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Exposing and Controlling Emergent Behaviors in a System of Systems (SoS) Model

An Overview for the INCOSE North Texas Chapter

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Last Year...

February 18, 2018

- Introduced this audience to Monterey Phoenix (MP), a Navy-developed lightweight formal methods framework for behavior modeling

- Presented use cases for MP, in particular detecting, classifying, predicting and controlling emergent behaviors

- Presented examples of both expected and unexpected emergent behaviors arising from three different MP models

Tonight's Agenda

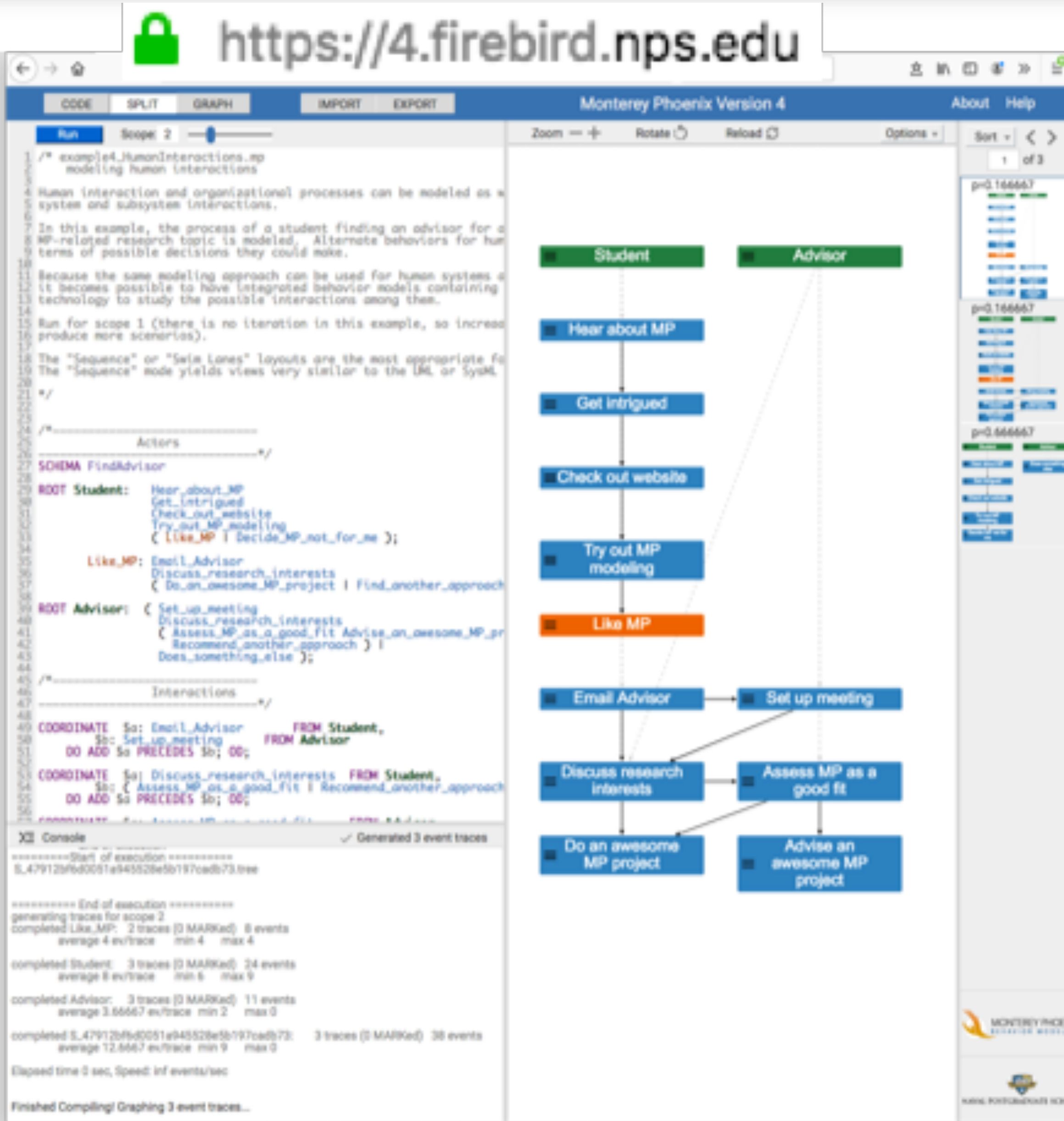
- Provide motivation & MP overview
- Show how to segment and extend a SysML activity model for emergent behavior analysis using MP
- Present, discuss and analyze examples of emergent behaviors found in the extended model
- Show how emergent behaviors may be classified as weak, strong, positive or negative.
- Conclude with some key takeaways and future work

