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An Agent Based Simulated Goods Exchange Market; A Prerequisite For Freight Transport Modeling

Omar Abed[a]*, Tom Bellemans[a], Gerrit K. Janssens[b],

Davy Janssens[a], Ansar-Ul-Haque Yasar[a], Geert Wets[a]

[a]*Transportation Research Institute – IMOB,Wetenschapspark 5 bus 6,Diepenbeek, Belgium*
[b]*Faculty of Business Economics Hasselt University, Diepenbeek, Belgium*

Abstract

Freight flows are in essence a result from the exchange of goods between producers and consumers and the transporting firms moving the goods. This essentially constitutes a market interaction among different type of firms, differentiated by many attributes like industry type, size, location and role in the supply chain. A usual final outcome of such an interaction manifests itself in the form of Production-Consumption (PC) matrices, tabulating regional production and consumption pairs for the different goods and geographical region being simulated. It is often the case that this information is obtained only at an aggregate level, either due to firms' unwillingness to share their trading information or the high cost of obtaining this data or both. Different techniques are used to disaggregate such data. This process often implies over simplified assumptions. In this paper we present a bottom up approach to simulate this goods interchange process between production and consumption firms. The proposed model is based on an offer negotiation and evaluation process among three types of firms; production firms, consumption firms and carrying (transport) firms. The interaction is based on actual firms' decisions. Agent based simulation technique is used to facilitate capturing some behavioral aspects of the different agents (firms) in the model. One outcome of this model is a set of PC matrices which can be used in further transport modelling steps.

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* Corresponding author. Tel.: +32 (0)11 26 91 11.
E-mail address: omar.abed@uhasselt.be

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1. Introduction

The primary goal of operational freight transport models is to serve as a planning tool for policy makers. Transport domain policy makers use such models to better assess decisions on e.g. infrastructure expansion or maintenance, effect of tolls or fuel price effect on modal splits[1, 2]. Traditionally, freight transport models borrowed elements from private transport models, namely; the four steps modelling approach. However, this approach – when applied for freight transport modelling – has a main limitation; it fails to capture important behavioral aspects directly linked with the amount of goods generated, transported and consumed[3, 4]. The subject four modelling steps (as used to model freight flows) are; production and attraction, distribution, mode choice and network assignments. Of special importance to us here are the first two steps of this traditional approach.

The production and attraction step is in essence the aggregation of total regional production and consumption quantities, expressed normally in tons. These are local totals produced and consumed in each division (geographical zone) of the study area with no underlying rule to match both sides. It is in the next step; distribution, where a mechanism to match production and consumption is used and from which, detailed goods exchange relations among zones is tabulated. Resulting tables are often called Production-Consumption PC matrices[5]. Both steps basically represent a good exchange market between firms producing the goods, final consuming parties (e.g. firms, individuals, government), and the transport firms who actually transport the goods among them.

The elements, motives, distributed decisions making processes and interconnected relationships in a real life economy are quite complex. However, if we limit ourselves to the objective of simulating goods flows, then we can focus only on those firms' activities which affect this final goal. Specifically, we would care about those firms decisions \ activities which influence the amount and location of goods being produced and consumed, basis to link both sides, size and frequency of shipments, mode choices and network usage.

With advancements in processing power and the emergence of new simulation techniques, a new generation of freight and logistics models came into existence, overcoming some drawbacks of the four steps modelling approach. Nevertheless, existing modelling efforts still suffer from the following:

- *Lack of data*:

Lack of disaggregate data on firms often drives modelers to use different disaggregation techniques in their models, which often implies making over simplified assumptions. Examples of such assumptions are made in [6], where the number of firms per geographical zone – and classified into size categories- have a "one size fits all" predefined rule of interaction. Another such an assumption is made in [7], where all goods producing entities and consuming entities are each represented by one agent in a given geographical zone. This assumption - although justified by lack of more detailed data- clearly prevents the model from fully exploiting the power of agent based simulation techniques. Lack of data is also the main reason why some modelling efforts stopped at providing conceptual model frameworks and did not enter the phase of implementation [8, 9].

- *Weak behavioral foundation*:

Existing operational models involving firm to firm interactions and firms decisions, rarely link their model assumptions to theories of individual \ firms decision making. Instead the assumptions – still logical of course- made often serve an operational goal of having a model that functions. In economics, there exists today a wide range of theories on decision making processes for individuals and firms alike. Examples are Utility Theory (UT), a more recent and formal version of UT; Expected Utility Theory (EUT) [10], Prospect Theory (PT) [11] and related concepts of perfect versus bounded rationality. Several of these theories and concepts have been empirically proven and even formally defined. Therefore borrowing elements from this theoretical foundation will enable modelers design more trustworthy models.

