SPECIFICATION OF A LOGISTICS MODEL FOR NORWAY AND SWEDEN

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1. INTRODUCTION

The national model systems for freight transport in Norway (NEMO) and Sweden (SAMGODS) are lacking logistic elements (such as the use of distribution centres). The same can be said about practically every other national or regional freight transport model system (exceptions are the SMILE model in The Netherlands and the model for Portland, Oregon) in the world. This paper contains the outcomes of a project to specify how a new logistics module for such model systems could look like. The project was carried out for the Work Group for transport analysis in the Norwegian national transport plan and the Samgods group in Sweden by RAND Europe, together with Solving International, Solving Bohlin & Strömberg and Michael Florian of INRO Canada. At the moment RAND Europe, together with Stein Erik Grønland is working out the proposed logistics module.

For the new freight model systems, an '**aggregate-disaggregate-aggregate**' model is proposed. The base matrix and the network model need to be specified at an aggregate level (with zones as unit of observation), for reasons of data availability and ease of interpretation. For the logistics model, that is positioned between these two models, we propose a disaggregate model, at the level of the firm, the actual decision unit in freight transport.

This logistics model itself consists of three steps:
   A. Disaggregation to allocate the flows to individual firms;
   B. Models for the logistics decisions by the firms (e.g. shipment size, use of consolidation and distribution centres, modes, loading units);
   C. Aggregation of the information per shipment to origin-destination (OD) flows for assignment.

The allocation of flows in tonnes between zones (step A) to individual firms can to some degree be based on observed proportions of firms in local production and consumption data and business register data. The logistics decisions in step B are derived from minimisation of the full logistics and transport costs (modelled as discrete choice models).

The paper will further work out the structure and components of the model sketched above, and also discuss the data requirements. Estimation and validation issues for the logistics model will be discussed as well.

2. SCOPE OF THE MODEL

The scope of the logistics model concerns the boundary lines with other parts of the national freight model systems, notably the base matrices and the network model.

The base matrices give the flows in tonnes between the production locations P and the consumption locations C. The consumption locations here refer to both producers processing raw materials and semi-finished goods and to retailers. The final step from retailer to consumer is handled in the shopping model in the passenger models. The logistics model then serves to determine which flows are covered by direct transports and which transports will use ports, airports, consolidation centres (CCs), distribution centres (DCs) and/or railway terminals. It will also give the modes and vehicle types used in the transport chains.

Two extreme options (and combinations of these) exist for the treatment of the wholesale sector (also see Figure 1):
• Incorporate the wholesale (W) in the base matrices by using flows from W as flows from P and flows to W as flows to C. We call this the PWC matrix option.

• Excluding all flows to and from W from the base matrix. We call this the pure P/C matrix option.

We recommend that both for Norway and Sweden the base matrices will initially be PWC (production-wholesale-consumption) matrices, using the current zoning systems and at least the current 12/13 commodity groups (these will probably be replaced by around 30 commodity groups). This means that not only flows from P (production) to C (consumption by intermediate producers and retail) are included in the base matrix, but that flows from P to W (wholesale) and from W to C are included as well (treating W just as C and P respectively). The use of consolidation centres and distribution centres between P, W and C by shippers and carriers is covered in the logistics model, which will produce transport flows at the origin-destination (OD) level. The logistics model will initially take the locations of the wholesalers as given. Later on, more complicated logistics models can be developed that explain the location of wholesale (as well as the location of all consolidation and distribution centres) and start from pure P/C matrices.
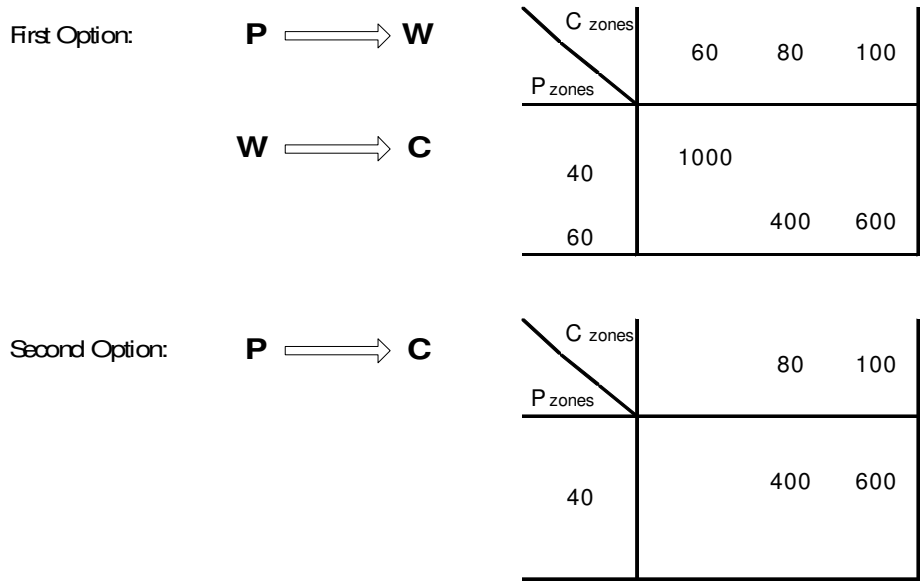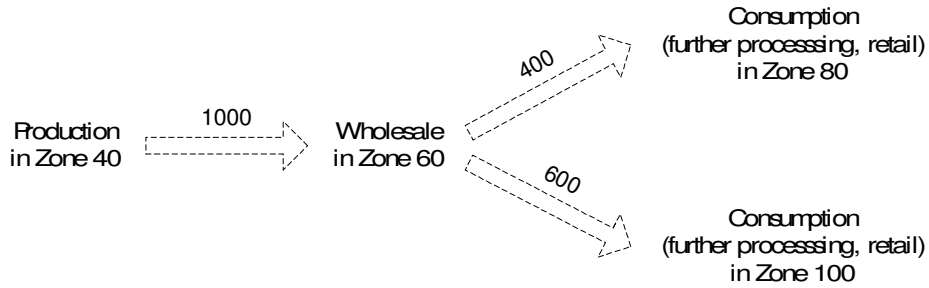
Figure 1 – P/C and P/W/C models

