

A Micro Simulated and Demand Driven Supply Chain Model To Estimate Regional Production and Consumption Relations

Omar Abed^a, Tom Bellemans^a, Gerrit K. Janssens^b, Ansar Yasar^a, Davy Janssens^a, Geert Wets^a*

^a Transportation Research Institute (IMOB), Hasselt University, Wetenschapspark 5 box 6, B-3590 Diepenbeek, Belgium ^b Research group Logistics, Hasselt University, Agoralaan Gebouw D, B-3590 Diepenbeek, Belgium

Abstract

The various operations of production, distribution and consumption of goods make up supply chain networks. The usual pre requisite to model freight flows on between geographical zones, is an understanding of intra zonal production and consumption relations. This is in essence an aggregation of all individual firm to firm interactions taking place in form of production and consumption of goods, as well as transportation firms involved in the goods exchange process. In this paper, a demand driven micro-simulated supply chain model is presented. The presented model is a microsimulation model modeling the main firm types present in a traditional supply chain. It is a demand driven model using quantity of goods requested at the consumer side as a starting point. The different interacting firms use a modified Economic Order Quantity (EOQ) model as the basis of the simulation process. The cost function used includes also transportation and labor costs. The model simulates also shipping and carrying firms and takes into account raw material suppliers able to supply all or some subcomponents needed by production firms. Different initial conditions can be used to mimic real life firm to firm interactions. Firm level and zone level scenarios are simulated and results are shown.

Keywords: supply chain microsimulation, production-consumption tables, optimized location choice

1. Introduction

Freight transport models are moving gradually from the traditional four steps approach towards more micro-simulated and behavior 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 zone division to another, as well as import-export traffic flows. The matrices are in essence an aggregation of the several individual firm to firm relations taking place in a certain zone. The rules by which firms interact with each other are rather complicated in real life. A good representation of real life scenarios and for the purpose of modeling, we usually assume a cost optimized governed relation among firms. In other words, firms usually

* Corresponding author. Tel.: +32(0)11 26 91 58

E-mail: geert.wets@uhasselt.be

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tend to achieve their goals with the most efficient and least costly manner.

Our proposed model here is a starting point to obtain regional estimates of PC flows. This is done by the assumption that firms will seek minimum travel time (translated to cost) when moving goods. The model is demand driven, i.e., the starting point is a good demand quantity requested at the consumption side.. The model uses realistic travel times, travel distances and geographical locations of firms. This is done using network information at hand defining travel times (peak and free flow values) and travel distance for the road network on a subzone level (a subzone is a zonal division with an approximate 1km² of area size). The model makes it also possible to enforce a set of Rules R as will be shown later where the modeler can specify a set of initial conditions to limit the level of firm to firm interaction in spatial dimension or cost based favoring among other types of constraints. This set of rules might be used as initial conditions for each run. Example of such rules are limiting the geographical range to find partner firms and so on. 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, therefore only carriers meeting travel time windows are simulated.

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. 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.

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 interaction

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 also present, and handle transportation between different other firms

2.1. Model cost functions based on modified EOQ relations

Below, we define the cost relations governing firms interactions. The modelled firms aim at minimizing their respective cost function. The functions are based on EOQ relations modified to include some transportation related costs and profit margins.

2.1.1. Consumption firms:

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

$$C_{\rm cf} = C_{\rm pf} + C_{\rm ff} + C_{\rm inv1} + .05 (C_{\rm pf} + C_{\rm ff} + C_{\rm inv1})$$
(1)

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

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

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

Where S is ordering cost, D is demand (units / year), H is holding or carrying (cost / unit / year), Q is units ordered. Cinv1 is minimum at Q_0 : $C_{inv1} = (Q_0/2)^* H + (D/Q_0)^*S$ $Q_0 = \sqrt{(2DS/H)}$, is Optimal order quantity.