In this paper, we address the lack of data problem by proposing a bottom-up approach to generate PC matrices. More specifically, we propose an agent based simulated goods exchange market model, where the agents are the different firms producing, consuming and transporting goods. Availability of disaggregate data on firms and using agent based simulation, our proposed model captures several real life firms decisions. Examples of simulated firms' decisions are; offers evaluation, partnerships formation, financial performance evaluation against quarterly goals and discount offerings. In our model, we make a distinction between tactical short decisions and strategic long term decisions, basing our assumptions on existing theories of firms' decision making. Although decision making in firms cover the whole range of the supply chain, in this work we are interested primarily in the demand and supply market sides, comprised essentially of goods producers and consumers. From the transportation and network usage side, we will focus here on the participation of carrier agents (transport firms) in the offer negotiation process and leave their actual usage of the network, routing algorithm and related topics to future work.

In the following sections we describe the different parts, data needed to run the model and included decision making processes. We then describe how events and actions in our proposed model link to this theoretical foundation. Followed we explain our motivation to use an agent based simulation approach and the specific use of the agent based platform; SARL. Then, we describe the building blocks of our proposed model; data used, agents' structure and interaction protocol and generated PC matrices. We conclude by an interpretation of the generated output, discuss model limitations and future work.

2. Agent Based Simulation

In this section we provide our motivation for choosing an agent based simulation approach in designing our model. We then discuss our choice of using SARL as an agent based simulation platform and main architectural concepts of this platform.

2.1. Why agent based

Agent based (AB) simulation technique has been adopted by several domains in recent years. In economics, agent based models were developed to simulate financial markets [12, 13], freight flows [7, 9], and markets simulation [14, 15]. Central concepts in agent based simulation are the agent, behavior rules, action and reaction among agents and \ or with their environment. There are key benefits to using AB models summarized here[15]:

- AB models capture emerging phenomena resulting from individual agent interactions with each other and with their environment. This is of special practicality when dealing with large numbers of agents governed by nonlinear rules and behaviors. When defining the rules of interactions for single agents or groups of agents, it is often the case that one can not anticipate ahead how the final emerging outcome will look like.

- AB models describe systems more naturally. This is mainly because AB models represent behavioral entities as opposed to processes, described by e.g. differential equations which become very complex and untraceable the more complex the behaviors. Evolution with time is a key occurring phenomena in real life systems and can be represented with AB models.

- AB models provide high levels of flexibility for modelers. This is realized in several ways; adding or removing large numbers of agents easily, working with different focus levels by zooming on a group of agents or a single agent or a combination of both. Moreover, modelers can specify different levels of behavioral complexity for different agents.

2.2. SARL platform

SARL is a new general-purpose agent-oriented programming language (APL). This language provides the fundamental abstractions to deal with concurrency, distribution, interaction, decentralization, reactivity, autonomy and dynamic reconfiguration. These meta-level features are considered to be main requirements towards an easy and practical implementation of modern complex software applications. The concepts of *skills* and *capacities* within the SARL architecture, simplifies our task to model detailed agent to agent interactions in our proposed model [16].

3. Data sources

The following data sources are used to run our model.

3.1. Bel-First firm database

This is a detailed database of all registered firms in the Benelux region (Belgium-Netherlands-Luxemburg). All firms are required by law to submit their firm registration and financial data to the national bank. Bel-first database provides information on several firm attributes of importance to us like address, industry sector, size, number of employees, yearly turn over and some information on which type of goods is the firm producing or processing \ consuming. This information is the basis to define our production, consumption and carrier agents (firms) [17].

3.2. Travel time database

This is a table of estimated travel time (under peak time and free flow conditions) and travel distance values between every zone pair (total of 2385 zones each with around 1 km^2 surface area) making up our modelled region; Flanders. This information will be used by carrier agents to calculate their offerings (transport contracts) in the negotiation process.

3.3. Vehicle registration database

This is a yearly updated database of the number of existing and newly registered vehicles (private and commercial). Since this data is given on a municipal level, this will help us estimate number of vehicles owned by carrier firms in the same region.

4. Model Description

In the following sections we present our model. A detailed sequence diagram is shown in Appendix A. We describe different agents in the model and their respective roles, and the interaction process among them. We finally discuss the model's generated outputs.

