Lecture Note

TRANSPORT PLANNING AND MODELING

--- MODAL SPLIT MODEL 01 ---

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INTRODUCTION

- The choice of transport mode is probably one of the most important classic models in transport planning
- This is because of the key role played by public transport in policy making. Almost without exception public transport modes make use of road space more efficiently than the private vehicle
- Moreover, if some drivers could be persuaded to use public transport instead of private vehicle, the rest of the private vehicle users would benefit from improved level of service

- The issue of mode choice, therefore, is probably single most important element in transport planning and policy making
- It affects the general efficiency with which we can travel in urban areas, the amount of urban space devoted to transport functions, and whether a range of choice is available to travelers
- The issue is equally important in inter-urban transport as again rail modes can provide a more efficient mode of transport (in terms of resources consumed, including space), but there is also a trend to increase travel by road

- It is important then to develop and use models which are sensitive to those attributes of travel that influence individual choices of mode
- We will see how far this necessity can be achieved, where alternative policies need to be expressed as modifications to useful if rather inflexible functions like the generalized cost of travel

FACTORS INFLUENCING MODAL SPLIT :

- **Trip Maker Characteristics**
  1. Income
  2. Car ownership
  3. Car availability
  4. Age

- **Trip Characteristics**
  1. Trip purpose: work, shop, recreation, etc.
  2. Destination orientation: CBD versus non CBD
  3. Trip length

- **Transportation Systems Characteristics**
  1. Waiting time
  2. Speed
  3. Cost
  4. Comfort and convenience
  5. Access to terminal or transfer location

CATEGORIES OF MODAL SPLIT MODELS

- Modal split can be carried out **as part of trip generation** whereby the number of trips made by a given mode is related to the characteristics of zone of origin. It means that transport trips are generated separately from private transport trips.

- Modal split may be carried out **between trip generation and trip distribution**.

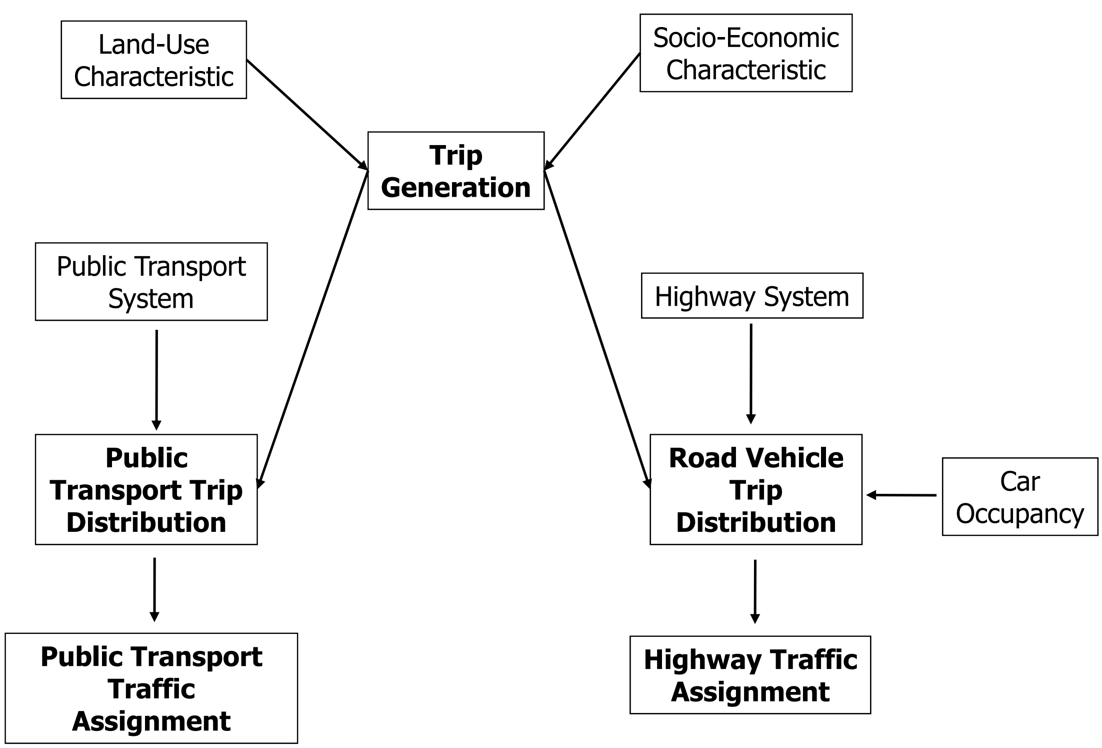
  Motor-vehicle owning households in the zone of origin have a choice of travel mode depending upon the motor-vehicle/household ratio while non motor-vehicle owning household trips are captive to public transport

