Modelling Transportation Systems

General Introduction

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Lecture Schedule

Lecture	Time	Location	Topic
1	9:50am, 30/April	YF301 Ji Zhong Building	General Introduction + Linear Programming I (Simplex Method)
2	9:50am, 7/May		Linear Programming II (Duality and Sensitivity Analysis)
3	9:30am, 11/May		Nonlinear Programming I
4	9:50am, 14/May		Nonlinear Programming II
5	9:30am, 18/May		Tutorial I
6	9:50am, 21/May		Integer Programming
7	9:50am, 28/May		Solution Algorithm
8	9:30am, 1/June		Tutorial II + CPLEX

7	四月	8	9	10	11	12	13	14	4月12日、13日，全校运动会，停课不补。
8		15	16	17	18	19	20	21	
9		22	23	24	25	26	27	28	
10		29	30	1	2	3	4	5	5月1日,国际劳动节放假。
11	五月	6	7	8	9	10	11	12	
12		13	14	15	16	17	18	19	
13		20	21	22	23	24	25	26	
14		27	28	29	30	31	1	2	
15		3	4	5	6	7	8	9	6月7日,端午节放假。

Teaching Assistant

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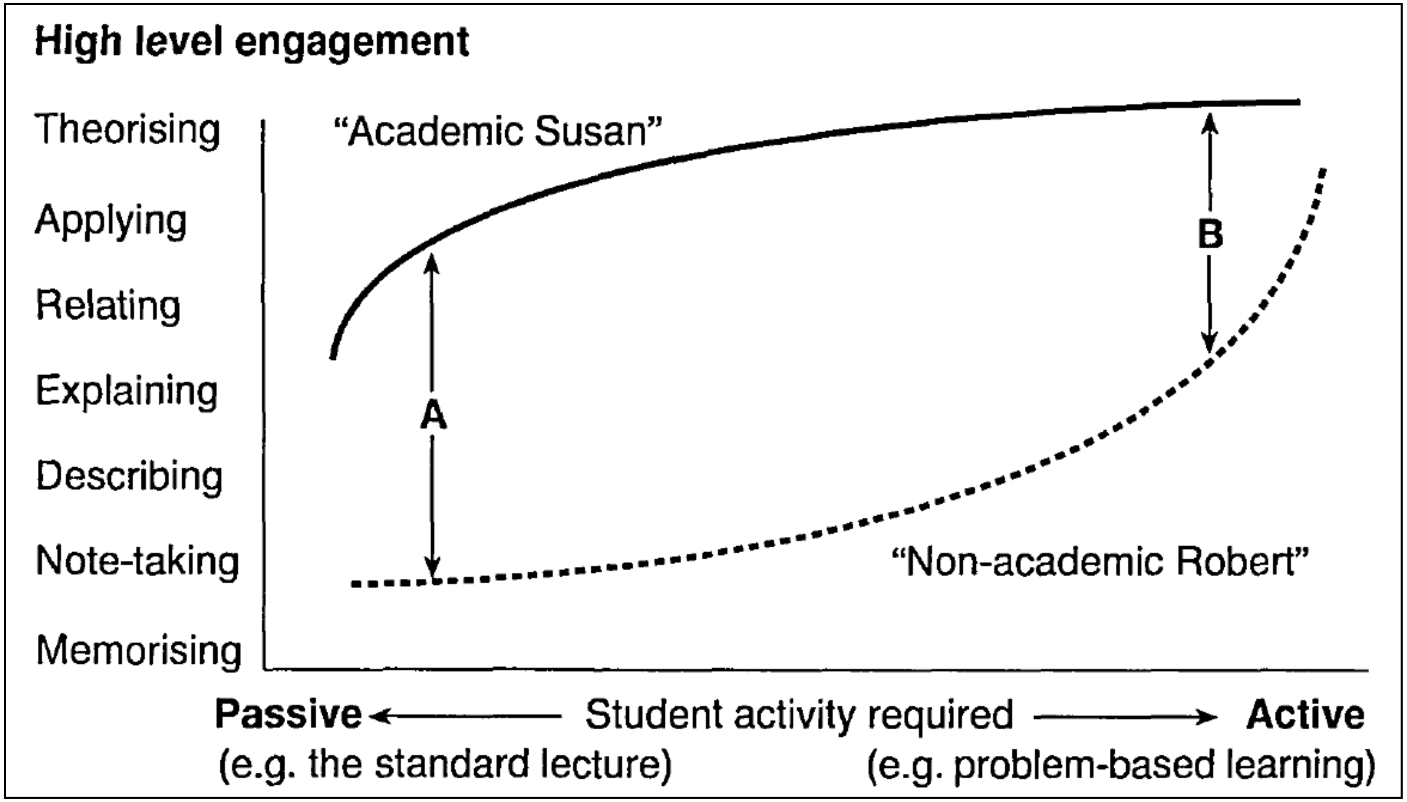
Teaching and Learning

