Solutions to Problems in Chapter 2

Transportation Modes and Characteristics

Problem 2-1
The capacity of a street or highway is affected by a) the physical design of the roadway – such features as the number of lanes, free-flow speed, and geometric design, b) the traffic composition – particularly the presence of trucks and local buses, and c) the control environment – such features as lane use controls, signalization, curb lane controls, etc.

Problem 2-2
The capacity of a rapid transit line is affected by: the number of tracks, the person-capacity of each rail car, the length of trains, and the minimum headways at which trains can operate. The latter is limited by either the control system or station dwell times.

Problem 2-3
The key element here is that trains may operate 1.8 minutes apart. In this case, the dwell time controls this limit, not the train control system, which would allow closer operation. Thus, one track can accommodate 60/1.8 = 33.3 (say 33) trains/h.

Each train has 10 cars, each of which accommodates a total of 50+80 = 130 passengers. The capacity of a single track is, therefore:

33*10*130 = 42,900 people/h

Problem 2-4
From Table 2-5 of the text, a freeway with a free-flow speed of 55 mi/h has a vehicle-capacity of 2,250 passenger cars/h.

Traffic contains 10% trucks and 2% express buses, each of which displaces 2.0 passenger cars from the traffic stream. At capacity, there are:

2,250*0.10 = 225 trucks
2,250*0.02 = 45 express buses

Each of these displaces 2.0 passenger cars from the traffic stream. Thus, the 225+45 = 270 heavy vehicles displace 2*270 = 540 passenger cars from the traffic stream. Thus, the number of passenger cars at capacity is:

2,250 – 540 = 1,710 passenger cars

Using the vehicle occupancies given in the problem statement, the person-capacity of one lane is:

(1710*1.5)+(225*1.0)+(45*50) = 5,040 persons/h

As there are 3 lanes in each direction, the capacity of each direction is 3*5040 = 15,120 people/h.

Problem 2-5

A travel demand of 30,000 persons per hour is virtually impossible to serve entirely with highway facilities. Even in the best case of a freeway with a 70-mi/h free-flow speed, and an assumed occupancy of 1.5 persons/car, a lane can carry only 3,600 people/h (Table 2-5). That dictates a need for 30,000/3,600 = 8.33 fully-dedicated freeway lanes to serve this demand. While this might be technically feasible if the area were basically vacant land with a new high-density trip generator being built, it would be intractable in most existing development settings.

That leaves various public transit options (Table 2-6). Given the observed capacities, it is doubtful that such a demand could be handled by bus transit (either on the street or on a private right-of-way) or light rail. A rapid transit line with one track in each direction would be able to handle the demand.

A lot depends on what type of development is spurring the demand. If it is a stadium or entertainment complex that generates high-intensity demand for short periods of time, the solution may be different from a case of a regional shopping mall, where trips are more distributed over time.

It is likely that some mix of modes would be needed. Rail transit is expensive, and any new service would have to be linked into a larger rapid transit network to be useful. Auto access is generally preferred by users (except for the traffic it generates), but involves the need to provide huge numbers of parking places within walking distance of the desired destination. A stadium could rely fairly heavily on transit, with heavy rail, light rail, and bus options viable. Some highway access and parking would also be needed. A regional shopping center would have to cater more to autos, as most people would prefer not to haul their purchases on transit.

Solutions to Problems in Chapter 3
Speed, Travel Time, and Delay Studies

Problem 3-1

The reaction distance is given by Equation 3-1:

$$d_r = 1.47\,S\,t$$

For a speed of 70 mi/h, the result is:

$$d_r = 1.47 * 70 * 3.5 = 360.2\ ft$$

Other values for the range of speeds specified are shown in Table 1. Figure 1 plots these values.

Table 1: Reaction Distance vs. Speed

Speed	Distance
30	154.4
35	180.1
40	205.8
45	231.5
50	257.3
55	283.0
60	308.7
65	334.4
70	360.2

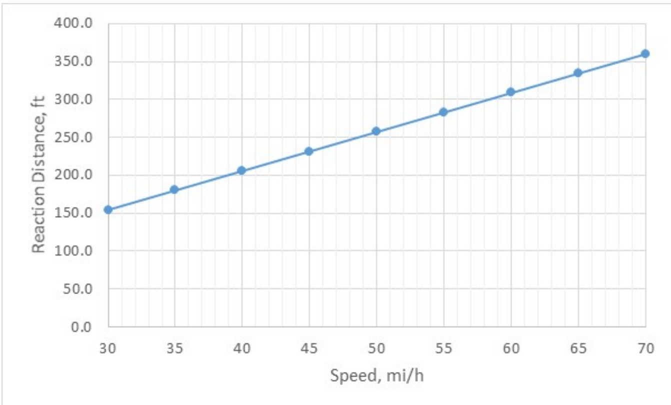


Figure 1: Reaction Distance vs. Speed

Problem 3-2

This problem involves several considerations. At the point when the driver notices the truck, the vehicle is 350 ft away from a collision. To stop, the driver must go through the reaction distance and then the braking distance. The two will be considered separately.