Motivation

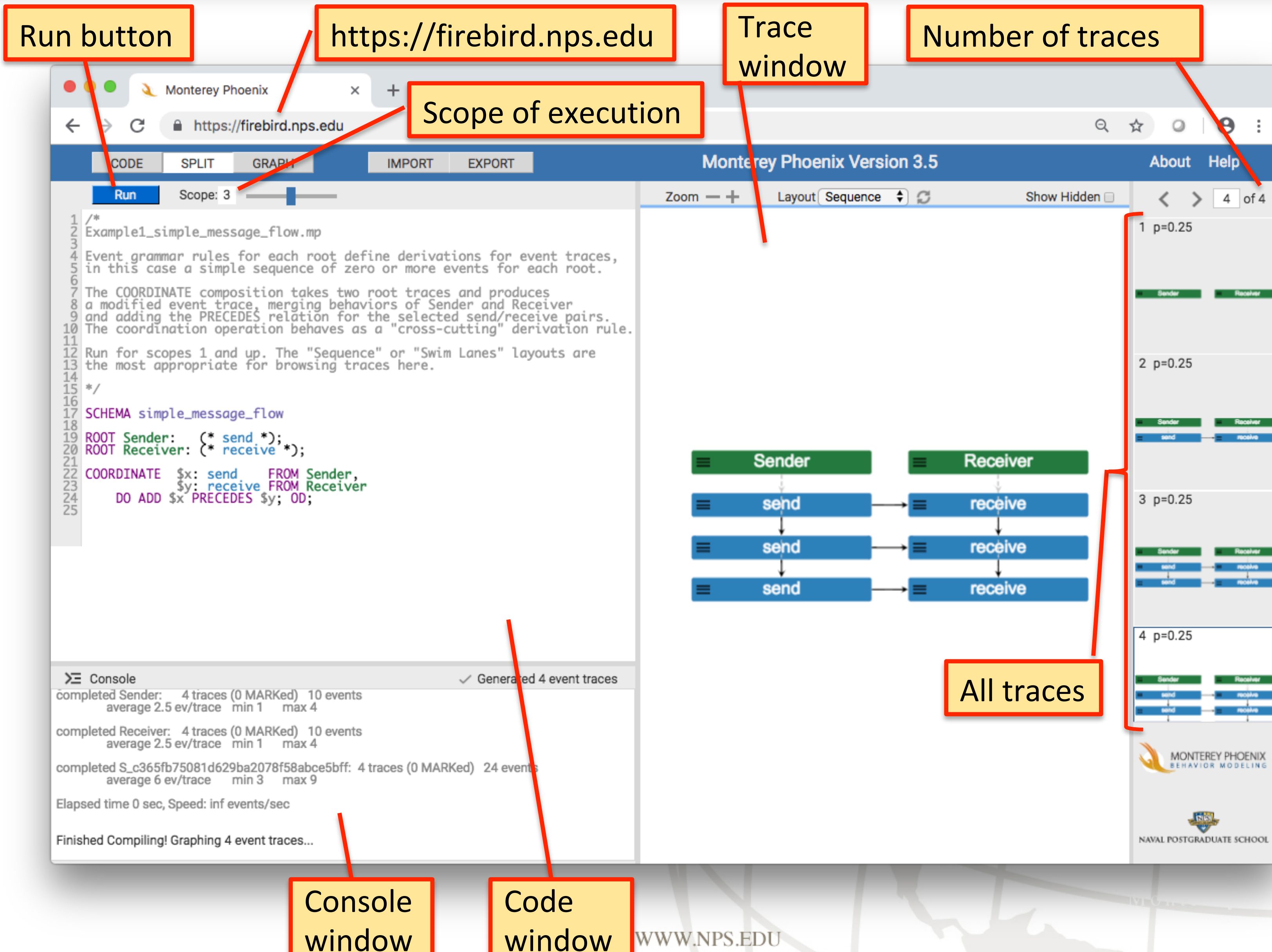
- SysML models are being developed in the Navy as, among other things, a basis for proposals from solution developers
- SysML models that are incomplete / incorrect could lead to requirements errors
- Complex system designs may permit “extra” unwanted system behaviors – how to we predict / expose these?
- This research developed methods and tools to help steer and shape behavioral design
  - to meet requirements (verification)
  - to meet expectations (validation)

What is Monterey Phoenix?

- Navy-developed lightweight formal methods framework for modeling human, technology, and environment behaviors
- *Behavior* is defined as a set of events with two basic relations: precedence and inclusion
- Generates sets of behavior scenarios that are exhaustive up to a user-defined scope (number of iterations)



