

AN AGENT BASED FREIGHT ACTIVITIES AND LOGISTIC CHAINS OPTIMIZED NETWORK SIMULATOR (FALCONS)

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KEYWORDS

Freight transport, Agent based, freight model, transport policy, node capacity.

ABSTRACT

Freight movements are a result of complex and diverse logistics decisions. One main objective of recent freight and logistics models is the ability to catch and represent some of the decisions made by the different actors throughout the freight generation and distribution process. Several efforts stopped shy at the stage of providing a conceptual framework of a freight or logistics model. This is mainly due to the lack of micro level data needed to make such models operational. Few operational agent based (AB) freight models were reported where such data could be obtained. In this paper we present a conceptual framework of an agent based freight model for Flanders. The model is in early implementation stage and is planned to be operational in the foreseeable future. Micro level data at hand will make the model a capacity and policy sensitive tool to serve a range of commercial and public planning bodies. It will be shown that using AB simulation paradigm combined with data availability enabled us to capture a wide range of decisions affecting goods generation and distribution.

INTRODUCTION

Modeling freight movements have moved in recent years from a traditional four steps models based simulation towards a more micro level, activity based simulation approach. This is mainly due to availability of micro level data, computational power and new simulation techniques, like the AB simulation paradigm (Wisetjindawat et. al. 2007; Samimi et. al. 2009; Harland et. al. 2005).

Agent based simulation techniques are suitable for simulating freight movements for the following reason. Freight movements are a result of complicated chains of actions, reactions and decisions made by different actors throughout the supply chain. Decisions about route choice, mode choice

and shipment size for example directly affects final total flows when aggregated. Such decisions constituting firms "behavior" take place at a micro level, matching the intrinsic nature of an agent, where fully and/or semi-autonomous agents are used to capture and represent such behaviors. Moreover, in micro level agents interactions, knowledge about the whole environment is distributed. In most advanced agent based simulation platforms, agents architecture, messaging schemes and roles can mimic some real life reactions in such an incomplete knowledge of environment. Examples of such is, a certain transport carrier firm (agent) can cease to exist if not contracted for a pre-specified period of time. The possibility to let different agent interactions evolve in time dimension and learn from history, is another reason of why AB simulation techniques are suitable in modeling freight transport chains (Davidsson et. al. 2008, Roorda et. al. 2010 ; Cavalcante and Roorda 2013).

Till now, freight flows simulation for Flanders had some limitations. The process relies on aggregate and outdated data about total flows of different goods categories. Moreover, to make future predictions, those total flows are tuned by altering Gross Domestic Product GDP indicator. Such a process is not very accurate, especially in not heavily industrialized economies. Which is the case with Flanders region, where in fact transit flows represent a significant part of freight flows across its borders. The aggregate flows of goods are then disaggregated with the ADA model (Ben-Akiva and De Jong 2013); a logistics model incorporating some logistics behaviors like shipment size and frequency and use of distribution and consolidation centers. The model takes the aggregate flows and disaggregated then to a firm to firm interaction level based on a global optimized cost function. Despite including logistics behavior elements, representation of firms population and sensitivity to link \ node capacity could be improved.

FALCONS is a freight activities and logistics chains optimized network simulator. It is an agent based model under development using the JANUS platform (Gaud et. al. 2008). Using AB simulation approach and recent availability of micro-level firm data , the model aims at a more optimized

simulation of freight flows. Using real production, consumption and carrier firms data, FALCONS uses a bottom up approach in simulating freights. The estimated goods are directly linked to production and consumption level of firms, of which yearly financial figures are available. This additionally provides an up to date estimation of goods quantities, instead of using proxies like GDP rate.

In the following sections, a review of existing efforts in using disaggregate models, AB models will be introduced. After that, FALCONS model and data sources used will be detailed. Finally, we will conclude with final remarks and outline current status of the model and future work.

LITERATURE REVIEW

Traditionally, freight transport models have been using macro level data as input. Several such models exists, such as SAMGODS (Swahn, H. 2001), ASTRA framework (Rothengatter et. al 2000) and the Flemish Mobility Plan (Flemish Government 2013). This type of models is taking into account several aspects of welfare and macroeconomics and use results from intra-disciplinary sub models to simulate passenger and freight flows. A main problem with these models is that they do not take into account some or any logistical operations, like choice of carrier and shipment size, and therefore do not include the actions that lead to the size and distribution of goods flows. Models that take some logistical aspects into account are for example GoodTrip (Boerkamps et. al. 2007), SMILE (Tavasszy et. al. 1998) and ADA (Ben-Akiva and De Jong 2013). These models however - despite being more microscopic than previous ones - do not include some of the actors in the decision making process, and are blind to the time evolution dimension with which ordering and delivery processes take place.

