TRANSOPE: a multi-agent model to simulate outsourcing networks in road freight transport. *v1.0.0*

Aitor Salas-Peña (author)

Blanca Rosa Cases Gutiérrez (collaborator)

DESCRIPTION AND OBJECTIVES

The TRANSOPE model simulates the interactions between the agents involved in transport outsourcing chains (TOC) and the territory in which they are located as a result of the exchange of information and knowledge around transport operations. Thus, the model aims at the following objectives:

1. To model the outsourcing process of road freight transport service providers and the formation of clusters in a geographical environment on a local and regional scale

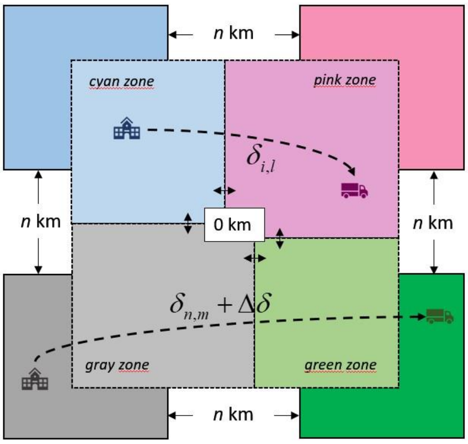
2. To simulate the learning process and the creation of value through the transfer of information and knowledge between companies and carriers in environments with a high density of transport activity.

3. To determine the importance of geographical proximity as a factor in the formation of outsourcing chains and the emergence of logistics clusters.

4. To measure the impact of other factors in the TSP selection process and the development of transport operations on the interaction between agents.

THE WORLD

In order to simulate the collaboration between different spatial entities and the formation of clusters as a product of whitin-zonal information exchanges, the space in TRANSOPE is divided into four areas of different sizes, each characterized by a color. By means of this difference of surfaces we intend to provoke different densities of agents in each area to later analyze their behavior and their impact on the formation of TOCs.



TIME RUNNIG OF THE SIMULATION

Each simulation in TRANSOPE occupies a given period of *n* days set at the beginning. Each day a number of TOCs must be completed equal to the number of transport operations that have been determined. During the course of a day the values of some variables are altered for different reasons. For example, availability is reduced depending on the "transportation market situation" (SMT).

THE AGENTS

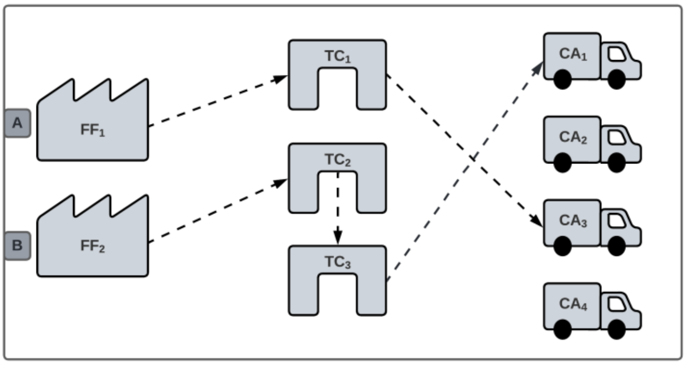
In TRANSOPE there are three types of agents, in order from the highest to the lowest hierarchical rank:

1) Freight Forwarders (FF). These are companies dedicated to logistics and warehousing that do not have their own trucks, so they outsource their transport needs to PST companies. In TRANSOPE, all TOCs start with them.

2) Transport companies (TC). These are usually small and medium-sized companies. They work for both other TCs and FFs. In TRANSOPE, this type of agent is found in the intermediate links of the chain.

3) Self-employed carriers (CA). These are micro-transport companies, where the entrepreneur is the driver himself. In TRANSOPE, CAs are therefore the last link in the chain.

As shown in the following figure, in TRANSOPE the agents are organized in TOCs in two possible ways: 1) chains of 3 agents (FF->TC->CA) or 2) chains of 4 agents (FF->TC->TC->CA). The order of agents is always the same.



AGENT VARIABLES

1- Competence variables:

a) Competitiveness (C). It provides a relative value for an agent's ability to offer better prices than its competitors.

b) Availability (D). This variable indicates the actual transport capacity of the agents in the event of being selected for a service. This capacity is not unlimited, except for FFs.

c) Trust (T). Confidence in the professionalism of the agent likely to be hired, that is, it provides a trust value based on the professionalism of each agent.

