Solutions Manual

TRANSPORTATION ENGINEERING AND PLANNING

THIRD EDITION

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NOTE TO THE INSTRUCTOR

This booklet supplements the 3rd edition of TRANSPORTATION ENGINEERING AND PLANNING. It contains solutions to exercises which require numerical calculations as well as selected answers to questions which elicit qualitative treatment. Solutions are not given for the computer programming of exercises because they can be programmed in Basic, Fortran, Pascal, C, C++, etc. or with commands in Excel or Lotus spreadsheet software.

Chapters 1 and 15 do not contain exercises. All exercises in Chapter 7 are essay type, thus, no essays are provided in this solutions manual. The open ended questions of Chapter 7 (and of other Chapters) intend to help the students appreciate the wide context of transportation engineering and planning, to develop tolerance to ambiguity, and to hone the ability to think critically. We consider these important elements which need to be cultivated and we are convinced that introductory transportation course(s) based on this textbook are effective means for accomplishing the task for developing and cultivating such skills to our students.

Requiring students to conduct research and to report on cases and issues pertinent to the students' locale is an excellent way to achieve an understanding of the more elusive concepts covered in the textbook. In line with this thesis, the students should be encouraged to interpret the results of quantitative exercises.

The use of computers by engineering and planning students has become essential. A good sense of proportion dictates (a) some computer programming in a basic computer language such as Fortran or C++, (b) hands-on experience with existing traffic and transportation software, (c) use of spreadsheets for analysis –including basic statistical modeling– and chart-making, and (d) use of presentation and word-processing software for the delivery of homework and class presentations.

Your comments on both the textbook and the exercises are always welcome and much appreciated. Although it is said that a perfect manuscript tends to develop defects in the publication process, in actuality, any errors and omissions are the sole responsibility of the authors.

Thank you for selecting our textbook for your course.

Constantinos S. Papacostas
Panos D. Prevedouros
(Honolulu, June 1999)

CHAPTER 2

2/1 $v_o = 12$ mi/h $= 17.6$ ft/s and $x_o = 0.0$ ft.

Interval $0 \leq t \leq 5$ s.

$\frac{dv}{dt} = a = t$ ft/s^2. By integration, $v = \frac{t^2}{2} + 17.6$ ft/s.

$\frac{dx}{dt} = v$ and $x = \frac{t^3}{6} + 17.6\,t + 0.0$ ft.

When $t = 5$ s, $v(5) = 30.1$ ft/s and $x(5) = 108.8$ ft.

Interval $5 \leq t \leq 15$ s or $0 \leq (t - 5) \leq 10$

$\frac{dv}{dt} = a = 5$ ft/s^2 and $v = 5(t - 5) + 30.1$ ft/s.

$\frac{dx}{dt} = v$. Therefore, $x = 5\,\frac{(t - 5)^2}{2} + 30.1(t - 5) + 108.8$ ft.

When $t = 15$ s, $v(15) = 80.1$ ft/s and $x(15) = 659.8$ ft.

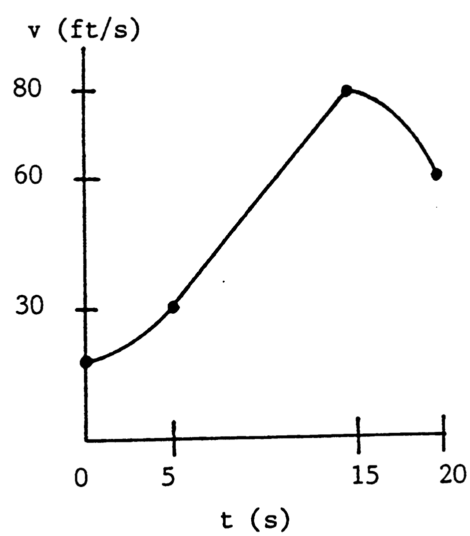
Interval $15 \leq t \leq 20$ s or $0 \leq (t - 15) \leq 5$

$\frac{dv}{dt} = a = -\frac{8}{5}(t - 15)$ ft/s^2 and $v = -\frac{8}{5}\,\frac{(t - 15)^2}{2} + 80.1$ ft/s.

