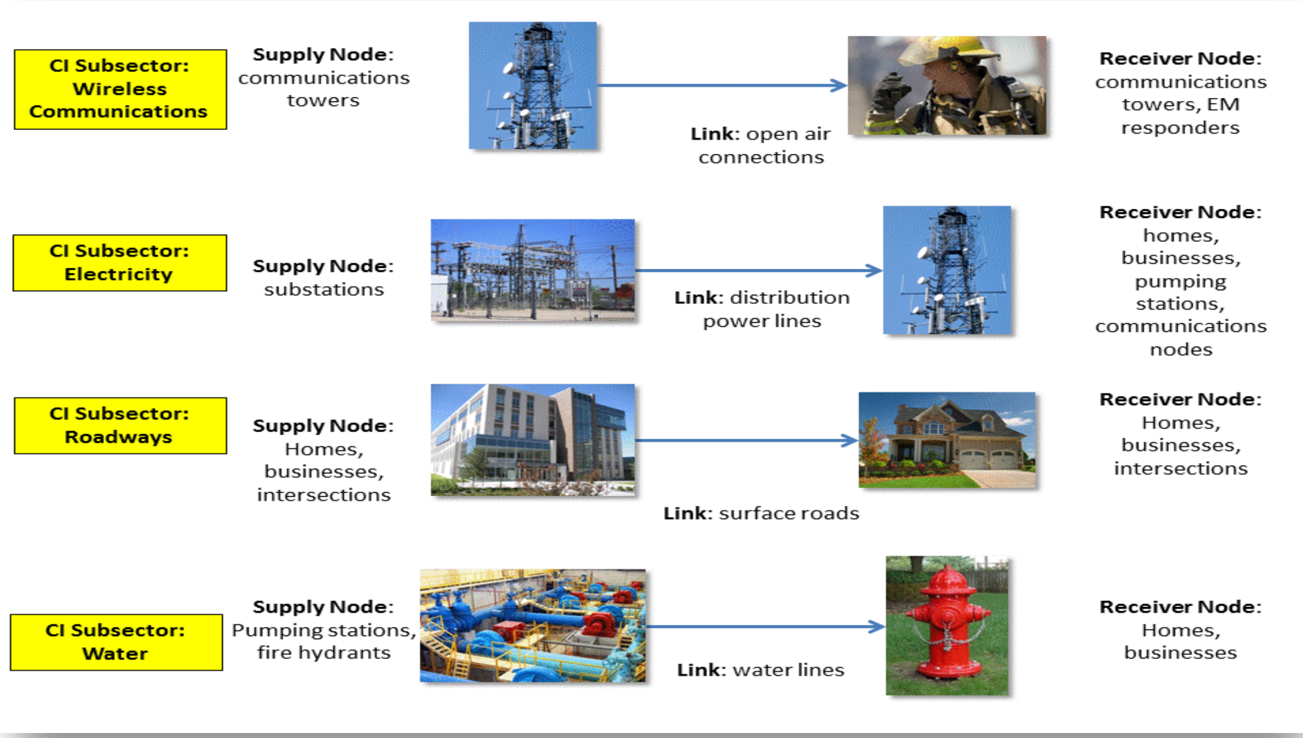
CI Sector Allocation to Mission Functions

- The four CI sectors that we will use in our example are: energy, water, communications, and transportation
- Each contribute at different points in the mission thread
- For this example, we will allocate one or more sectors to the functional interfaces which connect the successive functions
- This helps to keep a one-for-one allocation from the architecture to the model (see next slide)



CI Sector Allocation to Mission Functions

Function	Description	Energy	Water	Comms	Transportation
1.1	Monitor sensors				
1.2	Passively sense environment	x			
1.3	Determine if action meets threshold for action	x			
1.4	Actively initiate alarm	x			
1.5	Send incident report	x		x	
2.1	Query available units in vicinity			x	
2.2	Receive available units reply			x	
2.3	Receive unavailable units reply			x	
2.4	Select closest unit to dispatch			x	
2.5	Receive acknowledgement			x	
3.1	Transit to site and receive enroute updates			x	
3.2	Arrive on site			x	x
4.1	Setup equipment and connect to CI resources			x	x
4.2	Use successful CI resources	x	x		
4.3	Do not use unsuccessful CI resources	x			
4.4	Respond to incident	x	x		
4.5	Resolve incident and report completion	x	x		
5.1	Pack up equipment and disconnect from CI resources	x	x	x	
5.2	Transit to base and report on status	x	x	x	
5.3	Return to base			x	x