Reaction Distance
Reaction distance is given by Equation 3-1, and is dependent upon the reaction time, which, for this problem, will be varied from 0.50 s to 5.00 s. A sample solution for 0.50 s is shown, with all results in Table 3.

$$d_r = 1.47\,S\,t = 1.47 * 65 * 0.50 = 47.8 \;\; ft$$

Table 3: Reactions Distances for Problem 3-2

Speed (mi/h)	Reaction Time (s)	Reaction Distance (ft)
65	0.50	47.8
65	1.00	95.6
65	1.50	143.3
65	2.00	191.1
65	2.50	238.9
65	3.00	286.7
65	3.50	334.4
65	4.00	382.2
65	4.50	430.0
65	5.00	477.8

For any result > 350 ft, the driver will not even get his/her foot on the brake before colliding with the truck. Thus, for all reaction times, t ≥ 4.0 s, the collision speed will be 65 mi/h.

Braking Distance
For all reaction times < 4.0 s, the driver will engage the brake before hitting the truck, and therefore, will at least decelerate somewhat before a collision. How much deceleration will take place depends upon how much braking distance is left when the brake is engaged. In each case, this would be 350 ft – the reaction distance, d_r. Once the braking distance available is determined, the braking distance formula of Equation 3-5 is used:

$$d_b = \frac{S_i^2 - S_f^2}{30\,(F \pm G)}$$

The braking distance will be determined as indicated. For example, for a reaction time of 2.0 s, the reaction distance (from Table 3) is 191.1 ft. The available braking distance is then 350.0 – 191.1 = 158.9 ft. The initial speed (S_i) is 65.0 mi/h in all cases. The grade is given as level (G = 0.00), and the friction factor is found from the deceleration rate as:

$$F = \frac{a}{g} = \frac{10}{32.2} = 0.311$$

The final speed (S_f) is the unknown. Then for the example with a 2.0 s reaction time:

$$d_r = 158.9 = \frac{65^2 - S_f^2}{30(0.311 + 0.000)}$$
$$S_f^2 = 65^2 - (158.9 * 30 * 0.311) = 2{,}739.5$$
$$S_f = 52.4\ mi/h$$

Table 4 summarizes the results for all reaction times.

Table 4: Collision Speed vs. Reaction Time for Problem 3-2

Reaction Time (s)	Braking Distance (ft)	Collision Speed (mi/h)
0.5	302.2	37.5
1.0	254.5	43.0
1.5	206.7	47.9
2.0	158.9	52.4
2.5	111.1	56.5
3.0	63.4	60.3
3.5	15.6	63.9
4.0	NA	65.0
4.5	NA	65.0
5.0	NA	65.0

Figure 2 shows a plot of these results. Note that in no case is the driver able to stop the vehicle before colliding with the truck.

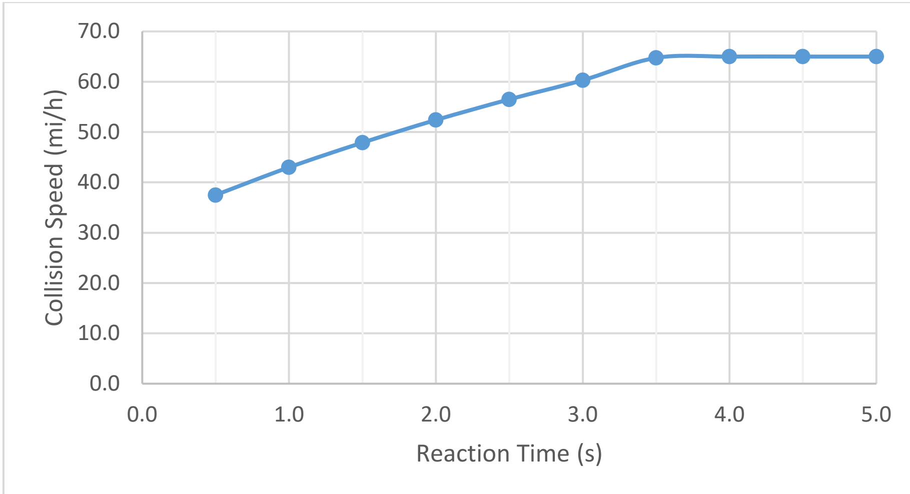
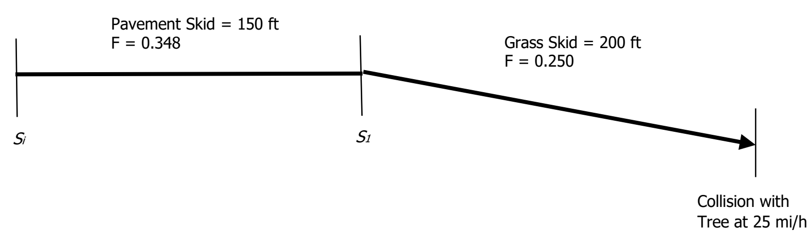