Initially these three variables are calculated in the same way:

$$CompVar_i = Var + X_{(k=1;\lambda=9)} - X'_{(k=1;\lambda=9)}$$

where $CompVar_i$ is the competence variable of agent *i*, *Var* is the value of variable *v* obtained from its assessment in the survey of transportation professionals, and *X* and *X'* are floating-point random numbers to which a gamma distribution with parameters *k* and λ is applied. Introducing these values the model creates variability in the competence values for each agent.

Once the values of the competition variables have been calculated for each agent, the **price** that each agent will ask for the transport service is calculated. If the structure of the chain is A->B->C,

$$P_{(A)} = trip\_kms \cdot (price\_eur / km) + C_{(A)} \cdot X$$

where $P_{(A)}$ refers to the price of agent A, *trip_kms* is the OD distance between the loading or origin point (O) and the unloading or destination point (D), *price_eur/km* is a standard quantity at market prices expressed in EUR, $C_{(A)}$ is the competitiveness value of agent A, and *X* is a random value between 1 and 100, whose purpose is to introduce variability among the agents.

After this calculation, the price of each OL remains unchanged throughout the simulation. For the other agents

$$P_{(B)} = P_{(A)} \left[\frac{100 - margin_{(A)} \cdot (2 - TMS) - C_{(B)}}{100} \right]$$

where *margin(A)* is the profit margin that agent A will receive and SMT is the coefficient of the transport market situation with values between 0.1 and 1.9, where values below 1 indicate greater supply than demand, i.e. more trucks available than operations to be carried out, with the result that TE profit margins are reduced as OL margins increase.

The CAs are the only agents that have costs derived from transport (G), since they are the ones who carry out the physical transport of the goods. After consulting the road freight transport cost simulator (OTEUS-Basque Government Transport Observatory, 2021), these were calculated using the following expression:

$$G_{(CA_i)} = (costs\_eur / km \cdot trip\_kms) + (regular\_costs \cdot trip\_kms) + X - X'$$

where $G_{(CAi)}$ are the costs of CA *i*, *costs_eur/km* are the variable costs per kilometer, *regular_costs* regular costs are constant carrier expenses and *X* and *X'* are random values between 1 and 10, which serve to establish cost differences between the TA. So, the costs will determine the availability of the CAs to be selected by the TCs when they are equal to or greater than the price they receive for transportation plus the average profit margin:

$$P_{(CA_i)} \leq G_{(CA_i)} + \frac{(margin_{(CA_i)} \cdot G_{(CA_i)})}{100} \Rightarrow D_{(CA_i)} = 0$$

In the case of **availability**, the functioning is different in FF, TC and CA. FF are always available. In the case of TC, his value depends directly on the number of available carriers to which it could outsource. Availability also depends on the situation of the transportation market (TMS). Therefore, the initial availability of TCs is in accordance with the expression

$$\forall TC \in TOC_i \Rightarrow D_{(TC)_t} = D_{(TC_i)} \cdot \frac{n_{(CA)}}{10 \cdot TMS}$$

However, the initial availability of contracted TCs will gradually decrease as they are selected to perform transport services, so the terms of last Equation are inverted as follows,

$$\forall TC \in TOC_i \Rightarrow D_{(TC)_{t+1}} = D_{(TC)_t} - \frac{10 \cdot TMS}{n_{(CA)}}$$

In the case of CAs, variable D determines the number of kilometers they can travel in a day. So, a TA will not be able to perform a complete transport service if it has used up its daily kilometers, according to the following expression

$$Q_{(CA_i)} = K_{\max} - 2\sum_{l=1}^{n} trip\_kms_l$$

where Q is the number of kilometers traveled by the CAi in a day, K_{max} K is the maximum kilometers per day that a truck can travel and *trip_kms* is the distance of the OD trip (origin-destination), which is doubled due to the need to return to the point of origin. Logically Q can never be negative. If a CA starts a trip that cannot be completed during that day, the kilometers that cannot be completed are computed on the following day.