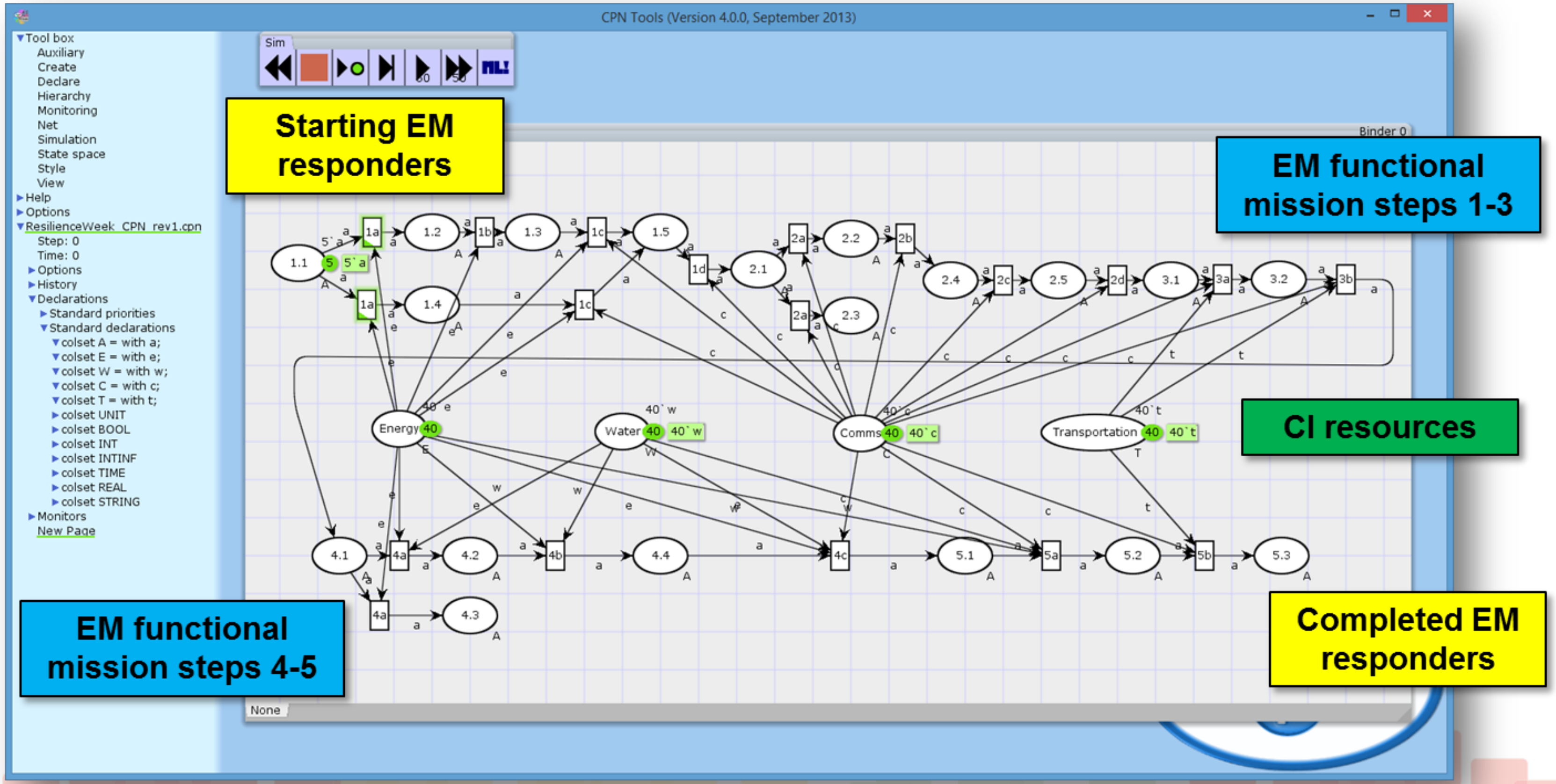


Description of CPN Model

- A CPN is a form of a Discrete Event Simulation
  - The two main components are places and transitions
  - Arcs connect the places and transitions
  - Colors are means to distinguish the different places and exchange tokens between the places via the transitions
  - Compound logics can then be described using multiple conditions in order to “fire” the transition
- We may convert our functional architecture:
  - Representing functions by the CPN transitions
  - Representing resources (CI sectors) by the CPN places
  - Allocating resources to the various places can then describe the amount of contribution that each function can accept
- By organizing the transitions as the sequential functions, we may then evaluate which functions are satisfied with the given resources

