Method Report - Logistics Model in the Swedish National Freight Model System (Version 2.1)

DELIVERABLE 6B FOR TRAFIKVERKET

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D6B

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Preface

In a project for the Swedish Samgods Group and the Working group for transport analysis in the Norwegian national transport plan, Significance (up to 31 December 2006: RAND Europe) has produced an improved and extended version of a logistics model as part of the Swedish and Norwegian national freight model systems. The national model systems for freight transport in both countries were lacking logistic elements (such as variation of shipment sizes, consolidation of shipments, scale advantages in transport and goods handling, the use of distribution centres). A project was set up to develop a new logistics module for both model systems. This method report describes the model that was developed for Sweden. A similar, but not identical logistics model was developed for Norway. This is described in a separate method report (D6A)

This technical report was made for freight transport modellers with an interest in including logistics into (national) freight transport planning models, in particular the Swedish national model systems for freight transport.

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CHAPTER 1 Introduction

1.1 Background and objectives of the project

The Swedish national freight model system is used for simulating development in goods transport in the short run (representation of the base year, transport policy simulations) as well as the long run (forecasting for scenarios, providing input for the assessment of infrastructure projects). The previous model system was lacking logistics elements, such as the determination of shipment size and the use of consolidation and distribution centres. In Sweden, as well as in Norway, a process to update and improve the existing national freight model system was started. An important part of this is the development of a logistics module. This module is described in this report. A similar, but not identical logistics module was developed for Norway; this is described in a companion report (D6A).

Apart from this methodological report, the following reports are available: General overview of the National Swedish Freight transport model SAMGODS, Generation of Base matrices (zone to zone flows) and disaggregation to firms to firm flows (Edwards 2008), Representation of the Swedish transport and logistics system, Program documentation for the logistics model for Sweden.

1.2 The ADA model structure

1.2.1 General model structure

The new Swedish freight model system, including the logistics model, can be described as an aggregate-disaggregate-aggregate (ADA) model system. In the ADA model system, the production to consumption (PC) flows and the network model are specified at an aggregate level for reasons of data availability. Between these two aggregate components is a logistics model that explains the choice of shipment size and transport chain, including mode choice for each leg of the transport chain. This logistics model is a disaggregate model at the level of the firm, the decision making unit in freight transport. Figure 1 is a schematic representation of the structure of the freight model system. The boxes indicate model components. The top level of figure 1 displays the aggregate models. Disaggregate models are at the bottom level.

The model system starts with the determination of flows of goods between production *(P)* zones and consumption (*C*) zones (retail goods for final consumption; and further processing of goods for intermediate consumption). Wholesale activities can be included at both the P and the C end, so actually the matrices are production-wholesale-consumption (PWC) flows. In various countries such models have been developed, usually based on economic statistics (production and consumption statistics, input-output tables, trade statistics) that are only available at the aggregate level (with zones and zones pairs as the observational units). Indeed, to our knowledge, no models have been developed to date that explain the generation and distribution of PC flows at a truly disaggregate level. For Sweden, additional data is available from the Commodity Flow Survey (CFS) 2001 and 2004/2005. In ADA, a new logistics model takes as input the PC flows and produces OD flows for network assignment. The logistics model consists of three steps:

A. Disaggregation to allocate the flows to individual firms at the *P* and *C* end;

B. Models for the logistics decisions by the firms (e.g., shipment size, use of consolidation and distribution centres, modes, loading units, such as containers);

C. Aggregation of the information per shipment to origin-destination (OD) flows of vehicles for network assignment.

This model structure allows for logistics choices to be modelled at the level of the actual decision-maker, along with the inclusion of decision-maker attributes.

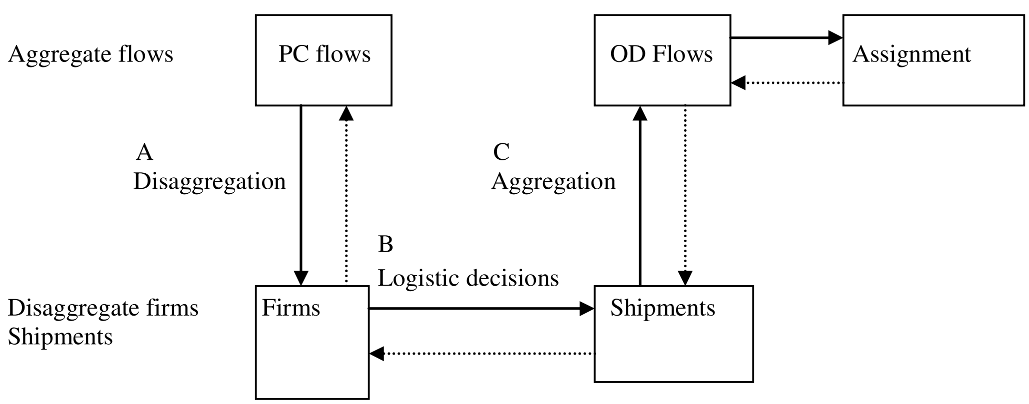


Figure 1. ADA structure of the (inter)national/regional freight transport model system

The allocation of flows in tonnes between zones (step A) to individual firms are, to some degree, based on observed proportions of firms in local production and consumption data, and from a registry of business establishments. In the Swedish model this is done in conjunction with the base matrix construction. The logistics decisions in step B are derived from minimization of the full logistics costs (including transport costs).

The aggregation of OD flows between firms to OD flows between zones provides the input to a network assignment model, where the zone-to-zone OD flows are allocated to the networks for the various modes.

There are also be backward linkages, as can be seen in Figure 1 (the dashed lines). The results of network assignment are used to determine the transport costs that are part of the logistics costs which are minimized in the disaggregate logistics model. The logistics costs for the various OD legs are summed over the legs in the PWC flow (and aggregated to the zone-to-zone level by an averaging over the flows). These aggregate costs can then be used in the model that predicts the PWC flows (for instance, as part of the elastic trade coefficients in an input-output model). The current version 2 of the logistics model for Sweden has not been used for this feedback to the PWC flows, but it is a possibility for future development.

1.2.2 Relation between the PWC flows and the logistics model

The PWC flows between the production (wholesale) locations *P (W)* and the consumption (wholesale) locations *C (W)* are given in tonnes and Swedish crowns (SEK) by commodity type. The consumption locations refer to both producers processing raw materials and semi-finished goods and to retailers. The logistics model serves to determine which flows are covered by direct transports and which transports will use ports, airports, lorry terminals or railway terminals (kombi terminals and marshalling yards). It also gives the modes and vehicle types used in transport chains. The logistics model, therefore, takes PWC flows and produces OD flows. An advantage of separating out the PC and the OD flows is that the PWC flows represent what matters in terms of economic relations -- the transactions within and between different sectors of the economy. Changes in final demand, international and interregional trade patterns, and in the structure of the economy, have a direct impact on the PWC patterns. Also, the data on economic linkages and transactions are in terms of PWC flows, not in terms of flows between producers and trans-shipment points, or between trans-shipment points and consumers.

1.2.3 Relation between the logistics model and the network assignment

Changes in logistics processes (e.g., the number and location of depots) and in logistics costs have a direct impact on how PWC flows are allocated to logistics chains, but only indirectly (through the feedback effect of logistics choices and network assignment) impact the economic (trade) patterns. Assigning PWC patterns to the networks would not be correct. For instance, a transport chain road-sea-road would lead to road OD legs ending and starting at ports instead of a long-haul road transport that would not involve any ports. A similar argument holds for a purely road-based chain that uses a van first to a consolidation center, then is consolidated with other flows into a large truck, and, finally, uses a van again from a distribution center to the C destination. In this scenario, The three OD legs might be assigned to links differently than would be the case for a single PWC flow. Therefore, adding a logistics module that converts the PC flows into OD flows allows for a more accurate assignment. The data available for transport flows (from traffic counts, roadside interviews and interviews with carriers) also are at the OD level or screenline level, not at the PWC level.

1.3 Contents of this report

This report contains the technical description of version 2 of the logistics module for Sweden. The previous versions of the logistics module are described in RAND Europe and SITMA (2005, 2006) and Significance (2007).

The logistics module program version 2 consists of three sub-programs:

- A program to generate the available transport chains (including the optimal transfer locations between OD legs): BUILDCHAIN.
- A program for the choice of the optimal shipment size and optimal transport chain (including the number of OD legs and the mode, vehicle/vessel type and unitised or non-unitised for each leg): CHAINCHOICE.
- Programs to extract costs output for specific relations and to extract OD matrices (EXTRACT).

In chapter 2 of this report we describe firm-to-firm flows that are input to the logistics model. The Swedish base matrix project has already converted zone-to-zone flows from the base matrices into "representative" firm-to-firm flows (see 1.1., Base matrix report). The costs functions that are used in the logistics module (in chain generation as well as chain choice) and the parameters in those functions are given in chapter 3. In chapter 4 we describe the transport chain generation program and the transport chain choice program. This includes a description of the determination of shipment size, as well as of the transport chains. Chapter 4, also contains the treatment of consolidation. Chapter 5 deals with the production of output matrices in terms of tonnes and in terms of vehicles. This chapter also includes the generation of empty vehicle flows. In chapter 6, a summary and conclusions are given.

CHAPTER 2 Firm-to-firm flows from base matrix project

For the Swedish program versions 1 and 2, there is an extra commodity type (compared to version 0): air freight. These are goods that will all be transported by airplane as main mode. Other goods will not use air transport in the model.

In step A (see section 1.2) for Sweden, the production of firm-to-firm (f2f) flow was carried out by Henrik Edwards (Vägverket Konsult), to ensure consistency with his work on base matrices. A description of the work can be found in the base matrix report (Edwards, 2008). Below we summarise the key points that refer to step A.

New production and consumption files by firm, commodity type and zone were developed by Henrik Edwards. This relies on employment statistics by firm: although turnover statistics are also available, the more detailed turnover breakdown is based on employment data, so that it would not provide a significant. The production files distinguish one production commodity category per firm and the consumption files allow for several consumption commodity categories.