- Modal split can be carried **out between the trip distribution and the trip assignment process**. Trip distribution allows journey times both by public and private transport to be estimated and then the mode choice between public transport trips may be made on the basis of travel time and cost

1. Modal Split considered as a part of trip generation

- In this case, usually modal split is made on the basis of:
  a. car ownership in the zone of origin,
  b. distance of the zone of origin from the city centre
  c. residential density in the zone of origin
  d. accessibility of the zone of origin to public transport, etc.

A Generalized Trip End Modal-Split Procedure



- This approach makes it difficult to take into account:
  a. changes in the public transport network
  b. improvement in the highway system
  c. restraint of private vehicle use

- Usually, these model indicate a very high future car use and arbitrary modal split has to be imposed after assignment process

- For these reason, modal split now rarely considered at this early stage in the modeling process

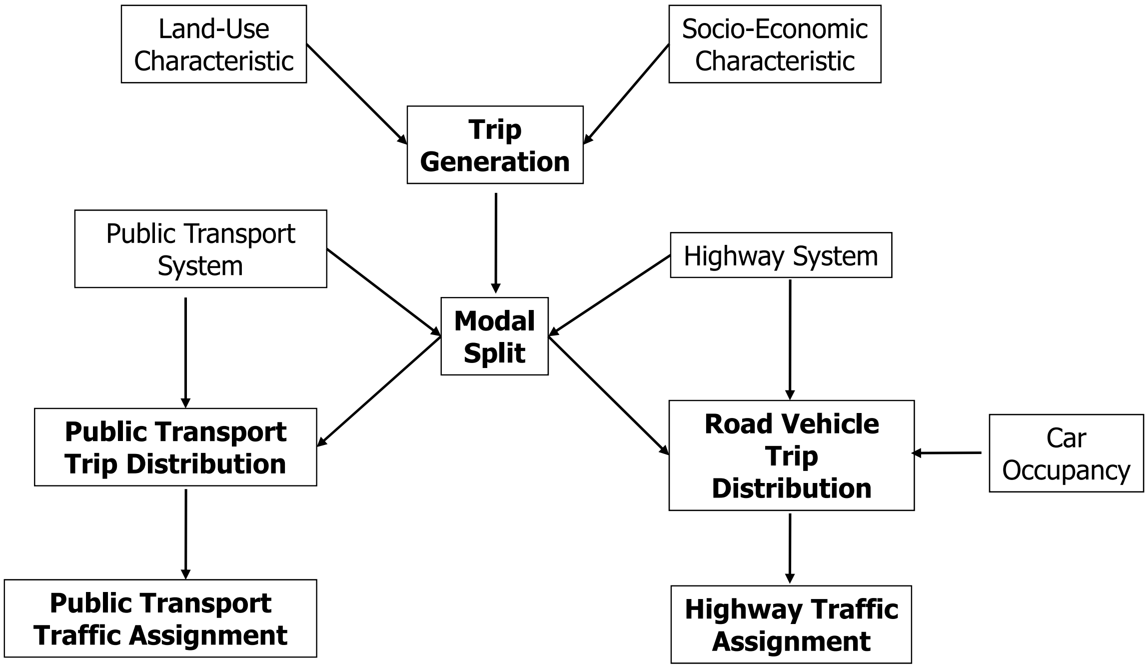
2. Modal Split carried out between trip generation and distribution