In the current SAMGODS and NEMO model systems, the network model carries out both the modal split and the assignment to the networks (multimodal assignment). We could leave this as it is (option II in Figure 2), but prefer to handle mode choice in a stochastic way in the logistics models (option I), instead of the deterministic optimisation that is being used now in the network model.
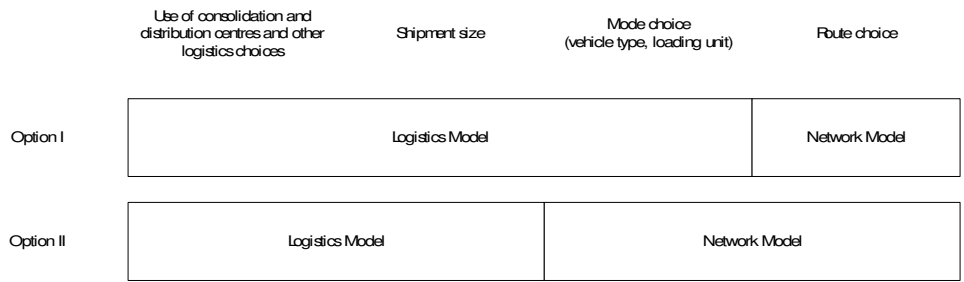

Figure 2 - Two options for combining the logistics and the network model

3. MODEL SPECIFICATION

Figure 3 is a schematic representation of the envisaged structure for the national model systems. The boxes indicate model components.
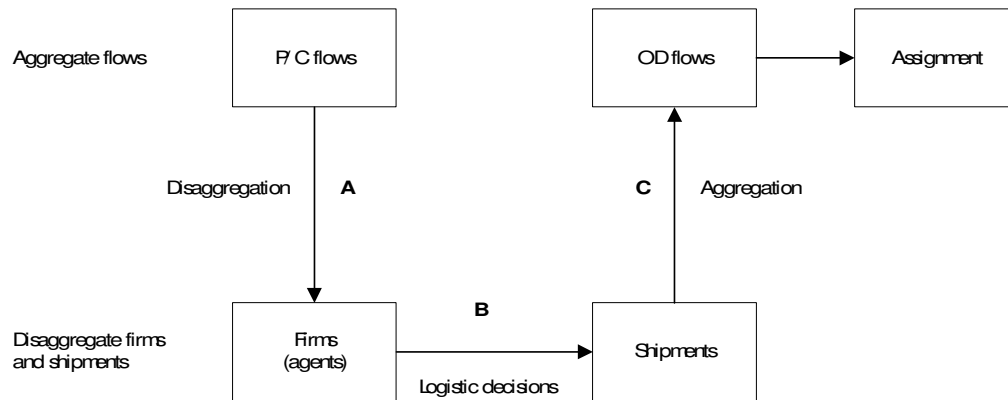

Figure 3 - Envisaged structure of the national model systems

The logistics model consists of three steps:
  A. Disaggregation to allocate the flows to individual firms at the P (W) and C (W) end;
  B. Models for the logistics decisions by the firms (e.g. shipment size, use of consolidation and distribution centres, modes, loading units);
  C. Aggregation of the information per shipment to origin-destination (OD) flows for assignment.

3.1 Step A

Step A is not a choice model, but rather a prerequisite to get down to the level of the decision-making unit, so that the nature of the industry can be captured at the actor level. Instead of trade between zones we shall get trade between firms. These firms are manufacturers, wholesalers or retailers. Carriers come into the picture in step B. Preferably the commodity types used in this simulation would be more detailed than the 12-13 currently used in Samgods and NEMO. Currently the plan is to use a commodity classification with close to 30 groups in both Norway and Sweden.

Consider the following three general approaches to generate a disaggregate population or sample of firm-to-firm flows:
  1. Re-weighting -- use an existing sample or population and re-weight using marginal distributions (i.e. the row and column totals);
  2. Synthetic -- draw from a sequence of conditional distributions;
  3. Hybrid -- begin with re-weighting and enrich the set of characteristics using synthetic draws.