- What are the major difference between new teaching/learning concept and traditional teaching/learning concept?



Biggs, 1999. What the student Does

Key Skills of Graduate Studies

- Critical Thinking
- First Principle
- 站在制高点看问题
  - Tasks of Transportation Studies
    - Supply
    - Demand
    - Equilibrium
    - Adjustment from supply side
    - Adjustment from demand side

Modelling Transportation Systems

❑课程性质：

课程以交通问题的**定量分析**为主来研究交通建模问题，将交通工程思想和管理思想相结合，应用系统的、科学的、数学分析的方法，在数据分析的基础上，通过建立、检验和求解数学模型获得最优交通决策方案。

❑教学目的：

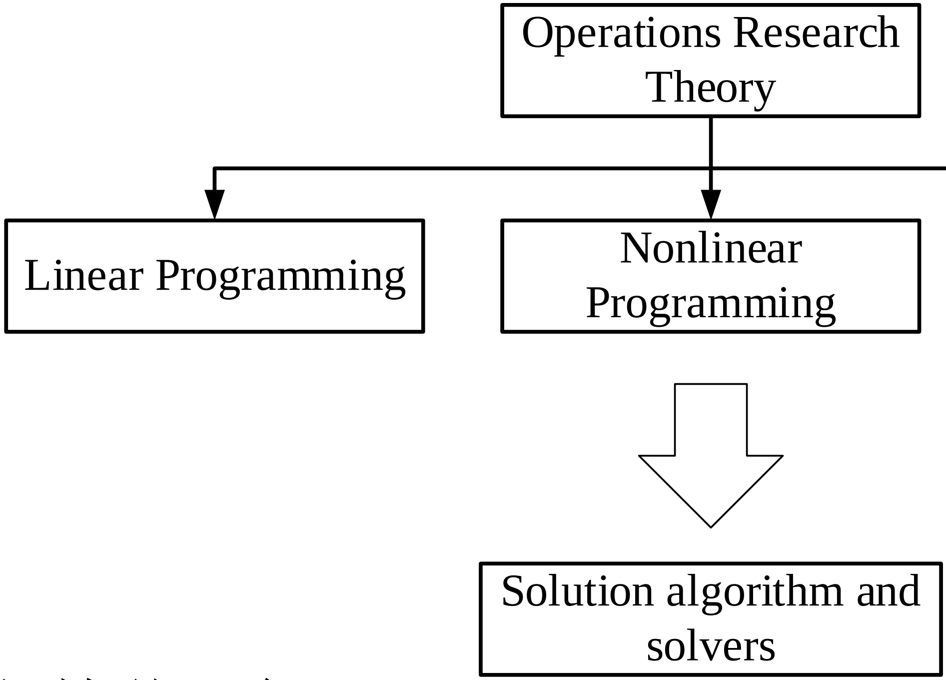
- 正确理解运筹学的基本原理和方法，掌握运筹学整体**优化思想**；
- 能够采用计算机软件对常用模型进行求解计算和分析，能正确应用各类模型分析、解决一些实际问题；
- 培养和提高学生**科学思维**、**科学方法**和**创新能力**，为进一步的研究和应用打下基础。

Modelling Transportation Systems

- Who are teaching/learning Operations Research?
  - Decision Science-Business School
  - Mathematical Programming-School of Mathematics
  - Industrial System Engineering
  - Other Disciplines requiring Systematic Analysis

