CEE 123 Transportation Systems 3: Planning & Forecasting

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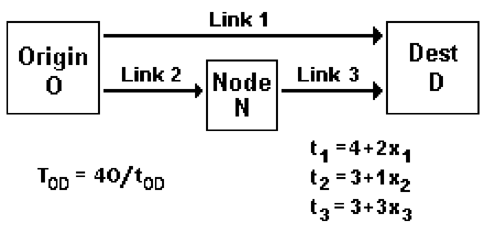
Midterm Solutions: Address all four parts; each part has a choice of problems to solve. Clearly identify the question that you are answering, label your answer, and show all work. You must turn in this exam paper!

Part A -- Answer EITHER Problem A1 OR Problem A2 [25 points]

Problem A1

Two zones are connected via a simple network of three links. Demand for trips between Origin O and Destination D is a function of O/D travel time as specified below; linear link performance functions are also provided (time is expressed in minutes, volumes in kvph). **Find** the equilibrium flow.



SOLUTION:

In addition to the demand functions and the three link performance functions, there is a UE/path travel time constraint and a flow conservation constraint. T(od) is OD demand volume (kvph) and t(od) is OD travel time (minutes), x(a) is link volume (kvph) and t(a) is link travel time (minutes): 6 equations & 6 unknowns.

OD Demand:	T(od) = 40 / t(od)
Link Perform 1:	t(1) = 4 + 2 x(1)
Link Perform 2:	t(2) = 3 + 1 x(2)
Link Perform 3:	t(3) = 3 + 3 x(3)
UE / Path Time:	t(od) = t(1) = t(2) + t(3)
Flow Conservat:	T(od) = x(1) + x(2) = x(1) + x(3)

The problem can be simplified since the lower path will have the same volume on each link and thus can be combined into a single performance function: t(b) = t(2) + t(3) = [3 + 1 x(2)] + [3 + 3 x(2)] = 6 + 4 x(2)

Equate the LPF for Path 1 (link 1) with the combined performance function for Path 2 (link 2 and 3); substitute this result into the demand functions:

- t(1) = 4 + 2 x(1) = 6 + 4 x(2) = t(2) + t(3) , thus, x(1) = 1 + 2 x(2)
- T(od) = x(1) + x(2) = 40 / t(1) , thus, 1 + 3 x(2) = 40 / (6 + 4 x(2))

Solve the resulting quadratic to yield:

- x(2) = 1 kvph
- From flow conservation: x(3) = 1 kvph
- From LPF 2: t(2) = 4 min
- from LPF 3: t(3) = 6 min
- From UE: t(1) = t(2) + t(3) = 10 min
- thus, x(1) = 3 kvph
- From flow conservation: x(3) = 1 kvph
- Check: T(od) = x(1) + x(2) = 40 / t(1) => 10 = 40/10 checks!

Problem A2

Three routes directly connect an origin and a destination with performance functions given as:

- Route #1: $t_1 = 5 + 1.5\ x_1$
- Route #2: $t_2 = 12 + 3.0\ x_2$
- Route #3: $t_3 = 2 + 0.2\ [x_3]^2$

with travel time t (in minutes), and route volume x (in kvph). The total O/D demand is 4.0 kvph.

a. If all routes are not used, at what volume will all routes be used?

1. At x=0, t(1) = 5, t(2) = 12, and t(3) = 2 , so R#3 is used 1st, R#1 2nd, and R#2 last;
2. At t = 5, x(3) = 3.873 kvph. Until this volume is exceeded, all traffic uses R#3;
3. At t = 12, x(3) = 7.07 kvph and x(1) = 4.67 kvph. Until demand exceeds 11.74, R#2 is not used;
4. At T(od) = 4 kvph, only routes 1 and 3 are used.

b. Determine user equilibrium flows (volumes and travel times)

1. O/D Demand: T(od) = 4.0 kvph 2
2. Perf Fct 1: t(1) = 5 + 1.5 x(1)
3. Perf Fct 3: $t(3) = 2 + 0.2[x(3)]^2$
4. User Equil: t(1) = t(3)
5. Solve simultaneously:
6. x(1) =0.065 kvph, t(1) = 5.1 min
7. x(3) =3.935 kvph, t(3) = 5.1 min

Part B -- Answer EITHER Problem 1 OR Problem 2 [25 points]