The re-weighting approach is the simplest, but the available data are not sufficient to enable this approach. In Sweden the Commodity Flow Survey (CFS) sample could be the starting point. The problem is that it is a sample of

suppliers (or rather of their shipments), whereas our focus is on the behaviour of the receivers. This problem can be solved by considering the CFS as a sample of supplier/receiver pairs. The fact that the CFS only has one-three weeks data on an observed supplier/receiver pair poses an additional problem. Due to this limitation, re-weighting this sample may not be a viable option. Finally, there is no such CFS in Norway. This all led us to the conclusion that we have to develop a synthetic or a hybrid approach for step A.

This approach could consist of the following steps (all within step A of the logistics module):

1. Use information on the existing distributions of producing and consuming firms (the latter including retail) by commodity type/sector and zone, and on their size distribution. Carry out proportional allocation by size of establishment to assign total supply and demand.

2. Assign suppliers to each receiver. This is the difficult step because the information is unavailable. We need a distribution of the number of suppliers per receiver and a model for the choice of supplier by the receiver. The way around this problem is to go backwards. Derive from the CFS the distributions of the number of receivers per supplier and a model for the choice of receiver by the supplier. A supplier can have more than one receiver. Therefore, receiver choice cannot be treated as selecting one receiver from a set of mutually exclusive receiver alternatives. Instead, develop a binary choice model: will a firm be receiving goods in this category from this supplier? Note that this model should depend on the establishment size. By applying this model we can generate a population of supplier/receiver pairs.

3. Assign annual tonnage to each supplier-receiver pair. In step 1 above we assign to each firm by proportional allocation of total supply and demand for the commodity. To obtain starting values use a gravity model (i.e. the product of total supply and demand and an exponential of minus a coefficient inversely related to average shipment length multiplied by a generalized cost estimate). Collect all the supplier-receiver pairs that belong to an OD pair from the PWC matrices and scale the starting values to match the total flow in the corresponding matrix.

4. After the scaling in step 3 the allocation of total P's and C's will be distorted. To amend this, add an iterative step 4 to balance total P's and C's by business establishment. This is done as in a doubly constrained gravity model where the starting values are calculated using modified P's and C's. After step 3 we will be consistent with the PWC matrices. Step 4 will allow us to also be consistent with the proportional allocations of step 1 but these should not be hard constraints because it is based on an assumption.

3.2 Step B

The different logistics decisions included in step B are:

- Frequency/shipment size (so inventory decisions are endogenous).
  The choice set for shipment size could be based on a categorisation in tonnes. Alternatively a functional classification (e.g. less-than-truckload, more-than-truckload) could be used. The latter will probably provide more insight.
- Choice of loading unit
  The choice set would contain categories such as container, pallet, refrigerated.
- Use (and location) of distribution centres, freight terminals, ports and airports and the related consolidation and distribution of shipments and formation of tours (batching shipments at consolidation centres, multi-stop deliveries).
  Choice set: chains of zones, with a specific activity (e.g. origin, consolidation, distribution and destination) at each zone. For the decision of the optimal location of consolidation and distribution centres only a limited number of candidate sites might be available.
- Mode used for each tour leg.
  Choice set: air transport, road transport (possibly several vehicle types), rail transport (possibly with different train types), and maritime transport (possibly with different vessel types).

Cutting the logistics choices in two parts (shipment size choice and transport chain and mode choice) will make the model more tractable and easier to develop and apply. For short-term applications of the model, location choice for consolidation and distribution centres is not required. The existing locations can be used to define the choice alternatives for the transport chain selection. However, for long-run applications, it would be of considerable value to have the locations of private sector consolidation and distribution centres produced by the model, while the locations of ports and airports would remain exogenous.

3.2.1 Shipment size and related logistics decisions
Large inventories reduce the risk of not being able to serve demand or use the required inputs in a production process. On the other hand, small and frequent deliveries lead to higher transport and stockout costs but lower inventory costs. This trade-off between transport and keeping inventories will be part of this model. This could be treated as part of a cost minimisation, as in operations research applications for optimal inventory decisions.

For company-internal transports, it is easy to determine the key decision-maker. When several firms are involved, the agent responsible for the logistic decision-making might be the sender or the receiver, depending on the market under investigation, or there might be a split of responsibilities. Both extremes exist today and there are divergent tendencies. On the one hand there is a trend towards control of the chain by the retailer ('factory gate pricing' in the food sector; Potter et al., 2003). On the other hand there is a tendency towards control by the sender ('vendor managed inventories' in for

instance the petrochemical sector; Waller et al., 1999; Disney et al., 2003). In both cases however, the information on which the size of the inventory is based stems from the receiver. The demand for his products or the peculiarities of his production process are the key determinant of stock size and shipment size. We shall assume that the inventory decisions (especially shipment size/frequency) are generally made at the C (W) end. Inventories at the P end are determined by production considerations ('production-smoothing inventories', see Shirley and Winston, 2004 for more information about this distinction). In the new freight model systems for Norway and Sweden, we need not go into production scheduling and the trade-off between production costs and inventories, since we do not model production.

