Lecture for Master Course Students, 2014 Autumn Semester

Transport Network Analysis

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Urban Transportation Network Analysis

- Individual's travel decision: whether or not, when, travel mode, where to go, route.
- Decision depends on congestion.
- Congestion depends on the amount of travel.

- This book describes; <u>interaction between congestion and travel decisions</u>,
- and obtains flow pattern throughout the urban transportation network.

Predicting the Impact of Scenarios: stage 1 = Prediction

- Engineers and planners would like to predict the impact of given transportation scenarios.

- 1st stage: Scenario is specified mathematically as a set of inputs used to predict flow patterns.
- Inputs are;

1. Infrastructure and services
2. System operating and control policies
3. Demand for travel

- Flow is measured in terms of the number of travel units in a unit time.

Predicting the Impact of Scenarios: stage 2 = Evaluation

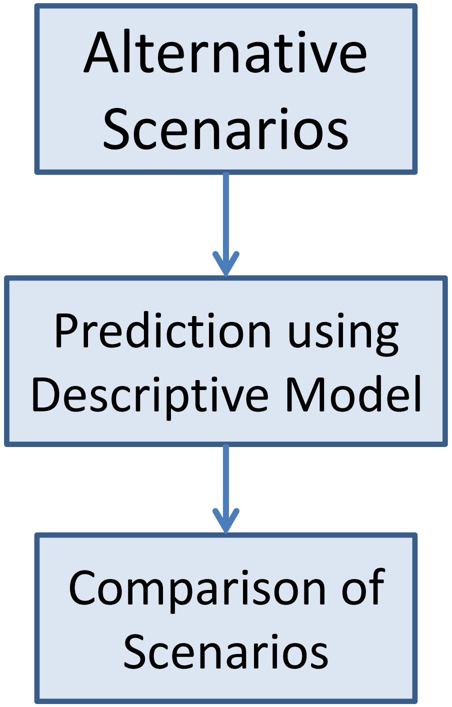
- 2nd stage: Flow pattern (output of stage 1) is used to calculate an array of measures.

1. Level of service measures: travel time and costs.
2. Operating characteristics: revenues and profits.
3. Flow by-products: ex. pollution, land values.
4. Welfare measures: accessibility and equity.

Descriptive Modelling Approach (vs Normative)

- It <u>describes</u> how individuals travel through an urban transportation system.
- It does not attempt to determine the optimal system configuration.

- Alternative scenarios are specified mathematically as a set of inputs to the descriptive analysis.
- Measures associated with each alternative scenarios are compared to a base case (do nothing).



1.1 Equilibrium Analysis of Transportation Systems

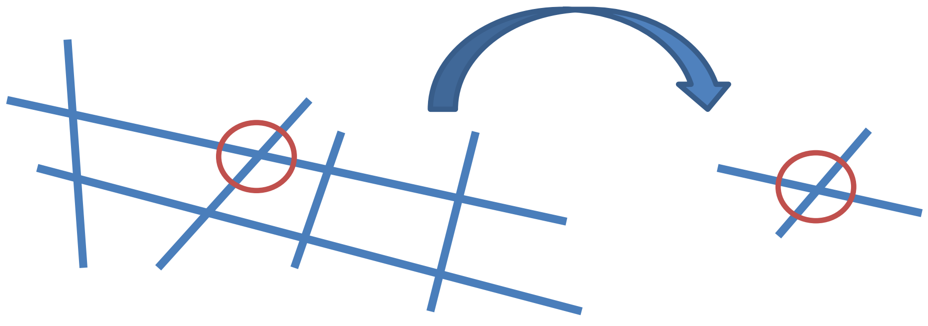
- Equilibrium analysis = systems-oriented view of urban transportation

1. need for the systems-based approach
2. general notion of equilibrium
3. application to transportation systems

Systems Approach to Urban Transportation

Traditional approach in engineering analysis

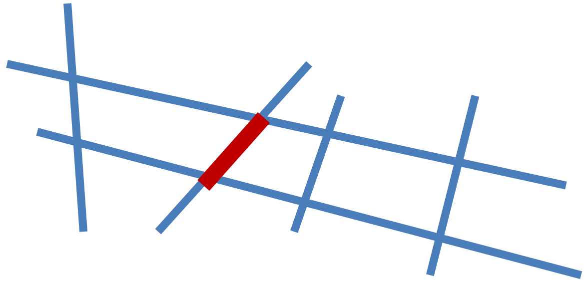
- To isolate a component of a system and analyze it individually.
- Examples: traffic lights design, parking regulation.



System Wide Effects: examples

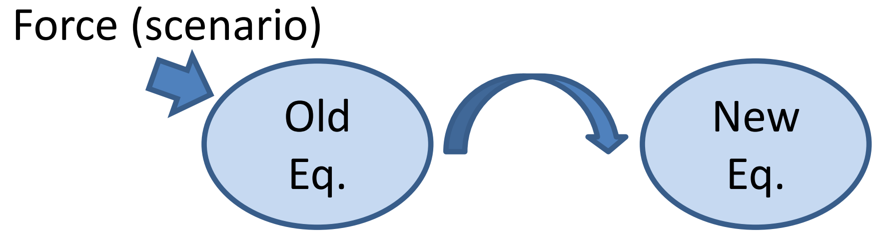
- When the change is more substantial, it will affect other parts of the system.

- Examples of ripple effect in a network.
- Widening a segment of an arterial.



- Transportation control policies are changed,
- New transportation services are introduced,
- Opening of a new shopping center.

Equilibrium



- After a short while, the ripple effects will lessen and stabilize at a new equilibrium point with no more significant changes occurring.
- The frequency of trips, the trip destinations, the modes of travel and the chosen routes are stable throughout the transportation network.

- The notion of equilibrium parallels the physical notion of stable equilibrium, which is the state in which there are no forces that try to push the system to some other state.

- In a transportation network, the flows are being pushed toward equilibrium by the route switching mechanism.
- There is no incentive for route switching.

Necessity of Systems Approach

- The equilibrium flow pattern may involve unanticipated flow levels and congestion in various parts of the urban network.

- Consideration of the entire system is necessary to account for the wide spectrum of effects associated with a particular scenarios.

- Equilibrium flow pattern can be found <u>only by analyzing simultaneously all elements</u> of the urban transportation network.

Equilibrium in Markets

- Two groups in economic market: producer and consumer.

- The behaviour of producers is characterized by a supply function, which expresses the amount of goods that the suppliers produce as a function of the price of the product.

- The behaviour of consumers is characterized by a demand function, which describes the aggregate behaviour of consumers by relating the amount of the product consumed to its price.

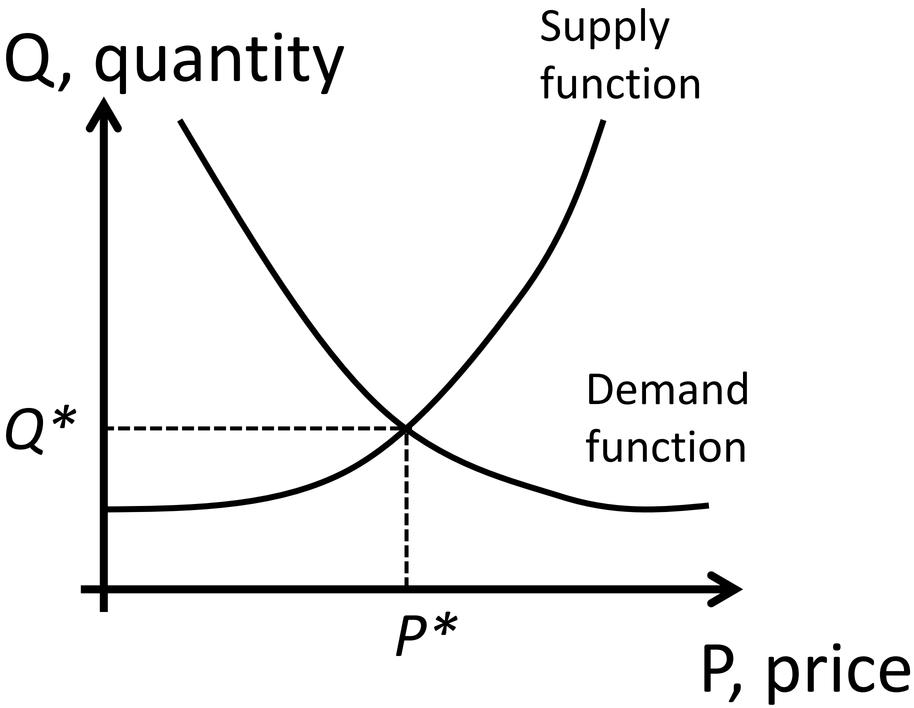
Market Equilibrium

- Figure 1.1
- Market clearing price P* and quantity consumed Q*.

- If price is higher than P*?
- If price is lower than P*?

- Market forces will tend to push the price toward its market clearing level.

  => Equilibrium



Various Attributes: Gas Station Example

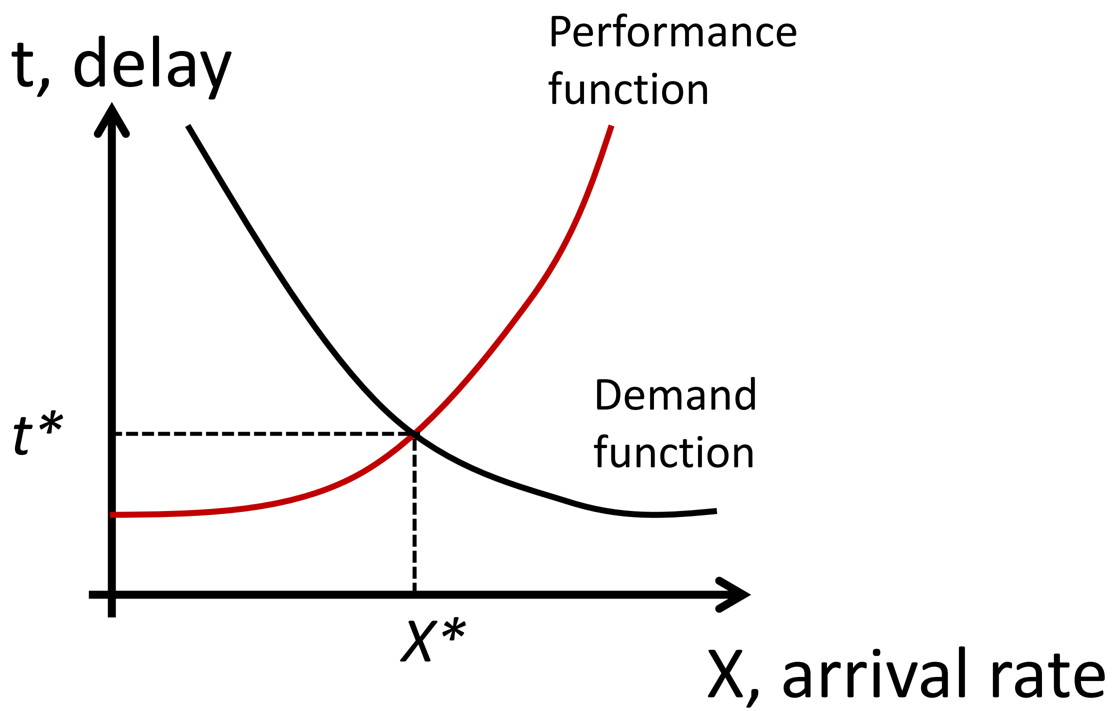
- Many attributes influence consumption.
- The number of customers is influenced by gasoline price and waiting time.
- The operator can set only the price. (cannot control the waiting time)
- The waiting time is influenced by the number of customers in the queue, and the willingness of customers to wait.

- For a given gasoline price, the situation can be characterized by a demand function (the number of customers entering the station per unit time as a function of waiting time) and a waiting time function (= delay associated with queuing).

- <Q> Discuss the characteristics of this function.

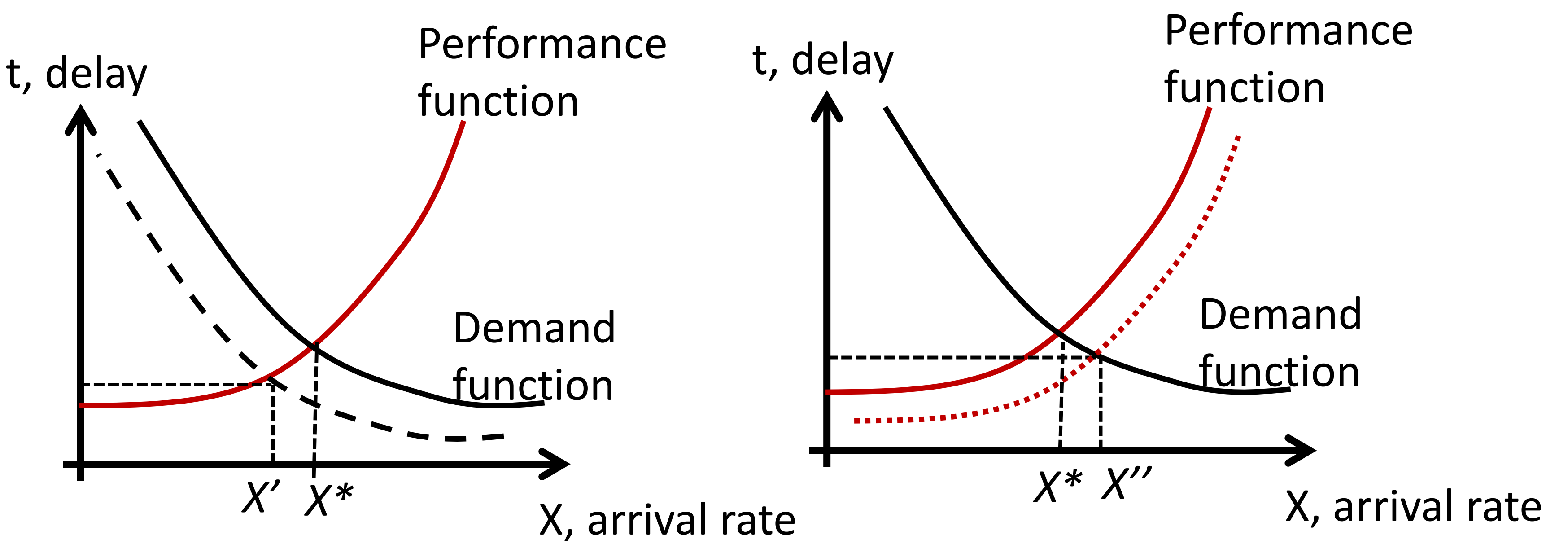
Demand/performance Equilibrium

- Figure 1.2.a, the only stable situation will be when the demand (arrival rate) is such that it creates a delay that corresponds to the same arrival rate.



Demand/performance equilibrium

- Figure 1.2.c, a different demand function (dashed line) and a different performance function (dotted line).



Demand/performance/supply equilibrium

- A complete economic analysis utilizes <u>supply, demand and performance functions</u> to solve simultaneously for the arrival rate, the delay and the price.

- The performance/demand analysis is a special case of the supply/demand equilibrium by fixing some of the variables.

Transportation Arena (equilibrium in transportation)

- Transportation is a service that the transportation industry (widely defined) offers travellers.

- Transportation products can be characterized by the level of service (LOS) offered in addition to the price charged.

- LOS can be measured in terms of travel time, reliability, safety, comfort, spatial coverage, accessibility to the service,…

LOS and Congestion

- LOS(level of service) is not fixed but rather is flow dependent.
- A performance function that describes how the level of services deteriorates with increasing volume.
- A demand function that describes how the volume of passengers with improved level of service.

Ex.

Bus congestion

↓

Waiting time increase
Seat is unavailable
Bus driver is unfriendly

↓

Move to car
Change timing

The framework for a performance/demand equilibrium analysis is set by fixing service characteristics (fare, schedule, equipment) that are under the operator's control.

Why network?

- Equilibrium in urban transportation market is necessarily reached over urban network of streets and transit lines.

1.2 Network Representation

- Network=*nodes* (a set of points) and *links* (a set of line segments)
- Physical network: ex. streets and intersections conceptual network: ex. human relations

- Links are associated with impedance.
- Impedance= *Level of service* (LOS): travel time, costs, disutility…

Graph is a set of nodes and links. But links of a graph are not associated with impedance.

Path in a connected network

- *Path (or route)* is a sequence of directed links leading from one node to another.
- A pair of nodes is connected by more than one path.

- Figure 1.3. From node 2 to node 4, paths are {9}, {6,7}, {6,3,4}, {1,2,7}, {1,4}.
- Impedance of links is assumed to additive along the path.

Roadway network

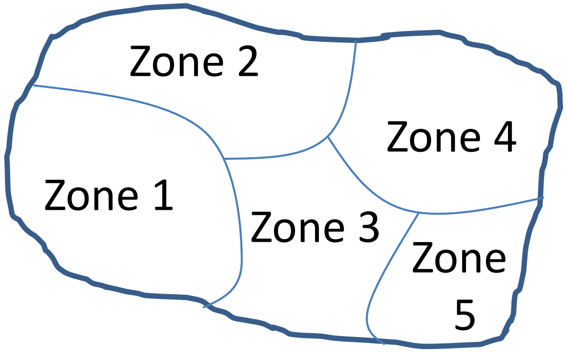
- Nodes=intersections, links=streets.
- Graph representation of a physical network is not unique.

- Figure 1.5(a) : the impedance of entering links represents intersection delay plus travel time of approach. This cannot represent turning restrictions, and the same travel time for all directions.
- Figure 1.5(b) represents the same intersection by 4 nodes and 10 links.

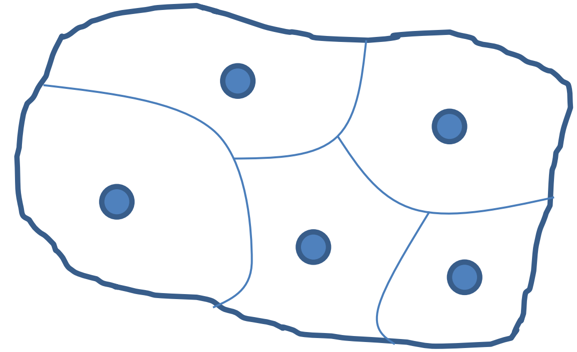
- Discuss whether this representation is enough?

Transit network

- Nodes=transit stations (or bus stops), links= line-haul portion.
- Impedance= in-vehicle travel disutility elements.
- Figure 1.6 (b) depicts the transit network associated with a loading link at an origin node and an unloading link at a destination.
- Impedance= waiting time, fare, walking time.
- Figure 1.6 (c) depicts a transit station serving two lines.
- Transfer links, loading links and unloading links.



Centroids



- Urban areas in transportation planning are divided into traffic zones.
- Size of each zone varies from a city block or a town.
- Each zone is represented by a node known as *centroid*; geometrical center of gravity.
- Centroids are source and sink nodes where traffic originates and destined.
- Each centroid represents an aggregation of all the actual origins and destinations in its traffic zone.
- The desired movements over an network can be expressed in terms of an *origin-destination matrix*.

Connectors

- A centroid is connected to the roadway network by special centroid connectors links (dummy links).
- Centroid connectors represent the ubiquitous street network within a traffic zones.

- The analysis of the flows in the urban area does not focus on the flows within each traffic zones.
- The centroid and connectors representation has to ensure only that the flows between traffic zones are correct.
- The size of the network to be analyzed is determined by the trade-off between the required accuracy and the available budget.

Travel time as the primary impedance

- Why is the travel time the primary component of impedance?
- A primary deterrent for flow.
- Highly correlated with other impedance measures.
- Easy measurement.

- Travel time can be understood as a generalized impedance which combines several measures.
- Impedance measures other than travel times (such as out-of-pocket costs, waiting time) should be expressed in travel time units.
- The conversion of coefficient (known as the value of time) should be rooted in traveler's values.

Link Performance function

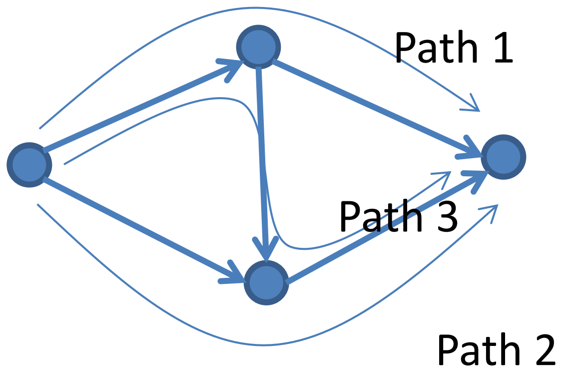
- The LOS of many transportation systems is a function of the usage of the systems.
- The function relates the travel time on each link to the flow traversing the link.

- Figure 1.8 represents a performance function for a typical approach to a signalized intersection.
- The time spent in traveling along the approach and the delay at the downstream intersection.
- The flow increases, the travel time monotonically increases.
- The performance function is asymptotic to a certain level of flow known as the *capacity*.

1.3 Equilibrium over Urban Transportation Networks

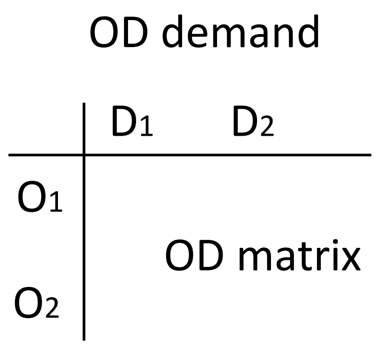
- Number of travellers between an origin and a destination (OD) is given.
- OD pair is connected by possible paths.
- How will these travellers be distributed among possible paths?

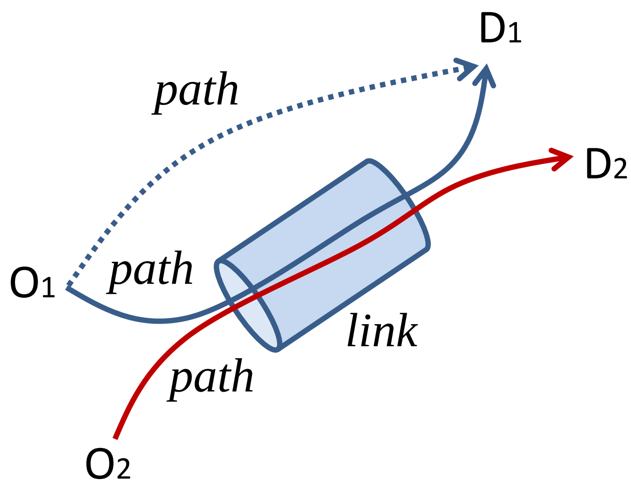
- Because of the congestion effect, the initial shortest path will not be the minimum travel time path. Some of the travellers will use the alternative paths.

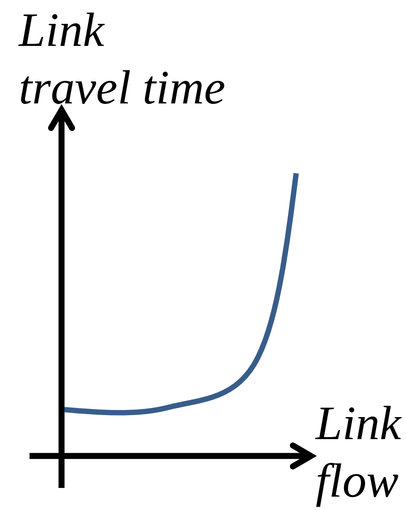


Demand/performance equilibrium

- Link flow is the sum of path flows.
- Link performance function is defined independently.
- OD demand is not defined for each link separately.







- 'Systems' nature of demand/performance equilibrium.
- No link, path, or OD pair can be analyzed in isolation.

Problem to be solved

- For simplicity, motorists' route choice in a road network, and only travel time is considered.

- Find the flow and travel time on each of the network links for given conditions:

1. a graph representation
2. the associated link performance function
3. an origin-destination matrix.

- This problem is known as *traffic assignment* since the issue is to how to assign the O-D matrix onto the network.
- Resulting link flows (and travel times) are used to evaluate planning scenarios.

Route choice and User Equilibrium (UE)

- Every drivers will try to minimize his/her own path travel time.
- Travel time can change with the flow, and path travel time changes as the link flow changes.

- A stable condition is reached only when *no traveler can improve his travel time by unilaterally changing routes*.
- At this point there is no force that tends to move this flows out of the equilibrium situation.

- UE definition (page 22): for each OD pair, at user equilibrium, the travel time on all used paths is equal and also less than or equal to the travel time that would be experienced by a single vehicle on any unused path.

Behavioural Assumptions and SUE

- Perfect (full) information; drivers know network configuration and travel times.
- Rational choice; Every motorist will try to minimize his/her own travel time.
- All individuals are identical.

- *Perceived* travel time is assumed as a random variable distributed across the population of drivers.
- *Stochastic UE* will be reached when no traveller believes that his/her travel time can be improved unilaterally changing routes.

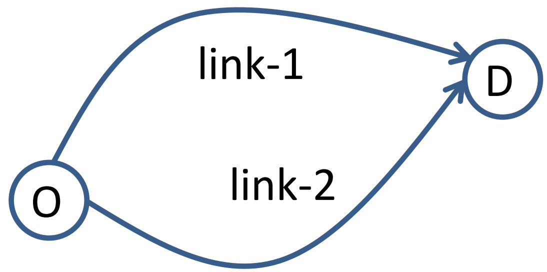
- <Q> What may occur for imperfect information, irrational choice and heterogeneity?

Extensions

- Deterministic to stochastic,
- Fixed demand to variable demand (mode choice, destination choice, ….),
- Static to dynamic (time of day dynamics, day-to-day dynamics),
- Passenger flow to goods movement (logistics and supply chain)

A simple UE example

- Single OD and two parallel links.



- OD flow conservation equation;

$$q = x_1 + x_2, \quad x_1 \geq 0, \quad x_2 \geq 0$$

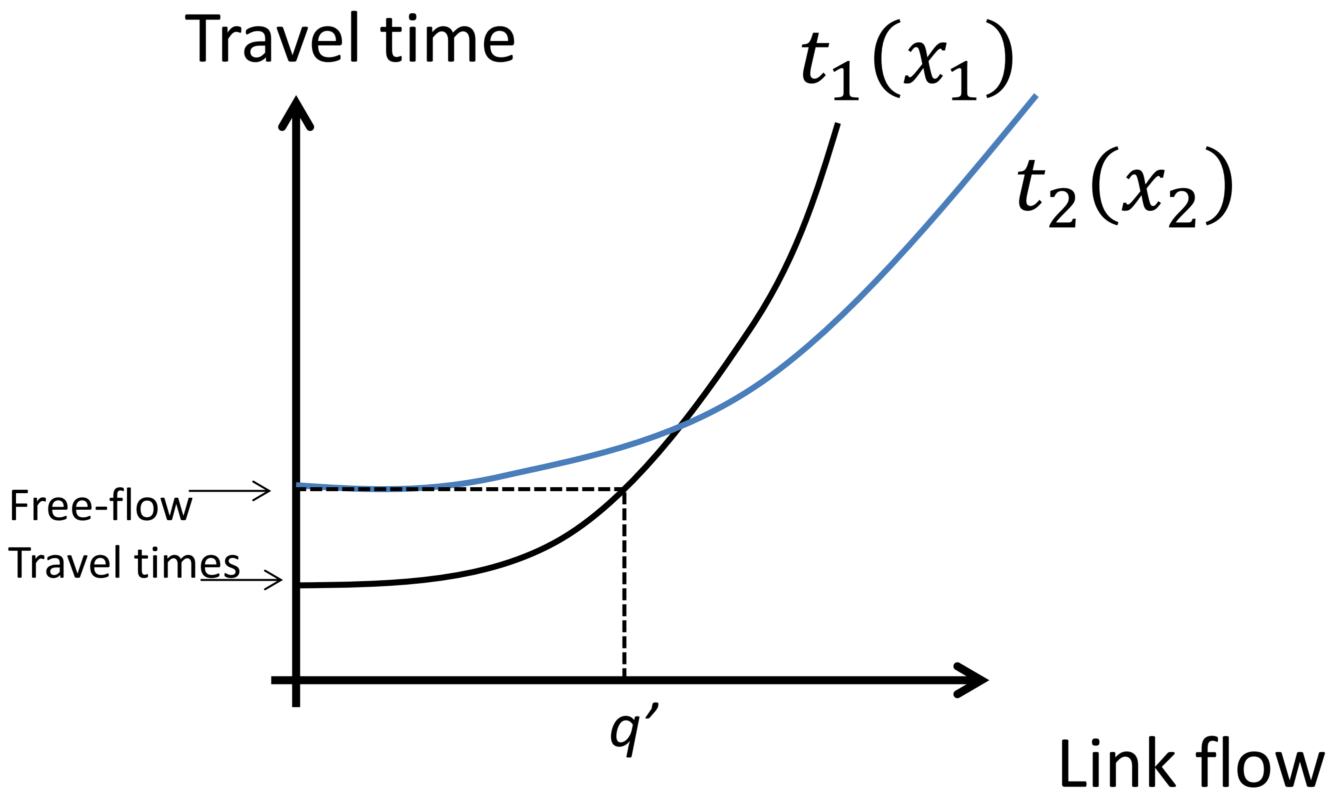
OD flow (given) link flows (variable)

- Link performance function

$$t_1(x_1), \; t_2(x_2)$$

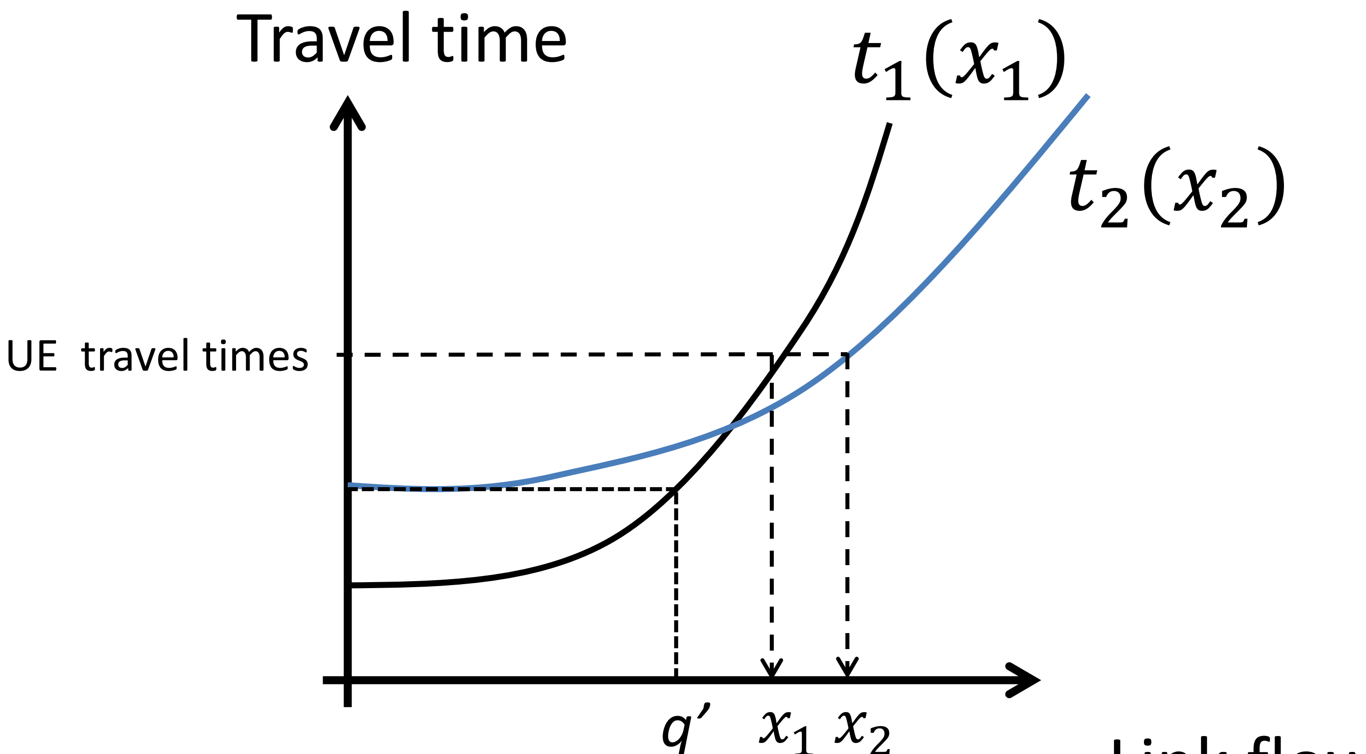
Assume that the free-flow travel time of link-1 is smaller than that of link-2.

When OD flow q is small (q<q')



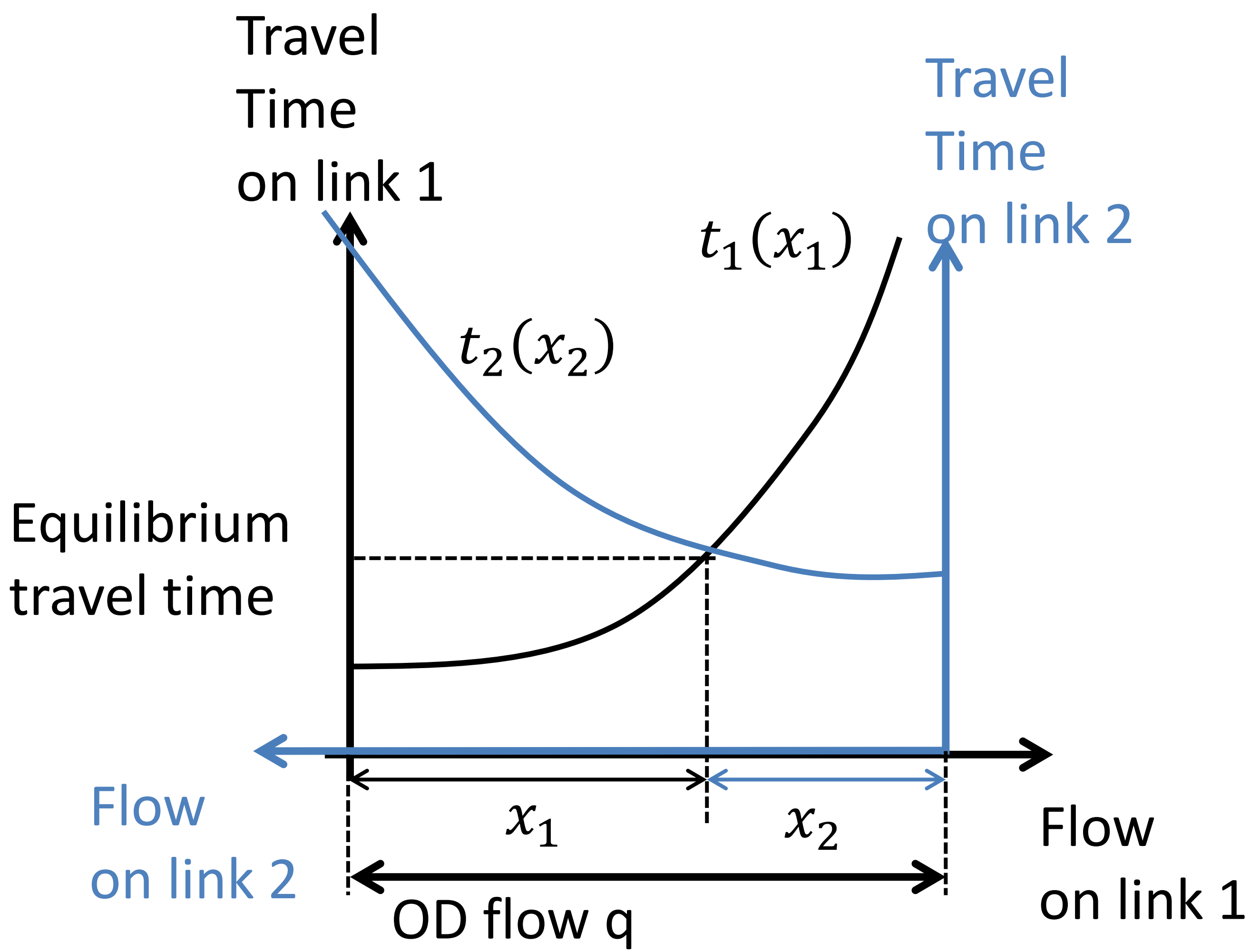
UE condition: all drivers use link-1 as the travel time of the link is shorter than that of link-2.

When OD flow *q* is large (q>q')



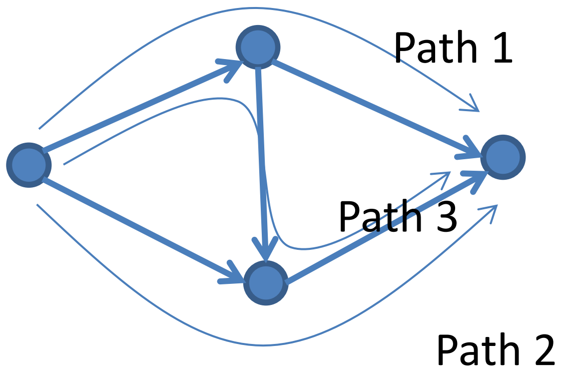
UE condition: drivers use link-1 and link-2 such that travel times of those two links are equal

When OD flow *q* is large (q>q')



Network User Equilibrium

- For each OD pair, at user equilibrium, the travel time on all used paths is equal and also less than or equal to the travel time that would be experienced by a single vehicle on any unused path.



- Paths of an OD pair can be divided into two groups; paths with positive flows and paths with zero flow.

If {f1 >0, f2>0 and f3=0} is UE,

$$T_1 = T_2 \leq T_3$$