Problem B2
The following summarizes three HBW trip production models.

```
  CORRELATION   POP         LABF        P-HBW
  Population    1.0000      0.9971      0.9652
  Labor Force   0.9971      1.0000      0.9693
  HBW Prods     0.9652      0.9693      1.0000

MODEL P#1:  DEPENDENT VARIABLE => HBW Productions

MULTIPLE R      0.9652      VARIABLE      B         BETA    S.E. B     T
R-SQUARE        0.9317      1. POP       0.3216    0.9652   0.0168   19.19
ADJ R-SQUARE    0.9292      Constant     9.2943
S.E. OF EST.  321.3973
F(1,27,0.05)  368.22

MODEL P#2:  DEPENDENT VARIABLE => HBW Productions

MULTIPLE R      0.9693      VARIABLE      B         BETA    S.E. B     T
R-SQUARE        0.9395      1. LABF      0.8214    0.9693   0.0401   20.47
ADJ R-SQUARE    0.9372      Constant   -14.7253
S.E. OF EST.  302.4908
F(1,27,0.05)  419.17

MODEL P#3:  DEPENDENT VARIABLE => HBW Productions

MULTIPLE R      0.9694      VARIABLE      B         BETA    S.E. B     T
R-SQUARE        0.9397      1. POP      -0.0672   -0.2016   0.2094   -0.32
ADJ R-SQUARE    0.9351      2. LAB       0.9917    1.1702   0.5326    1.86
S.E. OF EST.  307.6712      Constant   -17.7434
F(2,26,0.05)  202.64
```

The following summarizes two HBW trip attraction models.

CORRELATION	E-Basic	E-Retail	E-Other	E-Total	HBW Attr
E-Basic	1.0000	0.4155	0.5233	0.8329	0.7772
E-Retail	0.4155	1.0000	0.7611	0.7884	0.8113
E-Other	0.5233	0.7611	1.0000	0.8869	0.8585
E-Total	0.8329	0.7884	0.8869	1.0000	0.9654
HBW Attr	0.7772	0.8113	0.8585	0.9654	1.0000

```
MODEL A#1:  DEPENDENT VARIABLE => HBW Attractions

MULTIPLE R       0.9654      VARIABLE      B         BETA    S.E. B     T
R-SQUARE         0.9319      1. E-Total   0.8348    0.9654   0.0434   19.24
S.E. OF EST.   390.6000      Constant    50.4
F(1,27,0.05)   369.5

MODEL A#2:  DEPENDENT VARIABLE => HBW Attractions

MULTIPLE R       0.9688      VARIABLE      B         BETA    S.E. B     T
R-SQUARE         0.9387      1. E-Basic   0.7634    0.4431   0.1001    7.63
S.E. OF EST.   384.9976      2. E-Retail  1.2408    0.3572   0.2652    4.68
F(3,25,0.05)   127.7         3. E-Other   0.7055    0.3548   0.1620    4.35
                             Constant    79.04
```

Review each of the models, computing any missing statistics, and commenting on validity. **Select** and justify one production model and one attraction model.

SOLUTION:
HBW Production Model: *Both potential explanatory zonal variables, cars and labor force, are highly correlated with the dependent variable, HBW productions per zone. The first two bivariate models bear this out: both models are significant (based on coefficient t-stats and model F-stats), have proper signs, and high R-sq. A potential problem, high correlation between the two explanatory variables, is born out in Model 3 where multicolinearity drives the model insignificant, based on coefficient t-stats and an incorrect sign on POP. Either of the first two models could be used, but not the third. I'll choose: P(HBW) = 9.29 + 0.32*POP*

HBW Attraction Model: *Each potential explanatory variable is correlated. Both models are significant and logical. The difference is the simplicity of the first model (using only total employment) versus the greater policy sensitivity of the second model (using three categories of employment, each with different signs). Either choice is acceptable. I'll choose: A(HBW) = 50.4 + 0.83*E-Tot*

Apply these models to the following TAZ data and compare to survey results.

---- KWBASE00.DAT ----

TAZ	POP	LABF	E-Ret	E-Bas	E-Oth	E-Tot	Prod	Attr	Est P	Est A
1	1639	649	357	348	776	1481	478	1185	536	1287
2	2352	945	42	629	1071	1742	826	1043	766	1505
3	5355	2342	129	2294	204	2627	2187	2431	1731	2243

Since these are only 3 of at least 29 TAZs, do not balance Ps and As.

