An Evacuation Traffic Management Problem-Integer Program

November 4, 2016

The City of Los Angeles has secured a grant in the amount of $30 million from the Federal Emergency Management Administration (FEMA) to assist in its earthquake preparedness program. The City has determined that its top priority is design an effective evacuation plan for downtown L.A. in the event of a magnitude 7 (on the Richter scale) earthquake event along the San Andreas fault. In previous efforts, the City has established four Earthquake Evacuation Centers, as shown in Figure 1, where it will collect evacuees from the downtown area either to be transported to safety either by boat (Evacuation Centers at the San Pedro and Long Beach harbor areas) or rail (Evacuation Center at the Amtrak Train Depot in San Juan Capistrano), or loaded on busses at the Evacuation Center located at the Anaheim Convention Center. The current evacuation plan assumes that many downtown workers will be able to evacuate the downtown area using their own vehicles; the plan calls for positioning Emergency management personnel at key downtown spots to direct these vehicles to evacuation routes leading to the four Evacuation Centers. Based on a preliminary analysis, the City has estimated that as many as 5,000 vehicles per hour (vph) would need to be evacuated under this scenario.

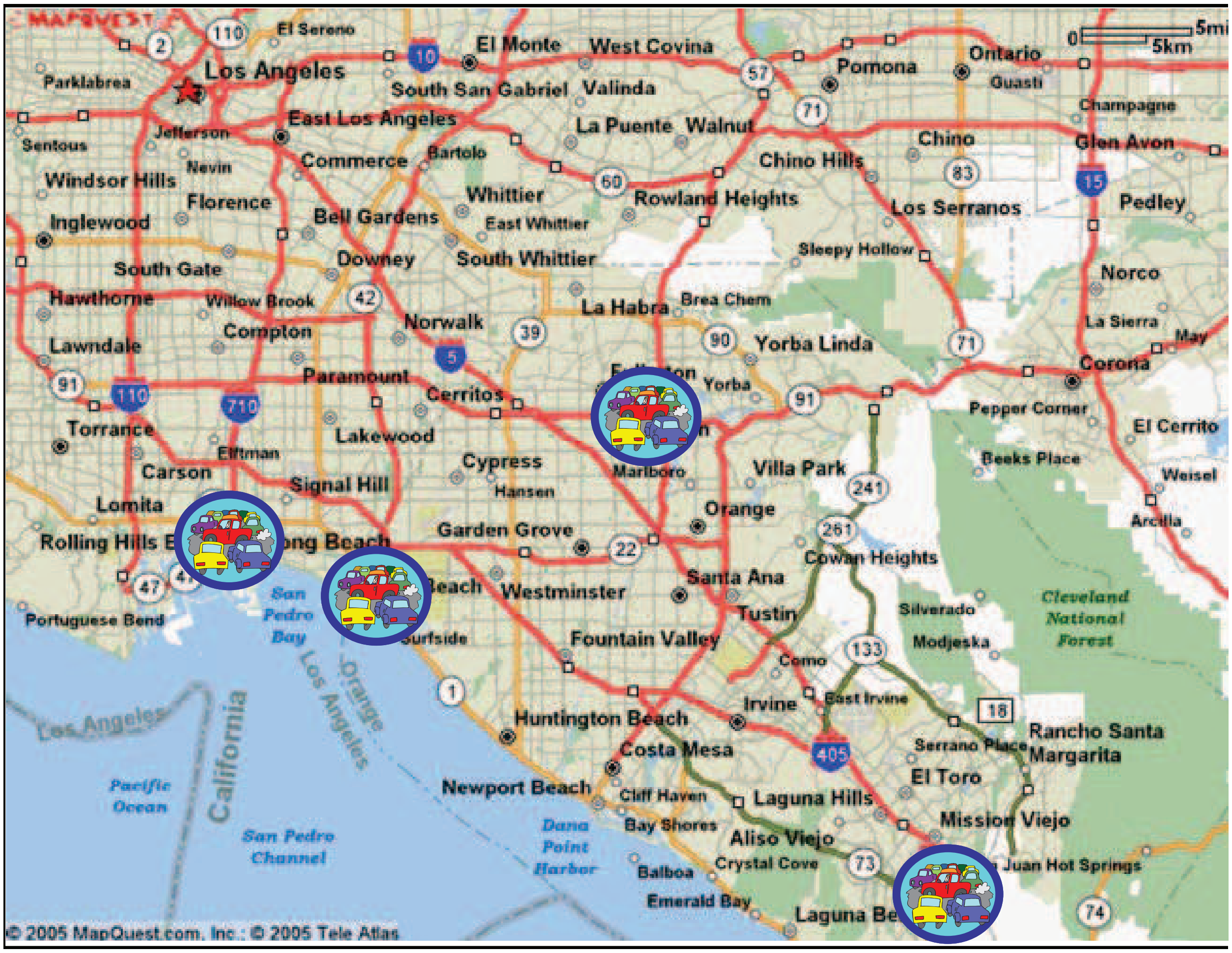

Figure 1: Location of the Four Evacuation Centers

The City has engaged your Civil Engineering firm to help guide it in how best to allocate the $30 million FEMA grant. Structural Engineers in your firm have concluded that five freeway overpasses in the L.A. freeway network are likely to fail in the event of a 7.0 magnitude earthquake, rendering them impassable. The locations of these overpasses are shown in Figure 2.

Figure 2: Locations of the Freeway Overpasses Subject to Failure

In previous work for the City, the Transportation Engineering team of your firm had coded the regional freeway network for a project designed to estimate travel times from Los Angeles to various locations in the region; the coding scheme is shown in Figure 3.

Figure 3: Network Coding Scheme

They have located the possible overpass failures and the four Evacuation Centers relative to this coded network (together with the link travel times), as shown in Figure 4.