Modelling Transportation Systems

❑课程知识体系：



MATLAB+CPLEX

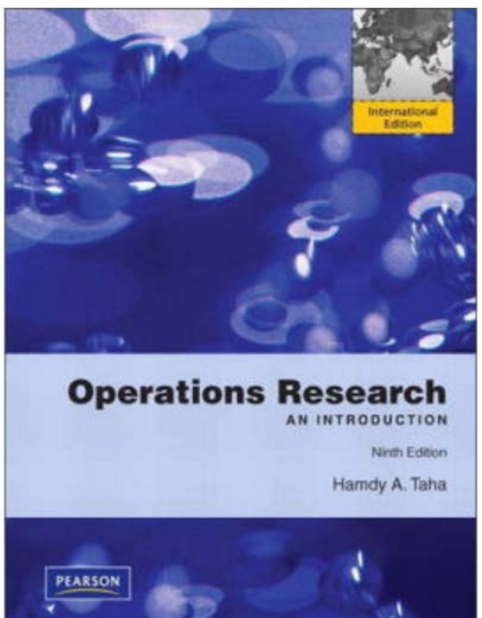
❑课程教学理念：

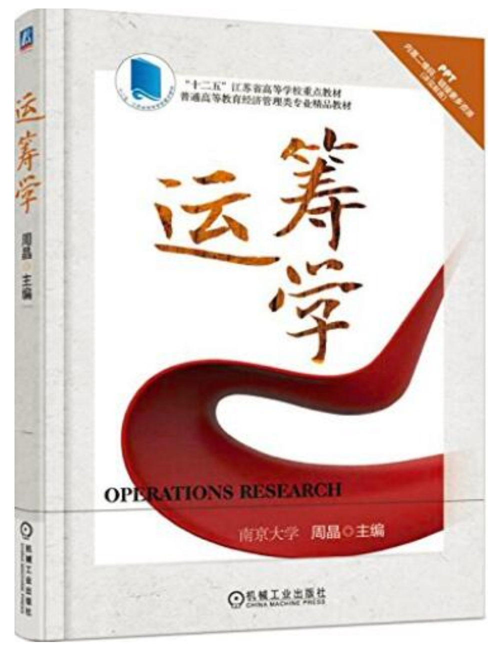
✓对研究生交通建模能力及创新能力的培养；

✓对研究生熟练运用求解软件能力的培养。

Modelling Transportation Systems

- Text Books：
  - Taha, H. A. (2013). Operations research: an introduction (Ninth Edition). Pearson.
  - 运筹学（第4版），清华大学出版社
  - 运筹学（第1版），机械工业出版社





Modelling Transportation Systems

- Some simple tests to check your capability of mathematical modelling.
  - How to solve f(x)=0, given that f(x) is a increasing and differentiable nonlinear function?
  - If you need to deliver pizza to 100 different costumers widely distributed in the city, how to determine the optimal route?
  - If you have one container to take lots of different furniture, how to load them?

Necessity of Course Project

- A holistic application and deep learning of the course contents.
- A trial/adventure of knowledge discovery.
- Publish High-quality papers
  - English skills
  - Writing skills
  - Models/algorithms
  - Data/case-study

Modelling Transportation Systems

Course Project

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Course Project

- **Objective**
  - This **Course Project** requires the student to use the models/methods learnt in this course to analyze a practical transport example.
- **Assessment**
  - 20% of final marks of the Modelling Transportation Systems component.
  - The Top 10% papers will get paper review comments as feedback, which represents good quality for publication.

❑ Requirements

You should provide the followings:

- **Topic: Transport Network Design or Management**

i.e. design of the optimal road network, optimal road pricing scheme, public transport network design, optimal design of coordinated traffic signals (Bi-level modelling is recommended).

- A description of the transportation problems and issues of concern.
- Clearly identify the objectives of your analysis.
- Describe what data input and parameters are needed.
- Model formulation and analysis.
- Use a solver such as **AMPL, Matlab+CPLEX, Excel** or program by yourself for the numerical analysis.
- <u>**The code should be submitted as appendix in your paper.**</u>

- **Submission requirement:**
  Please submit your report in **Word or PDF File**, with **your name, email and student number**.