Problem B2
Table 1 provides the results of a household travel survey for a 3 zone study area developing a category model for estimating trip productions using HH Income and Cars per HH as explanatory variables. **Complete** the specification for this total trip production model.

Number of Trips from HH Survey		HH Income Low	HH Income High
Cars per HH	0	460	150
	1	620	760
	2+	160	680

Number of Survey Households		HH Income Low	HH Income High
Cars per HH	0	150	30
	1	120	110
	2+	20	70

Trips per Household		HH Income Low	HH Income High
Cars per HH	0	3.1	5.0
	1	5.2	6.9
	2+	8.0	9.7

Apply your production model to the 3 zone study area as described below.

TAZ 1

Number of Forecast Households		HH Income Low	HH Income High
Cars per HH	0	2	0
	1	2	2
	2+	0	2

Household Trips		HH Income Low	HH Income High
Cars per HH	0	6	0
	1	10	14
	2+	0	20

Estimated TAZ Trips = 50

TAZ 2

Number of Forecast Households		HH Income Low	HH Income High
Cars per HH	0	1	0
	1	1	1
	2+	2	3

Household Trips		HH Income Low	HH Income High
Cars per HH	0	3.1	0
	1	5.2	6.9
	2+	16.0	29.1

Estimated TAZ Trips = 60

TAZ 3

Number of Forecast Households		HH Income Low	HH Income High
Cars per HH	0	1	2
	1	1	2
	2+	1	0

Household Trips		HH Income Low	HH Income High
Cars per HH	0	3.1	10.0
	1	5.2	13.8
	2+	8.0	0

Estimated TAZ Trips = 40

A Trip Attraction Model has been estimated for you. **Apply** the model using the forecast data provided and **provide** a summary of Ps and As that will satisfy standard modeling policy.

Attraction Model: $A_j^e = 4.0 + 2.0\ HH_j + 4.0\ RE_j + 3.0\ OE_j$

TAZ	HH	RE	OE	A_j^e
1	8	3	0	32
2	8	4	4	48
3	10	4	0	40
Total	26	11	4	120

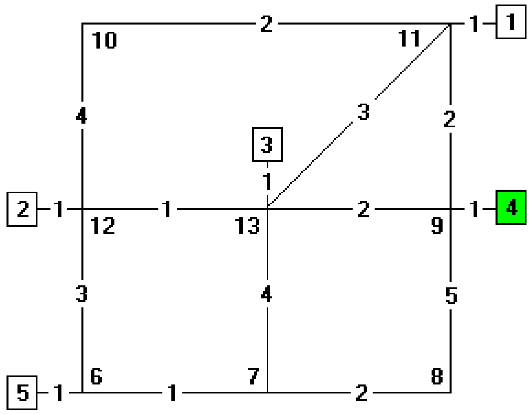
TAZ	A_j^e	P_i	A_j
1	32	50	40
2	48	60	60
3	40	40	50
Total	120	150	150

HH = households
RE = retail employment
OE = other employment
A_j^e = estimated attr.
P_i = trip productions
A_j = balanced attr.

The solution involves estimating trip production rates from survey data in the first table, then applying these rates to each TAZ's household distribution in the second table. The production totals for each TAZ carry to the third table where the attraction model is applied. Total attractions must be normalized to match total productions.

Part C -- Complete the following problem [10 points]

Find the shortest path tree from node 1 to all other nodes via Dijkstra's Algorithm; show all work in the tabular or graphic formats.



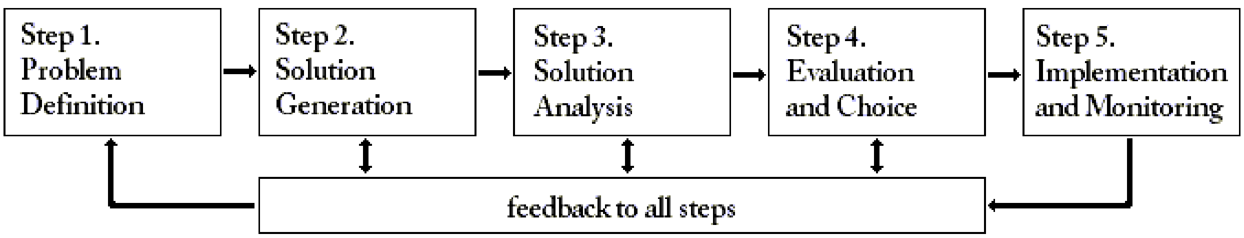
C. Solution Minimum Path Worksheet: From Centroid 4 to {1,2,3}