Figure 2: Reaction Time vs. Collision Speed, Problem 3-2

Problem 3-3

In this case, we are dealing with measured skid marks at an accident location. Because skid marks only occur when the brakes are engaged, the reaction time and reaction distance play no role in this solution.

The sketch below helps in the understanding of the solution:



The only know speed is at the collision point (at the end of the grass skid). The collision speed is 25 mi/h. Using the grass skid, we can work backwards to find the initial speed at the beginning of the grass skid (S_1). This is also the final speed at the end of the pavement skid. Working backwards again, we can find the initial speed (S_i) at the beginning of the pavement skid.

Both solutions use the braking formula of Equation 3-5:

$$d_b = \frac{S_i^2 - S_f^2}{30(F \pm G)}$$

$$d_{b,GRASS} = 200 = \frac{S_1^2 - 25^2}{30(0.250 + 0.03)}$$

$$S_1^2 = (200 * 30 * 0.280) + 25^2 = 2{,}305$$

$$S_1 = 48.0\ mi/h$$

$$d_{b,PAVE} = 150 = \frac{S_i^2 - 48.0^2}{30(0.348 + 0.03)}$$

$$S_i^2 = (150 * 30 * 0.378) + 2{,}305 = 4{,}006$$

$$S_i = 63.3\ mi/h$$

In an accident investigation, this result would be compared to the speed limit to determine whether excessive speed contributed to the accident.

Problem 3-4

This problem involves a reaction distance and a braking distance, as drivers must see a sign and reduce their speed to navigate a hazard. Level terrain is assumed, and standard values for *t* (2.5 s) *F* (0.348) and *a* (10.0 ft/s^2) are used. The full distance to respond is the sum of Equation 3-1 for reaction distance and Equation 3-5 or 3-6 for braking:

$$d = 1.47\,S_i\,t + \frac{S_i^2 - S_f^2}{30(0.348 \pm G)} = (1.47 * 60 * 2.5) + \frac{60^2 - 40^2}{30 * 0.348} = 220.5 + 191.6 = 412.1\ ft$$

The sign must *be seen* a total of 412.1 ft from the hazard. Since the sign can be read from 200 ft, it could be placed as close as 412.1-200.0 = 212.1 ft from the hazard. Other considerations, however, would also enter a final decision on the placement of the sign.

Problem 3-5

The *yellow* interval of a traffic signal is designed to let any vehicle that cannot safely stop before entering the intersection safely enter the intersection at the ambient speed, which is generally taken to be an 85th percentile speed. First, the safe stopping distance must be found for a vehicle traveling at 40 mi/h on a 0.02 downgrade, using Equation 3-10:

$$d_S = 1.47\,S\,t + \frac{S^2}{30(0.348 \pm G)} = (1.47 * 40 * 1.0) + \frac{40^2}{30(0.348 - 0.02)} = 58.8 + 162.6 = 221.4\ ft$$

As the vehicle is traveling at a speed of 40 mi/h, the *yellow* must be long enough to allow the vehicle to traverse 221.4 ft at 40 mi/h, or:

$$y = \frac{221.4}{1.47 * 40} = 3.77\ s$$

Problem 3-6

The safe stopping distance is computed using Equation 3-10:

$$d_S = 1.47\,S\,t + \frac{S^2}{30(0.348 \pm G)} = (1.47 * 80 * 2.5) + \frac{80^2}{30(0.348 - 0.02)} = 294.0 + 650.4 = 944.4\ ft$$

Problem 3-7

The minimum radius of curvature is given by Equation 3-3:

$$R = \frac{S^2}{15(e + f)} = \frac{70^2}{15(0.06 + 0.10)} = 2{,}041.7\ ft$$