Few AB freight or logistics models have been developed in recent years. several models are at the level of a framework or conceptual work, partially due to data unavailability. Examples of such frameworks are FREMIS (Cavalcante and Roorda 2013) which besides modeling different transportation agents, includes product differentiation and economies of scale. On the other hand, examples of operational AB models are INTERLOG (Liedtke 2009); a Germany data calibrated model, and TAPAS (Davidsson et. al. 2008); an AB transport chains simulator, used to evaluate infrastructure policy measures and business interactions. Both models captured several logistics processes, and represented most actors involved in the process of moving goods.

FALCONS will use real firm population data for the different industry sectors. Real nodes (distribution centers CCs, ports) locations and capacities. It will also use a dynamic load balancing approach to maintain node and link capacity limits. The model will also enable modelers to conduct some policy measures studies related to e.g. CO2 emissions or modal split. Or several “what if” scenarios related to firms location choice and future Production-Consumption PC scenarios, can be made using synthetic firms population generation techniques then simulated with FALCONS.

FALCONS – MODEL DESCRIPTION

In the sections following we will describe the FALCONS model, data needed to run it, agents and their interactions and expected outputs.

Introduction

FALCONS will follow a bottom up approach in modeling freight flows. Goods to be modelled follow the NST\R convention of grouping and there exists nine good categories to model. Those categories are listed in Table 1 below.

Table 1: Classification of goods categories for FALCONS

NST\R Category	Goods included
NSTR 0	Agricultural products and live animals
NSTR 1	Foodstuff and animal fodder
NSTR 2	Solid mineral fuels
NSTR 3	Petrol products
NSTR 4	Ores and metal waste
NSTR 5	Metal products
NSTR 6	Crude and manufactured minerals; building materials
NSTR 7 and 8	Fertilizers and Chemicals
NSTR 9	Machinery, transport equipment, manufactured articles...

Since the goal is to simulate freight flows for a period of a year, goods production (and hence consumption) will follow estimated time (monthly) based patterns, where certain goods will be produced and consumed more during certain times of the year. For example oil and gas production will see a small peak during winter months and so on. This time differentiation will be the entry point to the time dimension with which firms will interact with each other, and relative to which smaller time windows for ordering and delivering goods will follow.

Input and output tables (Leontif 1936) will were estimated to better match production side with consumption side, with percentage based shares as obtained from industry and literature. An example is crude oil decomposing into main final consumable products like car fuel, heating gas and pharmaceutical usage. Those approximated percentages will be used as upper limits for consumption side.

Although a complete nationwide firm database is at hand, only a sampled population of firms (representative of firm size, industry, and location) will be used. This is to overcome the computational intensive process of firm to firm interactions if all firms were modelled. Results for the sampled population will be reweighted to represent the original population. JANUS platform is able to handle approximately one million agent interactions at the messaging level used in FALCONS.

Agents in FALCONS are firms, in different sectors making a decision to deal with each other by optimizing a cost function. The cost function is a modified Economic Order Quantity (EOQ) (Muckstadt and Sapra 2010), to include further cost components as cost due to distance between agents. Cost structure for production firms is given below in (1).

$$C_{pf} = C_{shipper} + C_{inv.} \quad (1)$$

Where, C_{inv} is the firms inventory cost per volume it possesses, and $C_{shipper}$ is cost of contract with shipping firm when moving goods from production side to target consumption side. Each cost part further breaks down to other components as shown in (2) and (3) below.

$$C_{shipper} = C_{admin} + C_{carrier} + P \quad (2)$$

$$C_{inv.} = (I_{max} / 2) H + (D / Q) S \quad (3)$$

Where C_{admin} is administrative cost, $C_{carrier}$ is the carrier firm cost and is a function itself of distance, fuel, vehicle maintenance, labor (driver). P is a profit margin. I_{max} is maximum inventory level, H is holding or carrying cost (Euros/ unit / year), S is ordering cost (Euros), D is demand volume per year, Q is ordered quantity.