Step	Node From	Node To	Cum	Link	Total	Decision	Path
1	4	9	0	1	1	1. Add # 9	4- 9
New 2	9	8	1	5	6		
		11	1	2	3	2. Add #11	4- 9-11
		13	1	2	3		
2	9	8	1	5	6		
		13	1	2	3	3. Add #13	4- 9-13
New 3	11	1	3	1	4		
		10	3	2	5		
2	9	8	1	5	6		
3	11	1	3	1	4	4. Add C#1	4- 9-11-C1
		10	3	2	5		
New 4	13	3	3	1	4		
		7	3	4	7		
		12	3	1	4		
2	9	8	1	5	6		
		10	3	2	5		
4	13	3	3	1	4	5. Add C#3	4- 9-13-C3
		7	3	4	7		
		12	3	1	4		
New 5	C1	Centroid 1 (no mew outbound considered)					
2	9	8	1	5	6		
		10	3	2	5		
4	13	7	3	4	7		
		12	3	1	4	6. Add #12	4- 9-13-12
New 6	C3	Centroid 3 (no new outbound considered)					
2	9	8	1	5	6		
		10	3	2	5	7. Add #10	4- 9-11-10
4	13	7	3	4	7		
New 7	12	2	4	1	5		
		6	4	3	7		
		10	4	4	8	7. Del link	

```
     2    9    8    1     5      6
     4   13    7    3     4      7
     7   12    2    4     1      5     7. Add C#2   4- 9-13-12-C2
                6    4     3      7
New 8   10    No new nodes to reach outbound from #10
-----------------------------------------------------------------
     2    9    8    1     5      6
     4   13    7    3     4      7
     7   12    6    4     3      7
New 9   C2    Centroid 2 End of Search
-----------------------------------------------------------------
```

Part D -- Answer any 5 of the 8 questions [8 points each for a total of 40 points]

Problem D1
Concisely **describe** the stages of the Transportation Planning Process?
How does this process relate to the 4-step travel forecasting model?

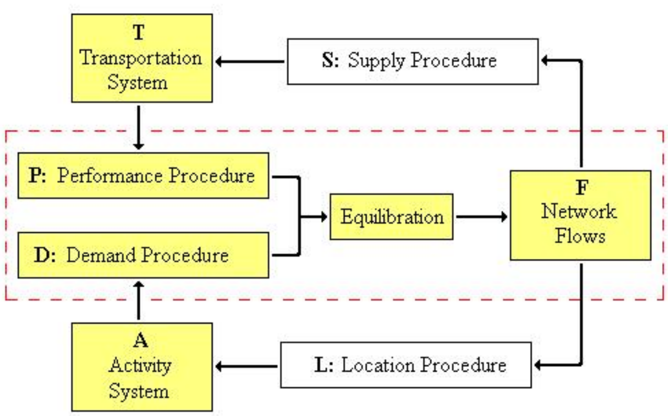


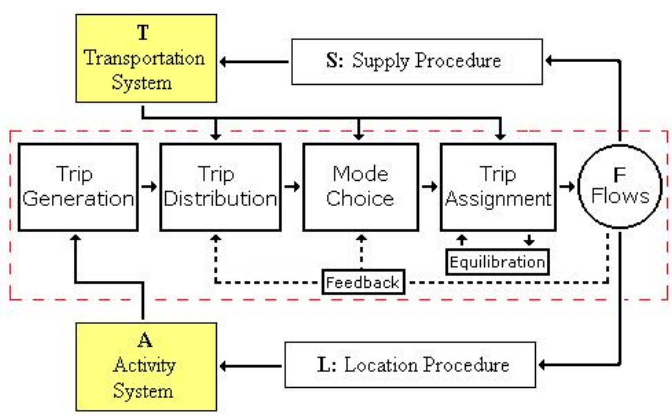
The Transportation Planning Process

The 4-step model applies in the Solution Analysis step.

Problem D2
Describe the Manheim/Florian Transportation Systems Analysis framework. **How** does this process relate to the 4-step travel forecasting model?

The top diagram displays the TSA framework; the bottom superimposes the Four Step Model in TSA.