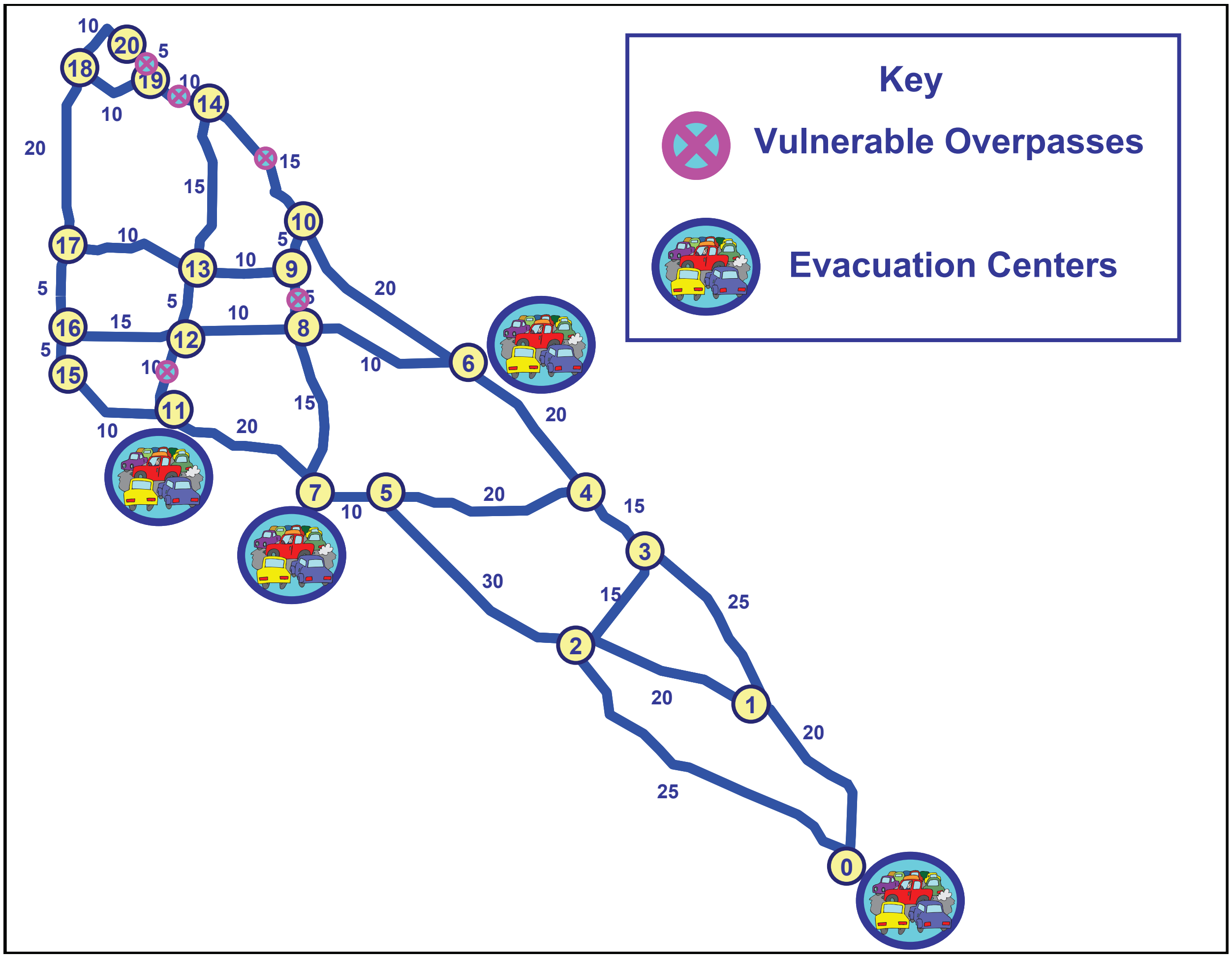

Figure 4: Location of Evacuation Centers and Vulnerable Overpasses

The City has given you information regarding the respective capacities of the four Evacuation Centers to handle and process incoming evacuees. Specifically, the Evacuation Centers at the San Pedro and Long Beach harbor areas can accommodate 1,500 vph and 500 vph, respectively; the Evacuation Center at the Amtrak Train Depot in San Juan Capistrano can accommodate 2,000 vph; and the Evacuation Center located at the Anaheim Convention Center can accommodate 1,000 vph. This is shown graphically in Figure 5.