$\frac{dx}{dt} = v$. Consequently, $x = -\frac{8}{5}\,\frac{(t - 15)^3}{6} + 80.1(t - 15) + 659.8$ ft.

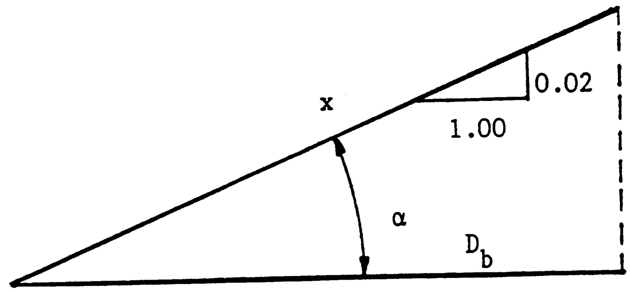
When $t = 20$ s, $v(20) = 60.1$ ft/s and $\underline{\underline{x(20) = 1027.0 \text{ ft. Answer}}}$

The relationship between speed and time is plotted below.



Note that the shape of the v–t curve can be inferred directly from the shape of the a–t diagram. At $t = 0$, the slope of the v–t diagram is zero since $a = 0$. The slope increases in a linear fashion until $t = 5$ s. Between $t = 5$ s and $t = 15$ s, the slope remains constant. At $t = 15$ s, it abruptly changes to zero, and then it decreases linearly.

2/2



From the above diagram $\tan\alpha = 0.02$ and $\alpha = 1.15°$.

Also $D_b = x\cos\alpha \simeq x$.

Eq. 2.2.6 gives $x = \dfrac{v^2 - v_0^2}{(2)(8)}$ and Eq. 2.2.13 yields $D_b = x = -\dfrac{v^2 - v_0^2}{2g(f + 0.02)}$

Therefore $16 = 2g(f + 0.02) = 64.4\ (f + 0.02)$.

Solving for the coefficient of friction, $f = 0.23$.

This value suggests a wet pavement.

2/3

Assuming the case of constant acceleration,

$$v = at + v_0 \quad \text{and} \quad (v^2 - v_0^2) = 2a(x - x_0) \qquad \text{[Eqs. 2.2.4 \& 2.2.6]}$$

The movement from the ground floor to the restaurant level involved:

Total distance = 140 ft.

Time to reach cruising velocity when $a = 5\ \text{ft/s}^2 = \frac{20}{5} = 4$ s.

Time to stop from cruising velocity when $d = 4\ \text{ft/s}^2 = \frac{20}{4} = 5$ s.

Acceleration distance = $20^2/[2(5)] = 40$ ft.

Deceleration distance = $20^2/[2(4)] = 50$ ft.

Cruising distance = $140 - 40 - 50 = 50$ ft.

Cruising time at maximum cruising speed = $50/20 = 2.5$ s.

During the movement from the restaurant level to the observation deck the elevator did not reach cruising velocity. The total distance of 20 ft consisted of accelerating (x_a) and decelerating (x_d) distances, i.e.,

$$x_a + x_d = 20 \text{ ft.}$$

2/3 (cont.)

Hence, $\dfrac{v^2}{2(5)} + \dfrac{v^2}{2(4)} = 20$ ft.