*The 4-Step (TDF) model requires specification of the Transportation System **T** and the Activity System **A**. The input to Trip Generation is the Activity System **A**; the output are productions Pi and attractions Aj by trip purpose. The Transportation System **T**, represented as skim trees, and the P's and A's from Step 1 serve as input to Trip Distribution; output are trip matrices Tij by trip purpose. The Tij matrices serve as input to Mode Choice as do additional Transportation System **T** (and sometimes additional Activity System **A**) variables; the outputs are mode-specific trip matrices. These trip matrices serve as input to the respective modal networks in Step 4 Route Assignment; the outputs are link volumes and travel times.*

Problem D3
What are the differences between calibration, validation, and forecasting?

- *A model is calibrated via a systematic adjustment of parameters so that model output matches known conditions. A trip generation model is calibrated so that the estimated parameters and the corresponding explanatory variables produce an estimate of the dependent variable that is reasonably close to the observed value. Transportation models are typically calibrated every 10 years.*
- *Validation occurs when a previously calibrated model is tested on data that was not used in calibration. Validation is typically completed every 2-3 years (minimally against ground counts).*
- *Forecasting is the application of a validated model with estimated, future values of explanatory variables to produce future estimates of the dependent variable.*

Problem D4
What is the difference between *user equilibrium* and *system optimal*?
Where is this reflected in the Four Step Model?

- *User Equilibrium (UE) results when all drivers try to minimize individual travel times, resulting in an equilibrium where, for a given O-D pair, no driver can unilaterally change routes and be better off. All routes used for a given O-D pair, thus, have the same travel time.*
- *System Optimal (SO) corresponds to the minimum total system travel time. Since there in general will not be equal route travel times for a given O-D pair, the result is not in equilibrium.*

These concepts apply directly in Step 4, Trip Assignment (and indirectly in the model system if full feedback is employed).

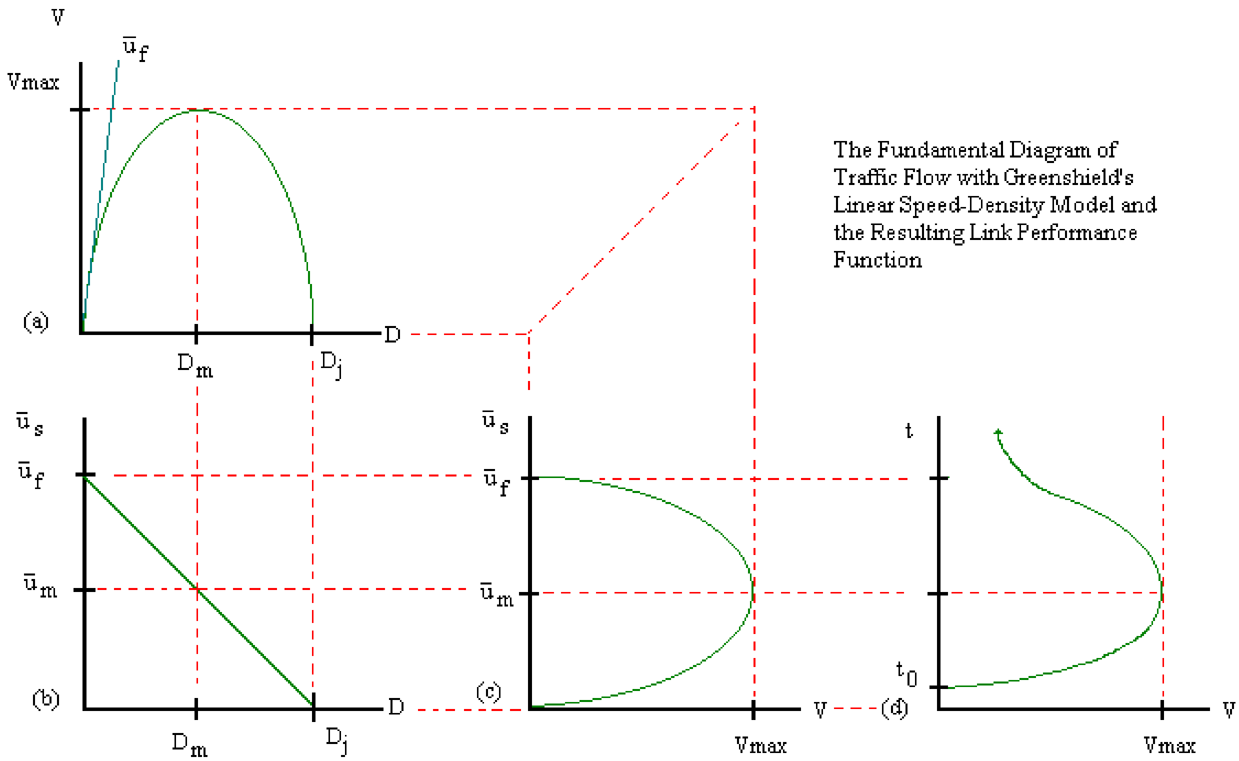
Problem D5
Compare productions and attractions (Ps & As) to origins and destinations (Os & Ds).
When are they the same and when are they different?