The behavioural mechanism of the model could be that of minimisation of the sum of the expected inventory, consolidation/distribution centre and transport costs. The model could be estimated as a discrete choice model (similar to Chiang, Roberts and Ben-Akiva, 1981, but with a greater range of choice alternatives; or the modal share and quality perceptions model of Park, 1995). It could also be estimated as a joint discrete/continuous model, since shipment size can be treated as a continuous variable (similar to McFadden, Winston and Boersch-Supan, 1985). The step B model differs from what is being done in the Portland model for commercial transport. We understand that many steps in the Portland model use existing distributions (e.g. to generate discrete shipments, allocate shipments to establishments, generate transhipment stops) based observed data (such as the US Commodity Flow Survey), from which random draws are made. This does not give a causal model in which endogenous variables are explained by exogenous variables, but a random process that just tries to replicate observed outcomes (descriptive model) without explaining them. Also in this approach there will be no policy variables that can be used to perform a policy simulation.

For different types of commodities the complexity of the proposed logistics model could be different. The number of market segments (in particular commodity types) to be used in the logistics model could be made dependent on the estimation results for the logistics model. In estimation one could test for differences in the behavioural parameters for a number of a priori defined segments. This could include segments in terms of commodity types and shipper/carrier and shipment (product weight, volume, value, handling characteristics) attributes (observed heterogeneity). Segmentations that produce significant differences will then be kept.

We are assuming that decisions on production and the location of production have already been taken. Also the location of demand (intermediate and final) is given. It is not required to model both the shipment size and the frequency of ordering (and thus transporting) a good. If the total annual demand Q for the good is known (from the PWC matrices and the application of step A we know the annual flows by commodity type), then $Q = f.q$, in which f is the frequency of ordering and transporting the good and q is the shipment size. Here we seek to model shipment size; and frequency will follow once we determine the optimal shipment size. Alternatively, we could model frequency.

The shipment size to be determined is the size of the shipment as it arrives at the destination end C. We assume that corresponding amounts of this good are produced at the P end, but in transport from the P zone, these amounts (shipments) may be consolidated into larger vehicle loads. A shipment is then defined as a certain quantity of the good that is ordered together and delivered together. It can exceed a full truckload, and, in the case of road transport, can consist of several trucks ('convoy').

As the shipment size increases, transport costs decrease, while inventory costs increase The trade-off between transport and inventories is modelled in the Economic Order Quantity (EOQ) model (first formulated by Harris of Westinghouse Corporation in 1915 (Winston, 1987)). The optimal shipment size is found by minimising the sum of the total logistics costs. The solution is called the 'economic order quantity'. Different inventory theoretic model specifications have been derived for this problem (see for example Baumol and Vinod, 1970; Chiang, Roberts and Ben Akiva, 1981; Vieira, 1990 or Park, 1995).

The total annual logistics costs G of commodity k transported between firm m production zone r and firm n in consumption zone s of shipment size q with mode chain h and using transhipment location chain z are:

$$G_{rskmnqhz} = O_{kq} + T_{rskqhz} + D_k + Y_{rskhz} + I_{kq} + K_{kq} + Z_{rskq} \qquad (1)$$

Where:
G: total annual logistics costs
O: order costs
T: transport, consolidation and distribution costs
D: cost of deterioration and damage during transit
Y: capital costs of goods during transit
I: inventory costs (storage costs)
K: capital costs of inventory
Z: stockout costs

In this minimisation, we assume that the subscripts for the specific firms m and n (and also for instance firm size) do not matter. This assumption may be relaxed to accommodate economies of scale in warehousing, ordering and transport. Also, variation in the discount rate for the inventory capital costs and of other preferences between firms could be included.

The purchase costs of the goods from different suppliers are not part of the optimisation, since the senders and receivers of the goods have already been determined in step A. However, the purchase costs do play a role through the capital costs of the goods that are included in the equation above.

Equation (1) can be further worked out (see RAND Europe et al, 2004; RAND Europe and SITMA, 2005):

$$G_{rskmnqhz} = o_k.(Q_k/q_k) + T_{rskqhz} + i.j.g.v_k.Q_k + (i.t_{rshz}.v_k.Q_k)/365 +$$
$$(w_k + (i.v_k)).(q_k/2) + a.((LT.\sigma_{Q_k}^2)+(Q_k^2.\sigma_{LT}^2))^{1/2} \qquad (2)$$

Where:

o : the constant unit cost per order

Q: the annual demand (tonnes per year)

q : the average shipment size.

i: the discount rate (per year)

j: the fraction of the shipment that is lost or damaged (might vary between modes)

g: the average period to collect a claim (in years)

v: the value of the goods that are transported (per tonne).

t: the average transport time (in days).

w: the storage costs per unit per year.

a: a constant to set the safety stock in such a way that there is some fixed probability of not running out of stock. For medium/high frequency products, a common assumption is that the demand (and lead-times) follows a Normal distribution. a will then be: $a = F^{-1}(CSL)$, where F^{-1} is the inverse Standard Normal Distribution and CSL is the cycle service level, that is the probability that the stock will not be empty during a replenishment cycle.

