CEE 123 Transport Systems 3: Planning & Forecasting

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Homework #1 -- Review of Pre-requisite Material (50 pts) [S O L U T I O N S]

Problem 1. [CEE121] Travel Forecasting (10 points)
Review Mannering *et al*. (2004) Chapter 8. Read 8.1-8.3; skim 8.4-8.5; read 8.6; skim 8.7 and Appendix 8A (note: this book was used in CEE121). The same material is available in most transportation texts and on-line (see, for example, The Four Step Model (MGMcNally) or Travel Forecasting Primer (Bierborn)).

Answer the following questions ***in your own words***:

a. What are the **steps** in the sequential approach to forecasting future travel?

   Mannering et al. identify (1) trip generation, (2/3) destination/mode choice, and (4) route choice.

b. What are the inputs and outputs of each forecasting step?

   The inputs to trip generation are demographic and socio-economic variables describing the activity system; the outputs of trip generation are the frequencies of trip origins and destinations by zone, typically categorized by activity type (M etal. include departure times, too). The inputs to destination choice (trip distribution) are the generation outputs (trip origins and destinations) and travel times between zones; the trip distribution outputs are the destinations (and departure times) for the total generated trips of an origin zone. Mode choice factors the resulting trip tables by mode shares. The input to route choice are (mode-specific) trip tables from trip distribution (and mode choice) as well as the transport network (paths and path travel times); the output is the set of (equilibrated) flows on the network (link volumes and travel times).

c. What is a **link performance function**? What role does it play in travel forecasting?

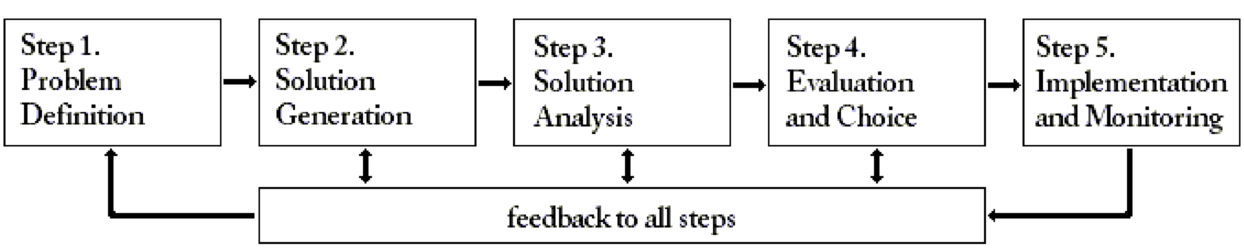
   The fundamental speed/density/flow relationship for a facility translates into a non-linear link performance function, with travel time increasing at an increasing rate as link volume approaches link capacity. LPFs represent the performance of a link relative to the demand for travel. The equilibration of demand and performance produces the flows (volumes and travel times) on a network.

d. What is the difference between **User Equilibrium** and **System Optimal** route choice formulations?

   UE (a result of Wardrop's 1st principle) states that routes utilized by travelers for a given O-D pair have equal travel times (a Nash equilibrium). SO simply states that total system travel time is a minimum that, in general, is not an equilibrium state.

e. What is the Transportation Planning Process?

   TPP is the standard problem solving approach for identifying and resolving transportation problems at all spatial layers.



The Transportation Planning Process

Problem 2. [CEE11] Statistical Methods (20 points)

The following speed and density data was collected on a local freeway segment.

Table 2. Speed and Density Measurements (2022)

Observation		Units	1	2	3	4	5	6	7	8	9	10
Speed	SMS	mph	50	45	40	30	25	50	35	35	25	20
Density	D	veh/mi	10	20	35	40	70	15	40	50	80	100

a. **Estimate** a linear speed-density regression model with X = density (D) and Y = Speed (u_s). You may perform the calculations by hand or use available software (include model input and output).

Sample hand calculations (any software can be used):

Obs	X Den	Y SMS	X-sq	Y-sq	XY
1	10	50	100	2500	500
2	20	45	400	2025	900
3	35	40	1225	1600	1400
4	40	30	1600	900	1200
5	70	25	4900	625	1750
6	15	50	225	2500	750
7	40	35	1600	1225	1400
8	50	35	2500	1225	1750
9	80	25	6400	625	2000
10	100	20	10000	400	2000
Sum	460	355	28950	13625	13650
Mean	X'=46	Y'=35.5			
S.D.	29.4	10.7			

```
b1 = [Sum{XY} - nX'Y']/[Sum{X}sq - nX'sq]
   = [13650-(10)(46)(35.5)]/[28950-(10)(2116)]
   = -0.3440

b0 = Y' - b1 X' = 35.5 - (-0.3440)(46)
   = 51.3240

R = [Sum{XY} - nX'Y']/[Sqrt(Sum{Xsq}-nX'sq) Sqrt(Sum{Ysq}-nY'sq)]

             [13650-(10)(46)(35.5)]
  = -------------------------------------------------
    [Sqrt(28950-(10)(2116)) Sqrt(13625-(10)(1260.25))]

  = -0.9496

R-sq = R(R)
     = 0.9017

Sest = Sqrt [ (Sum{Ysq} - b0(Sum{Y}) - b1(Sum{XY}) ]/(n-k-1) ]
     = Sqrt [{13625-(51.324)(355)-(-0.3440)(13650)}/8]
     = Sqrt [100.58/8]
     = 3.5458

Sb = Sest / [Sx Sqrt(n-1)]
   = 3.5458 / [(29.4)(3)]
   = 0.0402

t = b1/Sb
  = -0.3440/0.0402
  = -8.5572
```

```
Model:
Y = 51.3240 - 0.3440 X
```

b. **Define** and **find** mean free speed (u_f) and jam density (D_j) and express the results in Greenshield's format:

$u_s = u_f (1 - D / D_j)$

Mean Free Speed *is the average speed of vehicles traveling unimpeded on a defined section of roadway.* ***Jam Density*** *is a facility's maximum density (vehicles per mile), where spacing and space mean speed approach zero (cars are "bumper to bumper").*

```
Greenshield's:  us  =  uf ( 1 - D/Dj )
                    =  51.3 - 0.3440 D =  51.3 [ 1 - 0.0067 D]
                    =  51.3 [ 1 - (D/150) ]
thus:           uf  =  51.3 mph
and             Dj  =  150 vpm
```

c. Is the model **significant**? What **specific tests** support your contention?

Below is the Excel output for the regression above:

```
b1   =  -0.344030809    b0  =  51.3254172
se1  =   0.040157231    se0 =   2.160668026
R2   =   0.901714002    SEE =   3.544316447
F    =  73.39511416     df  =   8
ssr  = 922.0025674      sse = 100.4974326
```

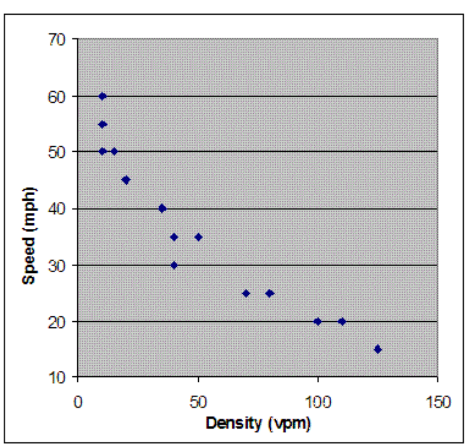
From the coefficients and associated standard errors, the t scores can be computed, showing that both the constant (t=23.75) and the density coefficient (t=8.56) are significantly (at 5%) as is the model's F-stat (73.40). The model is significant.

d. Consider four additional data points: {S,D} = {60,15},{15,125},{20,110},{55,10}. **How** will these points affect the estimated model? Does a **plot** suggest that the linear Greenshield's model might not be appropriate?

Below is the Excel output for the new regression:

```
b1   =  -0.339707043    b0  =  53.42075257
se1  =   0.035592255    se0 =   2.268570042
R2   =   0.883603344    SEE =   5.078470862
F    =  91.09574485     df  =  12
ssr  =2349.438176       see = 309.4903956
```

The plot suggests that the speed density curve may be non-linear.



Problem 3. [CEE121] Performance-Demand Equilibration (10 points)
Two single-link paths connect an origin and destination with performance functions:

$t_1 = 1 + 0.5\ x_1$
$t_2 = 2 + 1.0\ x_2$

with time t in minutes (min.) and volume x in thousands of vehicles per hour (kvph).

a. Determine UE flows if the total origin-to-destination demand is 800 veh/hr
b. Determine UE flows if the total origin-to-destination demand is 3,000 veh/hr
c. Calculate the total vehicle-hours of travel for both case (a) and (b)
d. Referring to Problem 1, how does this problem fit the sequential forecasting process? What elements are demand and what elements are supply?

Solutions:

(a) Determine UE flows if the total origin-to-destination demand is 0.8 kvph.

Test if both paths are used at the specified total flow under UE assumptions:

1. At T=0, t_1=1 and t_2=2 , thus Path #1 is used first.
2. At t_1=2, x_1=2.0 kvph. Until this volume is met (when $t_1 = t_2$), all traffic uses Path #1.
3. At T=0.8, only Path 1 is used so t_1=1.4 min, x_1=0.8 kvph.

(b) Determine UE flows if the total origin-to-destination demand is 3.0 kvph.

From part (a), both paths are used when T is greater than 2.0 kvph. Solve for T=3.0 kvph.

$t_1 = 1 + 0.5\ x_1$
$t_2 = 2 + 1.0\ x_2$
$t_1 = t_2$
$x_1 + x_2 = 3.0$

$1 + 0.5\ x_1 = 2 + (3.0 - x_1)$
$x_1 = 2.67$ kvph
$t_1 = 1 + 0.5\ (2.67) = 2.33$ min
$x_2 = 0.33$ kvph
$t_2 = 2.33$ min

(c) Calculate the total vehicle-hours of travel for both case (a) and (b)

Total Vehicle-Hours Traveled (TVHT) = $[x_1(t_1) + x_2(t_2)]/60$
Case (a): TVHT(a) = 800(1.4)/60 = 18.67 vht
Case (b): TVHT(b) = [2667(2.33) + 333(2.33)]/60 = 3000(2.33) = 116.67 vht

NOTE: You will need to perform similar calculations throughout the quarter.