MP-Firebird Layout



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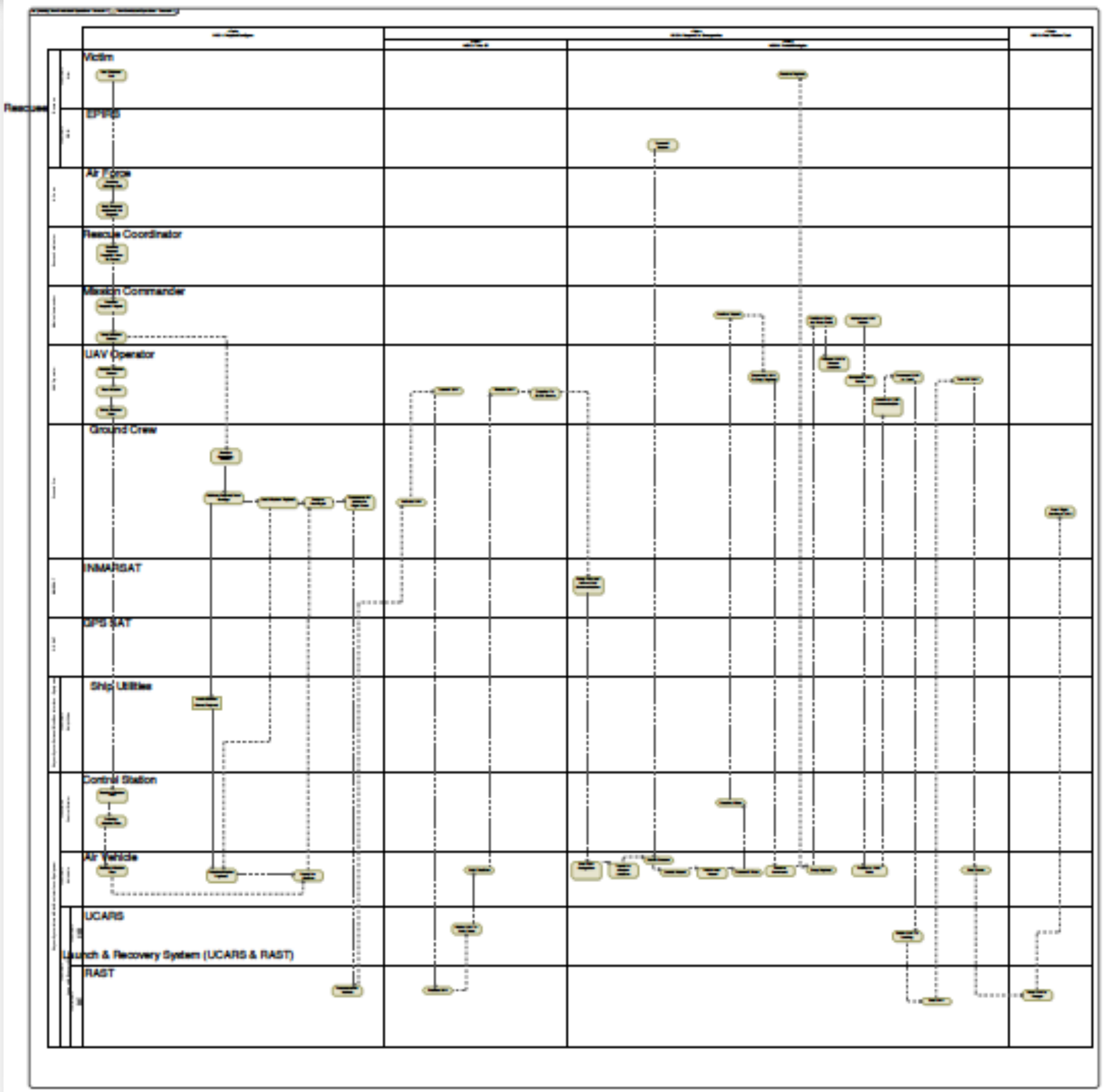
NAVAIR Systems Engineering Transformation (SET) Skyzer Model

Non-Combat Operations Scenario 1

- Fourteen (14) Actors / Swim Lanes
- Four (4) Phases
- Fifty-four (54) activities
- Zero (0) alternative behaviors
  - shows baseline desired scenario



Model V&V with MP

- Convert SysML model into MP model
- Segment the model into phases
- Elaborate each phase model with alternatives
- Generate exhaustive set of traces for each phase
- Inspect for incorrect or unintended behaviors