Using data on yearly turn over for firms, and combining this with data on cost per ton per good category, we can estimate yearly firms production and consumption volumes. Those volumes will be the starting point for every firm. Volumes to send e.g. by week will be obtained by distributing those volumes over the year, following the yearly consumption patterns mentioned earlier as a guideline. This process will also serve as basis for shipment size and frequency.

Production firms will first look at possible consumption partners around them, exchange goods with them and only move to next best (less costly) consumption firm if they still possess goods to sell. After each interaction, inventories are updated to reflect current quantities, and the process is repeated till all goods at initial time are consumed. Extra quantities remaining at production side will be assumed to go for export. Unfulfilled consumption quantities from local production firms will attract import flows. Till both production and consumption sides are fulfilled.

Real carrier firms will be modeled and they will be the agents who transport goods. An algorithm to rank carrier's level of service is used where firms will rank carriers to deal with in next orders if a carrier delivers in given time window. Otherwise, firms will look for other carriers. This will reduce computational complexity arising by each firm searching for most cost efficient carrier for each time they want to send goods.

Each shipment sent will include information on source firm, destination firm, quantity, sector type and a time window to deliver. Example shipment dependencies:

shipment (source agent ID, destination agent ID, NSTR, volume, time window, mode restriction)

To reduce computational complexity and runtime, a sample of the real firms is used in every run. This still makes a large sample when firms decide to search for optimized links for transport. To reduce this complexity, the road network was skimmed to include only those roads allowed for trucks. Reducing the total amount of available road links. Additionally, some goods were restricted to certain modes as they are in real life, e.g. food related categories uses only road links and ignore rail or waterways. Finally, production agents will search for best shippers to deal with only in the first run. After that, production agents will rank this shipper as preferred choice if future deliveries need to be done to same target zone. A new search for a shipper will take place if this ranked shipper fails to deliver in time window specified.

Model agents

We will next present a description of the different agents used in FALCONS.

Firm agents

Each production, consumption and carrier firm will be acting as one agent acting and reacting to other agents following its own roles in the simulation. Each agent will have a list of attributes differentiating it from other agents, as well as a set of rules defining its interactions with other surrounding agents.

Table 2 below summarizes example attributes of a production firm.

Table 2. Example firm attributes for firm ID 203

Attribute	Value
Firm ID	203
Zone ID	127
Industry	6
Size category	2
Type (prod.cons)	2
Yearly turnover (€)	175.850,00
Yearly production size	376 tons
Special access to node	yes
Node	Antwerp port
Mode restriction	yes
Mode	rail

Firm agents are either production, consumption, shippers or carriers firms. Firms which process goods to produce other types of goods are counted twice, once as a production firm and another as a consuming firm.

Agent_production (agent ID, zone ID, NSTR, volume, inventory level, shipment_ID, time window, agent_shipper, agent_carrier)

Carrier firms will actually handle the transport and there exist carrier firms for the three modes of interest, road, rail and waterways carriers. Each will possess a fleet of vehicles

(trucks, freight wagons or barges). Example carrier agent dependencies:

Agent_carrier (zone ID, carrier ID, mode, NSTR, # vehicles, vehicle_ID, vehicle_ID capacity, time windows, agent_shipper_ID, agent_production_ID, shipment_ID, agent_capacity_ID)

Last firm agent is shippers agents. Those agents represent shipping firms who will act as contractors of carrying services. Shippers will offer contracts to production firms in order to transport their goods to consumer firms. Shipper agents will make decisions of carrier choice, route choice, mode choice. They send their offers to productions firms based on optimized cost. They also must meet any policy constraint, coordinate with nodes (ports, DCs..) to meet delivery time windows.

Capacity agents

Capacity agents will be present in every zone and they will coordinate capacity of links and nodes usage with shipper and carrier agents. In case of restricted access to a node due to full usage of capacity at a time, capacity agents will ask carrier agents to choose next best route. Priority is given to delivery on time over cost. Example dependencies of capacity agents:

Agent_capacity (zone ID, road links, capacity road link, rail link, capacity rail link, # nodes, node type, capacity per node type, agent_shipper, agent_carrier)

Timing agent

This agent will serve as a universal clock for the simulation and make sure time windows are coordinated.

Example interaction flow

Below we illustrate a simplified example scenario of moving goods from one production site to a consumption site.