In the allocation of the Swedish zone-to-zone (z2z) flows to f2f flows, three firm size classes (with national threshold values for firm size class that are the same for all zones: national threshold values) are distinguished:

- small firms (first 33%)
- medium-sized firms (34-66%)
- large firms (67-100%).

Since the thresholds here are national averages, in a specific zone one or more of the three categories can be empty. Combining the senders and receivers, we have the following sub-cells:

1. flows from small firms to small firms
2. flows from small firms to medium-sized firms
3. flows from small firms to large firms
4. flows from medium-sized firms to small firms
5. flows from medium-sized firms to medium-sized firms
6. flows from medium-sized firms to large firms

7. flows from large firms to small firms
8. flows from large firms to medium-sized firms
9. flows from large firms to large firms.

Furthermore, singular flows (very large observed flows) can be distinguished separately in the outputs (category 0).

The distribution over small, medium-sized and large firms was derived from CFAR data (register data) combined with national accounts data, both for the production and the consumption side. For the determination of which senders will deliver to which receivers within a z2z flow, a procedure was developed. This procedure works as follows.

The starting point here is a proportional allocation (every sender in zone r delivers to every receiver in zone s). However, since this will lead to too many flows (in reality not all senders in a zone will deliver to all receivers in another zone, and the other way around), this allocation was adjusted on the basis of information from the Commodity Flow Survey for the number of shipments per commodity type. The idea here is that there are no reliable and useable data on the actual number of f2f relations or on the number of receivers per sender (Statistics Sweden calculated some averages for this from the CFS, but was not satisfied with the results). But the CFS does contain information on the total (over all firms) number of shipments per commodity type. Therefore we calculate the predicted average shipment size q for a sub-cell (e.g. small firms to small firms) from the model that allocates z2z flows to f2f flows and divide the annual demand Q in a sub-cell by the modelled shipment size to get the number of shipments in the sub-cell. These are added over the sub-cells to get the modelled total number of shipments for each commodity type, which can be compared to the CFS data.

To calculate the average predicted shipment size the Economic Order Quantity (EOQ) formula is used. This EOQ calculation only involves order cost and inventory cost; transport cost is not included. The calculation in this disaggregation step is only required to derive a measure (number of shipments) that can be compared against observed data (the CFS). After having compared the modelled number of shipments and the observed number of shipments by commodity type in the Commodity Flow Survey, the number of f2f flows is adjusted until the CFS target is reached.

[Note that in the subsequent transport chain generation and choice stages of the **logistics** model, an EOQ calculation is used which **includes** transport costs. The shipment size provided by the logistics model is the one from this full EOQ calculation.]

The adjusted number is used as the number of f2f flows in the subsequent steps of the logistics model. Henrik Edwards' program gives for each sub-cell, by zone pair and commodity type, the number of tonnes transported and the number of f2f relations involved. A distinction is made between production-consumption (PC) flows and wholesale-consumption (WC) flows, so that the flows are distinguished according to the nature of the **sender**. On the receiver end, "consumption" can

Table 1. Commodity types for Sweden

Nr	Commodity	NSTR	Aggregate commodity
1	Cereals	10	Dry bulk
2	Potatoes, other vegetables, fresh or frozen, fresh fruit	20	Dry bulk
3	Live animals	31	Dry bulk
4	Sugar beet	32	Dry bulk
5	Timber for paper industry (pulpwood)	41	Dry bulk
6	Wood roughly squared or sawn lengthwise, sliced or peeled	42	Dry bulk
7	Wood chips and wood waste	43	Dry bulk
8	Other wood or cork	44	Dry bulk
9	Textiles, textile articles and manmade fibres, other raw animal and vegetable materials	50	General cargo
10	Foodstuff and animal fodder	60	General cargo
11	Oil seeds and oleaginous fruits and fats	70	Liquid bulk
12	Solid mineral fuels	80	Liquid bulk
13	Crude petroleum	90	Liquid bulk
14	Petroleum products	100	Liquid bulk
15	Iron ore, iron and steel waste and blast-furnace dust	110	Dry bulk
16	Non-ferrous ores and waste	120	Dry bulk
17	Metal products	130	General cargo
18	Cement, lime, manufactured building materials	140	Dry bulk
19	Earth, sand and gravel	151	Dry bulk
20	Other crude and manufactured minerals	152	Dry bulk
21	Natural and chemical fertilizers	160	Dry bulk
22	Coal chemicals	170	Liquid bulk
23	Chemicals other than coal chemicals and tar	180	Dry bulk
24	Paper pulp and waste paper	190	Dry bulk
25	Transport equipment, whether or not assembled, and parts thereof	200	General cargo
26	Manufactures of metal	210	General cargo
27	Glass, glassware, ceramic products	220	General cargo
28	Paper, paperboard; not manufactures	231	Dry bulk
29	Leather textile, clothing, other manufactured articles than paper, paperboard and manufactures thereof	232	General cargo
30	Mixed and part loads, miscellaneous articles	240	General cargo
31	Timber for sawmill	45	Dry bulk
32	Machinery, apparatus, engines, whether or not assembled, and parts thereof	201	General cargo
33	Paper, paperboard and manufactures thereof	233	General cargo
34	Wrapping material, used	250	Dry bulk
35	Air freight (2006 model)		General cargo

include wholesale, so that, for example, some of the flows treated as PC could in fact be PW. The logistics model is then applied at the level of a firm-to-firm relation within each non-zero sub-cell and then expanded to the population using the number of firm-to-firm relations in the sub-cell. The possibility to distinguish PW flows (as well as PC and WC) from the CFS 2004/2005 is currently under investigation. These can be included in the PWC matrices and processed in the logistics model program as it is. The current model uses the same optimisation logic (within each commodity group) for PC and WC flows (see section 4.3), and could also do this for PW flows. Intrazonal flows are also distinguished. The Swedish commodity types are listed in Table 1.

CHAPTER 3 The cost functions

3.1 Cost functions in the current model

The cost functions give different logistics cost for all the different vehicle/vessel types distinguished. The Swedish vehicle/vessel type classification (see Table 2) has considerably fewer types than the Norwegian counterpart, but in Sweden the assumption is made that unitised transport can be used with most vehicle/vessel types (exceptions: the first three light/medium road vehicles, system train and airplane cannot be used for container transport; the Kombi train and the container vessels are for container transport only). This means that in the program for Sweden for most vehicle/vessel types we have a unitised and a non-unitised variant. The cost for the unitised variant is the same as for the non-unitised variant except that for unitised there are costs for initial stuffing of the container (at the sender) and final stripping (at the receiver) and that there are differences in the transfer costs (generally speaking container transfers are cheaper than other transfers at consolidation and distribution centres).

Based on these vehicle/vessel definitions, restrictions describing which commodities each vehicle/vessel type can carry and which transfers between vehicles are allowed were defined and implemented in the control/input files. The ambition is to have the model as open as possible, therefore very few restrictions are included. Only chain types with either a roro connection at the begin or end of the chain, or a roro connection with different transport modes on either side, are rejected.

The cost function parameters are in separate files to facilitate running policy variants. The cost functions include a component for waiting time, based on frequency.

The capacities per lorry, train, vessels etc. are maximum values, which may be lower for bulky goods.

Table 2. The vehicle/vessel types for Sweden

Mode[1]	Vehicle number	Vehicle name	Capacity (tonnes)
Road	101	Lorry light LGV, ≤ 3,5 ton	2
	102	Lorry medium ≤ 16 ton	9
	103	Lorry medium ≤ 24 ton	15
	104	Lorry HGV ≤ 40 ton	28
	105	Lorry HGV ≤ 60 ton	47
Rail	201	Kombi train	594
	202	Feeder/shunt train	450
	204	System train STAX 22,5	750
	205	System train STAX 25	833
	206	System train STAX 30	6000
	207	Wagon load train (short)	550
	208	Wagon load train (medium)	750
	209	Wagon load train (long)	950
Sea	301	Container vessel 5 300 dwt	5300
	302	Container vessel 16 000 dwt	16000
	303	Container vessel 27 200 dwt	27200
	304	Container vessel 100 000 dwt	100000
	305	Other vessel 1 000 dwt	1000
	306	Other vessel 2 500 dwt	2500
	307	Other vessel 3 500 dwt	3500
	308	Other vessel 5 000 dwt	5000
	309	Other vessel 10 000 dwt	10000
	310	Other vessel 20 000 dwt	20000
	311	Other vessel 40 000 dwt	40000
	312	Other vessel 80 000 dwt	80000
	313	Other vessel 100 000 dwt	100000

[1] Besides this distinction between modes at the highest level (road, rail, sea, ferry, air), we shall also distinguish more detailed sub-modes (e.g. light lorry, see Table 3). This is an intermediate level, between modes and vehicle types.

Mode	Vehicle number	Vehicle name	Capacity (tonnes)
	314	Other vessel 250 000 dwt	250000
	315	Ro/ro vessel 3 600 dwt	3600
	316	Ro/ro vessel 6 300 dwt	6300
	317	Ro/ro vessel 10 000 dwt	10000
Ferry	318	Road ferry 2 500 dwt	2500
	319	Road ferry 5 000 dwt	3000
	320	Road ferry 7 500 dwt	4500
	321	Rail ferry 5 000 dwt	5000
Air	401	Freight aeroplane	50

In the logistics model, we minimise the total annual logistics costs G of commodity k transported between firm m in production zone r and firm n in consumption zone s of shipment size q using logistic chain l:

$$G_{rskmnql} = O_{kq} + T_{rskql} + Y_{rskl} + I_{kq} + K_{kq} \quad (1)$$

Where:

G: total annual logistics costs

O: order costs

T: transport costs (incl. consolidation and distribution)

Y: capital costs of goods during transit

I: inventory costs (storage costs)

K: capital costs of inventory

All cost items above are defined as annual costs.