Convert SysML activity model into logically equivalent MP model

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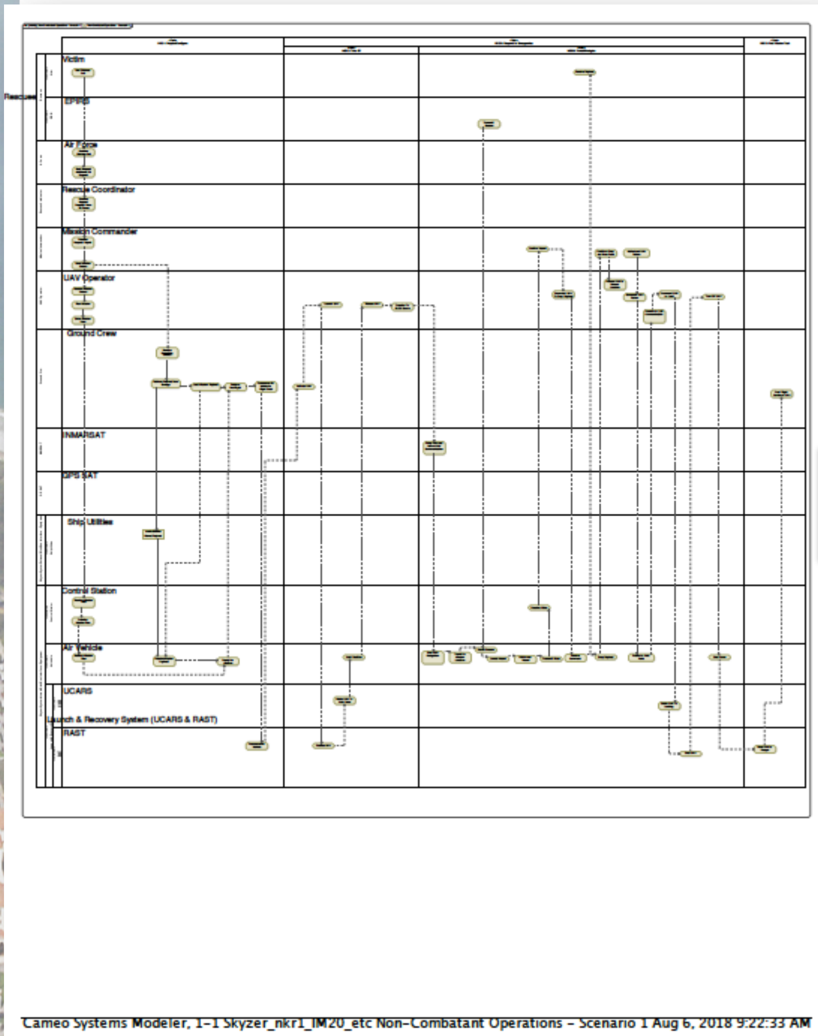