For home-based trips (e.g.,HBW or HBO), home is always the production and the non-home end is always the attraction. For non-home-based trips (NHB), the origin is the production and the destination is the attraction.

Classification	Production	Attraction
Home-based	Home	Non-home
Non-home-based	Origin	Destination

Problem D6
Briefly describe the relationship between a *link performance function* and the Fundamental Diagram of Traffic Flow for that link.

*For a given link, the Fundamental Diagram relates volume to speed and density (for a given speed-density model). The plot of volume versus speed is easily transformed into volume versus travel time for a facility of fixed length (that is, a link) -- this function *is* the link performance function. It illustrates how increasing volume will increase travel time at an increasing rate as volume approaches link capacity, and how travel time continues to increase as link volume drops off as density increases toward jam density (the backward bending* *phenomena).*



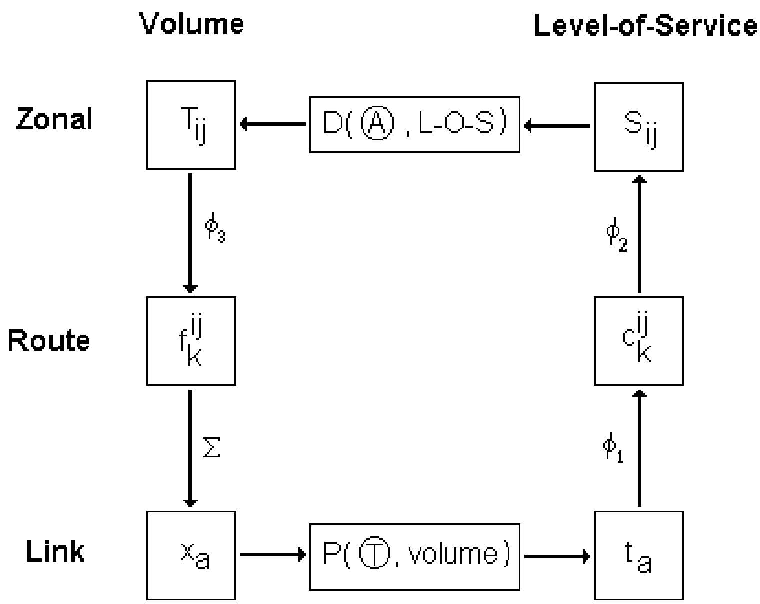
Problem D7
Compare the generic TSA forms of a demand function and a performance function.

Specification of A establishes a Demand Function D(•), with Flow Volume V varying with A options and Level-of-Service G, or V = D (A, G) , where: G = level-of-service (e.g., travel time) and V = volume of the flow pattern (typically, vehicles per hour, vph). The demand procedure is typically defined for individual origin-destination zone pairs; the zones are the basic spatial units defining the activity system.

Specification of T establishes a Performance Function P(•), with Level-of-Service (LOS) G varying with T options and Flow Volume V, or G = P (T, V) , where: G = level-of-service (e.g., travel time) and V = volume of the flow pattern (typically, vehicles per hour, vph). The performance procedure is typically defined for a link, the basic unit of analysis for the transportation network.

Problem D8
Transportation Systems Analysis has procedures defined at the OD, the path, and the link level. Briefly describe the procedures that connect these spatial levels.

The formal Demand Model is defined at the zonal (OD level), relating OD travel time to OD volume (Tij). The formal Performance Model is defined at the link level, relating link volume to link travel time. The path level relates link travel times to path travel times and then to OD travel times, and also related OD volume to path volume and then to link volume to complete the loop.


Volume
Level-of-Service
Zonal
Route
Link
T ij
D(A , L-O-S)
S ij
ϕ3
ϕ2
f ij k
c ij k
Σ
ϕ1
x a
P(T, volume)
t a