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A Micro Simulated and Demand Driven Supply Chain Model To Calculate Regional Production and Consumption Matrices

Omar Abed [a], Tom Bellemans, Gerrit Janssens, Bharat Patil ,Ansar Yasar, Davy Janssens, Gert Wets.

Transportation Research Institute (IMOB),Haaselt University,Wetenschapspark 5 box 6, B-3590 Diepenbeek, Belgium

Abstract

Detailed data on regional goods production and consumption are traditionally the starting point to model freight transport on a nationwide scale. The conversation of those goods afterwards into various vehicle load types and the different logistics operations needed to deliver the requested goods type and quantity, follow from that starting point in the modeling process. In this paper, a demand driven micro-simulated supply chain model is presented. The model shall be a first step towards calculating realistic production and consumption matrices. So far, government provided data has been used as the base to model freight transport for Flanders. The methodology used and accuracy level of this data is not clear. Modeling demand and production relations shall constitute a starting point towards an agent based freight model under development. The presented model is a microsimulation model incorporating the main firms (firms) of a traditional supply chain. It is a demand driven model using quantity of goods requested at the consumer side as a starting point. The model distinguishes also between shipping and carrying firms and takes into account raw material suppliers able to supply all or some subcomponents needed by production firms. Economic Order Quantity (EOQ) relations are used with modifications to include transportation and labour costs. The model is based on an optimized universal cost function and different initial conditions can be used to mimic real life firm to firm interactions. A certain good demand scenario is simulated and results are shown.

Keywords: Microsimulated supply chain ; logistics modelling; production-consumption matrices; agent based freight model

* Corresponding author. Tel.: +32(0)11 26 91 23.
E-mail address: omar.abed@uhasselt.be.

1. Introduction

Freight transport models are moving gradually from the traditional four steps approach towards more micro-simulated and behaviour based models. Such a move was mainly due to the four steps models inability to capture important logistics and transportation related decisions. This affected accurate modeling of freight traffic's size and distribution [1] [2]. Several transitional models implementing elements of the four steps models and supply chain decisions have been reported [3]. more recent micro-simulation freight models tend to fall into two categories; freight flows models [4][5][6] and tour based models [7].

The freight flow model [4] has been used so far to model freight transport for Flanders. The input to this model is a set of production and consumption matrices detailing the amount of goods in tons traveling from each subzone area division to another, as well as transit freight traffic. The methodology by which these matrices were obtained and its accuracy is not clear. Moreover, the model's authors recognize the lack of available information on disaggregate regional production \ consumption (PC) flows. Such information is vital to correctly model freight flows as demand and consumption relations change with time, so do firm locations, logistics nodes and supply chain structures.

Our proposed model here is a starting point to obtain real estimates of PC flows. To increase the accuracy of the obtained flows, the model is able to simulate real firms geographical locations and link them with regional demand. The model uses real travel times, travel distances besides geographical locations of firms. This is possible after using available OD matrices used for passenger traffic modelling. free floating (no traffic) as well as AM and PM peak time based data is available. The model makes it also possible to enforce a set of Rules ***R*** as will be shown later where the modeller can specify a set of initial conditions to limit the level of firm to firm interaction in spatial dimension or cost based favouring among other types of constraints. This set of rules will act as initial conditions set differentially for each run. Example of such rules are limiting the geographical range which firms can use to deal with other firms. Another example is to limit partner firm choice based on travel time needed to reach that partner. Food transport is an example of such a condition in real life where expiry dates are critical.

Additionally, supply chain models considered raw material suppliers able to supply all sub components of a finished product to production firms[9][10]. Our presented model takes into account that raw material suppliers might or might not necessarily supply all sub components of a finished product ***P***. in real life scenarios, a finished product might have several components provided by different suppliers and hence the amount of traffic and costs involved in supplying all components must be taken into account. The model will basically search for the optimal choice of raw material suppliers whether or not they can supply all subcomponents or not. This becomes useful when a supply chain of specific product with known subcomponents needs to be simulated.

The model uses optimal inventory cost economics based of the well-established Economic Order Quantity (EOQ) relations [8] with modifications. Additional costs related to shipper and carrier firms where introduced and the notion of profit margin was added to individual firms cost function. It is assumed here that in reality, the goal of each firm is to make profit and grow. Hence a breakeven deal is not enough to initiate a deal between two firms.

