The System Modeling and Analysis of Resiliency in STEReO (SMARt-STEReO)

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Motivation

➢ Wildfires increasing in size and number from 1984-2011 [2]

➢ Aerial Firefighting and suppression:
  ➢ Account for 26% of firefighter deaths from 2000-2013 [3]

➢ STEReO: Scalable Traffic for Emergency Response Operations
  ➢ Leverage new technology to improve safety and performance
Resilience: prevention, adaption, and recovery

Existing Models: BehavePlus, FARSITE, DEVS-FIRE, etc.

SMARt-STEReO Model: integrated fire propagation and suppression model, allows for resilience analysis and inclusion of emerging operations, such as UAS
Present Day Wildfire Response:

- **Airplanes** – airtankers, aerial supervisor, surveillance
- **Helicopters** – surveillance, drops, delivery
- **Engines** – direct attack, dust abatement, refills
- **Dozers** – fire line construction
- **Ground Crews** – fire line construction
- **Comms** – radio, line-of-sight

Emerging Fire Fighting: STEReO

- Improve operator decision making through improved data relay
- Replace high-risk tasks with autonomous systems
- Integrate UAS into an existing system
- Reduce aerial supervisor load
- An efficient, resilient system for emergency response
- Higher-bandwidth communications platform
Model Development: Outputs

Fire progression at $t=0$
Model Development: Outputs

Dynamic Response of ['GC1status'] to fault Critical tool breaking

- **GC1status: x**
- **GC1status: y**
- **GC1status: mode**
- **GC1status: fatigue**
- **GC1status: supplies**
- **GC1status: injury**

Legend:
- **faulty**
- **nominal**
Model Development: Outputs

Fire Metrics

- Total percent on fire
- Total percent burned
- Percent edges burned
- Percent edges on fire

Percentage

Time

0 10 20 30 40 50

0.0 0.1 0.2 0.3 0.4 0.5
Research Questions: Q1-Q3

➢ Q1. What is the appropriate scope of applications that the model is currently verified and valid for?

➢ Q2.
  ➢ a) Is there a difference in performance, in terms of metrics such as acres burned, when UAS is added into wildfire response?
  ➢ b) If so, is this difference apparent in both nominal and off-nominal conditions?

➢ Q3.
  ➢ a) Does the addition of UAS in wildfire response increase resilience in the system in response to an individual fault?
  ➢ b) If so, what is the effect size?
Verification and Validation Efforts: Q1

- Fire propagation:
  - Windspeed, slope

- Suppression Verification
  - State awareness, rate of fire line construction, rate of injury, assets
Experimental Analysis: Set-up

- Monte Carlo simulation for 2,000 grids with random fuel distribution
- Injection of 2 separate faults at t=20:
  - Major: major mechanical failure to aerial supervisor
  - Minor: critical tool breaking for ground crew
- Performance measured in acres burned
- Resilience:
  \[
  \text{Nominal}_{\text{acres burned}} - \text{Faulty}_{\text{acres burned}}
  \]
Q2: Is there a difference in performance when UAS is added?

➢ Major fault:
  ➢ Fault → more acres burned compared to nominal ($F = 1538.7; P < 0.001^{***}$)
  ➢ UAS → fewer acres burned compared to baseline ($F = 170.8; P < 0.001^{***}$)
  ➢ UAS + faulty or nominal → fewer acres burned ($F = 39.9; P < 0.001^{***}$)
Q2: Is there a difference in performance when UAS is added?

- **Minor Fault**
  - Fault → no significant difference in acres burned compared to nominal (F=0.1116; P=0.733)
  - UAS → fewer acres burned compared to baseline (F = 117.7; P < 0.001***)
  - UAS + faulty or nominal → no significant difference in acres burned (F = 0.095; P=0.758)
Q3: Does the addition of UAS increase resilience?

- **Major fault:**
  - UAS → increased resilience
  - \( T = -6.315, p < 0.001^{***}, d = 0.183 \)

- **Minor fault:**
  - No significant difference
  - \( T = -0.309, p > 0.05, \text{Cohen's } d = 0.010 \)
Discussion

➢ Q1: model is sufficient for these experiments
➢ Q2: Performance gains from UAS; etc., generalize over fault scenarios
➢ Q3: Resilience gains from UAS depend on the severity of the fault injected.
Conclusions and Future Work

➢ Developed integrated model of fire propagation and response with ability to simulate:
  ➢ Performance of operational concepts under a wide range of scenarios
  ➢ Performance of operational concepts under faults for resilience quantification

➢ Limitations and Future Work:
  ➢ Ongoing verification and validation efforts
  ➢ Model improvements
  ➢ Different types of resiliency analysis
  ➢ Adaptive stress testing
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 Additional Resources:
- SMARt-STEReO ConOps: https://ntrs.nasa.gov/citations/20205007665
- SMARt-STEReO Model Description: https://ntrs.nasa.gov/citations/20205007481
- Fmdtools: https://github.com/DesignEngrLab/fmdtools
- Robust Software Engineering: https://ti.arc.nasa.gov/tech/rse/