LT: expected lead-time for a replenishment (time between placing the order and replenishment)

σ_{LT}: standard deviation for the lead-time

σ_{Q_k}: the standard deviation for the yearly demand

The optimal shipments sizes will in the standard cases not be influenced by the safety stock, or vice versa. However, different transport alternatives with different transit times will have an impact on the safety stock through the lead-time (and possibly through the standard deviation of the lead-time), and thereby also on the inventory cost (and the total cost). This may be the case for alternative modes. In principle, lead-time should then be a function of the mode (h): $LT = LT(h)$.

3.2.2 Transport logistics

The simplest, but not necessarily cheapest, option would be to transport the shipment directly from P to C without using consolidation or distribution centres or transhipment. In this case the costs of consolidation, distribution and transhipment would not enter T in equations 1 and 2 above. However, the pure transport costs per tonne are decreasing clearly with increasing shipment size: larger road vehicles and rail and waterway modes usually have lower freight rates per tonne. Therefore, especially for less than full truckload shipments, it is quite likely that the savings from direct transport in terms of J, D and M are smaller than the additional pure transport costs X.

$$T^{direct}_{rskqh} = min_h(X^{direct}_{rskqh}) \tag{3a}$$

Mode availability depends on the specific spatial relation studied, as well as on the commodity group k and the shipment size q. The total set of modes h consists of:

- Road transport (with different vehicle types/sizes);
- Rail (with different train types, such as regular trains, block trains);
- Sea (with different vessel types);

- Air transport.

An additional dimension within h could be cargo unit (e.g. containerised). In practice, use of rail, sea and air transport can better be treated as indirect transport (see below) where the change of mode occurs at consolidation and distribution centres, unless both the P and C firm have their own sidings or quays (only then there can be direct rail and waterway transport). In this case equation (3a) would only refer to road transport, with different vehicle sizes.

Another alternative for this transport involves consolidation; using consolidation centres in the neighbourhood of the production location (see Figure 4). Here a distinction can be made between consolidation of shipments (for the same or different products) within the same production firm and consolidation of flows of different firms (presumably by a third party, e.g. a wholesaler or carrier).
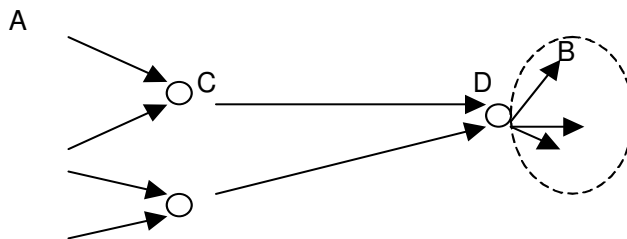

Figure 4 - Consolidation and distribution: the shipment of goods from location A to B is consolidated at C and distributed at D

For indirect transport there is an array of options, of which the minimum cost option, given in equation (3b), can be compared against equation (3a):

$$T^{indirect}_{rskqh} = \min_{h(1)h(2)h(3)cd}(X_{h(1)rckq} + J_{ckq} + X_{h(2)cdkq} + D_{dkq} + X_{h(3)dskq}) \qquad (3b)$$

The first term within brackets represents the transport cost from the producing firm at r to the consolidation centre c, the second term gives the consolidation centre cost of c, the third the transport cost from c to the distribution centre d, the fourth the distribution centre cost at d and the fifth the 'last mile' transport cost to the consuming firm at s. There are three mode choices: h(1), h(2) and h(3). Other logistic chains can be defined by dropping either the consolidation centre or the distribution centre, and omitting its costs, but if both are deleted, we have a direct transport again.

In principle, the minimisation in equation (3b) takes place over all available 'land' modes, the available consolidation centres c, and the distribution centres d. It includes mode choice as well as choice of which consolidation and distribution centre to use. The problem of routing different shipments to the consolidation centre and that of distributing multiple shipments from the distribution centre to the receivers is handled separately, and so is empty vehicle running (see section 3.4).

For overseas flows, the decisions on the use of ports and airports can be represented by inserting these at the place of the consolidation and distribution centres in equation (3b).

Direct transport is much more likely for shipment sizes q that allow full truck loads than for less than full truckloads. However, the comparison of equations (3a) and (3b) can be made for both types of shipments (and also for a larger number of shipment size classes, depending on the data). The model will then give the fractions that will be using direct transport and the fractions that will be consolidated and/or distributed. In both cases, consolidation implies that for the long-haul part of the transport chain, different shipments will be combined. The transport costs for each leg for different vehicle size classes will be generated by the network model.

3.3 Step C

In step C shipments for the same commodity types are aggregated to get OD flows in vehicles (not in tonnes). This is simply a matter of straightforward summation over shipments. The current network model (application of STAN) usually takes inputs in terms of flows in tonnes, but it can also handle flows in vehicles.