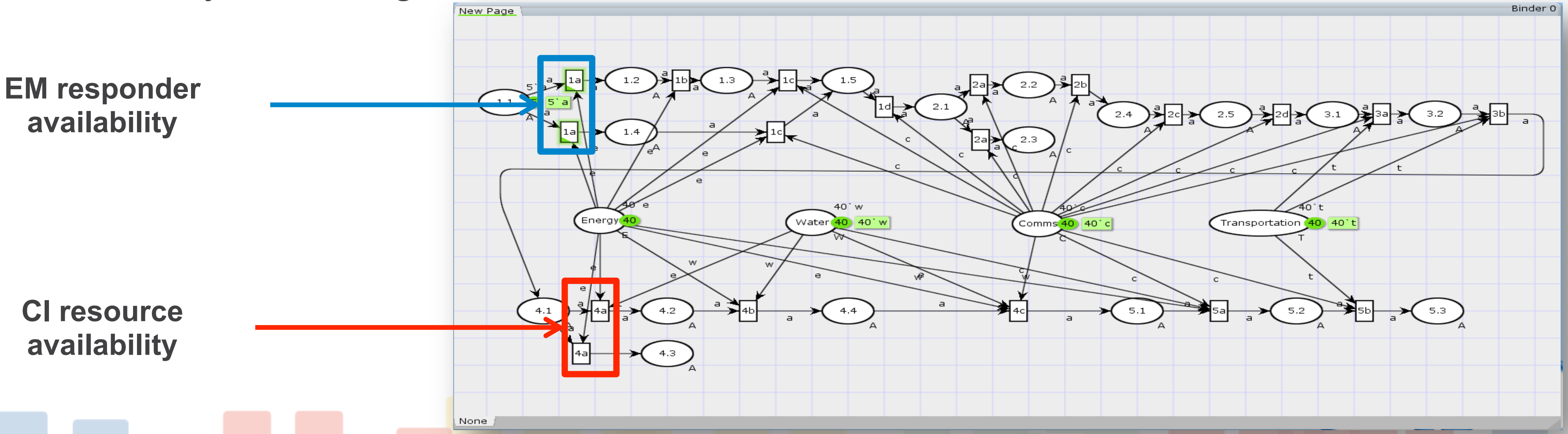
Development of Executable Model

- The mission flow is then converted into an executable model
  - In this case, we use the Colored Petri Net toolset (http://cpntools.org)