2.1.2 Freight forwarder firms:

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

$$C_{\rm ff} = C \operatorname{carrier} + 0.1 * C \operatorname{carrier}$$
 (2)

2.1.3 Carrier firms:

C_{carrier} = Fuel cost of carrier truck + driver cost of carrier truck

+ 10% profit margin

$$C_{\text{carrier}} = C_{\text{fuel}} + C_{\text{driver}} + 0.1 * (C_{\text{fuel}} + C_{\text{driver}})$$
(3)

2.1.4 Production firms

 C_{pf} = costs of contract of raw material firms + fuel cost + driver cost of production firm's truck + Inventory cost of Q_{inv2} + 8% profit margin

$$\begin{array}{l}C_{pf}=C_{rm}+C_{fuel}+\ C_{driver}+\ C_{inv2}+0.08\ *\ (C_{rm}+\ C_{fuel}+\ C_{inv2}+\ C_{driver}) \end{array}$$

 $\begin{array}{l} C_{pf=}C_{rm}+C_{fuel}\!+C_{driver}\!+C_{inv2}+8\% \ profit\ margin\\ C_{inv2}\ is\ the\ optimal\ (minimum)\ inventory\ cost\ ,which\ takes \end{array}$ place at optimal production / run size of Q_{opt} , which relates to Q_0 by :

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

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

2.1.5 Raw material firms

 C_{rm} = Inventory holding cost of Qcn + 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.

$$C_{rm} = \sum_{n=1}^{n=2} (Q_{cn} / 2) * H + (D / Q_{cn}) * S + 0.05 (\sum_{n=1}^{n=2} (Q_{cn} / 2) H + (D/Q_{cn}) * S)$$
(5)

2.1.6 Fuel and Labor cost

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

 $C_{\text{fuel}} = (1.37 \text{ euros} / \text{ liter})^* \text{ d }^* \text{ Vc}$,

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

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

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

Example fuel cost :

 $C_{\text{fuel2}} = 1.37 * d2 * V_c$

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

Labor cost, C_{driver} is the cost of truck drivers as a function of travel time. Example value:

 $C_{driver} = 25$ (euros / 60 mins.) * T_n , 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 .

2.2. 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 1 shows Flanders map with divisions on a subzone level with example firms locations.



Fig. 1. Example zonal distribution and numbering

2.3 Firms cost calculation flow chart

As explained earlier, firms involved in the simulation will look forward to minimize their given cost function. Below is the process flow of such calculation. Fig. 2 shows a diagram of this process.

1. Consum_1 \rightarrow all firms

The consumption firm broadcasts quantity request Q and yearly demand D to all other firms and calculates its own Cinv1 based on those values.

2. Rms_n \rightarrow Prod_n

Raw material supplier firms calculates their respective Cinv3 and send value to each Prod_n firm, provided that corresponding R rule is met.

3. Prod_n \rightarrow Rms_n

Production firms will read cost values sent from Rms_n firms, chose the lowest value for combined Qn, provided \overline{R} rule is

met, calculate its corresponding Cpf based on its individual production rates, usability rate, transportation and labor costs. 4. Prod $n \rightarrow$ Consum 1

Production firms will then send their corresponding Cpf value to Consum_1 firm.

5. Carrier $n \rightarrow$ Forward n

Carrier firms meeting R will then calculate their corresponding cost function and broadcast value to all Forward_n firms. 6. Forward_n \rightarrow 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 \rightarrow 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 \rightarrow Forward n

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

9. Cosum_1 \rightarrow 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. 2. Firms cost calculation flow chart

2.4 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. 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 labor 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.

Description	Value (unit)		
Demand, D	5000 units/year		
Holding cost, H	5 Euros/unit/year		
Ordering cost, S	30 Euros		
Vehicle fuel consumption, V_c	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 \rightarrow Prod_n : [T1 \leq 120 minutes] Consum_1 \rightarrow Forward_n : [subzone ID ϵ 0-2386] Forward_n \rightarrow Consum_1 : [D \geq 4000 units / year] Forward_n \rightarrow Carrier_n : [d1 \leq 175 kilometers] Carrier_n \rightarrow Forward_n : [Q \geq 375 units] Prod_n \rightarrow Rms_n : [d2 \leq 110 kilometers] Rms_n \rightarrow 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.