3.4 Empties

In the current Samgods model each vehicle is assumed to be half full. So every tonne transported from an origin r to a destination zone s will lead to the movement of an empty vehicle of the same size from the same origin r to the same destination s. It would be better to assign all product OD flows to vehicles first (mainly based on costs) and then define another product: 'empties'. The flows for these vehicles (similarly for vessels and aircraft) are the mirror image of the loaded OD flows: they go from s to r.

For empty vehicle running, we suggest using the Noortman and van Es (Holguin-Veras and Thorson, 2002) equation. Here the number of empty flows between zones r and s is a function of the commodity flow in the opposing direction, from s to r, multiplied by a constant p that is determined empirically. If one also assumes that the average payload from r to s is equal to that from s to r, the Noortman and van Es equation for empty trips becomes:

$$z_{rs} = \frac{m_{rs}}{\alpha_{rs}} + P(E)\frac{m_{sr}}{\alpha_{sr}} = \frac{m_{rs}}{\alpha_{rs}} + P(E)x_{sr} \tag{4}$$

Where:
z_{rs}: loaded plus empty trips from r to s in vehicle units
m_{rs}: flows in tonnes from r to s
$P(E)$: the probability of returning empty
x_{sr}: the loaded trips from s to r in vehicle units
α_{rs} and α_{sr} : parameters to be estimated.

In this formulation, the probability that some of the empty capacity will also be used for transporting goods in the opposite direction is taken into account.

4. DATA REQUIREMENTS

For the logistics model presented, the following data are needed for step A (disaggregation from flows to firms):
1. The number of firms by commodity type and municipality. For legal entities with units in different municipalities, we would like to have information at the level of these local units;
2. The turnover of these local units and/or the number of employees of these firms.

This information is required both at the production and the consumption end.

Step B (logistic decisions) requires information on the following items:
1. Data on individual shipments: sector of sender and receiver, origin and destination, value of the goods, modes and vehicle/vessel type and size used, cargo unit, shipment size/frequency, use of freight terminals (including intermodal terminals and marshalling yards), consolidation and distribution centres, ports and airports. Preferably this would be transport chain information: which shipments go directly from P to C, which use the above intermediate points?
2. Data on where the freight terminals, consolidation and distribution centres, ports and airports are located;
3. Data on transport and logistics costs: transport costs per km, terminal costs, handling and storage costs (not only for Sweden or Norway, but around the world for international flows) for all available alternatives.

Most crucial are the data on the shipments of individual firms (item 1 for step B above). The spatial detail needs to be that of the municipality (for consistency with the PWC matrices) and the commodity grouping needs to be consistent with the 12/13 or approximately 30 categories that will be used in the PWC matrix (and probably in assignment as well).

Step C requires no extra information.

5. ESTIMATION, CALIBRATION AND VALIDATION

Model estimation is required for step B, the part that deals with the logistics choices. The full model can be estimated from the equation for the total annual logistics costs, such as equation (2). A random utility discrete choice model can be obtained by using minus the total annual logistics costs as the observed component of utility and by adding random cost components ε that follow specific statistical distributions. These random components account for omitted variables, measurement errors and such.

$$U_{rskmnqhz} = - G_{rskmnqhz} + \varepsilon_{rskmnqhz} \tag{5}$$

Where:
$U_{rskmnqhz}$: utility derived from logistic and transport choices

$G_{rskmnqhz}$: observed component of total transport and logistics costs
$\varepsilon_{rskmnqhz}$: random cost component.

In equation (5) we use the subscript z for logistics options (choice of port, airport, intermodal terminal, consolidation and/or distribution centre). The subscript h could include alternatives in terms of specific transport mode as well as vehicle/vessel types and sizes within a mode.

Using equation (2) for $G_{rskmnqh}$ we get:

$$U_{rskmnqhz} = \beta_{0qzh} + \beta_{1k} \cdot (Q_k/q_k) + T_{rskqhz} + \beta_2.j.v_k.Q_k + \beta_3.(t_{rshz}.v_k.Q_k)/365 + (\beta_{4k.}+ \beta_5.v_k).(q_k/2) + a .((LT.\sigma_{Q_k}^2)+(Q_k^2.\sigma_{LT}^2))^{1/2}+ \varepsilon_{rskmnqhz} \qquad (6)$$

Where:
β_{0qzh} = alternative-specific constant
$\beta_{1k} = o_k$

$\beta_2 = i.g$
$\beta_3 = i$ (in transit)
$\beta_{4k}=w_k$

$\beta_5=i$ (warehousing).

What we have done in equation (6) is to include a number of items, such as order costs, storage costs and capital carrying costs, in the coefficients to be estimated. The reason for this is that data on these items will be very difficult to obtain. As a result, the coefficients have specific logistical interpretations. We distinguish between the implied discount rate (i) of the inventory in transit (β_3) and of the inventory in the warehouse (β_5), because these need not be the same (see Vieira, 1992). The transport costs T_{rskqhz} can be specified as in section 3 and do not include additional coefficients. However, these could include coefficients for transport time and other quality of service attributes within the generalised transport costs. Cost minimisation thus becomes equivalent to utility maximisation. Including revenues for the shippers and doing profit maximisation instead of cost minimisation is not required here, since the PWC flows (and therefore the sales) are already given.