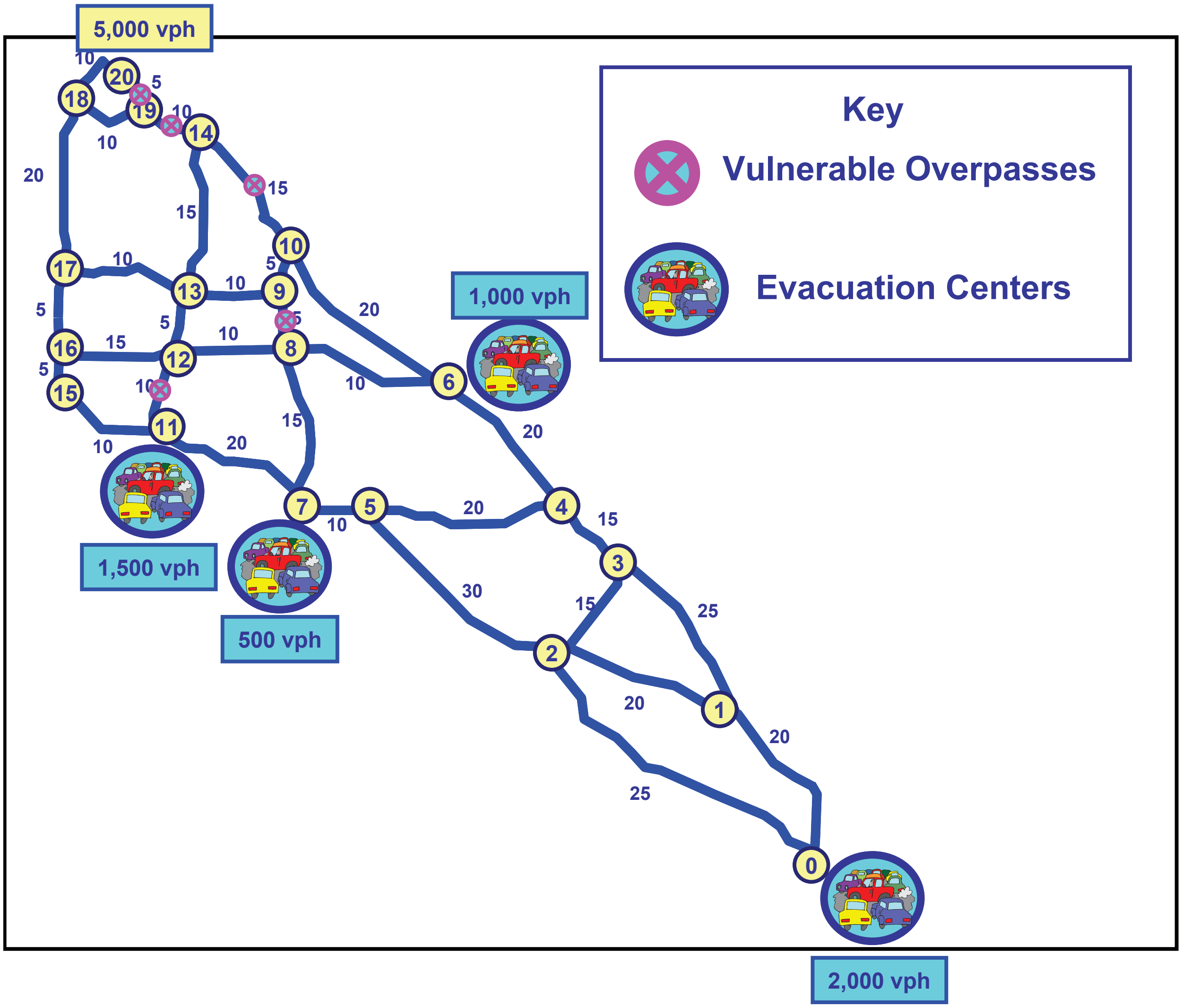

Figure 5: Capacities of the Evacuation Centers

In addition, based on your firm's transportation analysis, you estimate that the reserve capacity (over and above likely existing traffic on the roadways (links) at the time of an evacuation) is as given in Table 1.

Table 1: Link Reserve Capacities in Vehicles per Hour (vph)

Link	Capacity	Link	Capacity	Link	Capacity	Link	Capacity
(0,1)	3,953	(5,4)	4,829	(10,9)	6,863	(15,11)	1,000
(0,2)	4,941	(5,7)	3,799	(10,14)	6,739	(15,16)	5,435
(1,0)	3,521	(6,4)	4,136	(11,7)	5,497	(16,12)	5,707
(1,2)	3,219	(6,8)	3,225	(11,12)	4,278	(16,15)	4,071
(1,3)	5,574	(6,10)	3,156	(11,15)	5,685	(16,17)	6,327
(2,0)	3,670	(7,5)	6,892	(12,8)	4,848	(17,13)	3,690
(2,1)	3,264	(7,8)	3,774	(12,11)	3,785	(17,16)	3,144
(2,3)	5,006	(7,11)	3,389	(12,13)	4,356	(17,18)	6,903
(2,5)	5,386	(8,6)	5,352	(12,16)	3,485	(18,17)	5,517
(3,1)	6,213	(8,7)	5,472	(13,9)	4,567	(18,19)	6,340
(3,2)	5,955	(8,9)	5,823	(13,12)	5,661	(18,20)	4,987
(3,4)	6,640	(8,12)	6,164	(13,14)	6,901	(19,14)	6,237
(4,3)	4,035	(9,8)	4,401	(13,17)	3,081	(19,18)	6,331
(4,5)	4,532	(9,10)	6,497	(14,10)	5,238	(19,20)	6,040
(4,6)	5,183	(9,13)	4,078	(14,13)	6,194	(20,18)	6,563
(5,2)	3,369	(10,6)	3,067	(14,19)	6,722	(20,19)	3,428

Of course, if there is an earthquake event of magnitude 7.0 or above, any of the overpasses assessed as not meeting minimum standards for survival would likely fail, resulting in the network shown in Figure 6.

