Assignment 7: MATLAB Plots and Functions

Date Due: April 6, 2026 Instructor: Trani

Problem 1

A simple formula used in highway engineering to estimate the horizontal radius of a road is:

$$R = \frac{v^2}{g(e + f)} \tag{1}$$

Where:

R is the road horizontal radius (in meters)

v is the road design speed (m/s)

g is the gravitational constant (9.81 m/s^2)

e is the superelevation rate of the road (%/100). For example, a road with a superelevation rate of 0.06 implies the road is inclined at a slope of 0.06 meters vertical for each one meter in horizontal distance travel.

f is the lateral friction force coefficient developed between the vehicle tires and the pavement. Table 1 provides some values of f for various design speeds.

Table 1. Values of Lateral Friction Coefficient as a Function of Design Speed.

Road Design Speed (m/s)	Wet Pavement Lateral Friction Coefficient f (dim)	Dry Pavement Lateral Friction Coefficient f (dim)
0	0.190	0.227
10	0.162	0.194
15	0.150	0.177
20	0.135	0.160
25	0.120	0.144
35	0.090	0.108

a) Use MATLAB to plot the values of f (in y-axis) versus road design speed (x-axis). Plot both dry and wet pavement conditions in the same plot.

b) Estimate the best linear regression model to predict f for a given value of road design speed. Obtain equations for both dry and wet pavement conditions. Write down the equation to predict f given design speed for both pavement conditions. Use the Basic Fitting functions in MATLAB to accomplish the task.

c) Create a MATLAB function to estimate the radius of the curve (R) given the design speed (v), superelevation rate (e), and the pavement condition. Calculate f using the equations derived in part (a) of the problem. Your function includes as input, a string variable ('wet' or 'dry') to indicate if the horizontal radius of the road is to be calculated using dry or wet pavement conditions.

d) Create a separate MATLAB script (not a function) that uses the function created in part (c) to estimate the horizontal radius of the curve for speeds ranging from 0 to 35 meters/second at intervals of 0.1 m/s. Assume a constant value of superelevation rate at 0.06. Your new script created in this task, plots the horizontal radius as a function of road design speed (in the x-axis), for both dry and wet pavement conditions. Show both curves in the same plot to facilitate comparisons. Label the curves accordingly (use the legend).

e) Use the plot created in part (d) to estimate the horizontal radius on the Smart Road in Blacksburg if the design speed of the road was 55 mph.

Problem 2

The capacity of a subway system can be estimated by measuring the distance between successive vehicle operations (S) on the track. A Transit Unit (TU) is made with multiple cars (N) with each car having a length L. A formula used by train engineers to calculate the minimum safe distance between transit units is:

$$S_{min} = NL + S_o + Vt_r + \frac{v^2}{2b_2} - \frac{v^2}{2b_1} \qquad (2)$$

Where:

S_{min} is the minimum distance between transit units (in meters)

v is the transit unit line (or cruise) speed (m/s)

L is the length of each car (meters/car)

N is the number of cars in a transit unit (cars)

S_o is the desired minimum distance between transit units after the both trains stop (meters) if the lead train has a malfunction.

t_r is the reaction time of the transit unit conductor (seconds)

b_1 is the average deceleration rate of the lead transit unit (m/s^2)

b_2 is the average deceleration rate of the following transit unit (m/s^2)

The minimum headway (time between successive transit units along the track) is estimated as follows:

$$h_{min} = \frac{S_{min}}{v} \qquad (3)$$

Where:

h_{min} is the minimum headway (or time separation between two successive transit units) in seconds.

S_{min} is the minimum distance between transit units (in meters)

v is the transit unit line speed (m/s)

The guideway capacity (I.e., number of passengers transported per hour) is estimated as follows:

$$C_{guideway} = \frac{3600 C_v N}{h_{min}} \tag{4}$$

$C_{guideway}$ is the guideway capacity (i.e., number of passengers transported per hour) in passengers/hour.

C_v is the capacity of each car (passengers per car)

N is the number of cars in a transit unit (cars)

a) Create a MATLAB function to estimate the minimum distance between transit unit (S_{min}), the minimum headway (h_{min}), and the guideway capacity ($C_{guideway}$). The function should produce all three parameters in equations (2-4). The inputs to the function are: v, L, S_o, b_1, b_2, C_v, t_r, and N.

b) Create another MATLAB script to call the function created in part(a) and evaluate the guideway capacity from zero to 40 meters/second. Use vector operations. No need for a FOR loop. In your analysis assume that we want to estimate the capacity of the Washington subway with the following parameters:

v = 30 m/s

L = 22 meters

N = 8 cars

S_o = 100 meters

C_v = 80 passengers/car

b_1 = 3 (m/s^2) - normal braking rate

b_2 = 1.2 (m/s^2) - reduced braking rate

t_r = 3 (seconds)

c) Plot the guideway capacity (y axis) as a function of transit unit line speed (v) with the parameters above.

d) Find the transit line speed that maximizes the value of $C_{guideway}$

e) Plot the guideway capacity (y axis) as a function of transit unit line speed (v) when N is ten cars per transit unit.

f) To be conservative in the operations, some transit agencies study the extreme case where the **lead transit unit derails** and comes to stop at a deceleration rate of 10 m/s^2. Find the maximum guideway capacity and compare with part(d).

Problem 3

Steel is a very important material to civil engineers. The fabrication of steel requires the material to be heated to form beams of a distinct shape. The first order differential equation (dT/dt) that estimates the rate of change of temperature of steel as a function of time during fabrication is:

$$\frac{dT}{dt} = -K_1(T - T_a)^m + K_2 * K_1 sin(T/T_a) \qquad \text{Equation (5)}$$

Where:

$\frac{dT}{dt}$ is the rate of change of temperature with time (deg. C/minute)

T is the temperature of the material (deg. C)
T_a is the room temperature (deg. C)
K_1 is a heat release constant (1/minute)
K_2 is a second constant (deg.C.)
m is an adjustment factor (dim)

a) Create a function in Matlab to estimate the rate of change of temperature (dT/dt) as a function of time (t). The function should accept the parameters: T, K_1 , K_2,T_a, and m. The output of your function is (dT/dt) in deg. C per minute.

b) Create a Matlab script that uses the Matlab function created in part (a) to estimate (dT/dt). Use the values of K_1 and K_2 for steel as 0.097 (1/minute) and 450 (deg. C.), respectively. The value of m is 1.55 and ambient temperature is 30 deg. C. Evaluate the function created in part (a) with 1000 linearly spaced steel temperature (T) values ranging from 1500 deg. C to ambient temperature.

c) Create a plot of (dT/dt) versus Temperature.Label appropriately.