

Assessing the Vulnerabilities of the California Pipeline Structure

California contains a large amount of critical infrastructure. With extensive port facilities and several major military bases, it is an area of interest in regards to national security. We chose to look at the natural gas pipelines that run throughout the county, as it is a large and generally unprotected network, and could have sizable effects on both the civilian and military populations in the area.

The complete network is available in open sources, provided on the California department of energy website (<http://www.energy.ca.gov/>). For the modeling purpose, we did not use all the cities and thus all the sources. We basically focused on the San Francisco Bay area. For the analysis, it was broken down into source nodes; sink nodes (representing the consumption) and city nodes that represent the points where cities get their natural gas. The arcs represent the amount of natural gas flow into the cities with proportion to their respective population. And, also we have assumed that the 90 percent of the gas that is being processed is actually effectively used. The other 10 percent is somehow consumed during the process. A number of factors are involved in calculating how much natural gas a pipeline can carry. However, the most important factors are the diameter of the pipe and its operating pressure. When we built our model we used the diameter criterion proportional to the number of population it serves, we used the following simple formula:

$$\text{Flow of the city} = \frac{\pi * r^2 * 0.90 * \text{population of the city}}{\text{total population of SFO bay area}}$$

Here is some basic summary information about the model:

Network Goal	: Maximum Gas Flow
Total Flow Without Interdiction	: 5378.5
Total Population	: 4.043.988
Number Of Nodes	: 23
Number Of Arcs	: 50

All the related arcs, nodes, data, attack points, GAMS codes are attached in the program folder.

When running our program, we have used couple of different scenarios.

Firstly, when we have only a one attack, GAMS blocks San Jose, affecting over a million people. Before running the Gams, we were expecting that one of the source arcs would be cut off. So, we may infer that other 2 resources compensate for most the loss. That is why it goes to San Jose, instead of going to one of source arcs. In 2 attacks plan, the attacker chooses the 2 source pipelines. Over 3 million people are affected and %73 of the system is down. This also suggests that the solution is not nested for this case. In 3 attacks plan, the system is completely down.

Secondly, but the attacker may not be very satisfied with those results. He has some concerns. He is not sure whether the assets he has can actually explode the pipeline. Because those are pipelines with diameter over 40" and they are not close to the surface, he may need some extra assets such as more explosives and other equipment that may reveal his plans. Moreover, the arc that he disrupts in his first plan with 2 or more attacks occur in sparsely populated areas. Though he is successful at breaking down the system, that may not produce the effect he desires. Therefore, we introduced penalty to attack the larger pipelines tempting him to attack other pipelines. This may be done also by just extracting those arcs from the attack_points csv file. So, when only allowed to attack the pipelines that are 30" and below, with one attack, 408 572 number of people were affected. With two attacks, 768 648 number of people are affected. With three attacks, 1 021 580 number of people are affected. By increasing the number of attacks we have acquired the following resilience curve. As can be seen from Figure 1 below, the system is nearly saturated after 3 attacks. So, with this second scenario, there is no point in the attacker's point of view to attack more than 3 respective arcs.

