



**NAVAL
POSTGRADUATE
SCHOOL**

MONTEREY, CALIFORNIA

CLASS PROJECT

**SMUGGLER INTERDICTION MODEL BASED ON TRAIL
NETWORK IN YOSEMITE NATIONAL PARK**

by

MAJ Edward Masotti, USA

Interdiction of smugglers or insurgents is a challenge that our military faces often. Smugglers can travel by motor vehicle, foot, horse, donkey, or other pack animal. Network modeling enables us to manage this. Yosemite National Park, with its extensive trail network and varying terrain, represents smuggling networks found in many regions of the world. We model a smuggler moving contraband items through a region, develop an interdiction plan of roadblocks and patrols, and calculate the cost to the smuggler with the interdiction plan in place.

To model our network as shown in Figure 1, we make the following assumptions. Roadblocks require sustained logistical support which limits their locations. They are ineffective around the smuggler friendly city and will only delay the smuggler. Patrols block any path and capture the smuggler if he travels across that arc.

Figure 1.

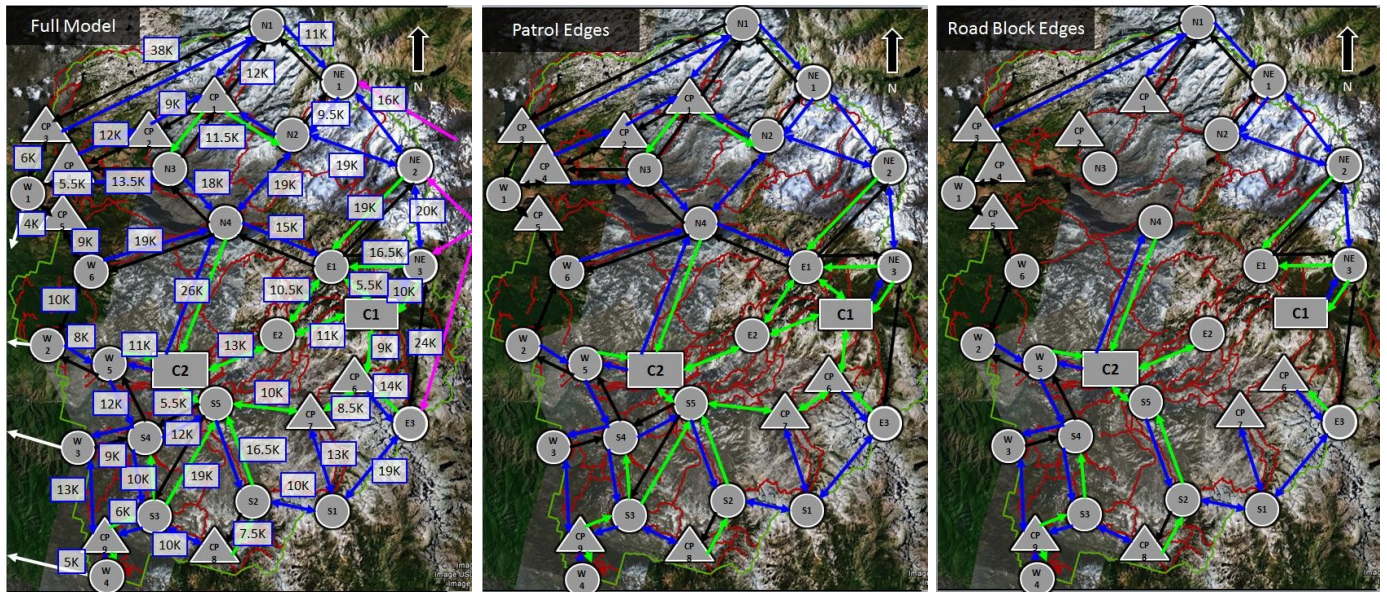


Figure 1. From left to right, complete network, the patrols edges, and the roadblocks edges. Values represent distance (km) of the arc, Rectangles labeled C1 (smuggler friendly) and C2 (coalition friendly) depict cities. Circles and triangles (surveyed) depict trail intersections or border crossings, Arrows give the arc direction. Arc colors depict as follows; pink – entering the region, white – exiting the region, green easy rate of travel (6km/hr), blue – moderate rate of travel (4 km/hr), and black – difficult rate of travel (2 km/hr).

