Technical Report on the Further Development of a Logistics Module in the Norwegian and Swedish National Freight Model Systems

DELIVERABLE 5 FOR THE SAMGODS GROUP AND THE WORKING GROUP FOR TRANSPORT ANALYSIS IN THE NORWEGIAN NATIONAL TRANSPORT PLAN

GERARD DE JONG, MOSHE BEN-AKIVA AND JAAP BAAK
(SIGNIFICANCE)

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Preface

In a project for the Work Group for transport analysis in the Norwegian national transport plan and the Samgods group in Sweden, Significance (up to 31 December 2006: RAND Europe) has produced an improved and extended version 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 are lacking logistic elements (such as the use of distribution centres). This report contains the outcomes of a project to further develop a new logistics module for these model systems.

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

For more information on this project, please contact Gerard de Jong:

Prof. dr. Gerard de Jong

Significance

Schipholweg 13-15

2316 XB Leiden

The Netherlands

Phone: +31-71-5253803

Fax: +31-71-5253801

e-mail: dejong@significance.nl

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CHAPTER 1 Introduction

1.1 Background and objectives of the project

The Swedish national freight model system (Samgods model) and its Norwegian counterpart NEMO are 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). Both model systems are logistics elements, such as the determination of shipment size and the use of consolidation and distribution centres. Both in Norway and Sweden a process to update and improve the existing national freight model system NEMO has started. An important part of this is the development of a logistics module. The specification of the logistics module was given in RAND Europe, Solving and Inro (2004). In RAND Europe and SITMA (2005), this specification was further worked out and a prototype version of the logistics module (version 0.1) was presented. Test with version 0.2 were presented in RAND Europe and SITMA (2006), which also describes version 0.3.

The purpose of the current project, which started in July 2006, is to:

develop a next (improved and extended) version ('version 1') of the logistics model for the Samgods group in Sweden and the Work Group for transport analysis in the Norwegian national transport plan (NTP).

The following deliverables are part of this project:

1. A Powerpoint presentation on the calibration method, for the meeting on 4 July 2006 (delivered).
2. A memo with proposals on how to implement the issues raised in the client memos, to be discussed at the meeting with the clients on 17 October 2006 (delivered).
3. Comments on a memorandum on step A (written by Henrik Edwards of the Swedish Road Administration), to be discussed at the meeting with the clients on 17 October 2006 (delivered)
4. A technical report on model development to be discussed at the meeting with the clients on 14 December 2006.
5. A first testable program version for Norway was delivered in November 2006, and a calibrated version was delivered in February/March 2007. The first testable version for Sweden was

delivered in April 2007. Both executable program code and source code will be delivered.
6. Documentation of the program (delivered together with the program).
7. A technical report on the calibration/validation of the models for Norway and Sweden, including tests carried out; this will be submitted in June 2007.

This report is an updated version of deliverable 4 from the list above.

1.2 Contents of this report

This report contains the technical description of version 1 of the logistics module form Norway and Sweden. How this module fits in the overall national freight transport model framework for these countries can be found in RAND Europe, Solving and Inro (2004). The previous versions of the logistics module are described in RAND Europe and SITMA (2005, 2006).

The logistics module program version 1 consists of three sub-programs:

- A program to generate firm-to-firm flows (for Norway only, since for Sweden, the base matrix project also included disaggregation to firm-to-firm flows).
- A program to generate the available transport chains (including the optimal transfer locations between OD legs).
- 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).

In chapter 2 of this report we describe the disaggregation procedure, which converts zone-to-zone flows from the base matrices into firm-to-firm flows. 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. The method used for the determination of shipment size is given in chapter 5 and the transport chain choice program is discussed in chapter 6, with a focus on the treatment of consolidation. Chapter 7 deals with the production of output matrices. In chapter 7 a summary and conclusions are given.

Please **note** that in the following chapters we first describe the Norwegian implementation (simply because this was programmed first). The subsequent section on the Swedish implementation only contains those things that are different from the implementation for Norway; all other things are handled in the same way and can be found in the description for Norway.