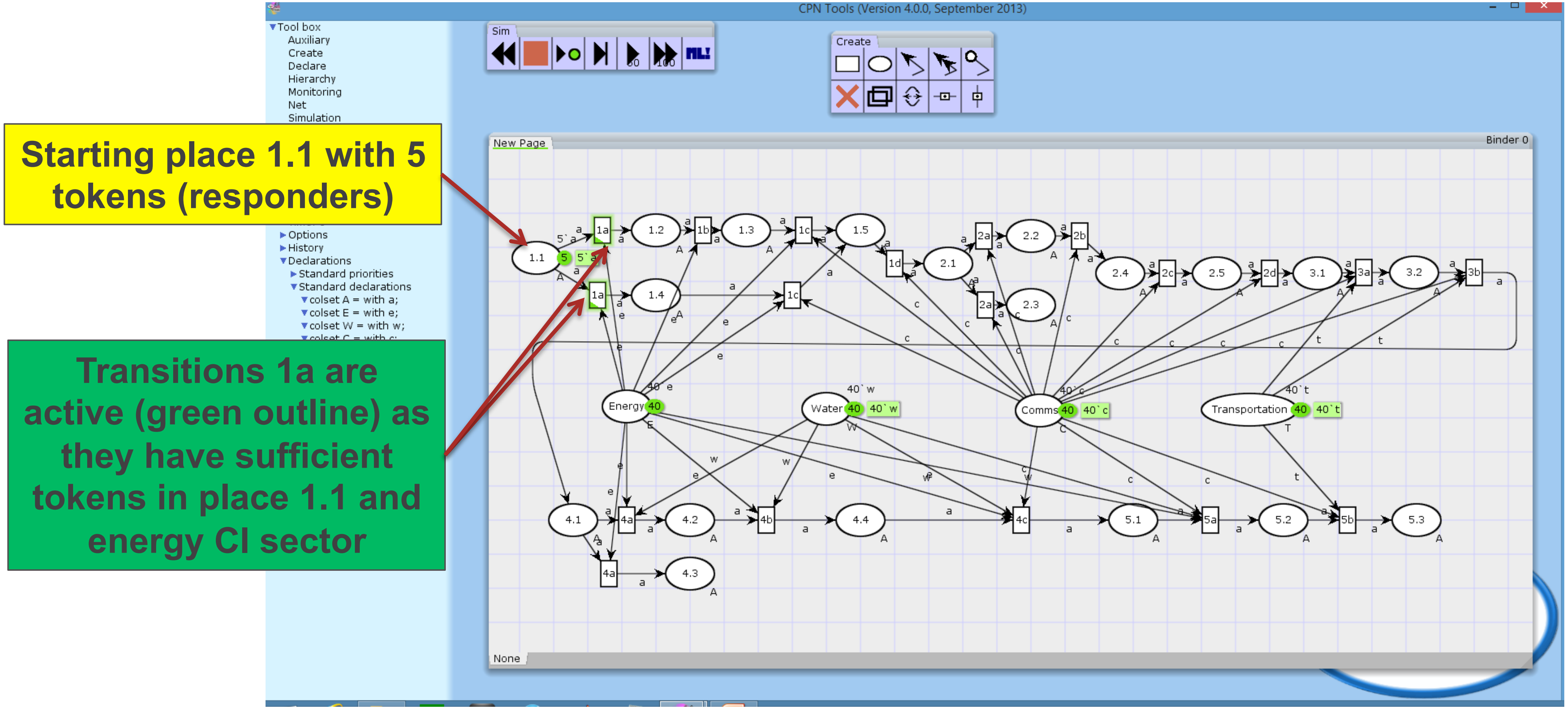


Run Execution

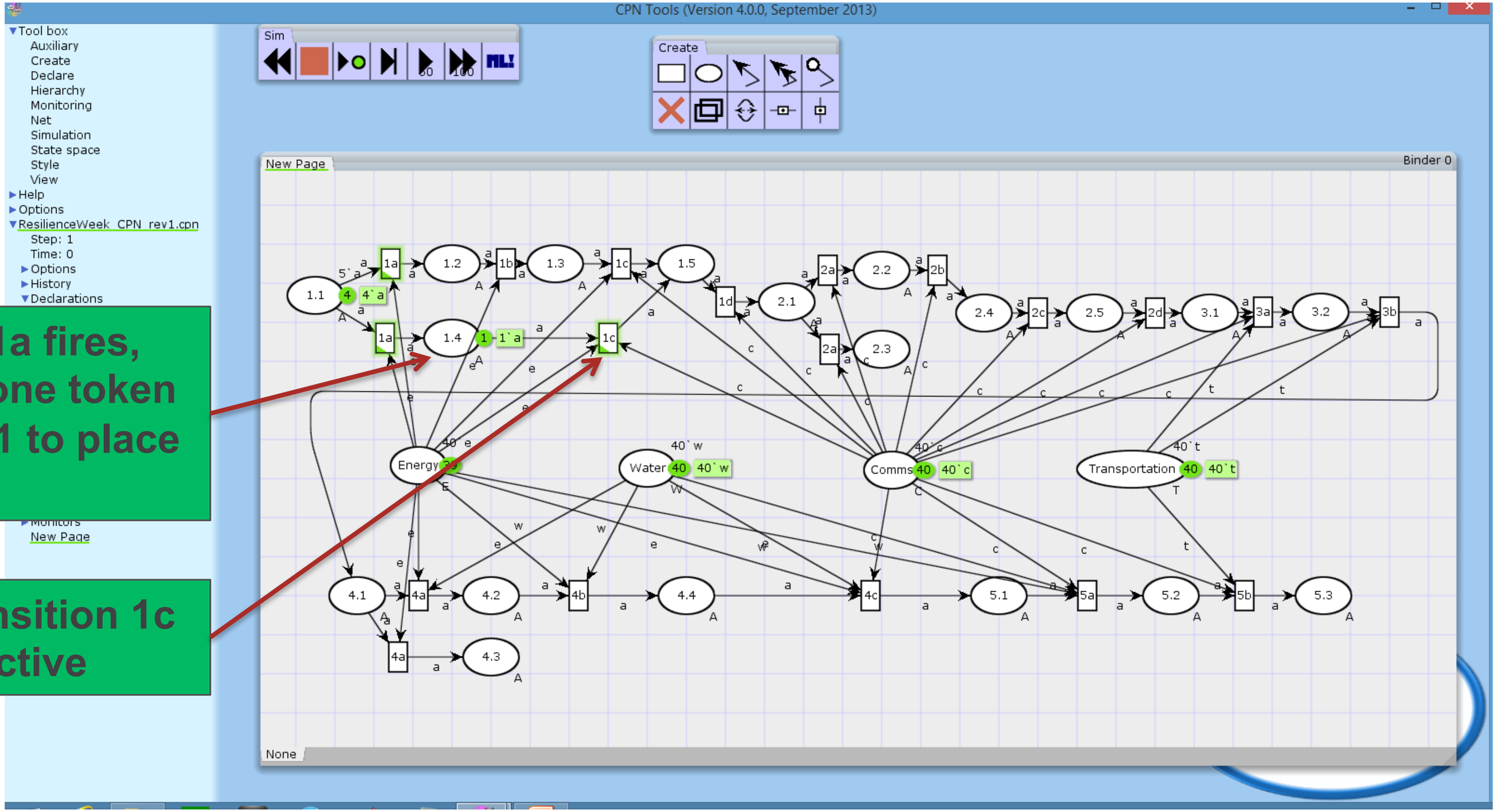
- The CPN tool is run to evaluate the level of EM mission accomplishment
- For a CPN, there are several areas where a stochastic element is introduced to select one of the two choices, in this case
  - Whether a EM responder is available or not (yes / no)
  - Whether a CI resource is available or not on scene (yes / no)
- The output is how many of the EM responders are able to complete their mission by successfully executing all of their functions