Consequently, the highest speedreached was v = 9.4 ft/s. In addition,

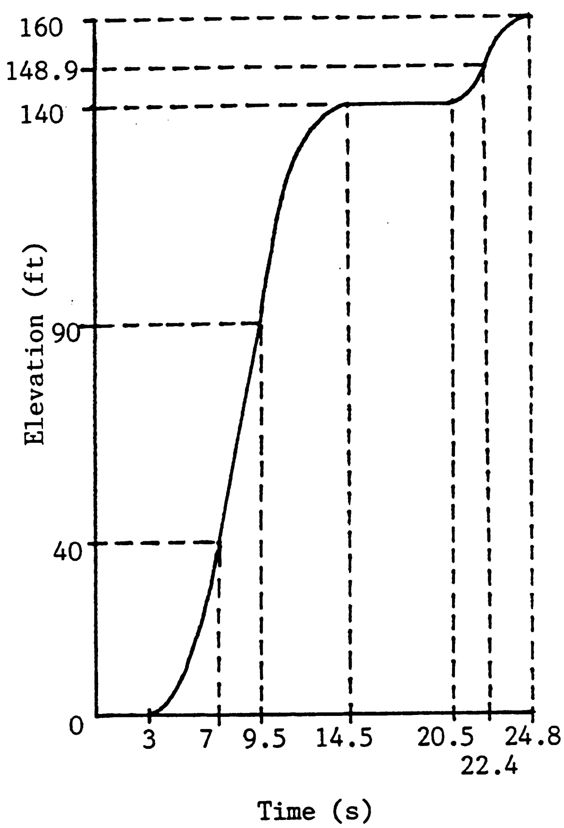
Acceleration distance ≃ 8.9 ft.

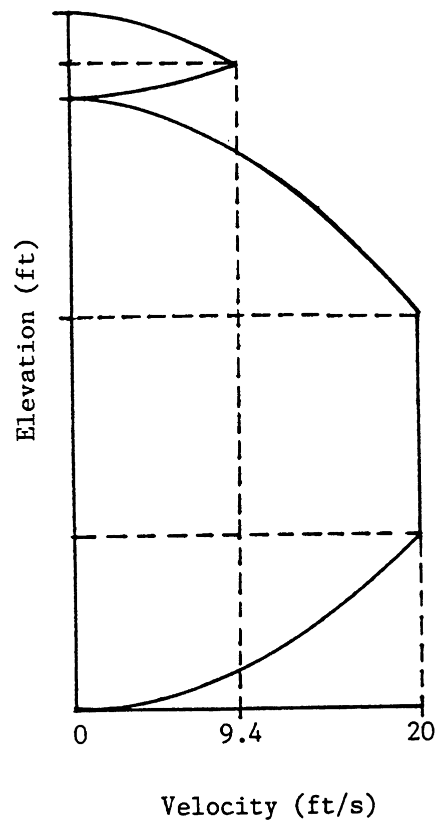
Deceleration distance ≃ 11.1 ft.

Acceleration time ≃ 1.9 s.

Deceleration time ≃ 2.4 s.

The required diagrams are drawn below.





2/4

A = 100 ft^2 W = 40,000 lb α = 100 lb/ft^2 β = 3.33 lb/ft^2-s

a) $F = (\Delta P)A = (W/g)a$

Solve for acceleration in terms of pressure difference ΔP:

$$a = \frac{g}{W} A\ (\Delta P) = \frac{32.2}{40{,}000}\,(100)(\Delta P) = 0.0805(\Delta P)$$

Also, $v = \int a\, dt$ and $x = \int v\, dt$.

For simplicity, set $t_0 = 0$ and $x_0 = 0$.

2/4 (cont.)

Acceleration phase ($0 \le t \le t_1$):

$$a = 0.0805(100 - 3.33t) = 8.05 - 0.268t \quad \text{ft/s}^2$$

$$v = 8.05t - 0.268(t^2/2) + v_0 = 8.05t - 0.134t^2 \quad \text{ft/s} \qquad \text{(Eq.1)}$$

$$x = 8.05(t^2/2) - 0.134(t^3/3) + x_0 \quad \text{ft.}$$

According to the given a-t diagram, $a = 0$ when $t = t_1$. Consequently, $t_1 = (8.05)/(0.268) = 30$ s. At this instant, cruising velocity is attained:

$$v_{cruise} = 8.05(30) - 0.134(30)^2 = 120.9 \quad \text{ft/s.}$$

The distance traveled during the acceleration phase is $x_a = 2416.5$ ft.