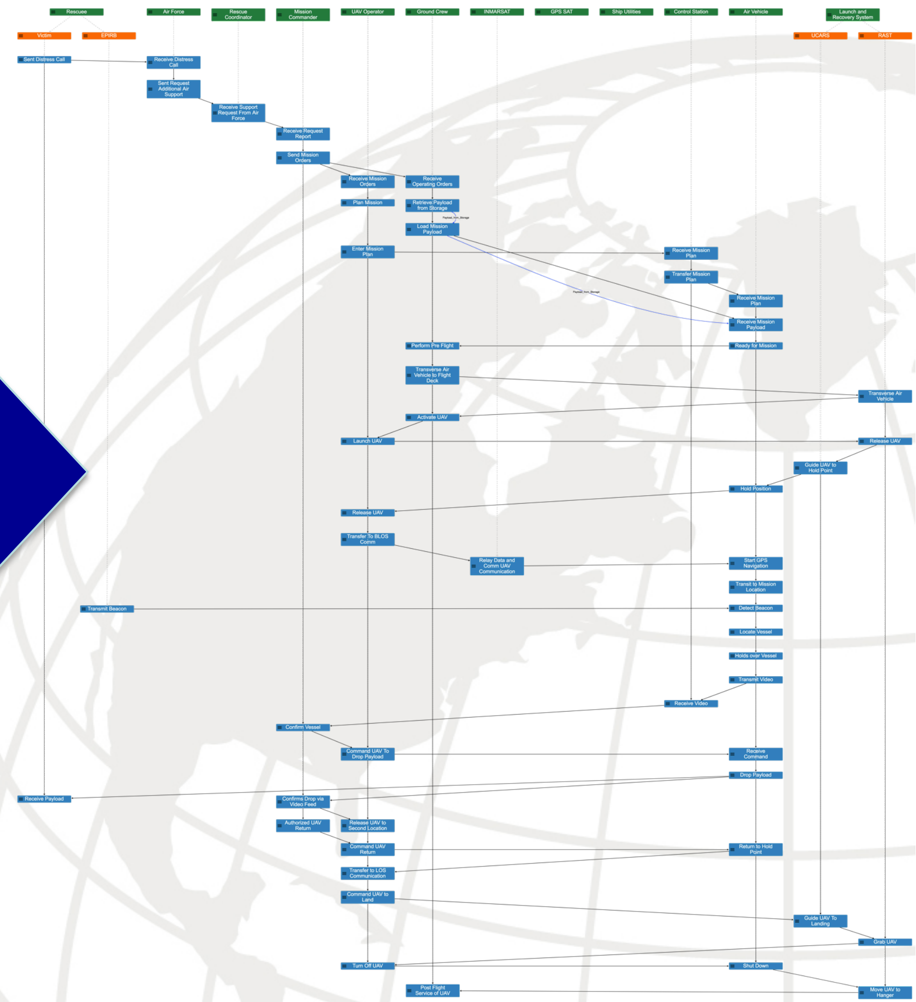
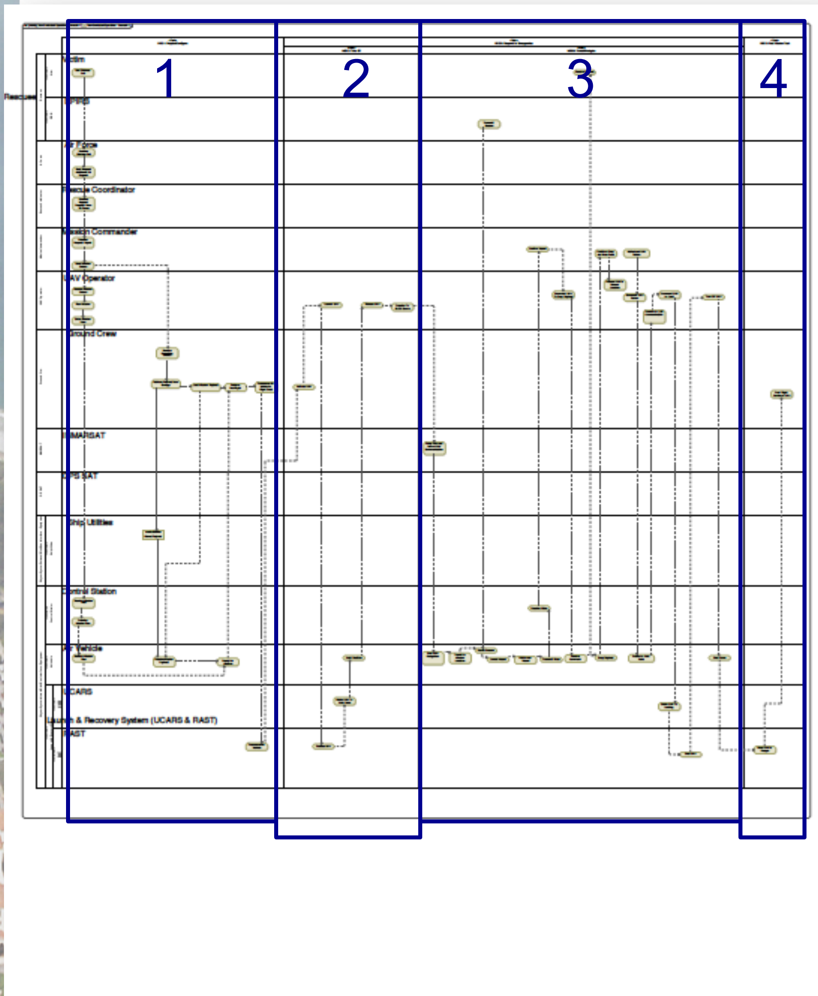
Non-Combat Operations Scenario 1



