Statement of Work:
A Gap Analysis of Wildland Fire Response Resources in the United States

1. Theme Areas: Risk Analysis; Economic Consequences and Costs
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5. Research Transition Lead: Dr. Hugh Medal
6. Keywords: economic impact, pyro-terrorism, risk analysis, risk assessment, wildfires

7. Brief Description:
This project is the second-component of the FY15 CREATE project entitled “Pyro-terrorism risk assessment and Management: A Pilot Study,” which was given development funding. The goal of this pilot study was to determine if there was evidence that pyro-terrorism is a risk deserving of further study. Thus far, we have found that 1) several pieces of evidence indicate that the likelihood of pyro-terrorism in the United States is non-negligible, and 2) the intentional setting of multiple wildfires simultaneously can have a much larger impact than a single wildfire (see the attached progress report for more details). Our work also brought us into contact with the research of Randy Wilson at the Mississippi Forestry Commission, which demonstrates that 1) several factors indicate pyro-terrorism is a real possibility, and 2) a coordinated pyro-terrorism attack could overwhelm emergency response resources. Due to the evidence that pyro-terrorism is an important risk, we propose to expand upon our original risk assessment by performing a quantitative gap analysis of fire suppression risk. This gap analysis will help analyze the risk of both pyro-terrorism and conventional wildland fires.

8. Research Objectives:
This research will perform a quantitative gap analysis of wildland fire in the United States via two main objectives:
1. Determine wildland response capacity and needs in the United States. We will expand upon our initial vulnerability assessment implemented in FY15 (“Pyro-terrorism risk assessment and Management: A Pilot Study”) by performing a capacity assessment and analyzing whether or not in-place wildfire suppression resources are adequate to respond to a coordinated pyro-terrorism attack.
2. Use mathematical programming to analyze the relationship between suppression capacity and landscape vulnerability. The models for our initial consequence assessment in our FY15 project did not account for the fact that firefighters may have to ration manpower and resources when responding to multiple simultaneous wildfires. In addition, a fire manager may not be able to distinguish between a natural wildfire and a coordinated pyro-terrorism attack, especially in the early stages. Thus, we will incorporate resource rationing into our consequence assessment models. These improvements of our models will help us provide a more accurate assessment of the consequences of a pyro-terrorism attack.

9. Research Transition Objectives
The end goal of this follow-on study is to produce a capacity gap analysis that can be directly used by DHS. Specifically, the Strategy, Planning, Analysis, and Risk (SPAR) group within DHS has a need for a quantitative risk assessment of both pyro-terrorism and naturally-occurring wildland fires. Thus, working closely with SPAR we will produce a gap analysis of fire response resources that is immediately usable by DHS. In addition, we will also produce a mathematical optimization tool that can measure the vulnerability of a given fire region.
10. Major Deliverables, Research Transition Products and Customers:

Project research deliverables will consist of a report and research publications that will document: i) local capacity available to respond to pyro-terrorism attacks, and ii) the difference in wildfire spread between a pyro-terrorism attack and a wildfire-induced without terroristic intentions.

Research transition deliverables will consist of fact sheets summarizing our gap analysis, which will be distributed to DHS as well as fire-specific agencies such as the U.S. Fire Administration. The main customer for this product will be DHS-SPAR.

The proposed research will fill a gap in knowledge about the gap between available and needed wildland fire suppression resources in the United States. It will also provide new optimization models for assessing the consequence of a pyro-terrorism attack.

11. Technical Approach:
We will perform a quantitative risk assessment of wildfire terrorism, which will involve improving the accuracy of our pilot consequence assessment.

**Determine wildland suppression capacity and needs in the United States**

**Assessment of existing fire response capacity:** We will perform a capacity assessment for one state in each of the ten regions defined by the U.S. Forest Service. First, we will obtain data on how many fire crews are in each county/district. We will then estimate the manpower required to effectively respond to a pyro-terrorism attack or naturally-occurring fire. The difference between capacity and required resources will indicate the level of vulnerability in each county and state. We will also use this data as an input to our fire resource dispatch model (see below).

**Survey of needed fire response resources:**

**Survey land managers to determine the wildland suppression capacity**

**Incorporate resource rationing into our consequence assessment models:** In Year 1 of our current CREATE research (FY15), we have developed a model that estimates the damage due to a fire. In this model, the response to the fire is modeled using a fire duration function, under which the fire is more likely to be extinguished (either by natural causes or fire suppression crews) as the fire lasts longer. Thus, we model the fire response only implicitly.

In the proposed project we will *explicitly* model fire response. Many have studied the fire resource dispatch problem, in which a fire manager must decide how to allocate resources to one or more fires (e.g., Haight and Fried, 2007). However, all of these studies assume that fires occur according to a random process. As a pyro-terrorism event, this is likely not the case. Thus, we will extend the fire resource dispatch problem for worst-case fires caused by a coordinated terrorist attack. In addition, we will also use this extended model for naturally-occurring fires.

Our extended model will be formulated as a bi-level mixed-integer linear program. In the outer level, the terrorist decides where to ignite fires. In the inner level a fire manager decides how to dispatch resources in order to suppress the fires, minimizing the number of escaped fires. The capacity information gathered in the previous task (see above) will be an input to our model. We will model the landscape as a network grid (see
Figure 1). This network representation will allow us to use efficient network optimization techniques when solving our optimization model.

![Network Diagram]

Figure Error! No sequence specified.: A network grid is used to model the spread of fire over a landscape. The landscape is divided into cells, and the midpoints of the cells are represented as nodes. The weight on the arcs represents the time for a fire to travel from the arc's tail node to its head node.

We will also use our model to estimate the relationship between fire response capacity and fire spread for naturally-occurring fires. In this case, we will examine several fire ignition scenarios for each county/district and model the spread of fire using a spread model that includes the dispatching of resources.

These extended models will be used in a set of experiments to answer the following questions. (1) How much more quickly do pyro-terror attacks exhaust fire suppression resources than natural wildfires? (2) What is the best rule-of-thumb strategy for dispatching resources during a pyro-terrorism attack? (3) What is the relationship between fire response capacity and the rate of fire spread?

12. Major Milestones and Dates:

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<td>Capacity assessment</td>
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<td>Survey of current resources</td>
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<td>Develop research transition plan</td>
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13. References