Deceleration phase ($t_2 \le t \le t_3$):

$$a = 0.0805(-3.33)(t - t_2) \qquad \text{where } t_2 \text{ depends on station spacing.}$$

$$v = -0.268\,\frac{(t - t_2)^2}{2} + v_{cruise} = 120.9 - 0.134(t - t_2)^2 \qquad \text{(Eq.2)}$$

$$(x - x_2) = 120.9(t - t_2) - 0.134\,\frac{(t - t_2)^2}{3}$$

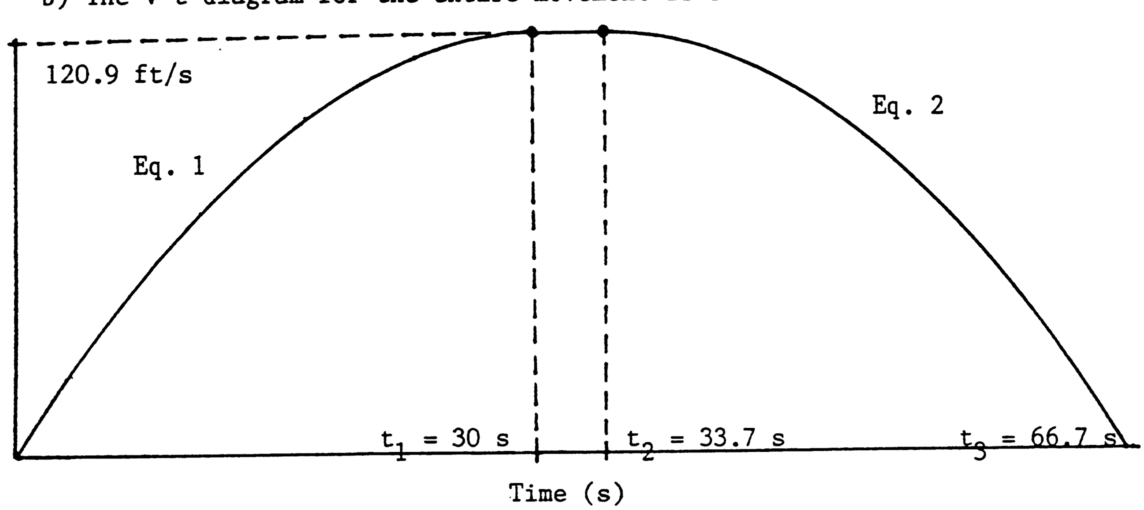
The deceleration time may be computed via Eq. 2 or by symmetry with the acceleration phase to be $(t_3 - t_2) = 30$ s. By similar reasoning, the deceleration distance x_d equals the acceleration distance x_a , that is 2416.5 ft.

Cruising phase ($t_1 \le t \le t_2$):

The total cruising distance equals the station spacing (1 mi = 5280 ft) minus $(x_a + x_b)$, or $x_{cruise} = 447$ ft. The required equations for the cruising phase are:

$a = 0$ ft/s^2 $\quad v = 120.9$ ft/s $\quad$ and $\quad x = 120.9(t - 30) + 2416.5$ ft.

b) The v-t diagram for the entire movement is shown below:



2/5

The estimated speed at impact was 15 mi/h or 22 ft/s.

α = arctan 0.03 = 1.72°.

D_b = x cos 1.72° = 20 cos 1.72° = 19.99 ft ≈ 20 ft.

In the absence of a measured value for f, use 0.6 as an approximation since the pavement was dry. Using v = 22 ft/s and G = +0.03, apply Eq. 2.2.13 to find v_0 = 36 ft/s ≈ 24.5 mi/h. Answer