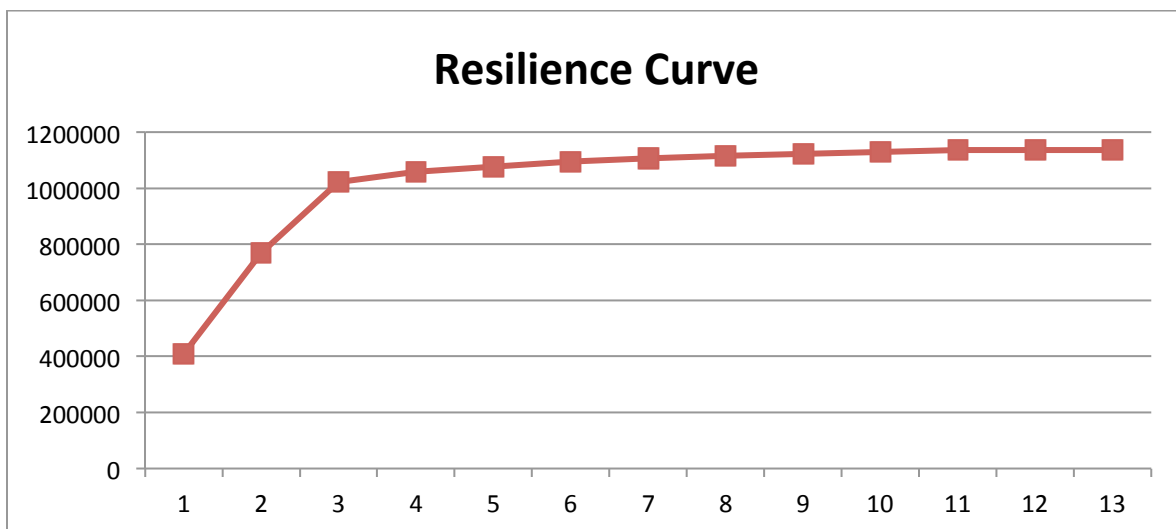


Figure 1

Thirdly, when we put big penalties to attack pipelines over 20". No matter how many attacks he makes; the attacker cannot achieve to break down the system more than %28. This can clearly be seen from the Figure 2 below. This point is very critical for the decision maker. He can decide where to put his patrols or security personnel accordingly.

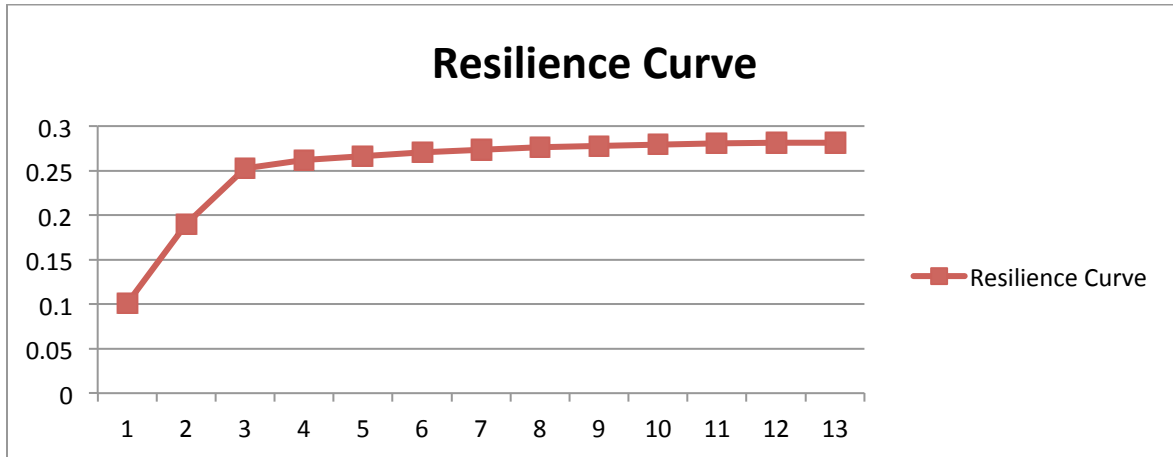


Figure 2

CONCLUSION

The system is not resilient. Only with one attack system performance drops down to % 45 affecting over 1 million people. Other than one example, all other attacks are nested. The effect of a pipeline disruption may vary according to the place it happens. Large diameter pipelines may cause the system to break down, whereas a smaller pipeline in highly populated area can cause causality and terror.

FUTURE WORK

We did not include the storage facilities in the system. These facilities can back up the disrupted pipelines. Expected causality rate of a pipeline explosion may be modeled with respect to population and diameter. As it was suggested in the class, the pipelines can be assigned with attack points that may be used in calculation of terrorist's attacks.