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

$$G_{rskmnql} = o_k.(Q_{mnk}/q_{mnk}) + T_{rskql} + (d.t_{rsl}.v_k.Q_{mnk})/(365*24) + (w_k+ (d.v_k)).(q_{mnk}/2) \quad (2)$$

Where:

o : the constant unit cost per order

Q: the annual f2f demand (tonnes per year)

q : the average f2f shipment size.

d: the discount rate (per year)

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

t: the average transport time (in hours).

w: the storage costs (in SEK per tonne per year).

We received information on the order cost O as part of the costs functions and parameter inputs. This information consists of fixed amounts of SEK per order, by commodity type.

The transport costs T consist of:

Link-based cost:

Distance-based costs (given in the cost functions as cost per kilometre per vehicle/vessel, for each of the vehicle/vessel types; these are calculated using network inputs for distance (LOS files).

Time-based costs:

These are given in the cost functions as cost per hour per vehicle/vessel for all the vehicle/vessel alternatives), based on network input for transport time (from LOS files). These are only the time costs of the vehicle. The time costs of the cargo are in Y.

Vehicle/vessel type specific costs:

Cost for loading at the sender and unloading at the receiver;

Vehicle/vessel pair specific costs:

Transfer costs at lorry terminals, ports, railway terminals and airports; the transfer costs are given per tonne per vehicle/vessel type. Unlike the Norwegian model, the Swedish model does not use fixed transfer costs, but only transfer cost per tonne. However, the minimum transfer cost in the Swedish model are the costs of transferring one tonne (the transfer cost of 1 tonne and 10 kg are the same), so effectively there is a fixed cost.

All these transport costs are calculated per shipment and should be multiplied by annual shipment frequency to get the annual total that can be compared against the other logistic costs items.

In the cost functions, the time-based cost only apply to the time on the link (including loading and unloading time), not to the wait time in the nodes. The wait time in the nodes is only used for the capital cost on the inventory in transit.

The service frequency of the modes (e.g. of liners), is used to determine wait time (calculated as half-headway), which has an impact on the capital cost of the goods in transit. For non-liner vessels ('tramp ships') we use wait time and positioning costs (in the Norwegian model mobilisation or positioning costs are included for all vehicle/vessel types as part of the vehicle/vessel type specific costs).

In version 1 and 2 of the Swedish logistics model we assume that if unitised transport is chosen, this will refer to all OD legs of the PWC relation: there is no stuffing and stripping of containers at consolidation and distribution centres, but only transfer of entire containers between sub-modes.

In the Swedish cost functions, the terminal costs (e.g. transfer costs at ports) differ between different classes of terminals to include economies of scale and technology differences in terminal operations. The “locally” defined technology factor (ranging from zero to one) is applied to the transfer costs (vehicle related costs and facility related costs). It is assumed that ports that handle more goods use more advanced technologies. The technology factor used in version 1 or 2 is not commodity specific.

Every OD leg has a a loading time and loading cost at its beginning (at O) and an unloading time and unloading cost at its end (at D), irrespective of whether the O and D are P (W) or C locations or terminals. The loading and unloading time represent the time costs of vehicles and drivers (which are added to link time); the loading and unloading costs refer to the costs (for instance cost of using cranes) for the physical loading and unloading. The base levels for time and cost are the same for loading and unloading (so loading a vehicle is as expensive as unloading it), but there can be differences between loading and unloading if the technology factor of the origin is unequal to that of the destination of the OD leg. The technology factor depends on the specific node (one of the inputs to the program is a list of nodes with their technology factors). When there is a transhipment at a terminal, we have the unloading costs of the OD leg that ends there and the loading costs of the next OD leg that begins there. If a node is more efficient than others, this will influence both of these legs in the same way.

The loading and unloading time (depending on the technology factors, as described above), together with wait time and link time give the total time that is relevant for calculating the capital costs of the goods during transit. Wait time is calculated as half of the headway (the interval between two services). The frequencies (on a weekly basis) of the services are a user-specified input.

The above principles for loading and unloading time and cost hold for both containerised and non-containerised transport, but the amounts of time and cost involved differ between containers and non-container transports. Furthermore, for containers, the OD costs for loading and unloading only refer to handling the container itself. The initial cost of stuffing the container and the final cost of stripping it are added separately. These costs only occur when the O location is also the P (W) location and when the D location is also the C location. We assume that containers are not refilled during a shipment from P (W) to C.

The costs for legs with the vessel types 318-321 (road and rail ferry) are calculated as follows.

Ferrylegcost=cargotimecost+vehicletimecost+vehicledistcost cargotimecost=NV*(loadt+waitt+ferryt)*(TPV*v*d/(365*24))

vehicletimecost=NV*(loadt+waitt+ferryt)*χ

Distcost= NV*ferryd*δ (3)

Where:

Cargotimecost refers to (one of the components of) the capital cost of the goods in transit Y.

Vehicletimecost and vehicledistcost refer to transport costs T.

NV=number of freight vehicles (lorries or trains) for the shipment that goes on-board of the ferry.

Waitt: waittime, based on half-headway and service frequency from frequency file.

Loadt: loadtime from vehicle input file.

Ferryt: ferry sail time, from Swedish LOS matrices for vessels 318-321.

χ: On-ferry unit time costs: the per minute cost of a lorry or train that is on the ferry

TPV: Tonnes per vehicle (as determined by the logistics model, se chapter 4)

v: value of the product per tonne

d: discount rate

Ferryd: ferry distance: from Swedish LOS matrices for vessels 318-321.

δ: On-ferry unit distance costs: the cost per km of a lorry or train that is on the ferry

For all three road ferries (318-320) the same costs is used (which differs between lorry types). So effectively there is only one road ferry vehicle type (the program in this case just takes the first one, 318). Given this, Significance suggest using one a single type of road ferry.

The capital costs of the goods in transit Y are calculated using commodity group specific average monetary values (SEK/tonne/hour), that are multiplied by the total transport chain time. The total transport chain time consists of link time, and time at the terminal (transfer time, waiting at the terminal for the vehicle/vessel for the main haul transport), but not mobilisation/positioning time at the sender or receiver. For Sweden we use an interest rate of 10% per year in total.

The inventory costs I are given in the costs function inputs as inventory holding costs per hour per tonne, by commodity type. The time here is the time at the warehouse of the receiver. This is calculated on the basis of the total annual demand for the product and annual shipment frequency.

The capital costs of the inventory K are calculated using the same time as for I together with the capital costs per tonne per hour as used for Y.

The following example is given for clarification (adopted from Bates, 2006). It is a f2f flow that uses a transport chain with two legs, each with a specific vehicle or vessel type. Below we discuss the various costs components for this transport chain.

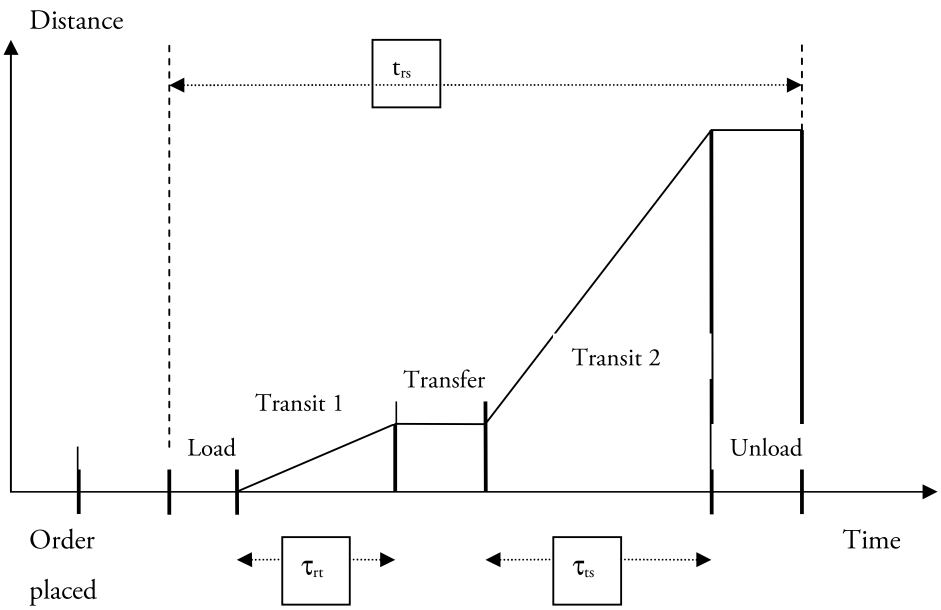


Figure 2. Example of a transport chain (in time and distance space) with two legs.

The cost of placing the order is in $O_{kq.}$

The load time, transit1 time (in-vehicle), transfer time, transit2 time (in-vehicle) and unload time (summed to t_{rs}) are used to calculate Y. Initial wait time (between placement of the order and the start of the loading) is not included, but the transfer time at the node between the two legs may include wait time for the vehicle of the second leg to arrive.

For Load and Unload, we include loading and unloading costs (vehicle/vessel type specific costs within T_{rskql}).

Transit1 and Transit2 give rise to distance-based and time-based costs of the vehicle (forτ_{rt} andτ_{ts} minutes respectively) . These are also in T_{rskql}.

The transfer costs are included as vehicle/vessel pair specific costs in T_{rskql}.

Not in the Figure, but included in the costs functions are inventory/capital costs I_{kq} + K_{kq}.

3.2 Possible improvements to the cost functions

Deterioration/damage of the goods and cost for stockouts (or safety stock costs) are not included in version 1 or 2 of the Swedish model due to lack of empirical information on these items. It might be possible to collect specific information on these items (from sending and receiving firms) and extend eq.(1) in the future to:

$$G_{rskmnql} = O_{kq} + T_{rskql} + D_k + Y_{rskl} + I_{kq} + K_{kq} + Z_{rskq} \quad (1a)$$

Where:

D: cost of deterioration and damage during transit

Z: stockout costs

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

$$G_{rskmnql} = o_k.(Q_{mnk}/q_{mnk}) + T_{rskql} + j.t_{rsl}.v_k.Q_{mnk} + (d.t_{rsl}.v_k.Q_{mnk})/(365*24) + (w_k + (d.v_k)).(q_{mnk}/2) + Z_{rskq} \quad (2a)$$

Where:

j: the decrease in the value of the goods (in SEK per tonne-hour)

CHAPTER 4 The simultaneous determination of shipment size and transport chain

4.1 Role of BuildChain and ChainChoice

In the Swedish logistics model there is a choice between 67 transport chains (with one to five legs and with different sub-modes and different vehicle/vessel types for each leg), as well as of shipment size. The sub-modes are aggregations of the vehicle/vessel types and include: light lorry, heavy lorry, Kombi train, feeder train, wagonload train, three types of system train, direct sea, feeder vessel, long-haul vessel, road ferry, rail ferry and plane.