The model at its current state is a first version of an agent based model under development . The eventual goal is to model the entire supply chain for different industry and good category types. Such modelling of production and consumption (PC) matrices will greatly improve the input to the currently used ADA model for Flanders [4]. Current PC matrices are for the base year 2000 and used to make future forecasts by tuning the yearly GDP percentage for different requested scenarios. There are several improvements still be done and will be discussed in the future work section of the paper.

2. The model and firms interactions

The model run starts as mentioned previously by setting some initial values needed by different firms to make their respective cost calculations. EOQ relations enables us to link demand side with production. The relations are based on optimal quantity demand, inventory and production costs. It is assumed here that firms base their decisions on optimizing costs to maximize profit when dealing with other firms [11]. The model include raw material suppliers *Rms_n* , production firms *Prod_n*, consumption firms *Consum_n*. freight forwarding firms *Forward_n*, who in turn contract carrier firms *Carrier_n* are also present and handle transportation between different other firms.

2.1. Initial conditions and assumptions

In the simulation, it is assumed that all firms are following EOQ economics to minimize their respective inventory and\or production costs [8]. Additionally, the cost of inventory holding H, and ordering cost S will be the same for all firms for the same ordered quantity Q. It will be also assumed that freight fleets have full road network usability for now. Raw material firms will have inventory costs only, equal in value for similar inventories, but will be differentiated through the cost of transport (shipping and carrying) to carry goods from their locations to production firms. Each firm will be located in a different subzone, and hence will have a corresponding subzone ID. This will be the basis for reading travel time and travel distance values available from the matrix. In order for the model to initiate, some input values need to be supplied and read by different firms. Values such as production rate and usability, demand D and required quantity Q, vehicle fuel consumption rates and labour cost per time units. Firms will read these input values and start calculating their respective cost function and pass the values to related firms. Example of input values are shown in Table 1.

Table 1. Example input values for the model

Description	Value (unit)	
Demand, D	5000	units\year
Holding cost, H	5	Euros\unit\year
Ordering cost, S	30	Euros
Vehicle fuel consumption, Vc	10	liters\100 Kms.
Order quantity, Q	415	units

Example set of rules ***R*** in order for firms interaction to take place as follows :

Consum_1 → Prod_n : [$T1 \leq 120$ minutes]
Consum_1 → Forward_n : [subzone ID ϵ 0-2386]
Forward_n → Consum_1 : [$D \geq 4000$ units \ year]
Forward_n → Carrier_n : [$d1 \leq 175$ kilometers]

Carrier_n → Forward_n : [$Q \geq 375$ units]
Prod_n → Rms_n : [$d2 \leq 110$ kilometers]
Rms_n → Prod_n : [$Q \geq 300$ units]

These conditions were set to mimic realistic firms interaction. For example, it won't be realistic to choose a carrier firm who is remotely located from production firms and hence, goods expiry dates become an issue. Or even, some regional policies might give incentives (e.g. tax reductions) when dealing with local service providers.

2.2. Firms Interaction flow

1. **Consum_1 → all firms**

The consumption firm broadcasts quantity request Q and yearly demand D to all other firms and calculates its own C_{inv1} based on those values.

2. **Rms_n → Prod_n**

Raw material supplier firms calculates their respective C_{inv3} and send value to each Prod_n firm, provided that corresponding ***R*** rule is met.

3. **Prod_n → Rms_n**

Production firms will read cost values sent from Rms_n firms, chose the lowest value for combined Q_n, provided ***R*** rule is met, calculate its corresponding C_{pf} based on its individual production rates, usability rate, transportation and labor costs.

4. **Prod_n → Consum_1**

Production firms will then send their corresponding C_{pf} value to Consum_1 firm.

5. **Carrier_n → Forward_n**

Carrier firms meeting ***R*** will then calculate their corresponding cost function and broadcast value to all Forward_n firms.

6. **Forward_n → Consum_1**

Freight forward firms meeting ***R***, will collect cheapest available carrier firm and calculates its own cost function and broadcast value to consumption firm.

7. **Consum_1 → Prod_n**

Consumption firm will finally compare all received cost functions from production firms and choses the lowest value, provided ***R*** rules are met .

8. **Consum_1 → Forward_n**

Consumption firm will then compare received costs values from Forwarder firms and picks up lowest value.