CPN Model in Action: Step 0



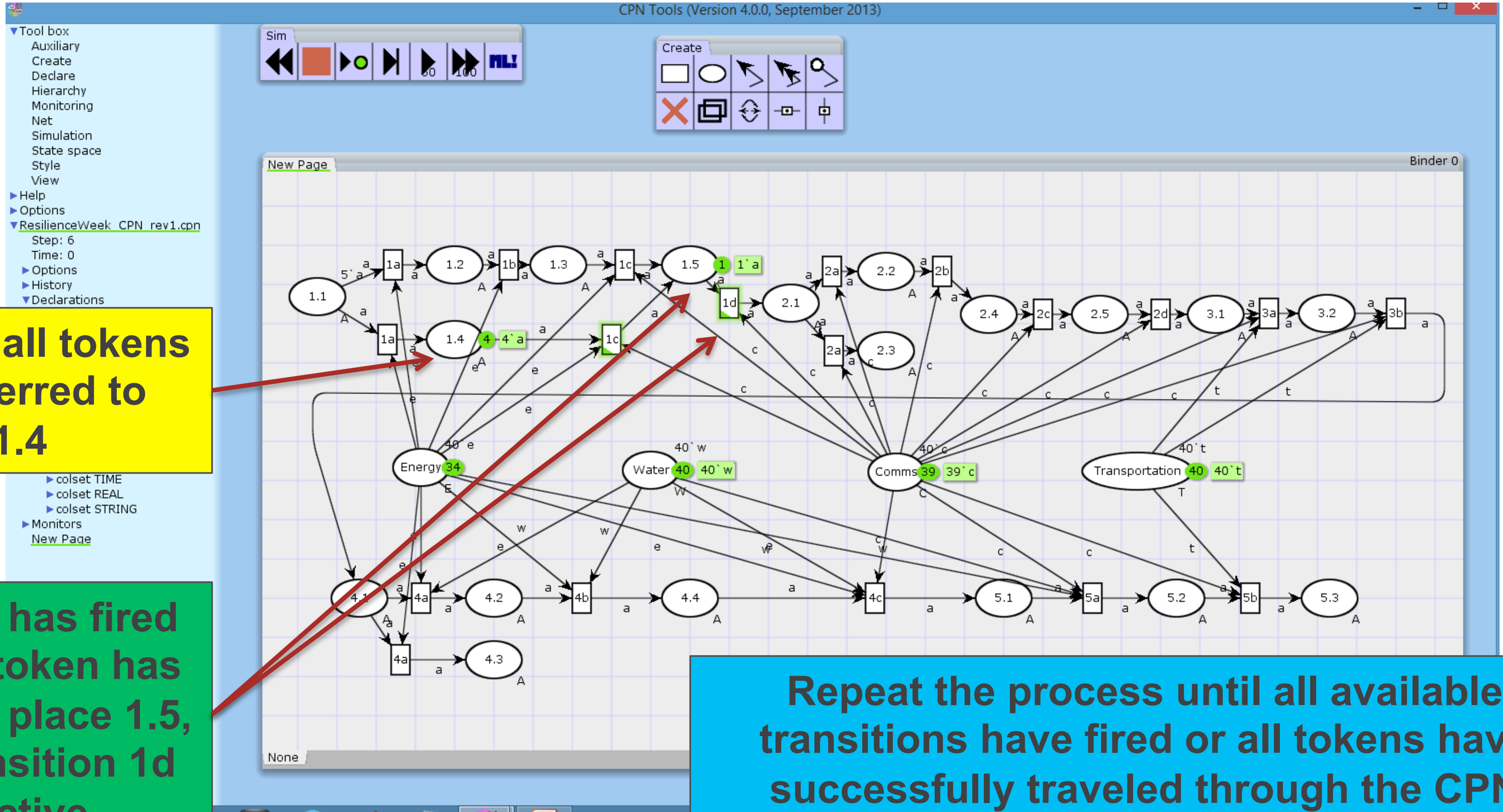
CPN Model in Action: Step 1



Transition 1a fires, transferring one token from place 1.1 to place 1.4

Note that transition 1c is now active

CPN Model in Action: Step 6



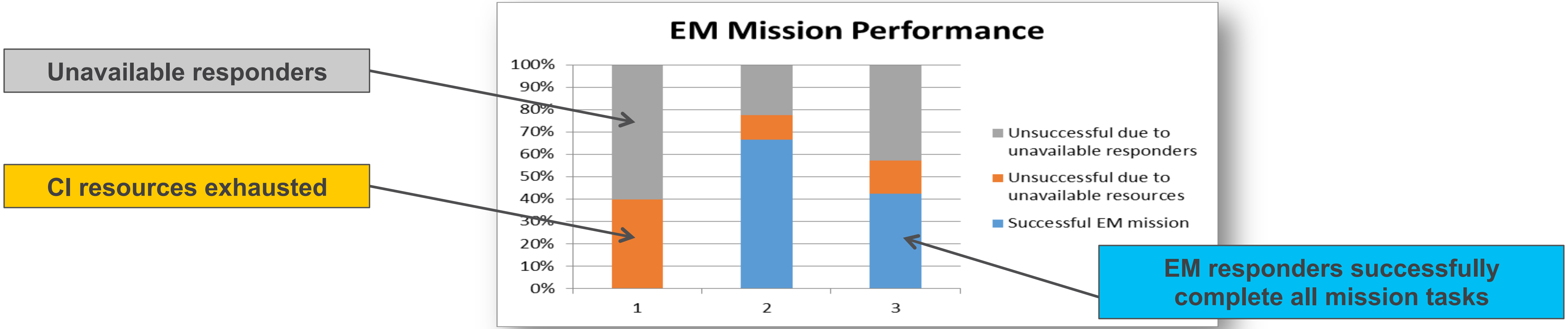
After 6 steps, all tokens have transferred to place 1.4