4.1. Consumer Agent

ConsAgent represents the demand side that triggers the model interactions. This agent represents the consuming firms or firms used as proxy to represent final consumer (e.g. hyper stores representing individuals' consumption). Each ConsAgent has a defined yearly demand proportional to the yearly turnover or consumption statistics. From this demand, each agent will formulate daily requests for quotations RFQs and broadcasts its requests to production agents around it based on defined rules. Received offers will be evaluated and the cheapest will be chosen. An order is then sent to book the goods to transport them as next step. The inventories levels are then updated on both sides, and next demand requests are initiated iteratively, until all demand is fulfilled. At the end of the simulation, any remaining unfulfilled demand will trigger import flows. Figure.1 below shows UML description of ConsAgent attributes, functions and dependencies.

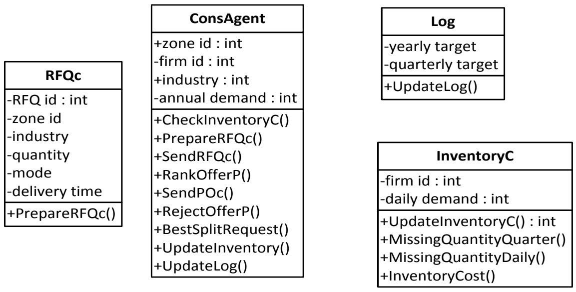


Fig.1. Consumer agent attributes events and ownerships

4.2. Production Agent

Production agent ProdAgent represents the supply side. This is essentially all the producing \ processing firms which supply goods to fulfil demand requests. ProdAgent has its own cost structure (inventory and goods cost) and for each demand requests within its scope (matching RFQ attributes and quantity availability), it contacts Carrier Agents to check for best offers to transport the goods. This combined costs offer is then sent back to the requesting ConsAgents. If and order is received, ProdAgents proceed to goods, acknowledge corresponding offer from Carrier Agents and update their supply inventories. Figure 2 below describes ProdAgent attributes, events and dependencies.

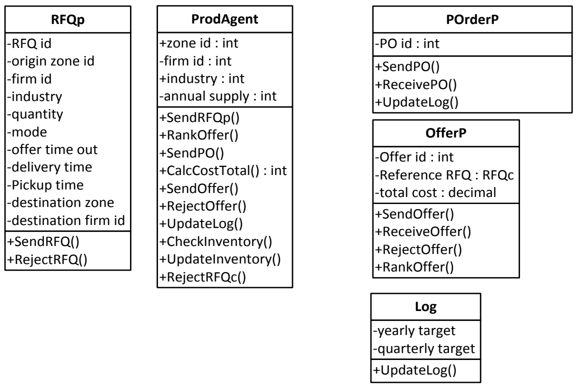


Fig.2. Production agent attributes, events and ownerships

4.3. Carrier Agent

Carrier Agents are the transportation firms which will actually perform the transport between production and consumption sides. This includes road transport carriers. For inland waterways (IWW) and rail transport, both modes and corresponding network data exist, and transshipment nodes are included in the model. Each road carrier firm is assigned a fixed number of trucks proportional to its yearly turnover. This will make the problem of vehicle availability more realistic. Some assumptions are made for IWW and rail firms. Carrier Agents receive transport requests from ProdAgents and decide on them based on vehicle capacity availability and cost optimization. The goal is to optimize capacity usage so that transport tasks are feasible. In this stage of the model, CarrierAgents calculates their costs based on an initial knowledge of travel time and travel distance data. Time dimension is taken into account in the simulation such as; all trucks are assumed to be back by 23:30 PM every day, so they are available for next day planning.

4.4. Key features

- Pre simulation quantities tuning: Leontief's table method is used to fine tune final demand and supply quantities before the simulation. This also accounts -to some extent- for the cross industry dependencies where output of some sectors is used as input to others.
- Partnerships formation: during the negotiation phase among agents, when a "best offer" is obtained 3 consecutive times from the same agent, a message is sent to offer a partnership formation between those agents. This not only mimics real life scenarios, it additionally reduces computation times as fewer messages are broadcasted. This partnership is subject to quantity availability, otherwise is cancelled.
- Optimal order size: it is left to the agent to decide on quantities to order. However in the possible scenario of receiving no offers due to quantity constrains, the agent can redefine its ordered quantities but must account for optimizing ordering costs.
- Discount offerings: for ProdAgents and CarrierAgents, an evaluation of performance target set quarterly controlled and in case of low performance, a two stage discount offering is made by first reducing profit margin or even offering a break-even price if needed.