- In this approach, person trips are predicted and the percentage of these trips made by public and private transport estimated from such:
  a. factors as socio-economic and land-use characteristics
  b. the quality of public transport system
  c. the number of car available

- The assumption is made in this method that the total number of trip generated is independent of the mode of travel

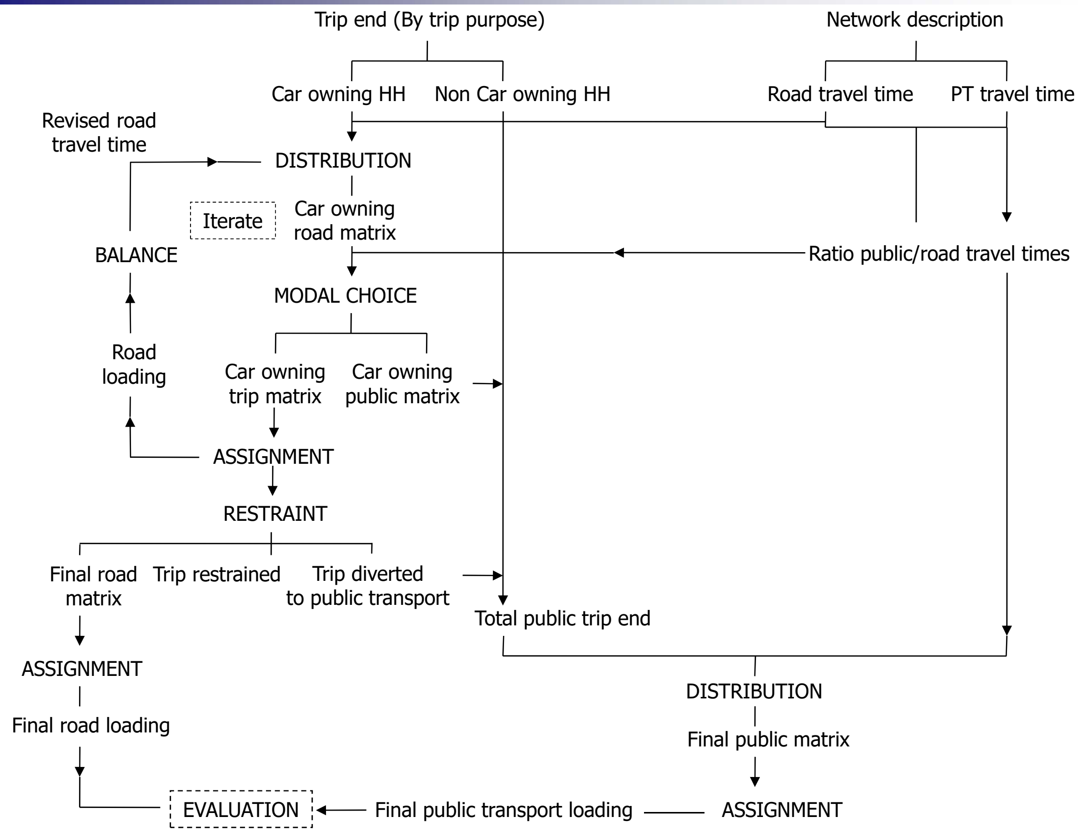
- This method is not generally adopted because it has to be assumed here that trip makers choose their mode of travel before deciding where to go

A Generalized Model When Modal Split Is Carried Out Between Generation And Distribution



3. Modal Split carried out between trip distribution and assignment

- This approach is frequently used in transportation studies because it allows the cost and level of service of a trip to be used as the modal split criterion
- Because of the complexity of the transportation process, travel time alone is sometimes used as the cost criterion.
- Normally travel times based on road speeds are utilized to distribute the choice trips.
- These travel times together with travel time by public transport are then used to determine modal split
- Then, the public transport portion of these trips is added to the captive public transport trip ends



PROBABILISTIC MODELS AND UTILITY FUNCTIONS

- Model have been developed recently for mode choice based on probability concepts

- Each competing model is described in a utility (or disutility) function, and these utilities, expressed mathematically, describe the probability associated with a trip maker's choosing of the competing alternatives

- These models require the selection of a mathematical form and the calibration of appropriate utility functions, which must allow the selected model to reproduce the available base year data

- A utility function in this context describes the degree of satisfaction that trip makers derive from their mode choices.
- A disutility function represents the generalized cost (or 'independence') associated with each choice.
- The magnitude of either depends on the attributes of each choice and of the individual making that choice (for example their socio-economy status)
- The utility function requires a selection of appropriate variables in an appropriate functional form, at a suitable level of aggregation (for example: regional, zonal, household, and individual), perhaps also varying by trip purpose and time of day

- The utility function is often expressed as the liner weighted sum of the independent variables, such as:

$$V = \alpha + \beta.X_1 + \gamma.X_2 + ... + a_n X_n$$

Where V is the utility derived from a choice defined by the magnitude of the attributes X_1 … X_n that are present in that choice, weighted by the corresponding model parameters $\alpha, \beta, \gamma, \ldots a_n$

- Separate utility models are sometimes calibrated for each mode, perhaps with similar attributes applying to each mode (such as cost, level or service or convenience) but with different model parameter values
- The mode-specific formulation does not present problems, however, when a new mode is introduced because the base year data necessary to calibrate its utility function would probably be unavailable

CALCULATION METHODS IN MODAL SPLIT MODEL

- Generally, there are 2 methods which is usually used in calculating mode choice:

  1. Probit Model
  - ✓ Binary Ordered probit model
  - ✓ Binary/Multinomial probit model

  2. Logit Model
  - ✓ Binary/Multinomial logit model
  - ✓ Mixed logit model
  - ✓ Nested logit model

PROBIT MODEL

- Equation :

$$P_1 = \int_{-\infty}^{\infty} \int_{-\infty}^{v_2 - v_1 + x_1} \frac{\exp\left\{-\frac{1}{2(1-\rho^2)}\left[\left(\frac{x_1}{\sigma_1}\right)^2 - \frac{2\rho x_1 x_2}{\sigma_1\sigma_2} + \left(\frac{x_2}{\sigma_2}\right)^2\right]\right\}}{2\pi\sigma_1\sigma_2\sqrt{(1-\rho^2)}} \partial x_2 \partial x_1$$

- Where the covariance matrix of normal distribution associated to this latter model has the form:

$$\sum = \begin{pmatrix} \sigma_1{}^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2{}^2 \end{pmatrix}$$

LOGIT MODEL

- Equation :

$$\Pr\left(V_{nm} > V_{nb}\right) = \frac{\exp\left(V_{nm}\right)}{\exp\left(V_{nm}\right) + \sum_{b \neq m} \exp\left(V_{nb}\right)}$$

- If only 2 modes compared :

$$\Pr\left(V_{nm} > V_{nb}\right) = \frac{1}{1 + \exp\left(V_{nb} - V_{nm}\right)}$$

- Where, as previously explained :

$$V = \alpha + \beta.X_1 + \gamma.X_2 + ... + a_n X_n$$

Deriving Logit Model

- If each alternative mode *m* has a person-specific utility for traveler *n* (U_{nm}), the utility can be expressed by linear function as follows:

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

- The random variable ε_{nm} in the utility function is the unobservable individual and alternative specific error term. According to Random Utility Maximization (RUM) theory, an alternative mode *m* will be chosen by traveler *n*, if the utility of that alternative mode is the maximum of all alternative modes (denoted as mode *b*)

$$U_{nj} > \max_{i=1,2,3...n,\, j\neq i} U_{ni}$$

$$V_{nj} > \left\{ \max_{i=1,2,3...n,\, j\neq i} U_{ni} \right\} - \varepsilon_{nj}$$

- Then, by using the probability function, it is obtained:

$$\Pr\left(U_{nm} > \max_{b=1,2,3\ldots n,m\neq b} U_{nb}\right) = \Pr\left(V_{nm} > \left\{\max_{b=1,2,3\ldots n,m\neq b} U_{nb}\right\} - \varepsilon_{nm}\right)$$

$$= \Pr\left(V_{nm} > \left(V_{nb} + \varepsilon_{nb}\right) - \varepsilon_{nm}\right)$$

$$= \Pr\left(V_{nb} \leq V_{nm} + \left(\varepsilon_{nm} - \varepsilon_{nb}\right)\right)$$

- It reveals that the systematic utility of a chosen alternative is a function of the difference between two random error terms: the error term of the chosen alternative (ε_{nm}) and the error term of the second best alternative (ε_{nb}).

- Assume that the error term is identically and independently distributed (IID) with Gumbel Distribution (Extreme Value Distribution Type 1)

- Referring to that distribution, the maximum over an IID Extreme-Value random variable is also extreme value distributed and the difference of two IID Extreme-Value random terms is logistically distributed. Hence, the implied cumulative distribution of the random error term of the chosen alternative can be written as :

$$\Pr\left(V_{nn} > V_{nb}\right) = \frac{\exp\left(V_{nm}\right)}{\exp\left(V_{nm}\right) + \sum_{b\neq m} \exp\left(V_{nb}\right)}$$

DEVELOPING OF MODAL SPLIT MODELS

Modal split models are developed from observed data on trip making available from home interview surveys. The analysis involves the processing of a variety of data for both demand and supply.

Aggregate Model

- Modal split models of the 1960s and early 1970s in most cases were based on an aggregate approach, which examined the mode choice of trip makers and their trips in groups based on similar socioeconomic and/or trip characteristics.
- These mode choice models usually involved two modes only: auto and transit.

- A detailed stratification scheme was used, and the share of each mode was determined for each stratified group of trips, which was then correlated with selected independent variables.
- The dependent variable was percent transit applicable to a group of trips of similar characteristics made by similar trip makers. Commonly used independent variables included the ratio of travel time by transit to that by automobile; the ratio of travel cost by transit to that by automobile; and the ratio of accessibility by transit to that by automobile.
- The relationship of the dependent variable, percent transit, with the independent variable, say ratio of travel times, commonly was expressed by a set of curves. These curves sometimes were referred to as modal diversion curves.
- The development of aggregate modal split models requires a large amount of data.

Disaggregate Model

- In late 1970s a new approach known as disaggregate behavioral method was developed and refined by a number of researchers.
- This approach recognized each individual's choice of mode for each trip instead of combining the trips in homogeneous groups.
- The underlying premise of this modeling approach is that an individual trip maker's choice of a mode of travel is based on a principle called utility maximization.
- Another premise is that the utility of using one mode of travel for a trip can be estimated using a mathematical function referred to as the utility function, which generates a numerical utility value/score based on several attributes of the mode (for the trip) as well as the characteristics of the trip maker. Examples of a mode's attributes for a trip include travel time and costs.
- The utilities of alternative modes can also be calculated in a similar manner. A trip maker chooses the mode from all alternatives that has the highest utility value for him or her.

AGGREGATE CASE

- The calculation method is as follows:

$$\Pr\left(V_{nm} > V_{nb}\right) = \frac{1}{1+\exp\left(V_{nb} - V_{nm}\right)}$$

$$\Pr\left(V_{nb} > V_{nm}\right) = 1 - \Pr\left(V_{nm} > V_{nb}\right) = \frac{\exp\left(V_{nb} - V_{nm}\right)}{1+\exp\left(V_{nb} - V_{nm}\right)}$$

- Taking the ratio of both proportions yields:

$$\frac{\Pr\left(V_{nm} > V_{nb}\right)}{\Pr\left(V_{nb} > V_{nm}\right)} = \frac{\Pr\left(V_{nm} > V_{nb}\right)}{1-\Pr\left(V_{nm} > V_{nb}\right)} = \frac{1}{\exp\left(V_{nb} - V_{nm}\right)}$$

- Thus:

$$\exp\left(V_{nb} - V_{nm}\right) = \frac{1 - \Pr\left(V_{nm} > V_{nb}\right)}{\Pr\left(V_{nm} > V_{nb}\right)}$$

$$\left(V_{nb} - V_{nm}\right) = \log_e\left(\frac{1 - \Pr\left(V_{nm} > V_{nb}\right)}{\Pr\left(V_{nm} > V_{nb}\right)}\right)$$

- Where:

$$V_{nb} - V_{nm} = \alpha + \beta\left(X_{nb} - X_{nm}\right)$$

- Finally:

$$\alpha + \beta\left(X_{nb} - X_{nm}\right) = \log_e\left(\frac{1 - \Pr\left(V_{nm} > V_{nb}\right)}{\Pr\left(V_{nm} > V_{nb}\right)}\right)$$

Exercise

- A mode choice survey has been undertaken on a corridor connecting 4 residential areas A, B, C, and D with three employment areas U, V, and W.

- Corridor is served by a good BRT link and a reasonable road network. The three employment zones are in a heavily congested area and therefore journeys by BRT there are often faster than by car. The information collected during the survey is summarized in the next slide.

- F_1 = in vehicle travel time in minutes
  F_2 = excess time (walking plus waiting) in minutes
  F_3 = out of pocket travel costs (petrol or fares) in 1.000 rupiah
  F_4 = parking cost associated with a one way trip, in 1.000 rupiah

- **Survey result**

OD Pair	Car				BRT			Proportion by Car
	F_1	F_2	F_3	F_4	F_1	F_2	F_3	
A – U	25	3	30	10	20	10	19	0.82
B – U	21	3	25	10	18	8	18	0.80
C – U	19	3	21	10	15	10	8	0.84
D – U	16	3	18	10	15	15	7	0.95
A – V	25	5	40	20	25	10	27	0.75
B – V	20	5	25	20	20	8	20	0.80
C – V	15	5	15	20	10	8	10	0.55
D – V	13	5	15	20	15	12	10	0.89
A – W	29	4	42	15	25	10	30	0.75
B – W	19	4	23	15	15	9	25	0.80
C – W	16	4	20	15	12	10	10	0.70
D – W	11	4	15	15	10	10	5	0.85

- From the analysis, it is understood that generalized cost (X) for Car and BRT:

  $X_{car} = (2.F_1) + (4.F_2) + F_3 + F_4$

  $X_{BRT} = (2.F_1) + (4.F_2) + F_3$

- Estimate the number of person using car when there is no difference between the utility values of using car and BRT !

- **Calculation Result**

P car	P brt	X car	X brt	X brt - X car (Xi)	Log e ((1 - P car) / P car) (Yi)	Xi.Yi	Xi ²
0.82	0.18	102	99	-3	-1.51635	4.549	9
0.8	0.2	89	86	-3	-1.38629	4.159	9
0.84	0.16	81	78	-3	-1.65823	4.975	9
0.95	0.05	72	97	25	-2.94444	-73.611	625
0.75	0.25	130	117	-13	-1.09861	14.282	169
0.8	0.2	105	92	-13	-1.38629	18.022	169
0.55	0.45	85	62	-23	-0.20067	4.615	529
0.89	0.11	81	88	7	-2.09074	-14.635	49
0.75	0.25	131	120	-11	-1.09861	12.085	121
0.8	0.2	92	91	-1	-1.38629	1.386	1
0.7	0.3	83	74	-9	-0.84730	7.626	81
0.85	0.15	68	65	-3	-1.73460	5.204	9
Total				-50	-17.34843291	-11.3438	1780
Average				-4.1667	-1.4457		

- Since $\log e\left(\frac{1-\Pr\left(V_{car} > V_{BRT}\right)}{\Pr\left(V_{car} > V_{BRT}\right)}\right) = \alpha + \beta\left(X_{BRT} - X_{car}\right)$ is equal to $Y = \alpha + \beta . X$, thus α and β can be calculated

- **Finding the value of α and β**

$$\beta = \frac{\left(n.\sum X_i Y_i\right) - \left(\sum X_i \sum Y_i\right)}{\left(n.\sum X_i^2\right) - \left(\sum X_i\right)^2} = \frac{\left(12x - 11.3438\right) - \left(-50x - 17.3483\right)}{\left(12x1780\right) - \left(-50\right)^2} = -0.0532$$

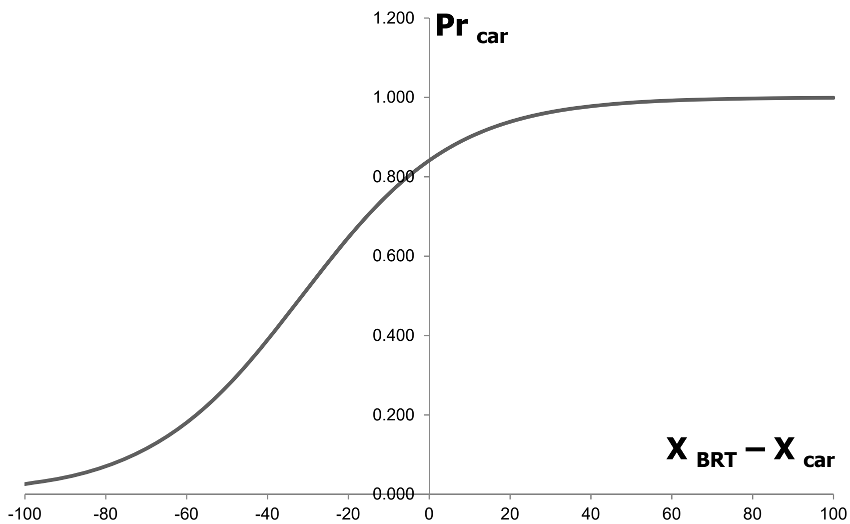
$$\bar{Y}_i = \alpha + \beta \bar{X}_i$$

$$-1.4457 = \alpha + (-0.0532x4.1667)$$

$$\alpha = -1.6674$$

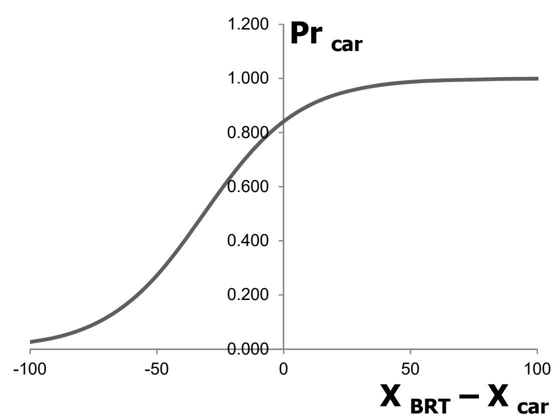
- **Finding the formula**

$$Pr_{car} = Pr\left(V_{car} > V_{BRT}\right) = \frac{1}{1+\exp-\left(1.6674+0.0532(X_{BRT}-X_{car})\right)}$$



- If there is no different generalized cost between car and BRT, 84% of residents use car

- If there is 20 difference between generalized cost of BRT and car (BRT is more expensive), 94% of residents using car, means 10% of BRT users shift to car



- If we hope that the demand of BRT and Car is similar, BRT operator has to increase the service level such that the difference of generalized cost between BRT and Car reaches 31

SCENARIO CASE

- Estimate the impact on modal split on each O-D pair of an increase in petrol price which doubles the perceived cost of running a car (F_3) !
- Estimate the shift in modal split which could be obtained if no fares were charged on the BRT system (F_3) !
- Which one is more effective in terms of shifting to public transport ?

THANK YOU