Transition 1c has fired and has one token has transferred to place 1.5, note that transition 1d is now active

Repeat the process until all available transitions have fired or all tokens have successfully traveled through the CPN

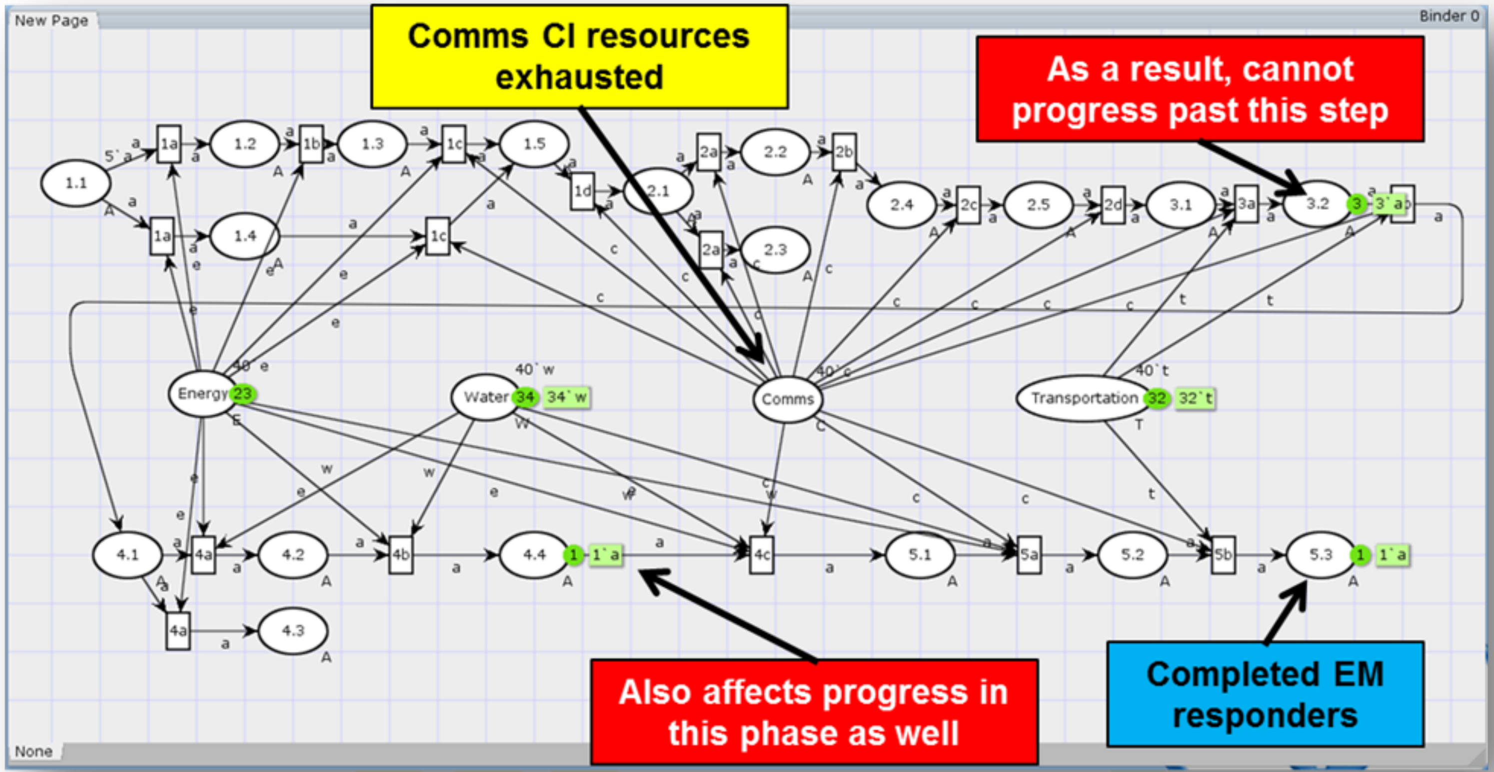
Results Interpretation

- We may execute the model numerous times to evaluate how well the functions are executed, how many unavailable responders and CI resources will affect the EM mission
- As more missions are successfully completed, the energy and communications sectors are used more in the latter phases of the mission
- Transportation is used when responders are more available to transit to the scene
- Water is used when the CI resources are available at the incident