We first measure the effect of interdiction with just roadblocks and see a steady decline through 7 roadblocks and then a large jump at 8 roadblocks. We also see that even with a completely saturated network of 21 roadblocks the lowest the POE becomes is 0.321. The operator resiliency curve for patrols shows a steady decline from 0 to 5 patrols and then completely blocks the network with 6. These are both shown in Figure 2.

Figure 2.

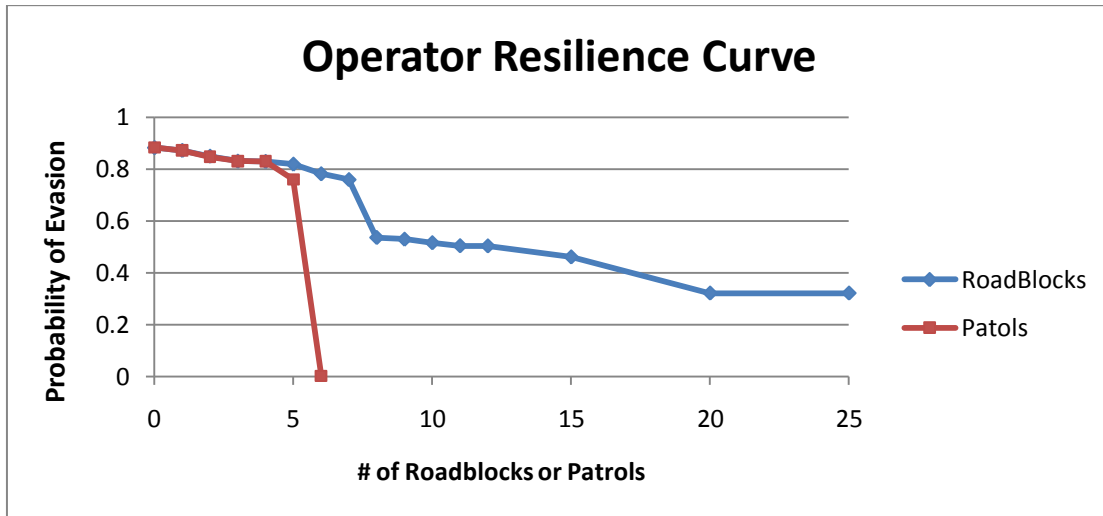


Figure 2. Shows the probability of evasion with respect to number of roadblocks and patrols separately. Key results for roadblocks: a large jump from 7 to 8 roadblocks due to blockage of all possible paths with at least one roadblock, POE never falls below 0.32, network is saturated with 21 roadblocks. Key results for patrols: a steady decline from 0 to 5 patrols and then complete blockage with 6 patrols.

The operator resiliency curve of combinations of roadblocks and patrols, the operator resiliency curve gives keen insight into the tradeoffs between adding roadblocks versus patrols. As we see in Figure 3.

Figure 3.