- **Deadline:**
  8pm on 29/June 2018

- Title
- Abstract-Keywords
- Introduction
  - 1.1 Literature Review
  - 1.2 Objectives and Contributions
- Problem Statement
- Mathematical Models
- Solution Algorithm
- Case Study
- Conclusion
- Reference List
- Appendix

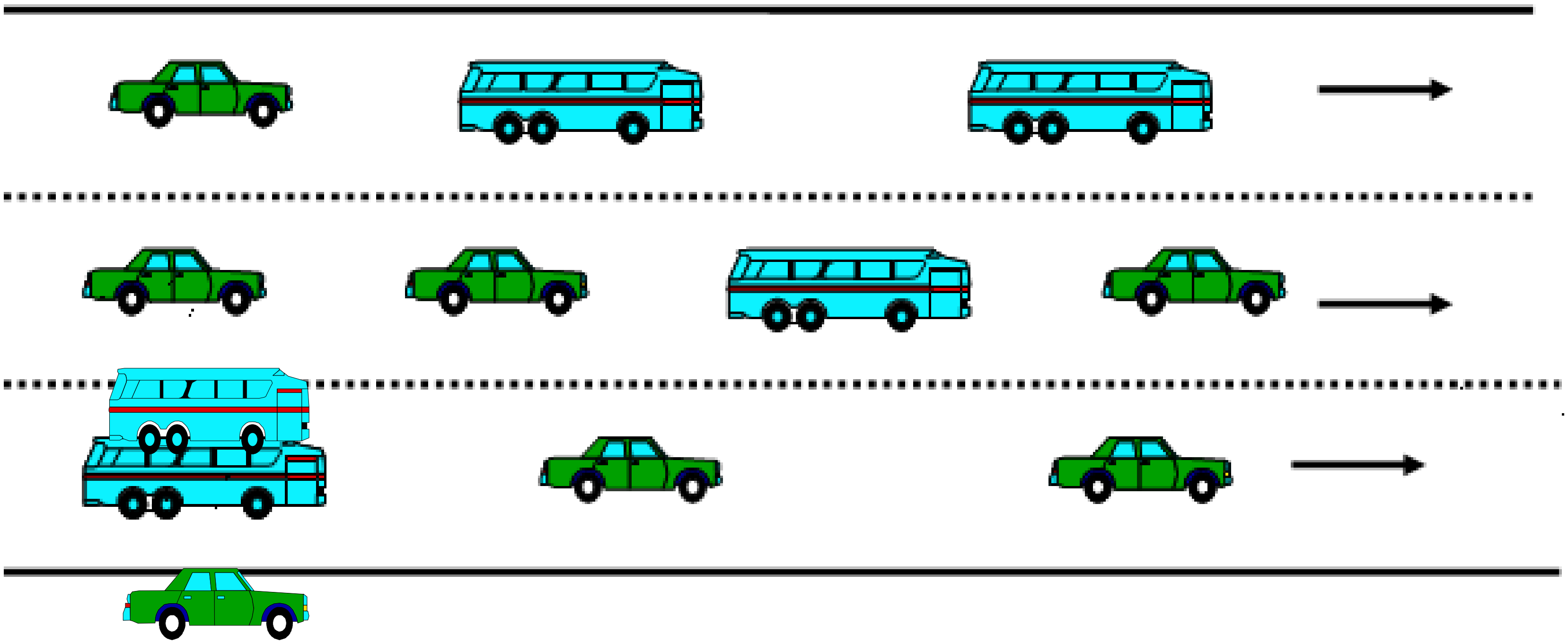
- Format requirement of the report.
  - Following the format requirement of Transportation Research (Part A, B, C, D, E, any one).
  - No less than 10 pages, excluding the reference list and the appendix.
  - 1.5 line space; 12 size font.
  - No less than 10 references.
  - Drafted in English;
  - Recommend to: use Endnote/Mendeley for citations and MathType for equations.