2- Topological variables:

a) Customer-supplier distance (**δ**). During the simulation, each potentially eligible supplier by a customer calculates the Euclidean distance from it. So,

$$d_{(i,j)} = d_{(i,j)} + proximity\_of\_zones$$

Where $d_{(I,j)}$ is the Euclidean distance between agent i and agent j expressed in kilometers, and proximity_of_zones is the variation of proximity between regions, controlled at the interface by a slider.

b) Geographic centrality (Cg). It consists of the sum of the distance of each agent with respect to the rest of the agents in its region divided by the number of agents (n) minus one. Cg is calculated for each zone separately and not taking all the agents in the system. Lower Cg values indicate greater centrality:

$$Cg_{i_{(reg\ x)}} = \frac{\sum_j d(i,j)}{n-1}$$

c) Mean grouping distance (Mgd) This measure is not an agent variable per se, as it provides a single value for the entire set of agents in a region. It is calculated as a matrix of Euclidean distances between all vertices of a network. This measure represents the theoretical cohesion value between all the agents in a region (n) if they were all connected to each other by undirected links.

$$Dg_{(reg\ x)} = \frac{\sum_{i>j} d(i,j)}{n*(n-1)/2}$$

THE SELECTION OF TRANSPORT SERVICE PROVIDERS (TSP)

The following expression is used by both FFs and TCs to select their providers. Both are looking for the TSP with the best transport skills, at a relatively short distance and with the possibility of benefiting from locational advantages thanks to the proximity of other agents and their centrality with respect to them. In addition, *K* refers to the knowledge accumulated by each agent, which allows those agents with location disadvantages to increase their chances of being chosen through indirect interaction with other agents.

$$S_{ij} = \frac{(T_j + C_j)D_j^2}{\delta_{ij}\left(\sqrt{Cg_j \cdot Dg_{(r_j)}}\right)^2} + K_j$$

LEARNING AND KNOWLEDGE TRANSFER

Direct learning has to do with the number of times an agent is part of a TOC and, more specifically, with the value it generates during the transport operation. Thus, learning level is accumulated operation after operation, although this value is only perceived by TCs and CAs, since FFs are guaranteed participation in TOCs due to their dominant position in the chain structure. It is calculated taking into account the number of times an agent has been contracted for a transport service. Thus,

$$DL_j = \sum_{m=1}^{n} \frac{kt}{V_{TOC_m^j}}$$

where *DL* is the direct learning of agent *j*, V_{toc} is the value generated by the TOC_m in which agent *j* has taken part, and *kt* is a slide of the level of knowledge transfer with values between (0,1].

Regarding knowledge transfer, the procedure is as follows:

1- The agents that have participated at least once in a TSA establish a zone of influence within a radius r. Each patch within that radius computes the number of contracts made by the agents located within radius r starting from its center, and calculates on this basis an indirect learning (IL) value according to the expression

$$IL_{(p_i)} = kt\,\frac{\sum_{j=1}^{m} contracts_{j(r_{p_i})}}{n_{(r_{p_i})}}$$

where *n* is the number of agents in r_{pi} , which is the radius from the center of the patch p_i, and *contracts* is the number of contracts that an agent has made. In this case, *contracts* computes the contracts of all agents located in r_{pi}. These values are updated at the end of each day.

2) Each patch transfers information to its neighboring patches (v) by distributing a percentage of IL among them, i.e., if for example it means that plot i distributes 20% of its accumulated

learning among its neighboring plots, and receives in the same measure the knowledge generated in those plots, so the final value of IL for each plot corresponds to the Equation

$$IL_{(p_i)} = IL_{(p_i)} - (IL_{(p_i)} \cdot kt) + kt\sum_{u=1}^{w} \frac{IL_u}{n_{v_u}}$$

3) Finally, each agent receives from the parcel on which it is located the value of IL, which comes in addition to its DL, i.e., its learning and direct experience,

$$K_j = DL_j + IL^j_{(p_i)}$$

where K_j is the accumulated knowledge value of agent *j* installed in patch *i*. During the simulation the amount of knowledge of the system increases as more TOCs are generated.

LOGISTIC CLUSTERS

In TRANSOPE, the product of interactions between agents generates shared value, which can result in the emergence of poles of attraction for transport activity and the formation of clusters. These poles can be considered as particularly favorable environments for the formalization of contracts and the formation of transport chains. As a consequence of the activity of firms participating in TOCs nearby patches increase their level of learning. The areas with higher learning become darker showing environments of high concentration of activity.