Results Interpretation

- An example of where the EM mission is successful and where it stalls



Results Interpretation

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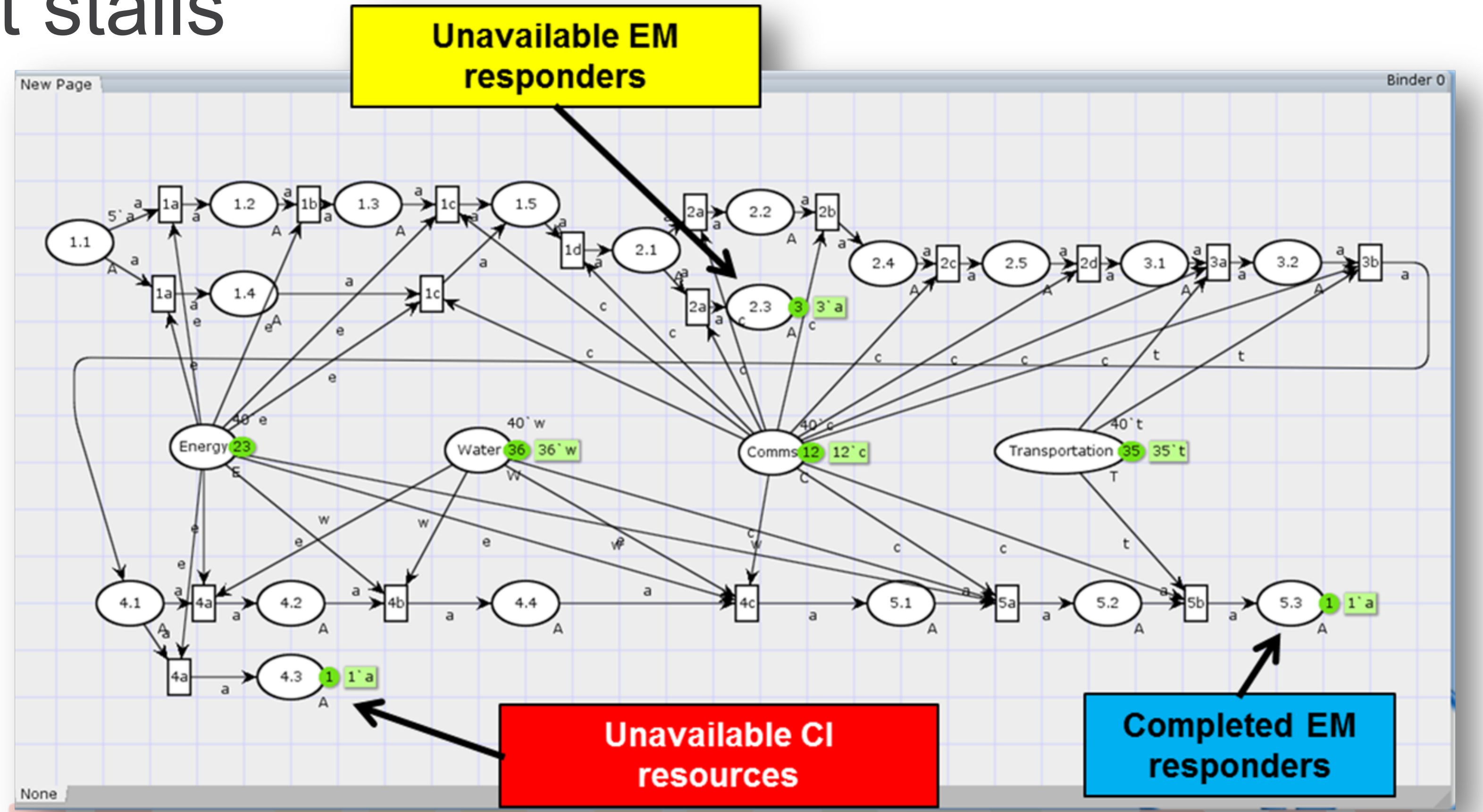
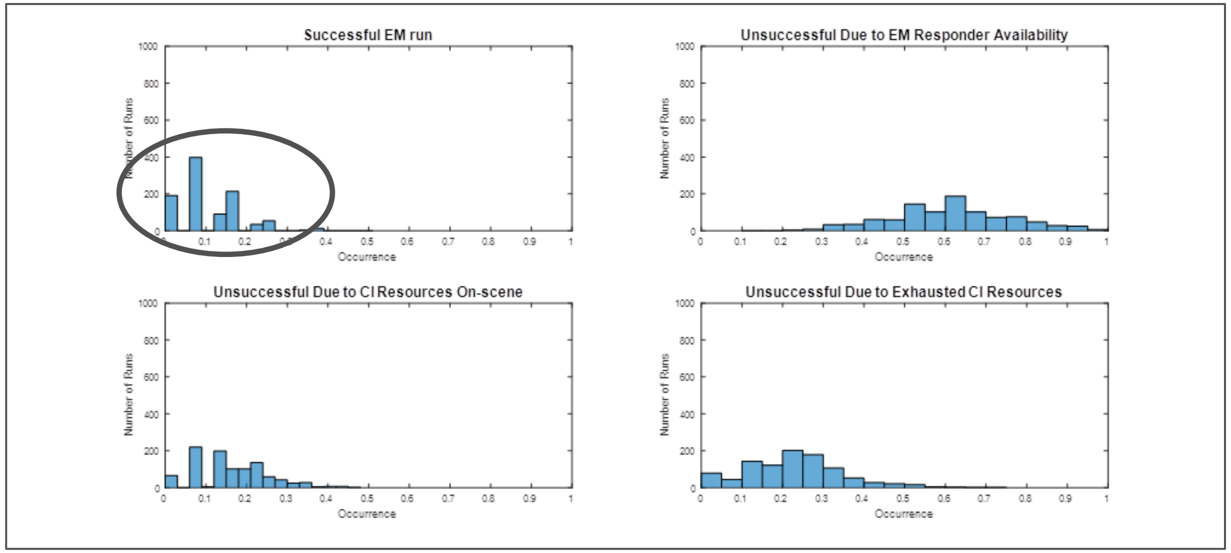