Readings

- Peng, Y. T., Li, Z. C., & Choi, K. (2017). Transit-oriented development in an urban rail transportation corridor. Transportation Research Part B, 103, 269-290.
- Strehler, M., Merting, S., & Schwan, C. (2017). Energy-efficient shortest routes for electric and hybrid vehicles. Transportation Research Part B, 103, 111-135.
- Lu, C. C., Liu, J., Qu, Y., Peeta, S., Rouphail, N. M., & Zhou, X. (2016). Eco-system optimal time-dependent flow assignment in a congested network. Transportation Research Part B, 94, 217-239.
- Kitthamkesorn, S., & Chen, A. (2017). Alternate weibit-based model for assessing green transport systems with combined mode and route travel choices. Transportation Research Part B, 103, 291-310.

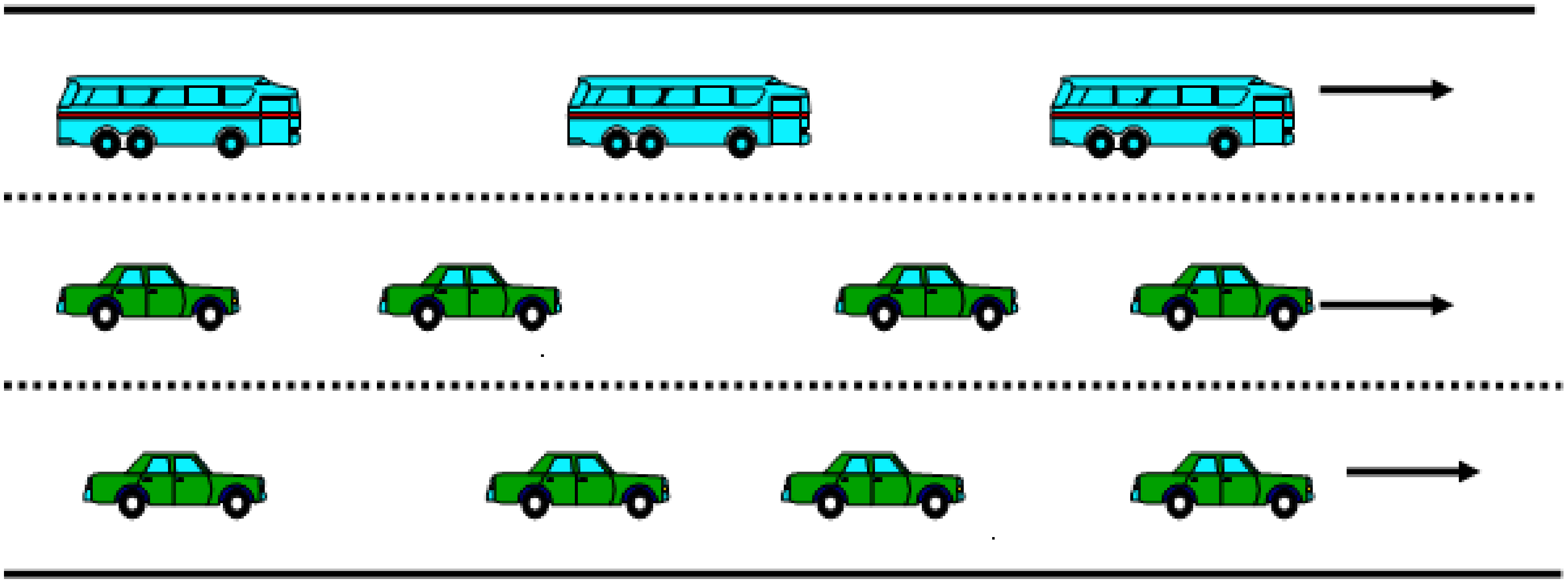
Example: Evaluation bus priority scheme

- Case 1. Without Bus Priority



Example: Evaluation bus priority scheme

- Case 2: With Bus Lane



Example: Evaluation bus priority scheme

- Remarks:

To encourage people to switch from personal modes of transport (private car), greater priority for public transport has been introduced on our roads in order to improve public transport services. For example, bus lane was introduced on Tuen Mun expressway (Hong Kong) during rush hour as a cost-effective alternative to address growing traffic congestion problems by providing priority treatment for buses. As a consequence of introduction of bus lanes, some auto drivers would switch to buses, thereby reducing total vehicle demand, whereas there would be fewer lanes available for the remaining vehicles, thus possibly increasing the time cost of remaining auto users. It is therefore an important issue to evaluate the efficiency of bus lanes based on some system-wide cost-effectiveness measures. This example presents a simple modal split model to evaluate the benefit resulting from bus lanes, and therefore determine whether or not bus lanes should be introduced in a multilane highway.