CHAPTER 2 Disaggregation from base matrices to firm-to-firm flows

2.1 Norwegian implementation

For Norway version 1, we used the production and consumption files from version 0 to generate new firm-to-firm flows starting from the new base matrices established in 2006. This means that basic information on the shares of the individual firms in production of a commodity type in a zone and in the commodity consumption in a zone stays the same as in version 0. But these shares are now applied to distribute new zone-to-zone (z2z) totals. These zonal shares are based on employment data.

The new base matrices we received for Norway are split into six categories of zone-to-zone flows:

PP: flow from production to production

PC: flow from production to consumption

PW: flow from production to wholesale

WW: flow from wholesale to wholesale

WP: flow from wholesale to production

WC: flow from wholesale to consumption.

However, in the logistics module we have stereotypes for logistics behaviour of firms (by commodity) in three categories: PC, PW and WC. Also see RAND Europe and SIKA, 2005 ('D4') and RAND Europe and SIKA, 2006 ('D4a'). We therefore aggregated the six categories to three categories, as follows:

- PP is added to PC: as in the previous versions of the logistics model, consumption is interpreted as both intermediate consumption (further processing) and retail (from where final consumption takes place).
- WW is added to PW (we do not distinguish two consecutive layers of wholesalers).
- WP is added to WC (same argument as for PC).

Determination of domestic f2f flows for PC relations

For the logistics module version 0.3 we had designed a procedure for the allocation to f2f flows that is consistent with the numbers of receivers per sender as given in Annex 2 of D4 while still preserving the PWC flows. We use this procedure here as well for Norway, but made some changes to the assumed number of receivers per sender to decrease the difference between observed and modelled average shipment size per commodity that we found in D4a. The assumptions for the number of receivers per sending firm are in Table 1 (second column: version 0.1 and 0.3; third column: this version 1.0).

Table 1. Numbers of receivers per sender and number of f2f relations per model version

Commodity	Version 0.3 receivers per sender - domestic	Version 1.0: receivers per sender - domestic	Version 0.3 number of f2f relations	Version 1.0 number of f2f relations
bulk food	30	30	972508	224067
consumption food	500	300	425477	174167
beverages	1000	300	390561	50516
fresh fish	150	100	293096	177965
frozen fish	150	100	234167	198192
other fish	100	100	59413	84693
thermo input	30	30	25925	102401
thermo consumption	150	150	2771208	1306022
machinery and equipment	100	100	419978	197050
vehicles	30	30	60348	66981
general cargo: high value goods	1000	500	107985	81679
general cargo: live animals	15	15	21857	1562
general cargo: building materials	500	500	257058	139531
general cargo: other inputs	500	500	260502	142119

Commodity	Version 0.3 receivers per sender - domestic	Version 1.0: receivers per sender - domestic	Version 0.3 number of f2f relations	Version 1.0 number of f2f relations
general cargo: consumption goods	2000	500	7030097	691843
timber-sawlogs	15	15	57471	7927
timber-pulpwood	15	15	55651	6347
pulp	5	5	12396	1509
paper intermediates	10	10	16950	31249
wood products	300	300	319308	739114
paper products	50	50	128710	164324
mass commodities	10	10	20855	8881
coal, ore and scrap	10	10	12170	5113
cement, plaster and cretaceous	200	100	11128	5095
non-traded goods	10	10	0	0
chemical products	40	40	82695	99538
fertilizers	20	20	46850	40877
metals and metal goods	300	300	417587	183317
aluminium	10	10	98158	34819
raw oil	0	0	4854	158
petroleum gas	0	0	159	149
refined petroleum products	2000	500	23583	58887
total	9250	4650	14638705	5026092

In the last two columns of Table 1 are the number of firm-to-firm relations in version 0.3 and 1.0 of the logistics model. The differences are not only caused by using other numbers of receivers per sender but also arise because we are using a new PWC matrices as input to the logistics model for Norway.

Below the procedure is explained for a hypothetical z2z relation. This example is for a commodity type k, but we drop the subcsript k for convenience.

There are 400,000 tonnes going from zone r to s according to the PWC matrices. We should preserve this number. Therefore we should allocate this number to firm-to-firm relations within the zone pair rs instead of drawing destination zones per sender.