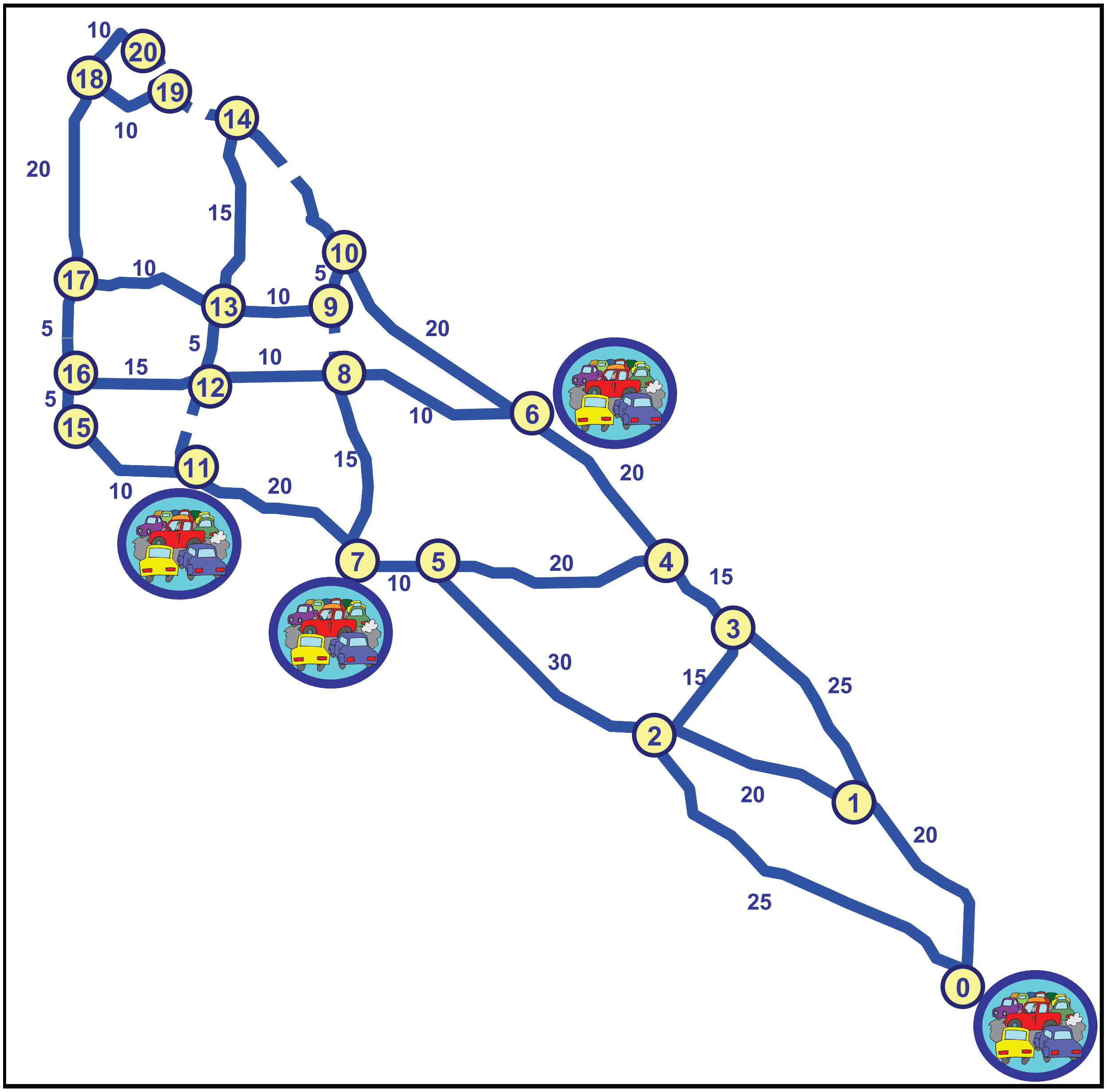

Figure 6: Expected State of the Freeway Network if None of the Vulnerable Overpasses is Retrofitted

The Earthquake Engineering Division of your firm has analyzed the suspect overpasses and has provided the cost estimates shown in Table 2 for retrofitting each respective overpass to withstand a magnitude 7.0 earthquake. (Note: since the structural integrity of each overpass depends on the overall structure, any decision to retrofit an overpass must include both directions of the associated roadway. Note further: partial retrofitting is NOT an option.)

Table 2: Earthquake Compliant Retrofit Costs ($ Millions)

Link	Retrofit Cost
(8,9)	2.0
(9,8)	2.0
(10,14)	3.0
(14,10)	3.0
(11,12)	4.0
(12,11)	4.0
(14,19)	5.0
(19,14)	5.0
(19,20)	4.0
(20,19)	4.0

You are to develop the optimal strategy for utilizing the funds available from the FEMA grant to retrofit the vulnerable overpasses, based on the goal of routing the evacuees from downtown Los Angeles to the Evacuation Centers as quickly as possible. To do so, ensure you have done the following:

1. (8 points) Define the flow variables.
2. (16 points) Write the main problem constraints.
3. (16 points) Construct the link constraints on flow capacity.
4. (8 points) Remember to enforce the condition that any decision involving retrofitting involves both directions on the link.
5. (8 points) Formulate the budget constraint.
6. (8 points) Formulate the objective function.
7. (16 points) Solve the problem using MS Excel Solver.

   Note: This is a fairly large problem for Excel Solver. You will probably need to adjust the following parameters (click "Options" in the Solver window):

   - Max Time: 10000
   - Iterations: 10000

- Precision: 0.00001
- Tolerance: 1
- Convergence: 0.00001