If we use the extreme value type I distribution for ε, the model becomes multinomial logit (MNL). Nested logit (NL) can be attractive to test, because it seems likely that some alternatives (e.g. road and rail transport) will have a greater degree of substitution than other alternatives (e.g. road and sea transport). This is an empirical question: statistical tests, particularly likelihood ratio tests using the Chi-square distribution, will show whether or not the NL gives a significantly better log-likelihood value than MNL.

The mixed MNL model (MMNL) is an extension of the MNL model and provides additional flexibility in the correlation structure and variation between observations. This might be relevant for the logistics model, given the heterogeneity often found in freight transport. The MMNL model can be obtained in two different ways:

- By distinguishing two error components in ε:
    - one following the extreme value type I distribution;
    - and the other following, for instance, a multivariate normal distribution to allow for more complicated correlation structures between alternatives than the NL model allows for;
- By allowing the coefficients in G (the β's) to follow a statistical distribution instead of being a point estimate. This is the random coefficients model or taste variation model. It looks particularly attractive for this application in freight transport, because it is often stated and sometimes observed that preferences in freight transport decision-making are very heterogeneous.

For MNL, many existing software packages can be used. For NL the choice is more limited, while for MMNL only a few estimation programmes can be used (e.g. Alogit, Biogeme, Nlogit and special-purpose programming in Gauss).

Instead of estimating a model for all logistics choices simultaneously, it might be more practical to estimate a model for mode choice and use of consolidation and distribution centres, intermodal terminals, ports and airports first and then estimate a model for shipment size choice. Both models can then be combined by using a measure of minus the expected costs (expected utility) from transport logistics decisions, in the form of the logsum, in the inventory logistics choice.

In Figure 5 the proposed estimation, calibration and validation process for the Swedish and Norwegian national model systems for freight transport are depicted. The estimation data are shown above the boxes, while the validation data are below the boxes. The P/C matrices are partly based on observations and partly synthetic (model-generated). The data used in this process come from the CFS (Sweden only), regional input-output systems, economic statistics from national accounts and foreign trade data, and from the questionnaire-based OD surveys (origin, destination, costs, commodity) for truck, rail and sea (in the current Norwegian procedure). The logistics model will be estimated on the CFS (Sweden only), information on terminals, new disaggregate data from large logistics service providers in Norway and possibly on other new survey data, and then transforms the initial PWC matrices into OD matrices.
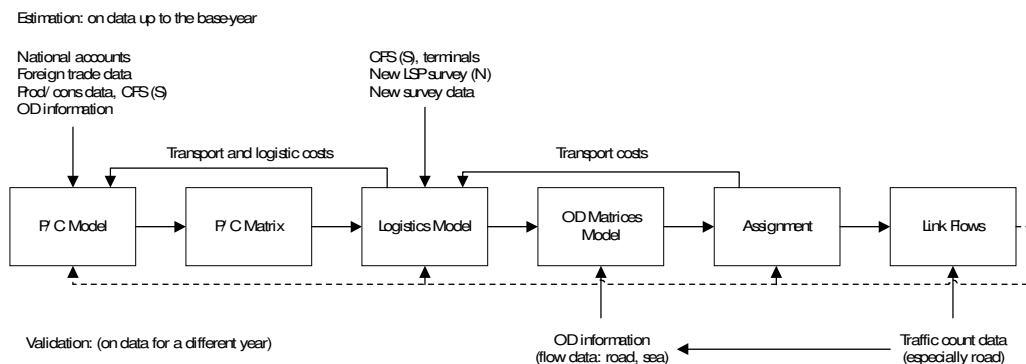

Figure 5 - Estimation and validation of the model systems (S: Sweden; N:Norway)

When no disaggregate estimation data would be available or could be made available in the near future, there are some possibilities to use a normative logistics model, that optimises the logistics choices. This normative model could be made more realistic by calibration to aggregate data (OD information). One could use a normative logistic costs function, assume this works as a logit model with alternative-specific constants and a scale parameter, aggregate the initial results, compare with aggregate data and then adjust the constants and/or scale in an iterative process. This is clearly inferior to estimation on disaggregate data, but could provide a way out if these data would be unavailable.

The model application process is iterative (see Figure 5, middle and upper part): after assignment, the new generalised costs matrices need to be used to adjust the PWC matrices, etc. This gives rise to an **inner loop** (the outer loop is described later in this section):
1. The base matrix projects (Norway and Sweden) provide initial PWC matrices;
2. The logistics model transforms these into OD matrices, using transport cost provided by the network model;
3. The network model assigns the OD matrices to the networks;
4. The network model and the logistics model provide transport and logistics costs matrices to the base matrix projects;
5. The base matrix project calculates new base matrices on the basis of the new transport and logistics costs and provides these to the logistics model.