Because the choice or optimisation problem in the logistics module is quite complicated (many choice dimensions), we split it up in two parts: BuildChain and ChainChoice.

Separately for each commodity and each pair of zones r to s, the BuildChain module determines which transport chains will be available and, for each chain that includes transfers between the modes (sea, rail, road, air) and within road rail and sea transport, selects the optimum transfer points (including road terminals, ports, railway stations, airports).

BuildChain does not use all vehicle and vessel types. If we had to evaluate all possible transfer locations for all non-direct transport chains at the level of the 35 vehicle/vessel types, the optimisation problem would become unduly complex and would consume an enormous amount of computer time. Therefore, in BuildChain transport chains are defined in terms of the sub-modes (see above and in Table 3), and the costs of each leg are determined by using typical vehicle and vessel types (defined separately for each commodity).

In addition, BuildChain works at the level of zones r to s, not at the level of individual firm-to-firm (f2f) flows m to n. So, all f2f flows with the same zones r and s and the same commodity type will have the same set of feasible alternatives (transport chains). Note that they will not necessarily all choose the same transport chain (in ChainChoice), because the f2f flows are of a different size. Since at the zone-to-zone (z2z) level, there is no unique shipment size, BuildChain uses a general average shipment size, representative for the specific commodity type. This average shipment size is set in the BuildChain control files (values used for Sweden are in Annex 1). The user has the option to choose different shipment sizes in BuildChain, which are dependent on the annual demand Q.

For reasons of computational efficiency, the optimisation within BuildChain takes place at the level of the OD-leg (and from these optimised OD-legs, transport chains from r to s are build up), except for chains with ferry and ro/ro, where the chain-building takes place for the transport chain from r to s as a whole.

Given the available chains and associated optimal transfer points from Buildchain, the ChainChoice module works at the level of the flow from firm m to firm n. It calculates the optimal shipment size and selects the single 'best' transport chain, in terms of number of legs and specific vehicle and vessel types for each leg. All vehicle and vessel types for the available sub-modes are evaluated in ChainChoice, not just the typical ones used in Buildchain. ChainChoice can read in vehicle-type-specific level of service files (LOS-files), so that policies that only affect a specific vehicle type (e.g. heavy lorries) can be simulated.

Unlike BuildChain, ChainChoice works at the level of the flow from firm m to firm n. The optimal shipment size is not an average for all z2z flows for some commodity type, but is specific for that f2f flow. All vehicle and vessel types for the available sub-modes are evaluated in ChainChoice, not just the typical ones.

In the logistics model, BuildChain (BC) and ChainChoice (CC) are used in an iterative fashion: each module is used three times, so the order of execution is: BC-CC-BC-CC-BC-CC (see section 4.4).

4.2 Generation of potential transport chains (BuildChain)

The transport chain generation program BuildChain determines the optimal transfer locations on the basis of the set of all possible multi-modal transfer nodes. The terminals are coded as separate nodes and the program uses unimodal network information on times and distances between all the centroids and all the nodes for all available sub-modes (LOS matrices).

The transport chain generation model for Sweden uses the following sub-modes (also see Table 3):

- Two road modes: road light (the first two road vehicles in Table 2) and road heavy (the last three road vehicles in Table 2), partly to account for vehicle weight restrictions on the network
- Six rail modes: feeder trains, wagonload trains, combi-trains and three different system trains with maximum axle loads (STAX) of 22,5 ton, 25 ton and 30 ton); feeder and wagonload train will be used in combination in a transport chain. Combi-trains are only for container transport and system

trains only for unconsolidated non-container transport; the latter requires direct access/egress at the sender, receiver or the port.

- Three sea modes: feeder ships to/from ports in Europe, long-haul ships to/from overseas ports and direct sea vessels. Feeder ships and long-haul ships can only appear together in a transport chain. The available options thus are (both for containerised and non-containerised): feeder vessel - long-haul vessel or long-haul vessel – feeder vessel (in combination with several other modes for other legs of the transport chain).
- Air.

Ferry links are handled as sea legs within road or rail chains, for which we use uni-modal network inputs on ferry distance and ferry travel time.

We distinguish transfer locations within the rail system between feeder trains and wagonload trains for the main-haul. The options are:

- Feeder – wagonload (in combination with several other modes for other legs of the transport chain). Feeder trains are only specified within Sweden.
- Wagonload – feeder (in combination with several other modes for other legs of the transport chain).

Both can be used for containerised and non-containerised transport.

Transfers between feeder and long-haul vessels in version 1 and the current version 2 for Sweden are only allowed at the major Northwest European ports (Hamburg, Bremerhaven, Rotterdam and Antwerp). For instance for a transport from Sweden to the United States, this will give a choice between a direct sea transport to the US and a feeder transport to one of the four ports mentioned with a long-haul heavily consolidated transport (from these four ports we always assume 90% consolidation) from the mainport to the US (since we do not model the non-Swedish flows from these ports). Transfers can only take place at transfer nodes (including ports, airports, railway terminals), not at the zone centroids.

Direct rail access and direct sea access is handled on the basis of a list of zone-commodity combinations. Contrary to the approach for Norway, for Sweden we assume that only large firms within the eligible zone-commodity combination have the direct transport chain available. Large firms are defined here as the 67-100th percentile of the firm size distribution, as used in the production of base matrices (see section 2.2). Direct access at both ends is available if at least one of the firms involved is a large firm (this could be restricted to the end where the large firm is located, if that would be deemed more appropriate). This concerns the following sub-cells from the PWC matrices:

- flows from small firms to large firms
- flows from medium-sized firms to large firms
- flows from large firms to small firms

- flows from large firms to medium-sized firms
- flows from large firms to large firms.

As with Norway we assume that no other zone-commodity combinations have such direct access. For overseas locations (e.g. Africa, Midle East, Far East, North-America, South America) we have assumed that direct sea and direct air access is available (both into and out of these zones), because there are no land-based network links in the Swedish model for these zones. Otherwise these zones in the model would not be connected to Sweden.

Whether a certain sub-mode is available or unavailable for a specific zone or terminal node pair (e.g. no direct sea connection for two land-locked zones) is taken into account in the link-based inputs (LOS-matrices).

For Sweden 67 possible transport chains are used (see Table 4). These chains were selected on the basis of the possible combinations of the sub-modes, using five as the maximum number of legs in a transport chain. A number of illogical chains (e.g. long-haul vessel before feeder vessel; wagonload train, before feeder train) were eliminated, as were chains with land-based sub-modes outside Europe (for which the Swedish model has no networks) and feeder trains outside Sweden.

In the calculations within BuildChain we use the same total logistic costs function and the same cost input parameters as for ChainChoice. BuildChain is applied by commodity type, because for different commodity types, different transfer locations (e.g. specialized ports) can be available. Also the specific vehicles/vessels used in the transport chain generation program can differ between commodity types (e.g. oil tanker for oil). For terminals (ports, rail, road, air), information is available on the location, which commodities can be handled, which sub-modes can be handled and maximum draught (for three broad commodity groups). Network restrictions for vessel types (size of vessel that a port can handle) are thus handled in the terminal file, not in the link output.

The fact that some ports cannot handle large vessels (maximum draught), is accounted for later on in ChainChoice, using data for each terminal (e.g. port) on vessel size restrictions. In the BuildChain program this check is only carried out for the ‘typical’ vehicle/vessel type within each sub-mode. If some port is not available for a certain chain another port can be chosen as the transfer location within this chain (instead of making the whole transport chain type non-available). If for example port A is small and cannot accommodate the typical vessel for commodity 1 (which is a 20.000 dwt vessel), this does not make road-sea-road chains unavailable for a specific z2z pair. It just means that another port will be selected for this road-sea-road chain. If the selected port for this chain can handle vessels up to 80.000 tonnes, the vessel types 313 and 314 cannot be selected for this leg in ChainChoice.