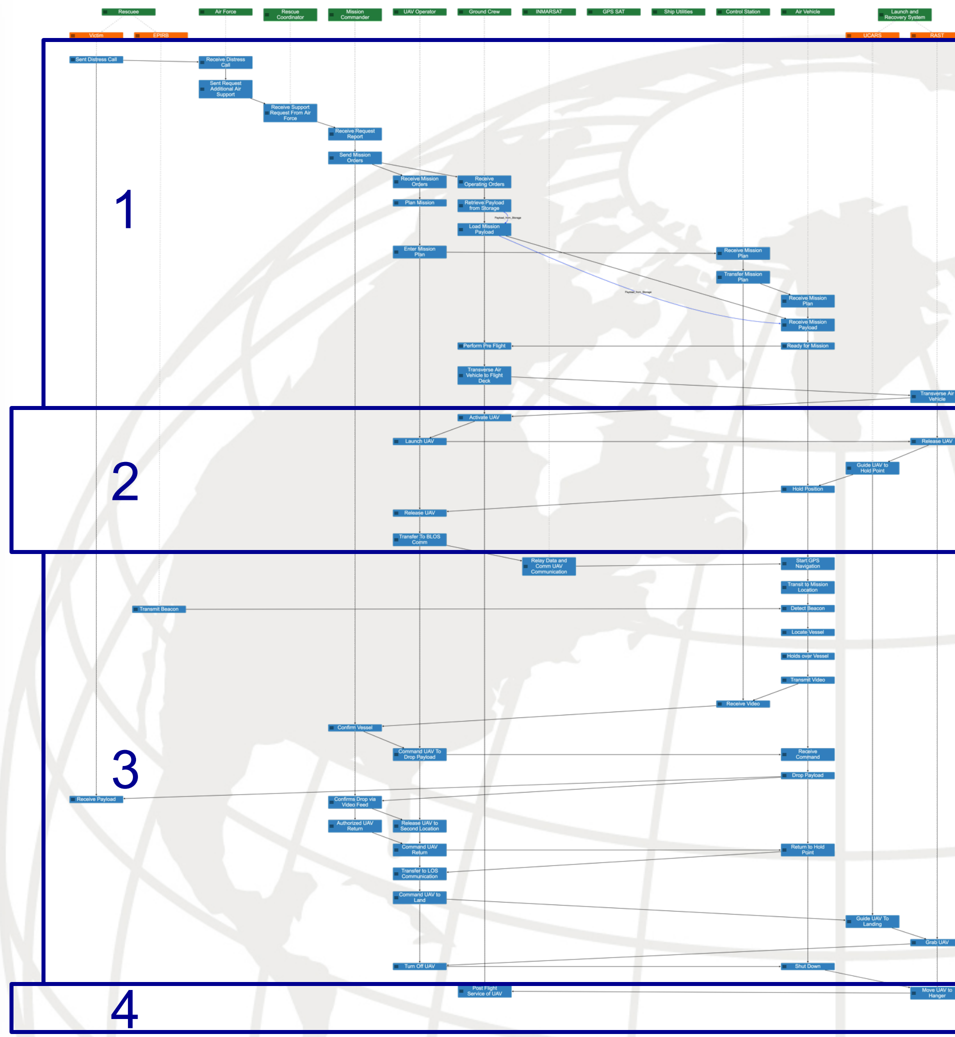


Segment the model into phases

Non-Combat Operations Scenario 1



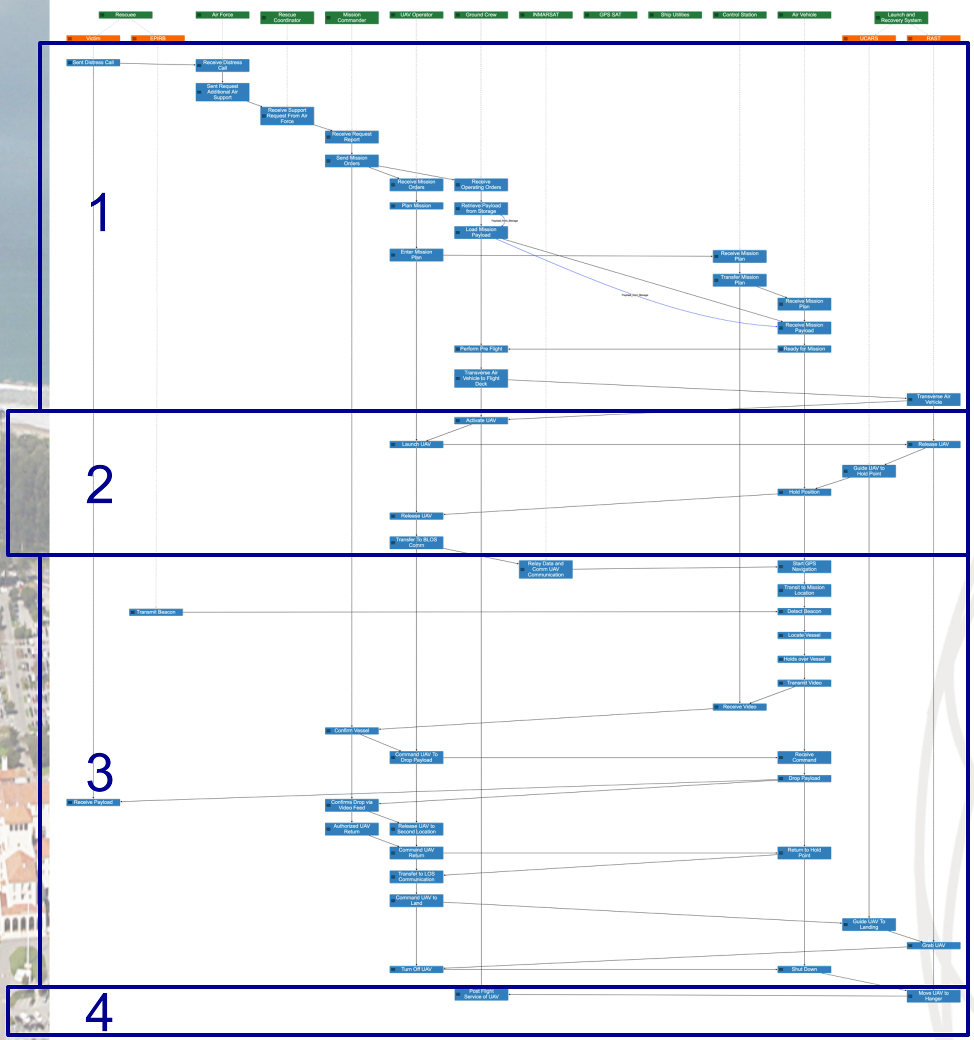
Cameo Systems Modeler, 1-1 Skyzer_nkr1_IM20_etc Non-Combatant Operations - Scenario 1 Aug 6, 2018 9:22:33 AM