2/6

The total stopping distance equals the distance traveled during δ, i.e., perception reaction time, plus the braking distance:

$$x_s = v_0\,\delta + \frac{v_0^2}{2g(f + G)}$$

For v_0 = 42 mi/h = 61.6 ft/s; δ = 0.8 s; f = 0.5 s; and G = 0

$$x_s = 49.28 + 117.84 = 167.12 \text{ ft.}$$

Since 167.12 < 175, there was no impact. Answer

2/7

According to Fig. 2.3.5 the length of the dilemma zone, L_D, equals $(x_c - x_o)$. Substitution of the given data into Eqs. 2.3.3 and 2.3.6 yields:

$$x_c = 1.0\, v_o + \frac{v_o^2}{32.2}$$

$$x_o = 4.5\, v_o - 80$$

and $$L_D = 0.03\, v_o^2 - 3.5\, v_o + 80$$

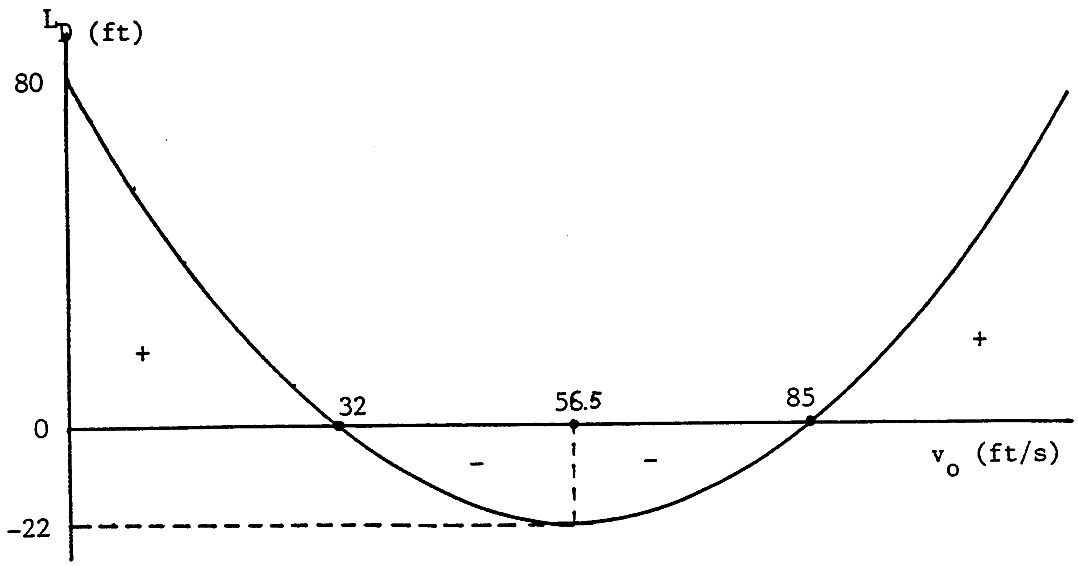
This is a quadratic equation with roots v_o ≈ 32 and v_o ≈ 85 ft/s. By setting the first derivative of L_D with respect to v_o equal to zero,

$$0.06\, v_o - 3.5 = 0$$

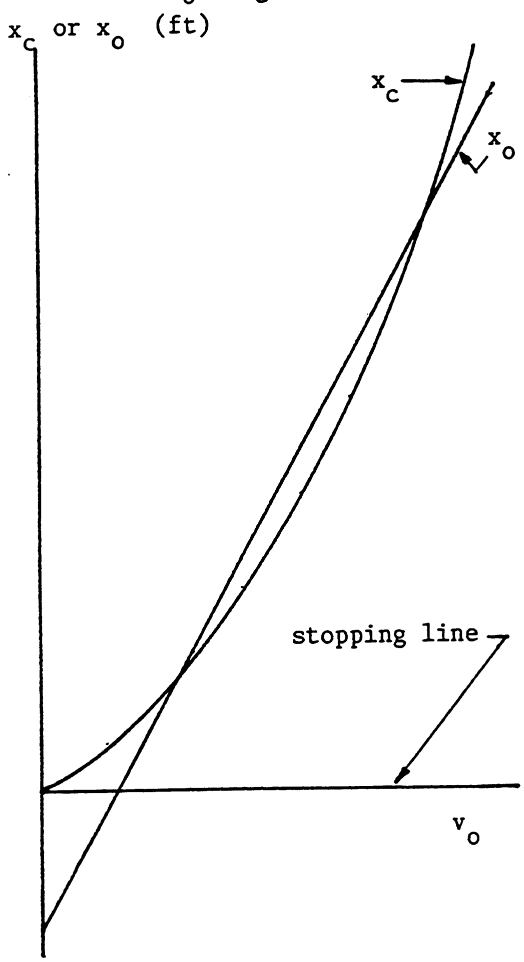
the critical point is found to occur at v_o ≈ 58 ft/s. Since the second derivative at this point is +0.06, the curve is concave upward and the critical point is a minimum. At this point the value of L_D is -22 ft. The relationship between approach speed and the length of the dilemma zone is plotted on the following page. Note that negative values of v_o are meaningless in this case; they may describe the situation in which the vehicle backs up to clear the intersection behind it! Also, negative values of L_D represent the situation illustrated by Fig. 2.3.5 in the textbook, a situation that does not present a dilemma zone problem. Thus for the data given the dilemma zone problem arises for the range of speeds