(d) Referring to Problem 1, how does this problem fit the sequential forecasting process?
What elements are demand and what elements are supply?

Total OD demand is fixed, at 800 vph for case (a) and at 3000 vph for case (b), which corresponds to the first three steps of the Four Step Model (FSM). This analysis thus corresponds to Step 4 (trip assignment) which, as for the basic FSM, is an equilibration of route choice only. The link performance functions provide the supply side expressions.

Problem 4. [CEE110] Project Evaluation (10 points)
In the final task of the CEE123 term project, teams will compare future alternative transportation systems in

terms of system performance and system cost relative to a "No Build" alternative. There are several project evaluation techniques that can be utilized.

The following data summarize the estimated costs and benefits of a proposed Miasma Beach shuttle bus system for 6 alternatives defined by system length (total route-miles covered). What is the **preferred alternative** based on these benefits and costs? Show all work.

```
    Table 4. Shuttle Bus Capital Costs and Expected Benefits
----------------------------------------------------------------
 Alternative               1      2      3      4      5      6
----------------------------------------------------------------
 System Length (miles)     5     10     15     20     25     30
 Capital Costs ($M)       80    100    130    180    270    380
 User Benefits ($M)      220    300    340    370    390    425
----------------------------------------------------------------
 Benefits-Cost ($)       140    200    210    190    120     45
 Marginal Benefits
 - Marginal Costs (4)        60     10     -20    -70    -75
 Alt. 1 BC Ratio:          2.75 (pick 1)
 Incremental BCR: 2 vs 1        4.00 (pick 2)
 Incremental BCR: 3 vs 2               1.33 (pick 3)
 Incremental BCR: 4 vs 3               0.60 (keep 3)
 Incremental BCR: 5 vs 3               0.36 (keep 3)
 Incremental BCR: 6 vs 3               0.34 (keep 3)
----------------------------------------------------------------
```

Project 3 is the best based on change in marginal benefits and costs as well as the incremental benefit-cost ratios. The increasing costs of the longer system exceeds benefits beyond Project 3's 15-mile system.

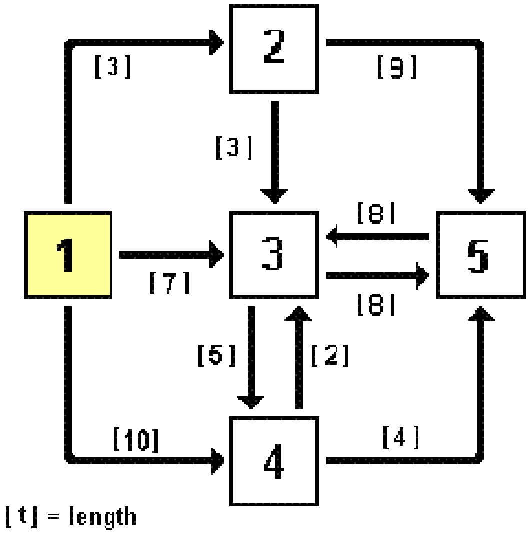
Problem 5. [CEE111] Network Models and Optimization (10 points)

Primal: Min $C = \Sigma_{ij}\, x_{ij}\, c_{ij}$
subject to:
$\Sigma_i\, x_{is} - \Sigma_j\, x_{sj} \geq -1$ . . . for each origin node s
$\Sigma_i\, x_{ik} - \Sigma_j\, x_{kj} = 0$ . . . for each intermediate node k
$\Sigma_i\, x_{it} - \Sigma_j\, x_{tj} \geq +1$ . . . for each destination node t

Dual: Max $D = w_t - w_s$
subject to:
$w_j - w_i \leq C_{ij}$ . . . for all links (i,j)

a. What do these equivalent mathematical program represent?
   These are two equivalent formulations of a mathematical program to find the shortest path from node s to node t.
b. Pick one and define the variables and what the solution means.
   The first is the primal problem which minimizes total cost for sending one unit of demand from s to t. The second is the dual problem that maximizes the total distance from origin node to the destination node under the constraint that the distance between any two connected nodes cannot be greater than the length of the link that connects them. Here, w_j is the node label containing the cumulative travel time to node j and c_{ij} is the cost on link (i,j). The two formulations are equivalent. The optimum value of D equals that of C, the length of the minimum path.
c. For the network depicted, **formulate** the linear program using one of the formulations above.

   Math Programming Formulation (inbound flow is positive)




```
Min C =
 3x12 + 7x13 +10x14 + 3x23 + 9x25 + 5x34 + 8x35 + 2x43 + 4x45 + 8x53
Subj to:
 -x12 -  x13 -  x14                                                      >=-1
  x12               -  x23 -  x25                                         = 0
         x13         +x23        -  x34 -  x35  + x43        + x53        = 0
                x14              +  x34         - x43 -  x45               = 0
                              x25       +  x35        +  x45  - x53       >= 1
```

Last Updated: 11 April 2024