Elaborate each phase model with alternatives & generate scenarios

1 scenario

Non-Combat Operations Scenario 1



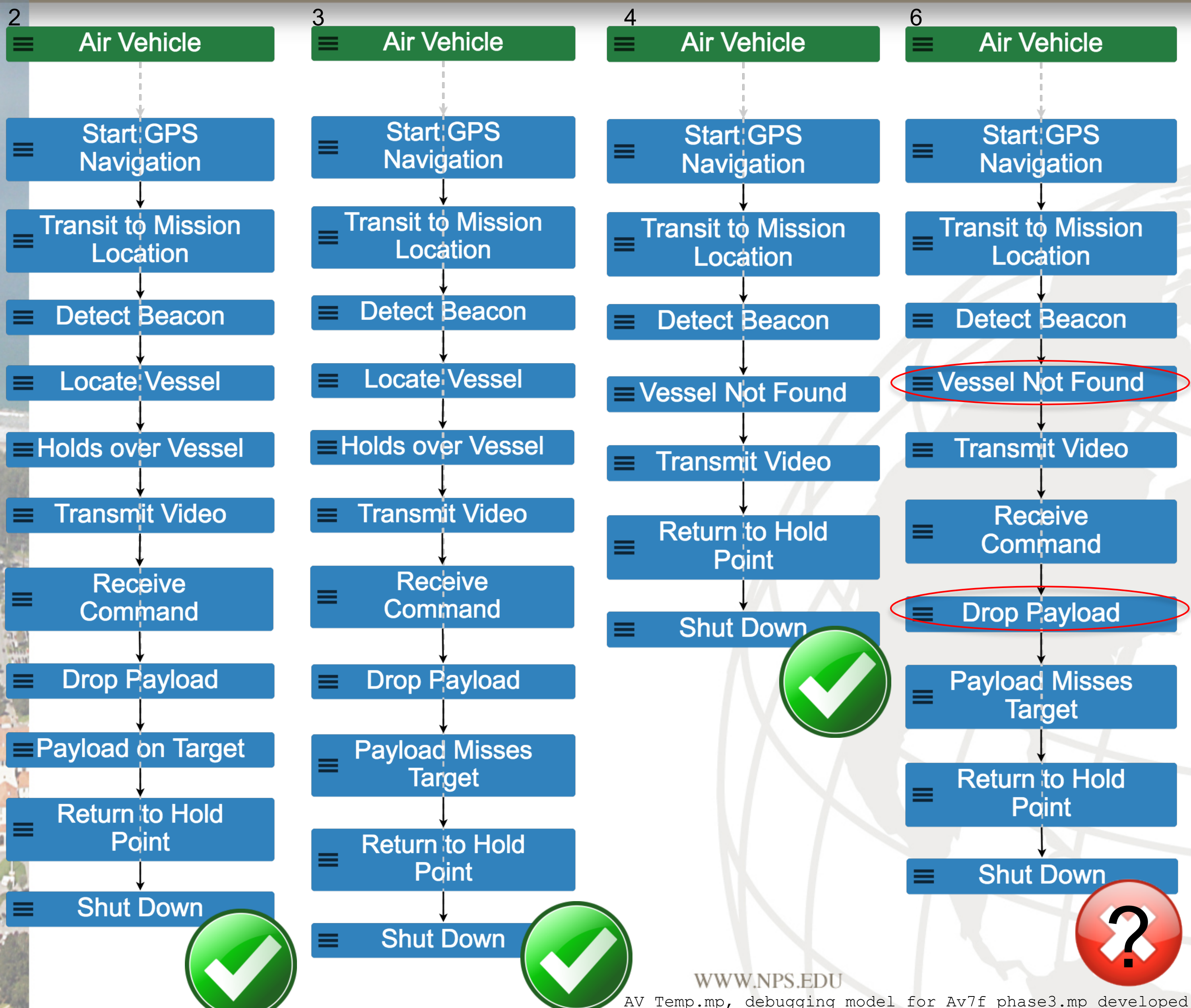
Phase 1 – Prepare/Configure → Phase 1 scenarios

Phase 2 – Take Off → Phase 2 scenarios

Phase 3 – Transit/Navigate → Phase 3 scenarios

Phase 4 – Post Mission Task → Phase 4 scenarios

Inspect for incorrect or unintended behaviors



Phase 3

Far left: Baseline scenario; vessel located and payload on target.

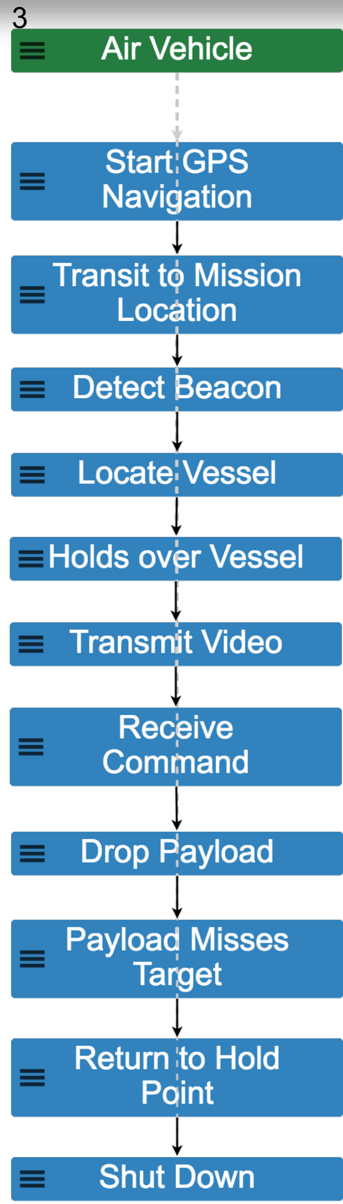
Middle left: Vessel located but payload missed target.

Middle right: AV needs to return before vessel is located.

Far right: Vessel not found but AV drops payload.