Table 3. Sub-modes and vehicle types for container transport and non-container transport

Sub-mode		Sub-ModeNr	VhclNr	Vehicle type
Containers	Heavy lorry	A	104	Lorry HGV max 40 ton
			105	Lorry HGV max 60 ton
	Kombi train	D	201	Kombi train
	Feeder train	E	202	Feeder/shunt train
	Wagonload train	F	207	Wagon load train (short)
			208	Wagon load train (medium)
			209	Wagon load tain (long)
	Direct Sea	J	301	Container vessel 5 300 dwt
			302	Container vessel 16 000 dwt
			303	Container vessel 27 200 dwt
			304	Container vessel 100 000 dwt
			305	Other vessel 1 000 dwt
			306	Other vessel 2 500 dwt
			307	Other vessel 3 500 dwt
			308	Other vessel 5 000 dwt
			309	Other vessel 10 000 dwt
			310	Other vessel 20 000 dwt
			311	Other vessel 40 000 dwt
			312	Other vessel 80 000 dwt
			313	Other vessel 100 000 dwt
			314	Other vessel 250 000 dwt
			315	Ro/ro vessel 3 600 dwt
			316	Ro/ro vessel 6 300 dwt
			317	Ro/ro vessel 10 000 dwt
	Feeder vessel	K	301	Container vessel 5 300 dwt
			315	Ro/ro vessel 3 600 dwt
			316	Ro/ro vessel 6 300 dwt
	Long-Haul vessel	L	303	Container vessel 27 200 dwt
			304	Container vessel 100 000 dwt
			317	Ro/ro vessel 10 000 dwt
	Road ferry	P	318	Road ferry 2 500 dwt
			319	Road ferry 5 000 dwt
			320	Road ferry 7 500 dwt
	Rail ferry	Q	321	Rail ferry 5 000 dwt

Sub-mode		Sub-ModeNr	VhclNr	Vehicle type
Non-Containers	Light Lorry	B	101	Lorry light LGV, ≤ 3,5 ton
			102	Lorry medium 3,5-16 ton
			103	Lorry medium16-24 ton
	Heavy lorry	C[2]	104	Lorry HGV 25-40 ton
			105	Lorry HGV 25-60 ton
	Feeder train	G	202	Feeder/shunt train
	Wagonload train	H	207	Wagon load train (short)
			208	Wagon load train (medium)
			209	Wagon load tain (long)
	System train STAX 22.5	I	204	System train STAX 22.5
	System train STAX 25	T	205	System train STAX 25
	System train STAX 30	U	206	System train STAX 302
	Direct Sea	M	305	Other vessel 1 000 dwt
			306	Other vessel 2 500 dwt
			307	Other vessel 3 500 dwt
			308	Other vessel 5 000 dwt
			309	Other vessel 10 000 dwt
			310	Other vessel 20 000 dwt
			311	Other vessel 40 000 dwt
			312	Other vessel 80 000 dwt
			313	Other vessel 100 000 dwt
			314	Other vessel 250 000 dwt
			315	Ro/ro vessel 3 600 dwt
			316	Ro/ro vessel 6 300 dwt
			317	Ro/ro vessel 10 000 dwt
	Feeder vessel	N	315	Ro/ro vessel 3 600 dwt
			316	Ro/ro vessel 6 300 dwt
	Long-Haul vessel	O	317	Ro/ro vessel 10 000 dwt
	Road Ferry	P	318	Road ferry 2 500 dwt
			319	Road ferry 5 000 dwt
			320	Road ferry 7 500 dwt
	Rail Ferry	Q	321	Rail ferry 5 000 dwt
	Plane	R	401	Freight airplane

[2] Consolidated heavy lorry is coded as mode S in the chains file, to distinguish it from the unconsolidated heavy lorry transport A and C. The default setting of the model however allows consolidation for all types of lorries; instead of this, the user can select a version that only has consolidation in road transport specifically for heavy lorries (as in version 2.0).

Table 4. Transport chains used for Sweden

Number	Potential chain	Explanation
1	A	Direct transport by heavy lorry, using containers (see Table 3)
2	ADA	Heavy-lorry – Kombi-train – heavy lorry, with containers
3	ADJA	Etc.
4	ADJDA	
5	ADKL	
6	AJ	
7	AJA	
8	AJDA	
9	AKL	
10	APA	
11	B	
12	BR	
13	BRB	
14	BS	
15	BSB	
16	C	
17	CGH	
18	CGHC	
19	CGHM	
20	CH	
21	CHG	
22	CHGC	
23	CM	
24	CMC	
25	CMI	
26	CMT	
27	CMU	
28	CPC	
29	CUM	
30	GH	
31	GHC	
32	GHG	
33	GHM	
34	GHMI	

Number	Potential chain	Explanation
35	GHMT	
36	GHMU	
37	GHQH	
38	HC	
39	HG	
40	HGC	
41	I	
42	IM	
43	IMC	
44	IMHG	
45	J	
46	JA	
47	KL	
48	LK	
49	LKA	
50	LKDA	
51	M	
52	MC	
53	MHG	
54	MHGC	
55	MI	
56	MT	
57	MU	
58	RB	
59	SB	
60	T	
61	TM	
62	TMC	
63	TMGH	
64	U	
65	UM	
66	UMC	
67	UMGH	

The typical vehicles/vessels used in BuildChain for each commodity are in Table 5.

Table 5. Vehicle type in BuildChain for each sub-mode by commodity type for Sweden (see Table 1 for commodity group numbers and Table 3 for sub-mode and vehicle numbers)

Commodity	A	D	E	F	J	K	L	B	C	G	H	I	M	N	O	P	Q	R	T	U
1	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
2	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
3	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
4	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
5	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
6	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
7	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
8	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
9	104	201	202	208	-	-	-	101	104	202	208	204	310	315	317	319	321	401	205	206
10	104	201	202	208	303	301	303	101	104	202	208	204	310	315	317	319	321	401	205	206
11	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
12	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
13	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
14	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
15	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
16	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
17	104	201	202	208	303	301	303	101	104	202	208	204	310	315	317	319	321	401	205	206
18	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
19	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206

Commodity	A	D	E	F	J	K	L	B	C	G	H	I	M	N	O	P	Q	R	T	U
20	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
21	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
22	104	201	202	208	-	-	-	102	104	202	208	204	310	315	317	319	321	401	205	206
23	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
24	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
25	104	201	202	208	303	301	303	101	104	202	208	204	317	315	317	319	321	401	205	206
26	104	201	202	208	-	-	-	101	104	202	208	204	310	315	317	319	321	401	205	206
27	104	201	202	208	303	301	303	101	104	202	208	204	310	315	317	319	321	401	205	206
28	104	201	202	208	303	301	303	102	104	202	208	204	317	315	317	319	321	401	205	206
29	104	201	202	208	303	301	303	101	104	202	208	204	310	315	317	319	321	401	205	206
30	104	201	202	208	303	301	303	101	104	202	208	204	317	315	317	319	321	401	205	206
31	104	201	202	208	303	301	303	102	104	202	208	204	310	315	317	319	321	401	205	206
32	104	201	202	208	303	301	303	101	104	202	208	204	317	315	317	319	321	401	205	206
33	104	201	202	208	303	301	303	101	104	202	208	204	317	315	317	319	321	401	205	206
34	104	201	202	208	303	301	303	102	104	202	208	204	317	315	317	319	321	401	205	206
35	-	-	-	-	-	-	-	101	-	-	-	-	-	-	-	-	-	401		

The BuildChain procedure for Sweden searches for 67 typical logistic chains. The search algorithm identifies the optimal chain for each of these chain types. For each type, BuildChain calculates the optimal transfer locations and logistic costs for the logistic chain. In doing so, the algorithm follows a stepwise approach in adding extra legs to chains and analysing the optimal transfer locations. This approach is explained in Figure 3 below.

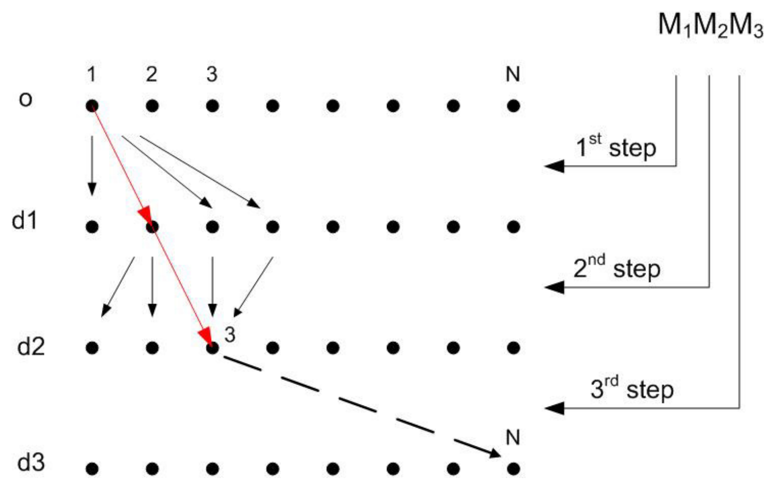


Figure 3: Search algorithm, the optimal two leg chain M1M2 from origin 1 to destination 3 is indicated in red

For each origin o, the procedure generates chains that can consist of one leg (M_1) to for instance three legs ($M_1M_2M_3$). All transport modes are taken into account. The optimal chain of just one leg (M_1) to each destination is trivial: the alternative with the least logistic costs.

The algorithm generates chains from this origin to each possible destination d, and tries to use the information from the chains that are produced for shorter chains as efficient as possible. Now, suppose the procedure is searching for the optimal chain of three legs ($M_1M_2M_3$) from origin 1, to destination N, under the condition that the second transfer is made in node number 3. The program has already determined the optimal logistic chain of two legs to this transfer point, as indicated in red in Figure 3. It will use this chain as the first two legs of the new three legged chain from origin 1, to N, with a second transfer at node number 3. The program only needs to determine the optimal third leg of this chain. Please note that the program searches for three legged chains from zone 1 to N through all possible transfer nodes, not only through node 3. The optimal two legged chain between this transfer node and zone 1 is already determined by the program.

The transport chain generation program builds up the optimal chains step by step and therefore cannot be used to yield second-best transport chains.

Transport chains that have a total logistics costs of more than five times that of the cheapest available transport chain (also including direct transport) for a specific zone-to-zone combination are excluded from further consideration.

4.3 Choice of shipment size and transport chain (ChainChoice)

As set out in Chapter 2 we now have annual flows from firm m (in zone r) to firm n (in zone s), by commodity type. We have got this for all flows in/to/from/through Sweden respectively that were in the PWC matrices. This is therefore not a sample to be expanded, but the population of commodity flows. In RAND Europe and Sitma (2005) different types of inventory behaviour have been discussed. For each commodity class this has provided the dominant type of optimisation behaviour (see Table 6). This determines the formula to be used for optimal shipment size.

The outcome will be an average optimal shipment size q for every f2f flow from sender m to receiver n for commodity k. This splits the annual total f2f flow into a number (the average optimal frequency) of shipments. We could represent this at the shipment level, by making each shipment an observation (with the same shipment size for each kmn combination), but it is more efficient to add this shipment size q as an attribute to the kmn flows. In other words: to have one shipment observation for each kmn combination, but with a certain weight (its annual frequency to give the total annual kmn flow). We make the simplifying assumption that all flows in a year for commodity k from m to n are of the same size.

In the version 2.1 model (as before) the same optimisation logic is used for PC and WC relations. Different assumptions could be used in future versions.