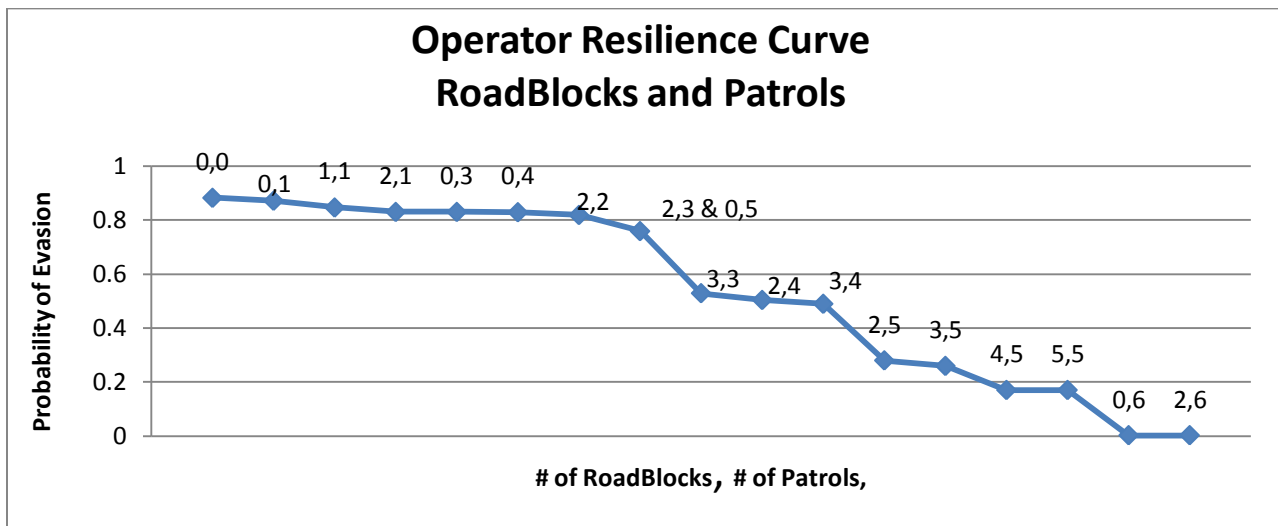


Figure 3. Shows the probability of evasion with respect to combinations of roadblocks and patrols (shown at the data points). Key results: a steady decline with combinations up 5 and then a large decrease due to the ability to affect every path with at least one delay within the network.

We complete our analysis by looking at the network under bad weather conditions. We assume the following. With bad weather, a difficult path becomes impassible, a moderate path becomes difficult, and an easy path remains easy. Given bad weather conditions, these are realistic assumptions. Easy paths are going to much more populated and therefore maintained even in bad weather conditions. And, as figure 4 shows, bad weather makes the Northwestern region impassible which mirrors known data of this region. It also shows without need of a resiliency curve that we only need one patrol to stop the smuggler in bad weather.

Figure 4.

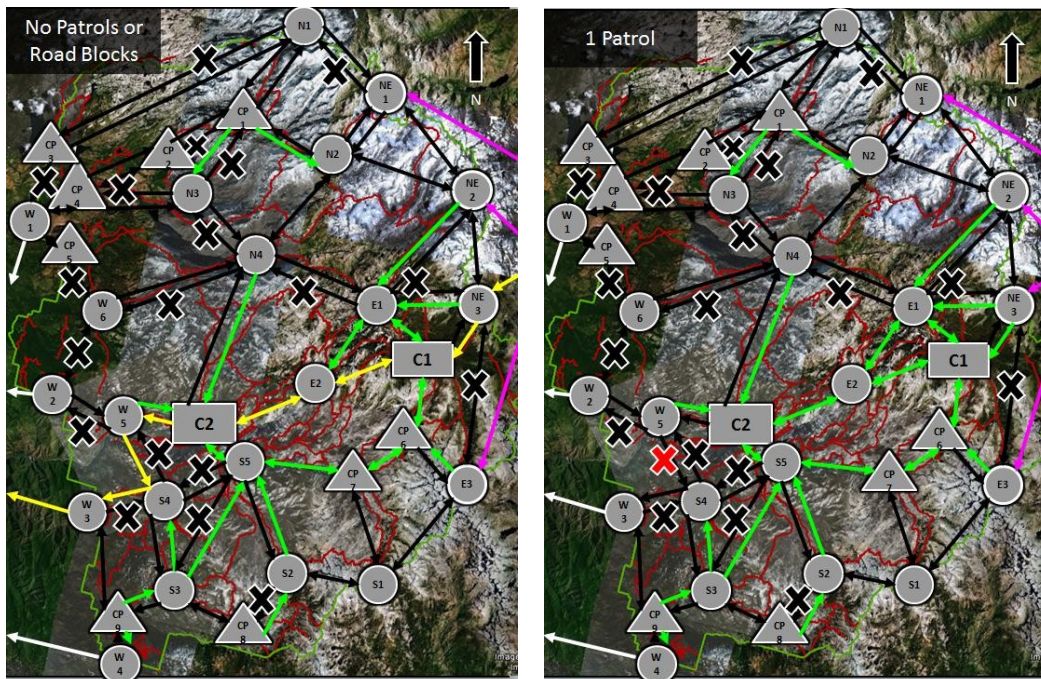


Figure 4. From left to right. Shows the path with no interdiction, and the interdiction with 1 patrols. Black X indicates a path blocked by weather. Red X indicates a Patrol. Yellow indicates the path taken. Key results: Only need one patrol to stop the smuggler. Bad weather favors the coalition.

Thus, if you have the ability to maximize patrols do so. It is more bang for the buck provided the costs associated with patrols and roadblocks are equivalent. The best case is using 6 patrols in which case we prevent the smuggler from moving through the region. If you need to employ combinations, this model can serve as a tool for leadership about the tradeoff costs of adding more patrols or more roadblocks using the operator resiliency curve of the various combinations. This model is a versatile model which can adapt to many regions of the world, expand to include multiple assets, and accommodate a larger network of nodes and edges.