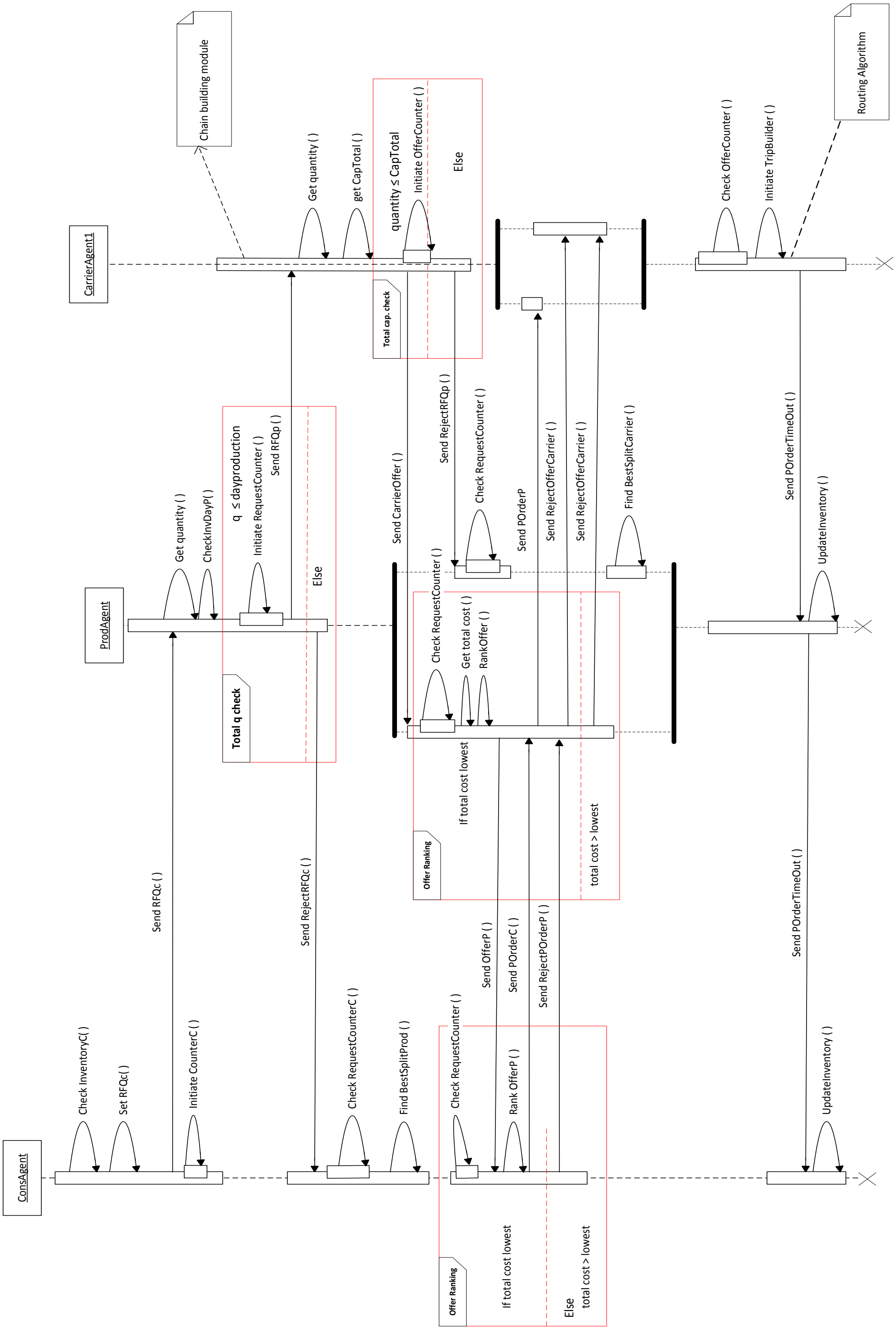
4.5. Model output

The final outcome of this model is asset of production consumption matrices, depicting the amount of goods moving from one zone to another. The advantage of this approach is that the PC matrices.

5. Summary

In this paper we presented a agent based model to simulate a goods exchange market. The output of the model is regional production and consumption tables used further to model freight flows. The approach enables a bottom up way to obtain these tables as a result of the actors interactions defined in the model. Rules of interaction we defined trying as much as possible to mimic real life occurrences like commercial requests, offers and evaluation of offers. The agents have each cost functions to optimize using an initial available knowledge. Simulated agents are firms producing, consuming and transporting goods. In a following work, we will use the output of this model simulate freight flows making use of network data, routing algorithms and learning algorithms. The learning algorithm used will enable transport agent to reevaluate their route choices, resulting in an agent based traffic assignments.

Appendix A. Negotiation sequence diagram



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