- Suppose, there exists a multilane highway connecting a residential area and workplace, and a certain number of identical individuals must commute to work on the highway everyday. Without loss of generality, we suppose there are two types of modes for travel: commuters can either drive a car alone to work or take a bus. For simplicity, here we assume there is only one person in one car.
  - The following variables are introduced in this model:

N: Total number of commuters;

N_{car}: Number of commuters by car;

N_{bus}: Number of commuters by bus;

n: Number of highway lanes;

n_{bus}: Number of lanes for bus (if bus lane is introduced);

n_{car}: Number of lanes for private cars;

Obviously, $N_{car} + N_{bus} = N$ where N is assumed to be given, while N_{car} and N_{bus} are determined endogenously by a modal split model; $n_{\mathrm{bus}} + n_{\mathrm{car}} = n$.

- To develop a modal split function, we use generalized cost to characterize each travel mode below.

$$C_{car} = t_{car}, \quad C_{bus} = t_{bus} + \Delta \tag{1}$$

where t_{car} and t_{bus} are travel times (in minutes) by car and bus, respectively, Δ is a constant that lumps the additional cost in equivalent time (positive or negative) for individual riders of buses compared to car users. Note that Δ may be seen to consist of the extra cost for walking from home to bus terminal and from bus terminal to office and waiting time at bus terminal.

- Suppose at equilibrium, the mode split at aggregate demand level is governed by a logit formula specified below.

$$N_{bus} = N \times \frac{\exp(-\beta C_{bus})}{\exp(-\beta C_{bus}) + \exp(-\beta C_{car})} = \frac{N}{1.0 + \exp\left\{-\beta\left(C_{car} - C_{bus}\right)\right\}}, \tag{2}$$

$$N_{car} = \frac{N}{1.0 + \exp\left\{-\beta\left(C_{bus} - C_{car}\right)\right\}} \quad \left(= N - N_{bus}\right) \tag{3}$$

where β is a positive parameter whose value can be estimated from survey data. The total system travel cost can thus be calculated as

$$TC = N_{bus} \times \left(t_{bus} + \Delta\right) + N_{car} \times t_{car} \tag{4}$$

- For a given commuter demand N and a given n-lane highway, we are facing the problem of whether a bus lane should be introduced. To do this, we can compare the total system costs in the cases with and without bus lane. The cost-effectiveness (CE) can thus be measured by

$$CE = TC_n^{n_{bus}} \big/ TC_n^0 \qquad (5)$$

where $TC_n^{n_{bus}}$ represents the total system cost at equilibrium when there are n_{bus} bus lanes on an n-lane highway, and TC_n^0 is the total system cost in the case without bus lanes ($n_{bus} = 0$). Consequently, bus lanes should be introduced on the highway if $CE < 1.0$.

- Suppose the total travel demand N=5000 passengers/hr, travel time for each highway lane is determined by

$$t = 9.0 + 12.0 \times 10^{-3} q \qquad (6)$$

where t is travel time in minute, q is traffic flow in veh/h/lane. For simplicity we assume passenger car equivalence for bus is 1.0 (this means that a bus is equivalent to a car in calculation of congested travel time) and a fixed fleet of buses **110 bus/h** to provide bus service. We also assume that the fleet of buses is able to accommodate any level of passenger demand in the current case. It is also assumed that buses and cars will move at the same speed when there is no bus lanes.

- Assume $\beta = 0.50$, $\Delta = 5.00$(min), calculate the value $CE = TC_3^1 \big/ TC_3^0$. In other word, to assess the effect of introducing one bus lane in a 3 lane expressway.

Solutions

1) Calculate TC_3^0

In other words, to evaluate the total travel cost when there is no bus lane
on the 3-lane highway.