2/7 (cont.)

$v_o < 32$ ft/s and $v_o > 85$ ft/s



Another way of viewing the same phenomenon is by superposing the $v_o - x_o$ and the $v_o - x_c$ curves:

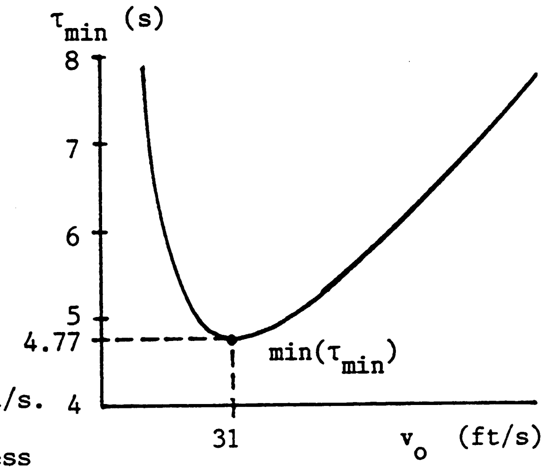


The vertical distance between the two curves represents the length of the dilemma zone at the corresponding speed. The graph illustrates that both the <u>length</u> and the <u>location</u> of the dilemma zone depend on speed. At very low speeds the dilemma zone extends beyond the stopping line (i.e., the horizontal axis). This means that a vehicle that happens to already be within the intersection may not be able to clear the intersection prior to the onset of red. Again, "positive" dilemma zones are seen at low- and high-speed-limit ranges. Also, not all approaching vehicles will be affected by the presence of a dilemma zone: Only those approaching at the speed limit v_o that happen to be located within the confines of the dilemma zone will be affected. This discussion is based on the assumption of zero acceleration.

2/8

Equation 2.3.7 describes the relationship between τ_{min} and v_o. For the given data:

$$\tau_{min} = 0.9 + \frac{v_o}{16} + \frac{60}{v_o}$$



To find the critical point(s), set the first derivative to zero and solve for v_o:

$\frac{1}{16} - 60\, v_o^{-2} = 0$ and $v_o = \pm 31$ ft/s.

Since negative speeds are meaningless in this case, the critical point is at $v_o = 31$ ft/s. Since the second derivative at this point is positive, the curve is concave upward and the point is a minimum. The corresponding value for τ_{min} is 4.77 s. Thus, for this case, the absolute minimum value of the amber duration is 4.77 s when the speed limit is about 20 mi/h.

2/9 (computer exercise)

2/10

The sign becomes legible to the driver at a distance of 100 ft. At a speed of 30 mi/h (= 44 ft/s), the sign remains in view for 100/44 = 2.27 s. The driver has enough time to read it.

2/11

The existing letter size can be read by a person with 20/50 vision from a distance of 300(40/50) = 240 ft. For the same person to be able to read the sign from a distance of 450 ft, the letter size should be 450/240 or 1.9 times as large.

2/12

The witness should have been at most 180(20/60) = 60 ft from the hit-and-run vehicle.

2/13

The relative speed between the two vehicles is 35 + 40 = 75 mi/h or 110 ft/s. According to Eq. 2.3.9, driver A will displace latterally at a distance of separation ℓ_A as follows: