Gravity Model

A Model of Spatial Interaction

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A spatial interaction is a realized flow of passengers or freight between an origin and a destination. It is a transport demand / supply relationship expressed over a geographical space.

1. Conditions for Spatial Flows:

- Estimating flows between locations is a methodology of relevance to transportation.
- These flows, known as **spatial interactions**, enable to evaluate the demand (existing or potential) for transport services.
- They cover forms of mobility such as journeys to work, migrations, tourism, the usage of public facilities, the transmission of information or capital, the market areas of retailing activities, international trade, and freight distribution.
- Mobility can be physical (passengers or freight) or intangible (information), and each form of mobility is subject to a form of friction.

- Economic activities are **generating** (supply) and **attracting** (demand) movements.
- The movement occurs between an origin and a destination underlines that the costs incurred by a spatial interaction are lower than the benefits derived from such an interaction.
- Personal reason occurs short distance interaction while concept of international trade for comparative advantages, benefits of specialization generates flows between distant locations.

Following three conditions are necessary for spatial interaction:

1. Complementarity. There must be a supply and a demand between the interacting locations.

2. Intervening opportunity (lack of). Refers to a location that may offer a better alternative as a point of origin or as a point of destination.

3. Transferability. Mobility must be supported by transport infrastructures, implying that the origin and the destination must be linked. Costs to overcome distance must not be higher than the benefits of the related interaction, even if there are complementarity and no alternative opportunity.

Why models are important ?

- Spatial interaction models seek to explain existing spatial flows.
- As such it is possible to measure flows and predict the consequences of **changes in the conditions** generating them.
- When such attributes are known, it is possible to better allocate transport resources such as conveyances, infrastructure, and terminals.

2. Origin / Destination Matrices

- Each spatial interaction, as an analogy for a set of movements, is composed of a discrete origin/destination pair.
- Each pair can itself be represented as a cell in a matrix where rows are related to the locations (centroids) of origin, while columns are related to locations (centroids) of destination.
- Such a matrix is commonly known as an **origin/destination matrix**, or a spatial interaction matrix.
- The sum of inputs or outputs gives the total flows taking place within the system.
- It is also possible to have O/D matrices according to the age group, income, gender, etc.

Why Spatial Interaction is important ?

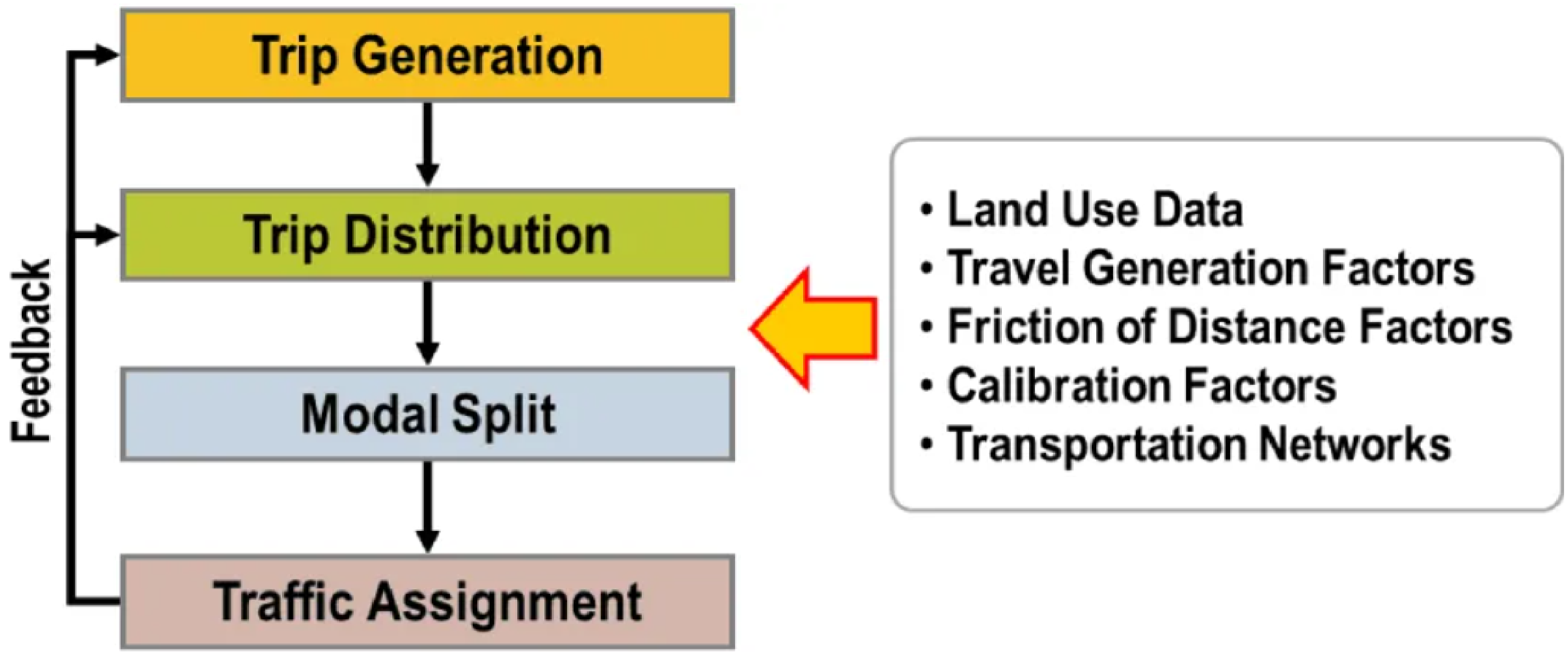
- With economic development, the addition of new activities and transport infrastructures, spatial interactions tend to change very rapidly as flows adapt to a new spatial structure.

Limitations of O/D Matrix:

- The problem is that an origin/destination survey is very expensive in terms of efforts, time and costs.
- In a complex spatial system such as a region, O/D matrices tend to be quite large.

3. Spatial Interaction Models

Four Stages Transportation / Land Use Model



Source: adapted from EPA420-R-97-007.

The four stages (or four steps) transportation/land use model follows a sequential procedure:

- **Trip Generation**: For each discrete spatial unit, it is estimated the extent to which it is an origin and destination for movements. The output is usually the **number of trips** generated and attracted by a given spatial unit.
- **Trip Distribution**: Commonly a spatial interaction model estimates movements (flows) between origins and destinations and which can consider constraints such as distance. The output is a **flow matrix** between spatial units.
- **Modal Split**: Movements between origins and destination are then disaggregated by modes. This function depends on the availability of each mode, their respective costs, and also social preferences.

- **Traffic Assignment**: All the estimated trips by origin, destination and mode and then “loaded” on the transportation network, mainly with the consideration that users want to minimize their travel time or have to flow through existing transit networks. If the traffic exceeds the capacity of specific transport segments (which is often the case), congestion occurs and negatively affects travel time. This in turn, through a feedback process, may influence trip generation and distribution.
- This procedure is consequently iterative and converges towards a solution, often measured as the minimal transportation cost considering a given travel demand and the characteristics of the existing transportation network. It relies on an extensive array of data that can be obtained through census information, surveys and estimates.

- Spatial interaction models are usually the first two steps of the above described four step transportation model:
  - Spatial generation and
  - Distribution of trips.
- The basic assumption concerning many spatial interaction models is that flows are a function of the **attributes of the locations of origin**, the **attributes of the locations of destination** and the [friction of distance] between the concerning origins and the destinations.
- The general formulation of a spatial interaction model is as follows:

$$\mathbf{Tij = f(Vi, Wj, Sij)}$$

Where:

Tij **:**

- Interaction between location *i* (origin) and location *j* (destination).
- Its units of measurement are varied and can involve the number of passengers, tons of freight, traffic volume, etc.
- It also relates to a time period such as interactions by the hour, day, month, or year.

Vi **:**

- Attributes of the location of origin *i*.
- Variables often used to express these attributes are socio-economic in nature, such as population, number of jobs available, industrial output or any proxy of the level of economic activity such as gross domestic product.

Wj **:**

- Attributes of the location of destination *j*.
- It uses similar socio-economic variables than the previous attribute to underline the reciprocity of the locations.

Sij **:**

- Attributes of separation between the location of origin *i* and the location of destination *j*.
- Also known as **transport friction, friction of distance** or **impedance**.
- Variables often used to express these attributes are distance, transport costs, or travel time.

4. The Gravity Model

- The gravity model is the most common formulation of the spatial interaction method.
- It is named as such because it uses a similar formulation than Newton’s law of gravity.
- Gravity like representations have been applied in a wide variety of contexts, such as migration, commodity flows, traffic flows, commuting, and evaluating boundaries between market areas.
- Accordingly, the attraction between two objects is **proportional to their mass and inversely proportional to their respective distance**.
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- The **elementary formulation** of the gravity model:

$$\boxed{T_{ij} = k\,\frac{P_i\,P_j}{d_{ij}}}$$

- ***Pi* and *Pj*** : Importance of the location of origin and the location of destination.
- ***dij* :** Distance between the location of origin and the location of destination.
- ***k*** is a proportionality constant related to the rate of the event.
- Thus, spatial interactions between locations *i* and *j* are proportional to their respective importance divided by their distance.

The gravity model can be extended to include several calibration parameters:

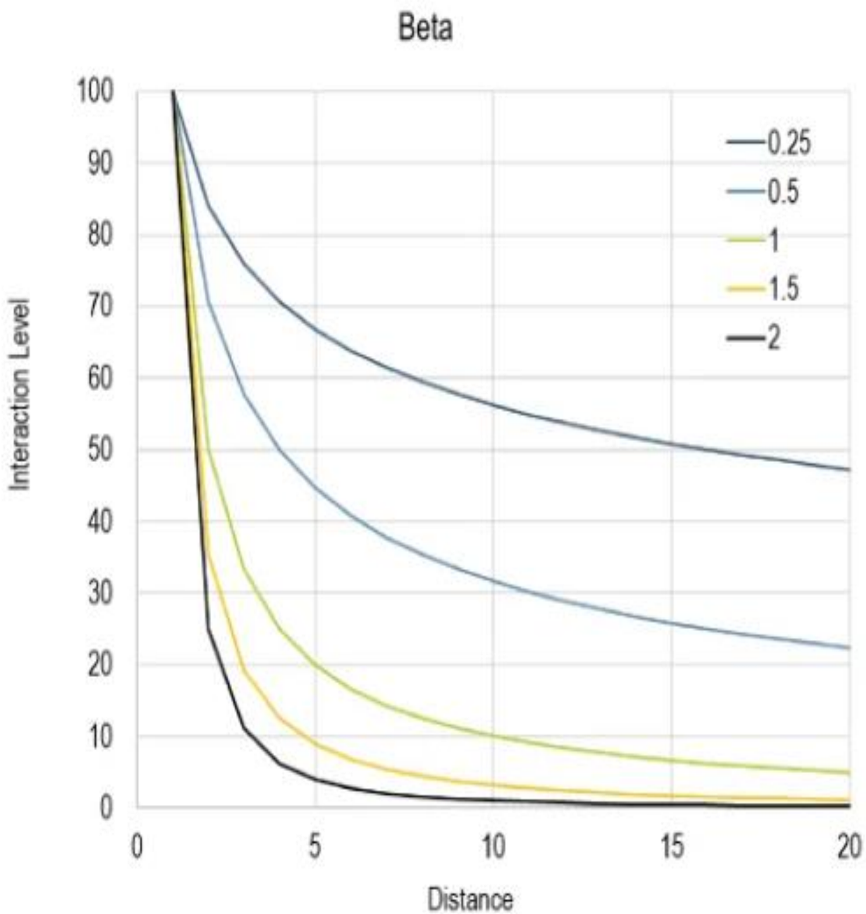
$$T_{ij} = k \frac{P_i^{\lambda} \, P_j^{\alpha}}{d_{ij}^{\beta}}$$