9. **Cosum_1 → o\p file**

Consumption firm will then add up chosen cost functions to its own Cinv1 and displays total value, and lists corresponding firms IDs constituting this lowest cost leg to an output file.

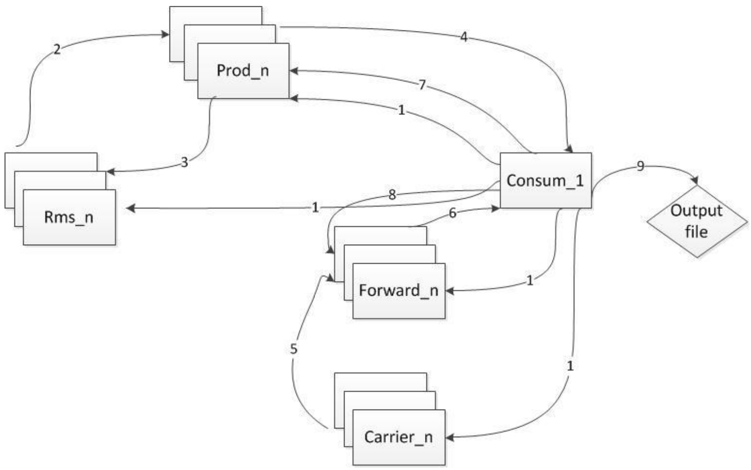

Fig. 1. Firms interaction flow.

2.3. Model cost functions based on modified EOQ relations

Consumption firms:

C_{cf} = Production firm cost + Freight forwarder cost + inventory cost + profit

$C_{cf} = C_{pf} + C_{ff} + C_{inv1} + 5\%$ profit,

C_{inv1} = annual carrying cost + annual ordering cost

$C_{inv1} = (Q \setminus 2) *H + (D \setminus Q) *S$,

Where S is ordering cost , D is demand (units \ year), H is holding or carrying (cost \ unit \ year), Q is units ordered.

C_{inv1} is minimum at Q_0 : $C_{inv1} = (Q_0 \setminus 2)* H + (D \setminus Q_0)* S$

Q_0 = sqrt (2DS \ H) , is Optimal order quantity ,

$$\mathbf{C_{cf} = C_{pf} + C_{ff} + C_{inv1} + .05\,(C_{pf} + C_{ff} + C_{inv1})}$$

Freight forwarder firms costs:

C_{ff} = Cost of contract with carrier firm + 10% of profit margin

$$\mathbf{C_{ff} = C_{carrier} + 0.1 * C_{carrier}}$$

Carrier firm costs:

$C_{carrier}$ = Fuel cost of carrier truck + driver cost of carrier truck + 10% profit margin

$$\mathbf{C_{carrier} = C_{fuel} + C_{driver} + 0.1 * (C_{fuel} + C_{driver})}$$

Production firms costs:

C_{pf} = costs of contract of raw material firms + fuel cost + driver cost of production firm's truck + Inventory cost of Q_{cn} + 8% profit margin

$C_{pf} = C_{rm} + C_{fuel} + C_{driver} + C_{inv2}$ + 8% profit margin

$$\mathbf{C_{pf} = C_{rm} + C_{fuel} + C_{driver} + C_{inv2} + 0.08 * (C_{rm} + C_{fuel} + C_{inv2} + C_{driver})}$$

C_{inv2} is the optimal (minimum) inventory cost ,which takes place at optimal production \ run size of Q_{opt}, which relates to Q_0 by :

$Q_{opt} = Q_0 * \text{sqrt}(p \backslash p-u)$, where p is production rate (unit \ day), u is usability rate (unit \ day).

$C_{inv2} = (I_{max} \backslash 2) H + (D \backslash Q_{opt}) S$, where I_{max} is maximum inventory level, H is holding or carrying cost (euros\ unit \ year), S is ordering cost (euros).

$I_{max} = (Q_{opt} \backslash p) * (p - u)$

Raw material suppliers costs:

C_{rm} = Inventory holding cost of Q_{cn} + 5% profit margin

$C_{rm} = \sum C_{inv3}$ + 5% profit margin , where C_{inv3} is the yearly inventory cost of Q_{cn} at raw material firms inventories.

$$\mathbf{C_{rm} = \sum_{n=1}^{n=2} (Q_{cn} \backslash 2) * H + (D \backslash Q_{cn}) * S + 0.05 (\sum_{n=1}^{n=2} (Q_{cn} \backslash 2) H + (D \backslash Q_{cn}) * S)}$$

Fuel cost

C_{fuel} is the fuel cost and is a function of traveled distance and liter fuel price.