2.5 Model output

We will simulate two scenarios and obtain an output accordingly. The first scenario is a random scenario for a firm level simulation with different firm types react to a certain good demand. The second scenario is a zone level scenario, where we will see how travel distance acts as an impedance factor when choosing which zone is likely to fulfill demanded quantity.

2.5.1 Firm level simulation

In this simulation run, we assume a scenario where a consumption firm request a certain amounts of goods, 5000 units. The firm is located in one zone. Other actors are located in other zones and include different type of firms. We included several production firms, freight forwarders, carriers and raw material suppliers. Raw material supplier firms included a hybrid combination of firms having inventories for both components of the final product requested, or only one component. The initial values are taken from Table 1.

Table 2 below shows example model output for the above assumed scenario:

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			
Firms chain for minimum cost	raw_supplier_4 , production_firm_6 , Carrier_3			

Table 2. Example model output

2.5.2 Zone level simulation

In the zone level simulation, we will let one consumption firm acting as the zonal demand for a certain good quantity, and let several production firms located each at a certain zone act as the zonal production of that zone respectively. For the purpose of testing distance's – and therefore travel cost and travel time - effect on goods attractiveness, we will locate one carrier firm at every production zone. Demanded good quantity is kept constant. We will also locate raw material suppliers with inventories containing both product components at the same production zone. in doing so, we will force a scenario where only distance between production and consumption are the decisive factor in the simulation process. Initial values are again used from Table 1. The output of this simulation with assumed zonal attributes are shown below in Table 3.

Table 3. Zo	ne a	ttributes	for a	zone leve
simulation	with	obtained	trave	l cost.

Zone (subzone ID)	Allocated firms	Distance from Cons. firm in Kms.	Simulated total cost at consumption zone in Euros
Hasselt (1954)	Cons.1, Prod.1, Carrier1, Raw1	2	€229.57
Antwerp (29)	Prod.2, Carrier2, Raw2	79	€311.82
Leuven (802)	Prod.3, Carrier3, Raw3	58	€283.08
Bruges (908)	Prod.4, Carrier4, Raw4	170	€461.47
Ghent (1619)	Prod.5, Carrier5, Raw5	139	€449.11

The result of the above simulation show the effect of distance translated into travel cost on the process of choosing a supplier. Of course, in real life and at a firm level, more complicated market dynamics take place and choice based on distance alone might not be always the decisive factor. For example, quality of service might have a priority. however, on a zonal level, distance play a big role in intra-zonal good exchange as implied by gravity law application in zonal or import-export trade flows.

2.5.3 Optimized location choice

Since the model makes a link between firms location information, inventories , transport firms and travel cost associated in each case, we can use this property to simulate optimized resource location. A possible scenario is when a certain firm is planning to choose a carrier to move its goods or a raw material supplier. Distance from that resource is a critical actor as usually such relations are long term. In the model, all available suppliers, carriers and shippers can be assigned to zones and costs calculated based on travel time and travel distance.

2.6 Discussion and Future work

We have presented a micro-level supply chain simulation model. The model is based on EOQ relations to optimize inventory costs among model actors (firms), taking into account other costs related to transportation and labor. The model can be used optimally when firm level information on production volumes, production rate and usability is available. A specific firm level demand driven scenario can be simulated as well as aggregate zonal demand and supply. The model takes into account several real aspects of a supply chain. Such as distance restriction, raw material suppliers with all or part of the components of a final good type. The model can also be used to simulate optimized resource allocation (location of partners) based on travel distance and related cost.

The model is by far limited to the use of road network data. Information on production volumes has become recently available but still missing is a systematic method to estimate productivity and usability figures. A possible line of thought in this regard is assuming Just In Time (JIT) production, whereby EOQ formulas are further simplified.

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