AV_Temp.mp, debugging model for Av7f_phase3.mp developed by D. Shifflett 8/21/2018

Inspect for incorrect or unintended behaviors



Phase 3
Vessel located but payload missed target.

What should happen if the payload just misses the target?

Could the payload still be retrieved by target vessel?

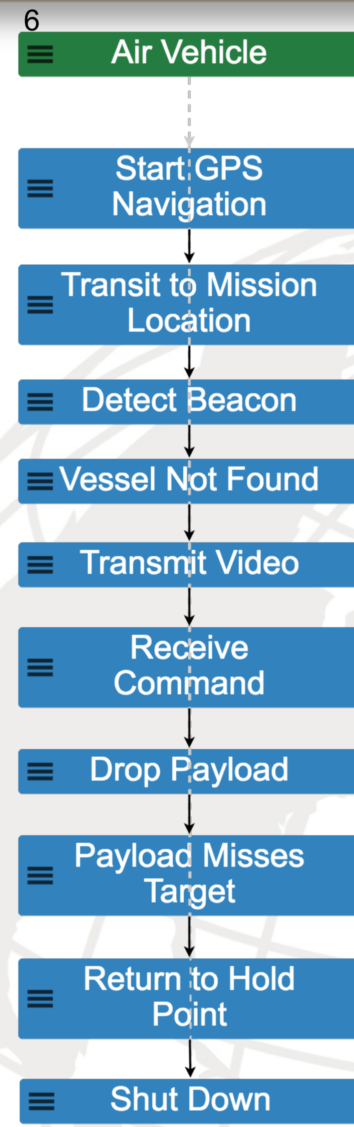
AV_Temp.mp, debugging model for Av7f_phase3.mp developed by D. Shifflett 8/21/2018

Inspect for incorrect or unintended behaviors

Could this scenario really happen?

Under what circumstances might this be negative behavior or positive behavior?

Though unintended, does trace 6 contain an idea for handling out of range vessels or AVs experiencing a return to base condition?



Phase 3
Vessel not found but AV drops payload.

AV_Temp.mp, debugging model for Av7f_phase3.mp developed by D. Shifflett 8/21/2018

General Analysis of Emergent Behaviors

Detection: Initial discovery of emergent behavior.

Classification:

- **Simple:** derived from element properties and relationships in non-complex or 'ordered' systems [5].
- **Weak:** desired (or at least allowed) emergence produced by a complex system [5].
- **Strong:** unexpected emergence not observed until simulation, testing, or operations [6].

Prediction: Postulation of potential future states of emergence based on detected behaviors.

Control: Management of positive or negative emergent behaviors through M&S or other analysis.

Definition set paraphrased from [4]

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Example Analysis of Emergent Behaviors with MP

Trace	Detected Behavior	Predicted Behavior	Classification	Control Strategy
2	Vessel located and payload on target.	Mission success - The payload meets the target and the patient is able to use the medication.	Weak Positive Emergence	Valid possible outcome (baseline scenario). Clarify the assumed outcome that the patient is able to use the medication.
3	Vessel located but payload missed target.	Mission failure - The payload misses the target and the patient falls into a diabetic coma.	Weak Negative Emergence	Valid possible outcome. Clarify the assumed outcome that the patient falls into a diabetic coma.
4	AV needs to return before vessel is located.	Mission failure - The AV detects the emergency beacon, but has to return before it can locate the vessel.	Weak Negative Emergence	Valid possible outcome. No further control recommended.
6	Vessel not found but AV drops payload anyway.	Mission failure - The payload is dropped into the ocean without knowing the location of the vessel. Either the system experienced a malfunction, or the command to drop the payload was sent too soon.	Strong Negative Emergence	Add new event `System_malfunction` as alternative to `Receive_command` in Air Vehicle root event. Downgrade to Weak Negative Emergence.
		Mission success - The payload is intentionally dropped without video on the vessel and it is ultimately received by the vessel. The AV Operator may know from another source (such as the beacon) that the vessel is close by, or the payload may be equipped to close the remaining distance so that the AV has the range necessary for its return trip.	Strong Positive Emergence	Add new events to the model to clarify the specifics, assumed outcome, and associated new requirements. Downgrade to Weak Positive Emergence.

Take Aways

- Operational “what ifs” were exposed through MP modeling of the provided baseline scenario.
- The MP model exposed some unexpected and unwanted behaviors, leading to discovery of requirements.
- MP modeling of SysML behavior diagrams can help to expose requirements that may otherwise not be considered until later in the lifecycle.

Future Work

- Automate model transformation between SysML and MP
  - MP version 4 can now generate many SysML -style diagrams
  - MP version 5 will synthesize MP models from a representative set of use cases
- Train model developers how to verify and validate contents of SysML models using MP

Questions?

RT-176 Reports and Models:
https://sercuarc.org/project/?id=35&project=Verification+and+Validation+%28V%26V%29+of+System+Behavior+Specifications

Monterey Phoenix and Related Work:
https://wiki.nps.edu/display/mp
https://4.firebird.nps.edu

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