Example Analysis

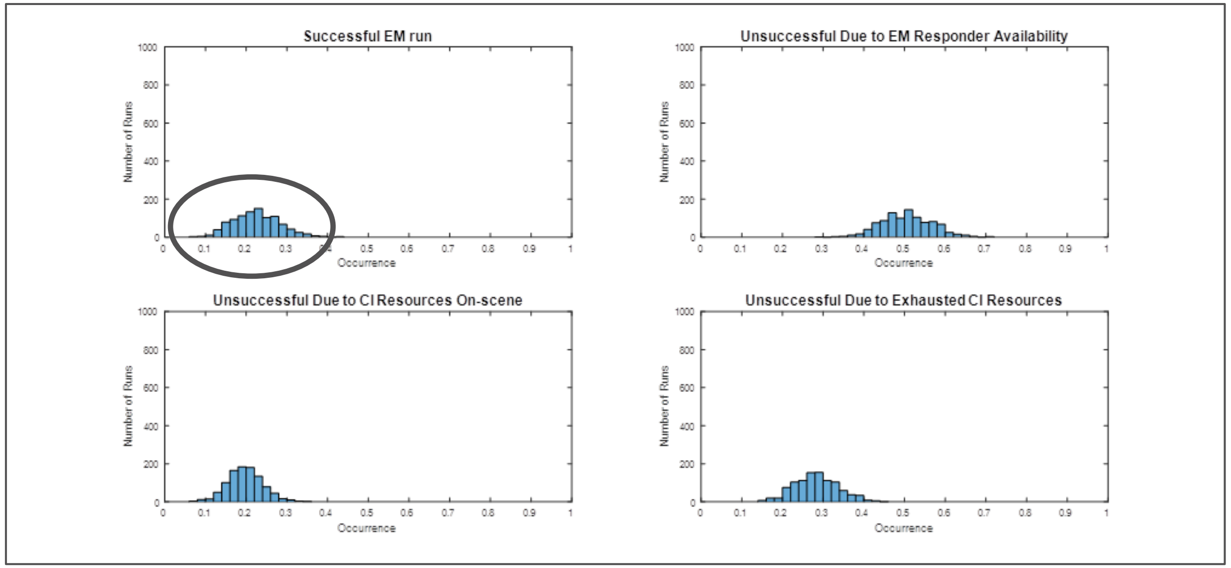
- We exercise this methodology and model for the EM mission
- The responder & resource availability was parametrically altered as well as the CI resources at the start of the run
- Two examples are shown – these are 1000 runs each to show the distributions of the successful or unsuccessful EM mission, and the causes of the unsuccessful runs

Example Analysis

Low decision percentage, low CI resource allocation



High decision percentage, high CI resource allocation



Advantages of the higher decision percentage and resource allocation shows a closer dispersion and higher frequency of successful runs

Next Steps

- We have developed a methodology to convert the functional architecture into an executable model
- By exercising the model with various inputs, we may show where the functional steps succeed and fail dependent on the amount of resources allocated to each of the functions
- By executing a fairly simplistic run matrix, we may also draw some conclusions on the importance of selected CI sectors to the functions
- Next steps would be to validate this model by varying the level of resources in the CI sectors and compare model results with EM responder results
- Once validated, extend this model to represent neighborhoods in greater detail from this top-level functional flow
- Further research may incorporate a series of more complex and interdependent mission sets

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