To obtain the optimal frequency, chain type and vehicle type(s) for a shipment, the costs for many different frequencies, chain types and vehicle types are evaluated and the alternative with either the lowest transport costs or the lowest logistic costs (depending on commodity, see Table 6) is selected. Most of the time this optimization can be done individual on subsequent chain legs, because transfer costs are calculated as the costs of unloading the first and loading the next vehicle. These (un)loading costs can thus be assigned to the leg costs, independent of the previous/next chain leg. Only when these costs are dependent of the previous/next chain leg, the individual optimization of subsequent legs will fail, and a simultaneous optimization of all legs is required. This can be controlled by the INDIVIDUAL_OD_LEG_OPTIMIZE switch in the ChainChoi control file.

Table 6. Optimisation logic per commodity type

Category:	Optimisation logic
1. Cereals	Joint transport and inventory optimisation
2. Potatoes, other vegetables fresh or frozen	Joint transport and inventory optimisation
3. Live animals	Cost minimisation for transport
4. Sugar beet	Cost minimisation for transport
5. Timber for paper industry (pulpwood)	Joint transport and inventory optimisation
6. Wood roughly squared or sawn lengthwise, sliced or peeled	Joint transport and inventory optimisation
7. Wood chips or wood waste	Joint transport and inventory optimisation
8. Other wood or cork	Joint transport and inventory optimisation
9. Textiles, textile articles and manmade fibres, other raw and animal and vegetable materials	Joint transport and inventory optimisation
10. Foodstuff and animal fodder	Joint transport and inventory optimisation
11. Oil seeds and oleaginous fruits and fats	Cost minimisation for transport
12. Solid mineral fuels (coal etc)	Joint transport and inventory optimisation
13. Crude petroleum	Joint transport and inventory optimisation
14. Petroleum products	Joint transport and inventory optimisation
15. Iron ore, iron and steel waste and blast-furnace dust	Joint transport and inventory optimisation
16. Non-ferrous ores and waste	Joint transport and inventory optimisation
17. Metal products	Joint transport and inventory optimisation
18. Cement, lime, manufactured building materials	Joint transport and inventory optimisation
19. Earth, sand and gravel	Joint transport and inventory optimisation
20. Other crude and manufactured minerals	Joint transport and inventory optimisation
21. Natural and chemical fertilizers	Joint transport and inventory optimisation
22. Coal chemicals	Joint transport and inventory optimisation
23. Chemicals other than coal chemicals and tar	Joint transport and inventory optimisation
24. Paper pulp and waste paper	Joint transport and inventory optimisation
25. Transport equipment, whether or not assembled, and parts thereof	Joint transport and inventory optimisation
26. Manufactures of metal	Joint transport and inventory optimisation
27. Glass, glassware, ceramic products	Joint transport and inventory optimisation
28. Paper, paperboards; not manufactured	Joint transport and inventory optimisation
29. Leather textile, clothing, other manufactured articles than 28	Joint transport and inventory optimisation
30. Mixed and part loads, misc. articles	Joint transport and inventory optimisation
31. Timber for sawmill	Joint transport and inventory optimisation
32. Machinery, apparatus, engines	Joint transport and inventory optimisation
33. Paper, paperboard and manufactured thereof	Joint transport and inventory optimisation
34. Packaging materials, used	Joint transport and inventory optimisation

4.3.1 Optimisation of transport and inventory costs (full logistics costs)

In Table 6, the situations where this optimisation logic applies are called joint transport and inventory optimisation. For this category, given the annual flow Q from sender m to receiver n for commodity k, we first determine the optimal shipment size q* without the influence of transport costs, using the economic order quantity formula to get a starting point. The initial optimal shipment size (for commodity group k) becomes:

$$q_k^* = \sqrt{\frac{(o_k * Q_k * 2)}{(w_k + i * v_k)}} \quad (4)$$

where o represents order costs per order, Q the annual firm-to-firm flow in tonnes, w the storage costs per tonne per year, i the annual interest rate and v the commodity value per tonne. For different commodities we have different input values for these variables.

The starting point for annual delivery frequency thus is Q/q* (rounding off to integer values). Then we generate twenty possible frequencies in the interval [0.2Q/q*, Q/q*], at uniform intervals. For each of those 20 possible frequencies, we calculate the total logistics costs (see eq. 1 and 2) for each of the available vehicle/vessel type sequences for the available transport chains, given the annual flow Q from sender r to receiver s for commodity k. From all these discrete alternatives, we select the one with the lowest total logistic costs G and use the corresponding frequency Q/q** and shipment size q** in the further calculations[3].

If the optimum frequency Q/q** is found at the lower boundary of the range (at 0.2Q/q*), then we perform another search using twenty points in the interval [0.2Q/q**, Q/q**].

The user can choose to abandon the shipment size optimisation below a specific annual demand level, to prevent having too many very small flows (but this is not the default). When the annual firm-to-firm flow is smaller than this threshold (specified in the CHAINCHOI control file by the specifier MINIMUM_ANNUAL_TONNE_DEMAND_4_FREQ_OPTIMIZE), the chosen frequency will be equal to the initial optimal frequency (Q/q*).

The order costs o_k are not necessarily fixed over the entire range of annual demand for the f2f flow. The user can choose to make the order cost dependent on annual demand Q, following:

$$o_k = o_{kFixed} + o_{kvar} * Q^{\alpha_o} \quad (5)$$

Where:

o_{kfix}: fixed order cost

o_{kvar}: variable order costs rate per unit of demand

[3] An alternative here might be using the golden rule (golden section); however, this requires a continuous parabolic cost function, whereas ours is discontinuous and not necessarily parabolic.

α_O: user-set coefficient.

4.3.2 Optimisation of transport costs only

For optimisation of transport costs only (within constraints on the shipment size and time) we start with a frequency one 1 (per year) and then keep increasing this frequency by steps of 1. We then stop as soon as two subsequent iterations have not produced a decrease in the total logistic costs or if the frequency reaches 15 per year. Please note that in the logistics costs functions for these commodity types we do not include the inventory (storage) costs I at the receiver. Other optimisation logics

For joint optimisation of inventory and transport with constraints on shipment sizes we use the same procedure as described above for joint optimisation without constraints.

4.4 Consolidation

4.4.1 The three iterations

Within the logistic model rail, sea and air chain legs are always consolidated (vehicle/vessel/plane is shared with other shipments). For lorry both consolidated and unconsolidated modes are distinguished. With the ALL_LORRY_TYPE_CONSOL switch in the control files, it is possible to make all lorry connections consolidated chain legs. To calculate the total logistics cost of transport chains that use consolidated vehicles/vessels, it is necessary to determine the degree of consolidation for these vehicles/vessels.

The consolidation depends –among other things- on whether there will be sufficient other cargo on an OD leg (especially a CC-DC leg, such as port-port). The issue of whether at some transfer location there will be sufficient other cargo (going in the right direction) for consolidation is treated by looking at the total amount of goods within certain commodity types that will be sent from a transfer point (e.g. a port) to another transfer point (see Figure 4).

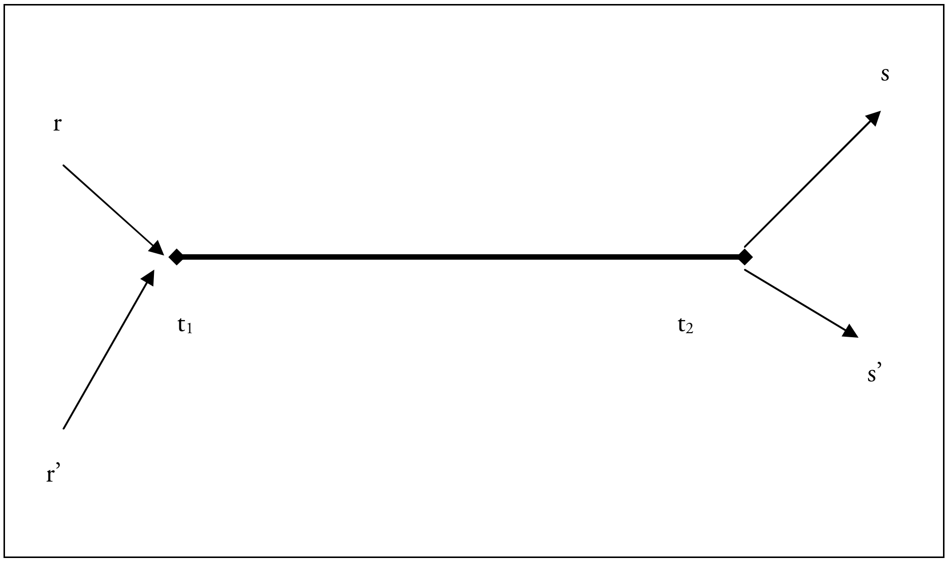


Figure 4. Different f2f flows using the same pair of transfer locations

The f2f flow from sender r to receiver s and the one from sender r' to receiver s' have the leg from transfer point t_1 to transfer point t_2 in common (in at least one of their available transport chains). So for each of these flows, the other flow is included in determining the degree of consolidation.

The degree of consolidation is determined in an iterative process that consists of three iterations. Each iteration consists of running BuildChain first and ChainChoice after that. The basic role of both BuildChain and ChainChoice is the same in every model iteration. What changes from iteration to iteration is the load factor φ, and this is being used in both BuildChain and ChainChoice, for consolidated legs. In ChainChoice, the shipment size for each f2f flow is optimized again in each iteration, and the same goes for the transport chain (number of legs, vehicle and vessel types per leg).

In the first iteration of the model, we use a load factor of 75% in both BuildChain and ChainChoice. This is just a starting point; another starting point can be defined in the command line statement that starts the program. For all consolidated legs of a transport chain (that is legs coming after a consolidation centre) we thus assume that 75% of the vehicle capacity is used, and the shipment studied only has to pay a costs proportional to its share in this total load.