HOW TRANSOPE WORKS

By pressing SETUP, a Freight Forwarder (FF) selects a Transport Company (TC), which in turn selects a Self-employed Carrier (CA) according to the supplier selection criteria. CAs can refuse transport operations if the price offered equals or exceeds their costs.

When GO is pressed, the model plays all the indicated operations during the days previously indicated. The AVAILABILITY value of an agent decreases with each participation.

If the FOUR_AGENTS_CHAIN option is set to "ON", the chain of 3 agents becomes a chain of 4. Thus, a FF chooses a TC, this one chooses another TC and this one chooses a CA.

Each time a day ends, the areas where more agent learning has taken place are darkened. The simulation stops when all operations of all days have been completed or when there are no agents available to perform them.

HOW TO USE TRANSOPE

Before starting the simulation:

1) Indicate number of agents in each group (FF, TC and CA). The ratio 10-40-80 is recommended.

2) Indicate how many DAYS the simulation lasts. Recommended 3-5.

3) Transport market situation (TMS) refers to the match between supply and demand of transport services, where TMS = 1 that means equilibrium between both, TMS > 1 means more operations for the same number of agents and TMS < 1 the opposite. The number of OPERATIONS is automatically calculated based on this parameter.

4) Adjust the competence variables (TRUST_LEVEL, COMPETITIVITY_LEVEL and AVAILABILITY_LEVEL). It is recommended to start with values = 1.

5) Indicate the PROXIMITY_OF_ZONES. The four zones (green, pink, cyan and grey) can simulate their separation between 0 and 40 km.

6) DISTANCE_IMPACT allows to reduce or increase the geographical proximity factor in the selection of suppliers. If DISTANCE_IMPACT = 1 there is no change.

7) Adjust the transport costs: % PROFIT is the profit margin of the agents in each operation; PRICE_EUR/KM is the price per km in Euro, it is recommended to start with PRICE_EUR/KM = 2; COSTS_EUR/KM are the variable costs of a CA, the reference is COSTS_EYR/KM = 0.5; REGULAR_COSTS are the fixed costs of each CA expressed in Euro, reference REGULAR_COSTS = 60.

8) Indicate the TRIP_KM for each transport. TRIP_KM are the outward km of a CA, but it must always return to the starting point. As a CA can only travel 600 km round trip per day, if KM = 150 it means that a CA can make only 2 transports in a day (150 x 2 X 2 = 600 km).

9) The KNOWLEDGE-TRANSFER slider allows to indicate how much of what is learned by an agent is transferred to the environment. KT = 0, nothing is transferred, KT = 1, everything is transferred.

10) Indicate the radius of knowledge diffusion SPREAD. It is expressed in meters.

11) In PROBABILITY_DISTRIBUTIONS we can choose between GAMMA, which introduces randomness in the competition variables, and NORMAL, which eliminates randomness.

12) Agents are randomly distributed in the world. WORLD allows three options: NEW will create a new distribution; LAST will repeat the previous distribution.

During the simulation:

Contracts between agents (links) are registered in an output-window. Likewise, the plots are updated at each tick.

At the end of the simulation:

Two files are generated: one with the values of the agents (nodes) and one with the values of the contracts (arcs). With these two files the graph can be built for further analysis.

THINGS TO NOTICE

The model attempts to analyze the behavior of inter-firm collaborations in an area by measuring the influence of three parameters:

1) Proximity between agents

2) Spatial knowledge transfer

3) Transport market situation.

By manipulating these parameters, different scenarios based on real situations are obtained that can be compared with each other.

THINGS TO TRY

Tests can be made on the influence of distance on sourcing by manipulating the controls PROXIMITY_OF_ZONES and DISTANCE_IMPACT. For example:

DISTANCE_IMPACT can be manipulated with different values and different distances between zones.

RELATED MODELS

See other network models.

RESEARCH CONTEXT

This model is part of the doctoral thesis "Road Freight Transport Operations and formation of Logistics Clusters. TRANSOPE: An agent-based model", presented by the author on 15 July 2022 at the Department of Geography of the Complutense University of Madrid.

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If you have any questions about the use of the model, please contact Aitor Salas-Peña at aisalas@ucm.es.