This loop continues until equilibrium is reached (in practice until a pre-set maximum distance from equilibrium is reached). The tasks consist of running the models as they are (estimation is not required within this inner loop). The inner loop is about the adjustment of model variables (inputs and outputs), not model coefficients.

The validation process is depicted in Figure 5 as well (bottom part of the figure). As part of the validation, the predicted OD flows can be compared to the observed OD flows from OD surveys (by mode: road, sea, maybe rail). The observed OD information would preferably refer to a different year than used in estimation, to make it an independent validation. Differences between observed and predicted can be due, apart from measurement errors in the observations, to both the PWC model and the logistics model. After the assignment of the OD flows to the networks, the predicted link flows can be compared to observed link flows from traffic counts (especially for road and maybe also for rail). If big discrepancies arise, these need to be analysed. Finally, the parameters in all the models can be recalibrated, which requires an iterative procedure. This is the **outer loop** (the inner loop was described earlier in this section), which concerns different equilibrium situations for the inner loop. In the outer loop or model calibration loop, model coefficients in all constituent submodels are adjusted to reach a good match with aggregate data.

6. CONCLUDING REMARKS

In a project for the Work Group for transport analysis in the Norwegian national transport plan and the Samgods group in Sweden, RAND Europe, together with Solving International, Solving Bohlin & Strömberg and Michael Florian of INRO Canada, has produced a specification of a logistics model as part of the Norwegian and Swedish national freight model systems. The national model systems for freight transport in both countries (and most other countries) are lacking logistic elements (such as the use of distribution centres).

The proposed logistics model consists of three steps:
   A. Disaggregation to allocate the PWC flows to individual firms;
   B. Disaggregate models for the logistics decisions by the firms (e.g. shipment size, use of consolidation and distribution centres, modes, loading units);
   C. Aggregation of the information per shipment to origin-destination (OD) flows for assignment.

A preliminary logistics module, based on existing data, will be developed in 2005. It will contain the step A disaggregation, but for step B it will be a normative logistics cost minimisation model, without disaggregate model estimation. New data (including data at the level of the individual firms) will be collected in 2005 and 2006. In 2006, the disaggregate logistics models will be estimated, probably by combining Norwegian and Swedish datasets and testing, where possible for differences in behaviour.

REFERENCES

Baumol, W.J. and H.D. Vinod (1970) An inventory-theoretic model of freight transport demand, **Management Science**, 16, 413-421.

Ben-Akiva, M.E. (2004) Choice analysis and market analysis for freight; presentation at the *colloquium in memory of Prof. Marvin L. Manheim,* Antwerp.

Chiang, Y., P.O. Roberts and M.E. Ben-Akiva (1981) Development of a policy sensitive model for forecasting freight demand, Final report, Center for Transportation Studies Report 81-1, MIT, Cambridge, Massachusetts.

Disney, S.M., A.T. Potter and B.M. Gardner (2003) The impact of vendor managed inventory on transport operations, **Transportation Research** E, 39, 363-380.

Holguin-Veras, J. and E. Thorson (2002) Preliminary insights into the practical implications of modeling commercial vehicle empty trips, Paper presented at the *European Transport Conference 2002*, Cambridge.

McFadden, D.L., C. Winston and A. Boersch-Supan (1985) Joint estimation of freight transportation decisions under nonrandom sampling, in Daughety, E.F. (Ed.): *Analytical Studies in Transport Economics*, Cambridge University Press, Cambridge.

Park, J.K. (1995) Railroad marketing support system based on the freight choice model, PhD dissertation, Massachusetts Institute of Technology.

PbConsult (2002) Commercial transport and transport supply components of the TLUMIP second generation model, *Third Oregon Symposium on Integrated Land Use and Transport Models*, 23-25 July, 2002.

Potter, A., C. Lalwani, S.M. Disney and H. Velho (2003) Modelling the impact of factory gate pricing on transport and logistics, **Proceedings** of the 8th *International Symposium on Logistics*, Seville, 6-8 July 2003.

RAND Europe, Solving and INRO (2004) The specification of logistics in the Norwegian and Swedish national freight model systems, Model scope, structure and implementation plan, Report for the NTP and Samgods group,TR-225-SIKA, RAND Europe, Leiden.

RAND Europe and SITMA (2005) The development of a logistics module in the Norwegian and Swedish national freight model systems, Deliverable 1b: further model specification, Report for the NTP and Samgods group, RAND Europe, Leiden.

Shirley, C. and C. Winston (2004) Firm inventory behavior and the return from highway infrastructure investments, **Journal of Urban Economics**, 5, 398-415.

SIKA (2003) Commodity Flow Survey 2001, Method report, SIKA Report 2003:4, SIKA, Stockholm.

Vieira, L.F.M. (1990) The use of stated preference data in freight transportation demand analysis, MIT, Cambridge, Massachusetts.

Waller, M., M.E. Johnson and T. Davis (1999) Vendor managed inventory in the retail supply chain, **Journal of Business Logistics**, 20(1), 183-203.

Winston, W.L. (1987) *Operations research: applications and algorithms,* Duxbury Press, Boston.