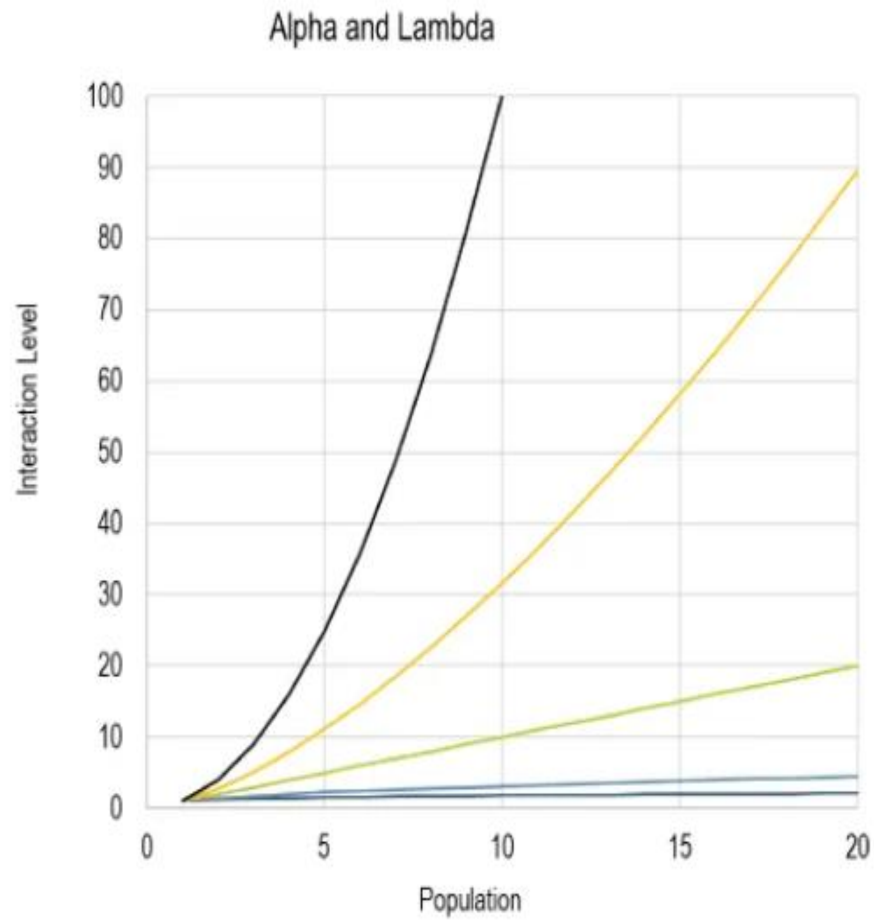
- *P*, *d* and k refer to the variables previously discussed.
- **β (beta):** A parameter of transport friction related to the **efficiency** of the transport system between two locations. This friction is rarely linear as the further the movement the greater the friction of distance. For instance, two locations serviced by a highway will have a lower beta index than if they were serviced by a regular road.
- **λ (lambda) :** Potential to generate **movements (emissivity**). For movements of people, lambda is often related to an overall level of welfare. For instance, it is logical to infer that for retailing flows, a location having higher income levels will generate more movements (customers).
- **α (alpha)** : Potential to attract movements **(attractiveness**). Related to the nature of economic activities at the destination. For instance, a center having important commercial activities will attract more movements.

- The gravity model, is related to their **calibration**.
- Calibration consists of finding the value of each parameter of the model (constants and exponents) to ensure that the estimated results are similar to the observed flows
- That those results can be replicated and that changing the parameters would generate valid results.
- The model is of limited use as it predicts or explains little.
- It is impossible to know if the process of calibration is accurate without **comparing estimated results with empirical evidence**. Consistent calibration enables the model to be more rigorous and adaptable to other contexts.

- In the two formulations of the gravity model that have been introduced, the simple formulation offers good flexibility for calibration since four parameters can be modified.
- Altering the value of beta, alpha and lambda will influence the estimated spatial interactions.
- Furthermore, the value of the parameters can change in time due to factors such as technological innovations, new transport infrastructure, and economic development.
- For instance, improvements in transport efficiency generally have the consequence of reducing the value of the beta exponent (friction of distance).
- Economic development is likely to influence the values of alpha and lambda, reflecting growth in mobility.

Effects of beta, alpha and lambda on Spatial Interactions:





- Calibration can also be considered for different O/D matrices according to age, income, gender, type of merchandise and modal choice.
- A part of the scientific research in transport and regional planning aims at finding accurate parameters for spatial interaction models.
- This is generally a costly and time-consuming process, but a very useful one.
- Once a spatial interaction model has been validated for a city or a region, it can then be used for simulation and prediction purposes, such as how many additional flows would be generated if the population increased or if better transport infrastructures (lower friction of distance) were provided.

THANK YOU

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