1. Agent_production (2, 127, 2, 100 tons, 600 tons, slot 3, shipper = unknown, carrier = unknown), picks (based on closest distance) agent_consumption (67, 127, 2, - 250 tons, - 670 tons, slot 3).
2. Agent_production (2, 127, 2, 100 tons, 600 tons, slot 3, shipper = unknown, carrier = unknown) contacts all shippers in its own zone ID (assumption made for simplicity) and asks for best offers to move his goods to agent_consumption (67, 127, 2, - 250 tons, - 670 tons, slot 3).
3. Every agent_shipper will contact pool of available and permissible agent_carriers in same zone first, and calculate cost of moving goods with different carriers.
4. Agent_production (2, 127, 2, 100 tons, 600 tons, slot 3, shipper = unknown, carrier = unknown), will receive offers and ranks best 3. He picks best one to use for now. Remaining 2 are preferred choices in next assignments if choice one is not available.

5. Agent_production (2, 127, 2, 100 tons, 600 tons, slot 3, 5, 35) updates his shipper and carrier values after he picks agent_shipper_5, who subcontracted Agent_carrier (127, 35, 1, 2, 5 heavy trucks, vehicle_2, vehicle_2 capacity = 50 tons, vehicle_3, vehicle_3 capacity = 50 tons, slot 3, agent_shipper_5, agent_production_2,shipment_1, agent_capacity_2).
6. Agent_capacity_2 checks that moving this shipment doesn't cause exceeding link capacity chose by agent_carrier_35. If yes, agent_carrier_35 will chose next available link maintaining the time window for shipment delivery. If not possible, it will use original link, but agent_capacity_2 will mark the link as over congested. Consequently agent_production_2 will downgrade ranking of agent_shipper_5.
7. Otherwise, Agent_production (2, 127, 2, 50 tons, 500 tons, slot 2, shipper = unknown, carrier = unknown) updates his inventory to reflect new levels and is ready for next shipment, 50 tons in this case. Agent_consumption_67 will update his inventories too and gets ready for next shipment.
8. Process is repeated till all consumption volumes (negative inventories are filled).

Data sources and zoning system

Below we summarize data sources needed to run FALCONS and the zoning system used.

Bel-First firm database

This is a firm database for Belgium and Luxemburg updated yearly by Bureau Van Dijk (Bureau Van Dijk). Firms can be filtered out using several criteria. Attributes of interest for us and used in this work are number of firms, industry classification, address information, size (C1: very large, C2: large, C3: medium or C4: small), yearly turn over for last year. As explained earlier, yearly turnover will be used for estimating firm production volume, from which shipment size and frequency are obtained.

Zoning system

The present-day Flemish Region covers roughly 13,522 km² and is divided into five provinces, 22 districts and 308 municipalities. Flanders is divided hence into 308 zones, each zone representing one municipality.

Network database

This is a database containing travel time data for road links. Data include free floating (no traffic) travel time, loaded network, AM and PM peak travel times and travel distances respectively. Work is in process to enhance existing rail link database. The database also includes information on nodes (ports, DCs, and CCs).

Other data sources

Few other data files are used to run the model. Examples are value to weight data describing monetary value per ton of each good categories. Data on vehicle types, dimensions, fuel and labor cost, etc.

Discussion

Since we are using yearly turnover data to estimate volumes sold, and since this data is available for the previous year, this means the simulation process is modeling a push transport rather than pull. This means estimated volumes at start must be consumed totally, as we know they did indeed get sold and hence transported. For the purpose of modeling yearly flows, this is an acceptable assumption. However, future work on the model will aim at incorporating additional logistics practices as produce on demand.

The model focuses on internal freight flows and use remaining production volumes or unfulfilled consumption volumes as basis to estimate import and export flows. However, transit flows are still not modelled due to the very complex nature of those flows. Some representation of transit flows might be achieved if one assumed if usually nodes are operating close to their maximum capacity, and any free capacity after all internal, import and export operations are complete, will attract transit flows.

SUMMARY

We have presented FALCONS; an agent based freight model for Flanders. The aim of the model is to simulate the annual freight flows in three modes of transport for now (road, rail, inland waterways), moving between 308 geographical zones. The simulation will allow several policy measures assessment. FALCONS uses agent based simulation technique to model in a bottom up approach the different actors directly related to the move of flows, namely; production and consumption firms, carriers and logistics nodes. Recent availability of up to date and micro level data will be used to run the model. The core of the model is a cost optimizing process that the agents will use as a basis to interact with one another. The model also will use a dynamic load balancing technique to maintain capacity limits on links and nodes. The model is at early implementation state, and a working prototype is planned before the end of 2014.

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