C_{fuel} = (1.37 euros \ liter)* d * Vc ,

Where , d is distance in kms., V_c is vehicle consumption in liters\100 kms., Distance d is in kilometers.

$$\mathbf{C_{fuel1} = 1.37 * d1 * V_c ,}$$

d1 is in kilometers and is here the trip; (carrier firm → production firm → consumption firm → back to start location).

$$\mathbf{C_{fuel2} = 1.37 * d2 * V_c ,}$$

d2 is in kilometers and is here the trip (production firm → raw material firm → production firm).

Labor cost

C_{driver} is the cost of truck drivers as a function of travel time.

$$\mathbf{Cdriver = 25 \ (euros \backslash 60 \ mins.) * Tn , \ n=1,2}$$

Where T_1 is travel time in minutes needed to travel d_1, and T_2 is corresponding value to travel d_2.

2.4. Zoning system

The unit of geography used here is defined by means of a hierarchy of three geographical layers. This hierarchy stems from the land use data being available at different levels of geographical detail. In order of increasing detail there are a total of 327 Superzones, 1145 Zones and 2386 Subzones. Figure 2 shows Flanders map with divisions on a subzone level with example firms locations.

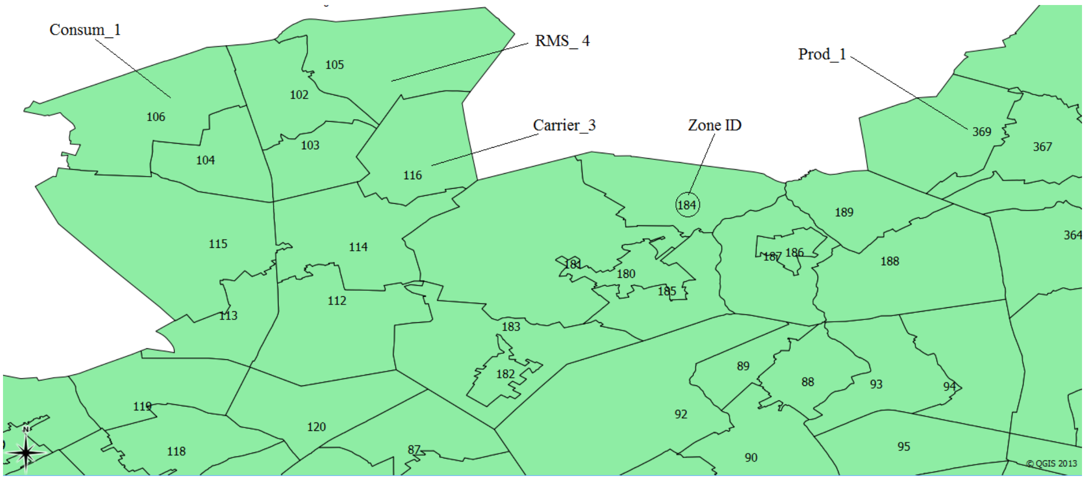

Fig. 2. A section of Flanders with Subzone level divisions and example firm locations

2.5. Output file

Table 2 below shows example model output. This model run involved 20 different firms of all types, distributed over 20 subzones, the following output was obtained as an example:

Table 2. Example model output

Criteria	Model output value (unit)
Total Consumer Cost	312.48 €
Production Firm Cost for production_firm_6	167.32 €
Total Minimum travel Distance	113.03 kilometers
Total Minimum Time	82.7 minutes
Minimum cost firms chain	raw_supplier_4 , production_firm_6 , Carrier_3

3. Discussion and Future work

As previously mentioned, this model is a first step towards an agent based freight model under development. The current model takes into account road mode only for now. Further improvements will include waterways and rail modes. The presented model is very useful when simulating traditional supply chains, and takes into account raw material suppliers able to provide all or parts of the final product's components to production firms. The model however still needs to include policies effect on flows and an algorithm assuring optimized capacity usage. Such requirements might be better met using agent based simulation paradigms using bottom up approach. The eventual goal is to have a complete model for both passenger and freight movements due to their correlated relationship, like shared network usage and policies affecting both.

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