Consider an O-D leg t_1- t_2 where consolidation is possible. Costs of using this leg will depend on the level of consolidation. Assume that the level of utilization is φ, defined as the vehicle load divided by vehicle capacity. Ideally, this needs to vary:

- by commodity k (with the possibility of some grouping…)
- by vehicle/vessel type v
- by leg t_1- t_2

Currently, it does not vary by v, but only by sub-mode h, since in the BuildChain module we use sub-modes with typical vehicle types to keep the dimensionality manageable.

For a shipment of size q the costs paid for the consolidated transport are then

$$\text{vehicle cost} * q/(\varphi * Cap) \quad (6)$$

In the first place, we have $\varphi_{t1-t2,h,k} = 0.75 \ \forall \ t_1 - t_2, h, k$

The aim of the iterations is to update the value of φ.

The Buildchain process is meant to produce the optimum transfer points t_1- t_2 for each chain type [ℓ] between r and s, separately by commodity k. Strictly, this should be dependent on shipment size, but this is not done in the current version.

Thus, as a result of the Buildchain process, which in the first iteration will use φ = 0.75, we will know, for flow between each r and s, whether there will be at least one chain ℓ using the leg t_1- t_2. All the demand flows from firm m in zone r to firm n in zone s Q_{mn} is accumulated for every transport chain ℓ that is available for this f2f flow mn that includes the leg t_1- t_2. This gives the "potential" Π. Note that there could be more than one chain for a f2f flow that contains this leg (e.g. a chain where it is the second and a chain where it is the third leg); in that case the f2f volume is counted more than once. The calculation is done separately for each sub-mode h that can use the leg t_1- t_2.

In equation form, this boils down to:

$$\Pi_{t_1-t_2,h,k} = \sum_{mn} \sum_{l \text{ with } t_1-t_2 \text{ using } h \text{ in optimal chain}} Q_{mn}^k \quad (7)$$

In the current implementation, these "potentials" are merely used in relative terms (that is, in a purely ordinal ranking). The combinations of possible "t_1- t_2" pairs are ranked according to total potential and allocated values of $\varphi_{t1-t2,h,k}$ uniformly in a certain range between 0 and 1. In version 2.0 this range was 0.05, 0.95] for all submodes. In the current version 2.1, this range is submode-specific and can be set by the user, with [0.10, 0.95] as default. These values can be adjusted –by commodity type- by the user in the control files.

In the case of port-to-port legs, the potential calculated in this way is further multiplied by the observed total port flows for domestic ports (N.B. not port-to-port flows), prior to the ranking process. For foreign ports in the model, a very high port output has been inserted into the program so that these will end up at the top of the ranking. This is to make use of observed information about the relative activity of each port. Within the data on observed port outputs, we distinguish between port-specific container flows and port-specific other freight flows that can be controlled via the input files. Other distinctions between different categories of sub-modes are not made.

The potential is calculated merely based on BuildChain output (plus observed port data) – i.e. without running ChainChoice. In spite of this, the 0.75 value for φ in the first iteration is also used for ChainChoice. In later iterations, φ can only be calculated **after** ChainChoice has been run

The next time the Buildchain and ChainChoice routines are run, these revised values of φ are used. Note however that for a given sub-mode, the value is invariant with vehicle/vessel type.

At the end of iteration 1 we now have a quantity $Z_{t1,t2}$ representing the current estimate of annual demand (over all rs) which is allocated to the transfer point pair (t_1,t_2). We also have a corresponding load factor $\varphi_{t1-t2,h,k}$. Both Z and φ are defined at the OD level. i.e. relating to a specific t_1-t_2 pair and a specific sub-mode h. The same φ is assumed for all vehicle types within the sub-mode h that are allowed for t_1-t_2.

In the third (and currently final) iteration, the ranking process (as in eq. (7)) is then repeated, but, based on the previous iteration, the actual chain chosen (the chain predicted to be selected in iteration 2) is used, rather than the available optimal chains for each type. In this case, it is possible that the chain ℓ **will** depend on the shipment size in relation to a particular f2f movement. Hence the modified potential calculation Π′ is:

$$\Pi'_{t_1-t_2,h,k} = \sum_{mn} Q^k_{mn}.\delta_{[mn],optimal\ chain\ has\ t_1-t_2\ u\sin g\ h} \qquad (8)$$

where δ is a (0,1) variable only having the value 1 if the particular f2f movement chooses a chain with sub-mode h using leg t_1- t_2.

In iteration 3, this modified potential is used to produce a ranking, and subsequent allocation of $\varphi_{t1-t2,h,k}$ in the range [0.05, 0.95]. The observed port output is not only used in iteration 2, but also in iteration 3. So in iteration 3 the modified potential is multiplied by the port output, before doing the ranking.

To summarise, the iterative process works as follows:

Iteration 1: φ = 0.75 → BC → CC

Iteration 2: potential → BC → CC

Iteration 3: OD-flow → BC → CC

4.4.2 Consolidation without deconsolidation?

A question is whether there can also be consolidation without deconsolidation (then not t_1 and t_2, but t_1 and s). An example would be a chain road-sea, or road-rail, or road light-road heavy. In these transport chains (which might be included in the set of feasible alternatives), there is a consolidation centre, but the second leg takes the shipments to the different receivers. This seems unlikely for sea and rail in the second leg: different receivers should have direct sea or rail access at the same place. It might be possible within road transport, where the heavy vehicle would do a delivery tour ('deconsolidation en-route'). We have chosen to rule consolidation out for such chains, with the following exceptions. These exceptions relate to foreign zones where we do not have inter- and intra-zonal road egress information for all road ports, airports and railway stations and no information on road terminals, so that we cannot add a road-based deconsolidation leg.

4.4.3 Restricting the vehicle type choice set for consolidated legs

Without bounds on the vehicle type choice set within each sub-mode, the above consolidation process has a tendency to select the largest vehicle type v within a sub-mode h for potentially consolidated flows. To prevent this, a restriction of the vehicle choice set, suggested by John Bates, was implemented in the program. This works as follows.

For any transfer point pair (t_1,t_2), consider each vehicle in turn (strictly this involves looping over sub-modes h and vehicles v(h) within each sub- mode). Vehicle type v has capacity Cap_v. If all the annual demand $Z_{t1,t2}$ was allocated to that vehicle type, with the assumed loading factor φ, this would require $Z_{t1,t2}/(\varphi * Cap_v) = F(v:t_1,t_2)$, say, vehicle trips per year. It follows that if any particular f2f shipment mn potentially using transfer point pair (t_1,t_2) requires a frequency > F, then the utilization of vehicle type v for that movement is bound to be lower than the assumed φ.

Within the optimisation loop in Chainchoice, the program calculates, for each mn, the maximum frequency f* = Q/q* from the EOQ rule (see section 4.3.1), and then proceeds to test different values for f (in the first place, down to 0.2Q/q*).

Now in ChainChoice, both in iterations 2 and 3, for each evaluated frequency f for a specific shipment, the vehicle types that are too large are removed from the choice set. More formally, any v for which $F(v:t_1,t_2) > f$ (where t_1,t_2 is the relevant transfer point pair for mn) will be dropped from the vehicle set. The general result will be that the set of vehicles in the choice set will increase as the assumed frequency falls. This will counteract the general tendency of the consolidation process described above to shift shipments on to the largest possible vehicle.

However, the above rule does not yet take into account that the annual demand is distributed over time (an entire year). The actual volume available for consolidation at some point in time is likely to be considerably lower. Therefore in version 2.l we introduced an additional coordination factor:

As long as the number *f* of vehicles v consolidated up to the consolidation fraction of the capacity amounts to less than the consolidation volume, then it is allowed to use vehicle v:

$$CoordFactor \times f \times \varphi_v \times Cap_v \leq Z_{t1,t2}$$

The coordination factors can be vehicle-type specific and are set in a specific input file (with defaults setting that the user can change).

4.4.4 Cost calculation for consolidated and unconsolidated legs

After having determined the load factor or utilisation rate φ (within one of the iterations) on the basis of the ranking, the transport cost of each leg can be calculated as follows.

In general: for a shipment of size q the costs paid for a transport on vehicle/vessel type v are calculated in the following way:

Unconsolidated legs:

NV_v = INT(q/cap_v) and load factor in cost log = q/(NV_v * Cap_v)

$Cost_v = NV_v$ * [vehicle cost] $_v$ (9)

Where:

NV: number of vehicles

INT: operator that gives nearest higher integer

q: shipment size

Cap: vehicle capacity

Consolidated legs (load factor in cost log: φ):

Define $load_v$ = φ * Cap_v (on an OD basis)

If q < $load_v$, then consolidate and pay [vehicle cost]$_v$ * q/(φ * Cap_v), 1 vehicle

If $load_v$ < q < Cap_v, then use q as vehicle load and pay all (1 vehicle) – i.e. **not** consolidated.

If q > Cap_v, then NV_v=q/Cap_v , where NV_v is rounded of to the next higher integer: pay NV_v * [vehicle cost] $_v$ - i.e. not consolidated (10)

4.4.5 A worked out example

This subsection 4.4.5 contains a worked out example of how the estimated amount of consolidation affects the transport costs in each of the three iterations.

We consider a f2f relation of commodity 29 (leather, textile, clothing, other manufactured articles other than paper,, paperboard and manufactures thereof) from Stockholm (zone 828000) to Malmö (zone 718000). The f2f relation contains 2.29 tonnes per year. In all three iterations, the optimal frequency is 3 per year and the optimal shipment size is 0.7652 tonnes. The optimal transport chain is also the same in each iteration: ADA (containerised, heavy lorry – Kombi train – heavy lorry) and in each iteration this chain uses the road-rail terminals 718012 (close to Stockholm) and 828011 (close to Malmö). The optimal transport chain in this example happens to be a consolidated chain: in the Kombi train, the shipment of the f2f relation studied is consolidated with other shipments of commodity 29 that also go from terminal 718012 tot terminal 828011 by Kombi train.