$t_{bus} = t_{car}$ in this case (according to assumption)

So $$N_{bus} = \frac{N}{1.0 + \exp\{-\beta(c_{car} - c_{bus})\}}$$

$$= \frac{N}{1.0 + \exp\{\beta\Delta\}} \qquad \begin{pmatrix} c_{car} = t_{car} \\ c_{bus} = t_{bus} + \Delta \end{pmatrix}$$

$$= \frac{5 \times 10^3}{1.0 + \exp(0.5 \times 5.0)} \qquad (\beta = 0.5, \Delta = 5.00)$$

$$= 379 (\text{persons/h})$$

$$N_{car} = 5000 - 379 = 4621 (\text{veh/h})$$ (one car one person)

$$q_{total} = 110 + 4621 = 4731 (\text{veh/h}) \qquad \begin{pmatrix} \text{including buses} \\ \text{and cars} \end{pmatrix}$$

$$\therefore\ \mathrm{t}_{\mathrm{bus}} = t_{car} = 9.0 + 12 \times 10^{-3} q \qquad \begin{pmatrix} \text{distributed uniformly} \\ \text{over 3 lanes} \end{pmatrix}$$

$$= 9.0 + 12 \times 10^{-3} \times \frac{4731}{3}$$

$$= 27.924 (\text{min})$$

$$\therefore \mathrm{TC}_3^{\mathrm{o}} = 379 \times (27.924 + 5.00) + 4621 \times 27.924$$

2) Calculate TC_3^1

. In other words, to determine the total travel cost when one bus lane is introduced

$$\begin{aligned} c_{bus} &= t_{bus} + \Delta \\ &= 9.0 + 12.0 \times 10^{-3} q_{bus} + \Delta \\ &= 9.0 + 12.0 \times 10^{-3} \times 110 + 5.0 \\ &= 15.32(\text{min}) \end{aligned}$$

(one lane for busses)

$$\begin{aligned} c_{car} = t_{car} &= 9.0 + 12.0 \times 10^{-3} \times \frac{N_{car}}{2} \\ &= 9.0 + 6.0 \times 10^{-3} \times N_{car} \end{aligned}$$

$$\left(\begin{array}{l} \text{cars are uniformly} \\ \text{distributed over the} \\ \text{remaining 2 lanes} \end{array} \right)$$

Thus, we have

$$\mathrm{N}_{\mathrm{car}} = \frac{N}{1.0 + \exp\left\{-\beta(c_{bus} - c_{car})\right\}}$$

$$= \frac{5.0 \times 10^3}{1.0 + \exp\left\{-0.5(15.32 - 9.0 - 6.0 \times 10^{-3} \times N_{car})\right\}}$$

$$= \frac{5 \times 10^3}{1.0 + \exp\left\{3.0 \times 10^{-3} N_{car} - 3.16\right\}} \qquad (1)$$

$$N_{car} = 1376(veh / h)$$

$$\therefore c_{car} = 9.0 + 12 \times 10^{-3} \times \frac{1376}{2} = 17.256(\mathrm{min})$$

$$TC_3^1 = 15.32 \times (5000 - 1376) + 17.256 \times 1376 = 0.793 \times 10^5 (\text{person-min/h})$$

3) $$CE = \frac{TC_3^1}{TC_3^0} = \frac{0.793\times10^5}{1.415\times10^5} = 0.560$$ or 44.0% reduction in total travel time

Using Newton's method to solve equ. (1)

Let $$f(x) = x - \frac{5\times10^3}{1.0+\exp(3.0\times10^{-3}x-3.16)}$$

determine x so that $f(x)=0$

$$f^{'}(x) = 1.0 + \frac{15.0\exp(3.0\times10^{-3}x-3.16)}{\left[1.0+\exp(3.0\times10^{-3}x-3.16\right]^2}$$

$$x^{(k+1)} = x^{(k)} - \frac{f(x^{(k)})}{f'(x^{(k)})}$$

k	$x^{(k)}$	$f(x^{(k)})$	$f'(x^{(k)})$
0	2000	1723.997	1.7823
1	1033	-1544.60	4.7464
2	1358	-72.528	4.0637
3	1376	-0.9528	3.9931
4	1376		

$$x^{(4)} - x^{(3)} = 1376 - 1376 = 0.0$$ Convergence is achieved

<u>Question: what is algorithm? In what case we need an algorithm?</u>