<u>Iteration 1</u>

In iteration 1, an assumed load factor of 0.75 is used. This implies that the number of Kombi trains needed for this shipment is:

(shipment size/vehicle capacity)/load factor = (0.7652/594)/0.75 = 0.00172

This particular f2f flow therefore only has to pay 0.18% of the full time and distance based transport cost of a Kombi train between these two terminals.

<u>Iteration 2</u>

In the second iteration, we calculate a volume between the terminals from all PC flows of commodity 29 of 8560 tonnes is calculated. This is a higher volume than for most other terminal-terminal relations for the same sub-mode and commodity (it is of course a relation between two major cities), which according to the ranking mechanism leads to a load factor of 0.8346 (high in the [0.10,0.95] range). As a result, the number of Kombi trains needed for this shipment becomes:

(0.7652/594)/0.8346 = 0.00154

This particular f2f flow only has to pay 0.15% of the full time and distance based transport cost of a Kombi train between these two terminals.

<u>Iteration 3</u>

After this, we calculate for this terminal-terminal pair an OD flow volume for commodity 29 of 13781 tonnes. This is one of the highest volumes of all terminal-terminal relations for the same sub-mode and commodity. After applying the ranking mechanism it gives a load factor of 0.9269 (close to the maximum of 0.95). For the shipment studied, the number of Kombi trains needed for this shipment becomes:

(0.7652/594)/0.9269 = 0.00139

This particular f2f flow only has to pay 0.14% of the full time and distance based transport cost of a Kombi train between these two terminals.

4.4.6 Consolidation along the route

Consolidation along the route (collection round or milk round) is not yet included in the Swedish model. We plan to include this (as for Norway) as an additional road-based transport chain. This chain, and its logistics cost, is not generated in the transport chain generation program, but will be included afterwards in the main logistics program, as direct road transport with an extra waiting time and distance (detour). This will be limited to consolidation in a single zone. The rule of the thumb that Inge Vierth provided (drive 10 km to get another tonne) will be used here, together with information on the total flow from zone r to zone s (the PWC flow) and on the zone size of zones r and s. The length of the detour will be calculated on the basis of the zone size for r and s (assuming uniform space) and the number of senders and receivers on this zone-to-zone relation. This additional transport chain alternative will be added to the available alternatives (if direct road transport was available) and in the transport chain choice program one of the alternatives (those from the chain generation or consolidation en-route) will be selected.

CHAPTER 5

Production of matrices of vehicle flows and logistics costs

5.1 Inputs and outputs of the programme

For the logistics module, a computer programme has been developed that is operated by means of a control file. The control file lists the input files for the programme and specifies the output files. It also contains switches to change parameters in he logistics costs function (such as trucking rates, unit inventory costs, transfer costs, values of time).

The input files are (<commodity> means: insert a commodity number here):

PWC-flows

PWC_<commodity>.txt	PWC flows in 10 sub-cells

LOS

v<vehicletype>_dist.314	Distance matrix
v<vehicletype>_ddist.314	Distance matrix for distances within Sweden
v<vehicletype>_timeh.314	Time matrix
v<vehicletype>_xkr.314	Cost matrix
freq<mode>.314	Service frequency matrix

Nodes

nodes_all.xls	Available nodes, allowed transfers, direct access, container handling

Costs

vhcls_<commodity class>.txt	Time, distance, loading costs per vehicle type
pilotfees.txt	Pilot fees
cargo.txt	Product value, inventory costs, order costs per commodity type

The programme then determines the shipment size and annual shipment frequency, determines the transport chains (legs, modes/vehicles/cargo type), and empty flows. Furthermore, there is a module called Extract that can aggregate to OD flows and produce logistics costs at the PWC level, taking into account the OD (chain) pattern. The outputs therefore are:

BUILDCHAIN

Chains<commodity>.dat	available chains per od
Connection.lst	list of connections that depart from each node

CHAINCHOI

chainchoi<commodity>.out	best chain (route, costs) per pwc-cell
chainchoi<commodity>.log	list of pwc-ralations without available chain
chainchoi<commodity>.fac	TotalTonnes, TotalVhcls and LoadFac per origin, destination and vehicle type
chainchoi<commodity>.cst	detailled cost log
chainchoi<commodity>.rep	Domestic and International Shipments, Vehicles, Kms, Tonnes and TonneKms per vehicle type and per chain type
consol_<commodity>_<mode>.314	od-matrix with consolidation factors (output of ranking)
volume_<commodity>_<mode>.314	od-matrix with tonnes

MERGEREP

chainchoi.rep	merged Domestic and International Shipments, Vehicles, Kms, Tonnes and TonneKms per vehicle type and chain type

EXTRACT

od_tonnes<vehicletype>.314	od-matrix with tonnes
od_vhcl<vehicletype>.314 od-matrix with vehicles	od-matrix with vehicles

By collecting all the OD legs from the transport chains determined above (including the empty vehicle flows, see section 5.2) for all PWC flows at the zonal level (adding over firms and transfer locations that are in the same zone), we get OD flows. These can be expressed in tonnes and in vehicles. For assignment we recommend to use vehicle flows.

5.2 Empty vehicles

BuildChain and ChainChoice give vehicle flows for loaded trips. But for assignment we also need the empty vehicles. Within the logistic model empty vehicle flows consist of two components:

- Asymmetric flows will generate an empty vehicle flow because overcapacity always has to return empty to the starting point
- Difficulty of matching incoming and outgoing flows will generate empty vehicle flows, regardless of the flow and reverse flow being balanced or not

Initially the empty vehicle model was intended for road vehicles only. By allowing the user to have detailed control over the model parameters, the model was extended to other modes too.

Asymmetric flows

Below the equations are worked out in more detail.

Define the total number of **loaded** vehicles arriving in zone s for a given sub-mode/vehicle type h to be:

$$V^{a}_{hs} = \Sigma_{r}(\Sigma_{k=1,35} V_{hkrs}) \quad (11)$$

The corresponding need for **loaded** vehicles leaving (for the same mode) is:

$$V^{L}_{hs} = \Sigma_{r}(\Sigma_{k=1,35} V_{hksr}) \quad (12)$$

Overcapacity in terms of more vehicles available than needed is:

$$\theta_{hs} = V^{a}_{hs} - V^{L}_{hs} \text{ (If } V^{a}_{hs} - V^{L}_{hs} > 0 \text{)}$$

$$\theta_{hs} = 0 \text{ (otherwise)} \quad (13)$$

The idea here is that overcapacity always has to return empty to the starting point.

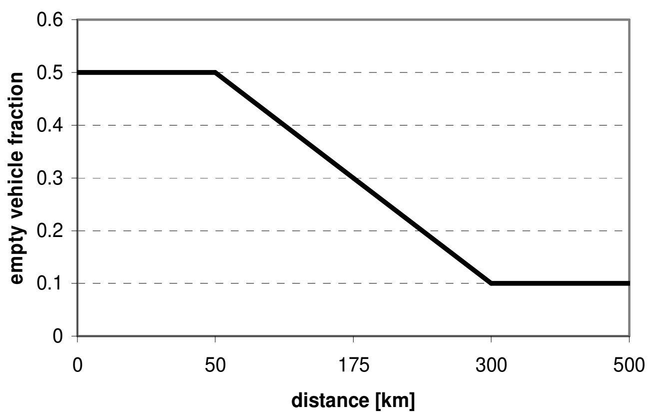
Difficulty of matching incoming and outgoing flows

The main tendency is to utilise available capacity first. For the other vehicles it is a question of matching the flows in and out, which we assume will be done more efficiently for longer distances.

$$V_{s,\,k=empty} = P(E)\Sigma_r x_{sr} = \Sigma_{k=1,35}\,\Sigma_{hr}(\alpha_{r,s}\,V_{hksr})$$

Where P(E) is the proportion that will return empty due to the difficulty of matching incoming and outgoing flows.

Although we do not have empirical studies of this, it is reasonable to believe that the α_s values would be falling with increasing distances. Within the model the user can specify the empty vehicle fractions as a function of distance and vehicle type. A typical distance function for the empty vehicle fraction of lorries is given in the figure below.



CHAPTER 6 Summary and conclusions

A new version (version 2) of the logistics model has been specified and implemented for Sweden (and a similar one for Norway as well) within the framework of its national freight transport forecasting systems. The Swedish logistics model takes as inputs firm-to-firm flows by commodity type from the base matrices. The flows from the production to the consumption zone also include the wholesale function.

After this disaggregation, the logistics decisions (shipment size, use of consolidation and distribution centres, mode and vehicle/vessel type and loading unit type choice) are simulated at this firm-to-firm level (micro-simulation). The basic mechanism for these decisions is minimisation of the total annual logistics cost function.

The output of the model consists of flows between origins and destinations (OD-level), where consolidation and distribution centres (including ports, railway terminals) are also treated as origins and destinations. Furthermore, the model can provide information on total logistics cost between zones, which can be used in trade or spatial interaction models.

The load factors of the vehicles between consolidation centres and distribution centres are determined in an iterative procedure which starts with an assumed average load factor, but in a subsequent iteration uses the flows between consolidation centres predicted in the previous model iteration.

Version 2 uses a deterministic logistics cost function and can be calibrated to data on mode shares between aggregate zones for Sweden.

Estimation of a random utility-based logistics model on disaggregate data (partly available, partly still to be collected) is foreseen for future years for both countries.

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Annex 1. Average shipment sizes used in BuildChain from Commodity Flow Survey (CFS) 2004/5

Commodity	Typical shipment size Sweden (tonnes)
1	41.0
2	3.8
3	3.8
4	0.3
5	41.2
6	9.2
7	122.8
8	43.4
9	0.2
10	1.8
11	14.1
12	164.5
13	19 739.1
14	103.1
15	4212.2
16	135.9
17	12.9
18	7.2

Commodity	Typical shipment size Sweden (tonnes)
19	20.5
20	29.1
21	55.6
22	3.2
23	3.1
24	173.9
25	1.7
26	0.9
27	1.1
28	23.3
29	0.6
30	No PWC flow for this commodity
31	40.9
32	18.2
33	0.3
34	0.6
35	2.9