We know (from the Access files) that there are 5 firms sending k from r (possibly to all s). We also know (Access files) that there are 10 firms receiving k in s (possibly from all r).

So within rs there could at most be 5x10=50 firm-to-firm relations.

As exogenous input (Annex 2 of D4) we know that for k there are 500 receivers per sender. In the Access files we find 2,500 receivers for k (all zones s).

We also know the number of senders of k (here: 1500) from all zones r in the Access files. So in total for k there should actually be 500x1500=750,000 relations. As a by-product this gives the implied number of senders per receiver: 750,000/2,500=300.

The potential overall number of relations for k is 2,500x1,500=3,750,000. So 750,000/3,750,000=20% of the potential number of relations materialises.

In equation form:

*fraction = (ReceiversPerSender*TotalSenders)/(TotalReceivers*TotalSenders)*

= ReceiversPerSender/TotalReceivers

In which:

ReceiversPerSender: average number of receivers per sender: domestic plus international (from Annex 2 of D4).

TotalReceivers: number of receivers in all the zones in the study area (domestic plus international).

TotalSenders = number of senders in all the zones in the study area (domestic plus international).

Now for rs we use this 20%. With 50 potential relations there should be 10 actual relations:

*Actual number of relations from zone r to zone s = fraction * (Senders*Receivers)*

In which:

Senders: number of senders in a zone r.

Receivers: number of receivers in zone s.

We now select these 10 mn relations at random from the 50 available by using proportionality to the product of the production volume of firm m and the consumption volume of firm n for the commodity in question. Then we can divide the 400,000 tonnes over the 10 relations proportionally to the share of a mn relation's product in the sum of the products over all 10 mn relations. The sum of the allocated flows over the 10 relations will equal 400,000 tonnes (preservation of PWC flow).

Sometimes, the data we use on firms in the domestic zones (production and consumption files) do not include any producing or consumption firm in a zone for a commodity type for which there is z2z information in the PWC base matrices. In these cases we have generated a single artificial firm (sender or receiver) for that commodity in that zone.

An extra rule to prevent getting too many small f2f flows was built in for Norway: if the total z2z flow (from the PWC) matrices is smaller than 0.5 tonne, then this will only be 1 f2f flow. This reduced the total number of f2f flows from 5.8 mln to 5.0 mln.

Determination of f2f flows for PW and WC relations and for export and import

The above procedure is used for domestic PC relations. For PW, WC and international z2z relations we use simpler procedures.

The very idea of the wholesaling function is to centralise the distribution of goods: to deal with various producers and/or consumers from one place. Therefore, we have assumed that if for a commodity type there is a z2z relation that has wholesale at either end, only a single wholesale firm in that zone will be involved. A PW flow can therefore have several senders, but only one receiver (per zone); a WC flow can only have one sender (per zone) but several receivers.

For export and import flows we have no information on firms at the foreign end. As in versions 0.1-0.3 we assume that there will only be one sender per zone for import and only one receiver per zone for export.

The resulting firm-to-firm (f2f) flows are consistent with the new z2z flows. The simulation for Norway takes place at the level of all f2f flows to/from/in the country within a year (no expansion procedure needed), as was the case in version 0.

Outcomes in terms of number of f2f relations

Version 0.3 had 14.6 mln f2f flows. This has been reduced to 5.0 mln f2f relations in version 1.0 (see Table 1). The reduction is largely due to the reductions in the assumptions in the number of receivers per sender, but the fact that we now have different base matrices (which may have more zero cells) could have played a role as well. The reduction from 14.6 mln records to 5.0 mln for which we now have to determine shipment size and transport chain, will lead to important savings in runtime. Furthermore, the program has been made more efficient to reduce runtime further and to facilitate running separate components (step A, chain generation, chain choice) and running commodity types separately. Intrazonal flows are included.

2.2 Swedish implementation

For Sweden there now 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 the old commodity classification, these goods were not distinguished separately, whereas the Norwegian classification has consumption food, fish, thermo products and general cargo (high value goods, consumption goods) that can possibly be transported by airplane.

In step A for Sweden, RAND Europe has been working together with Henrik Edwards (Vägverket), who performed the calculations (to ensure consistency with his work on base matrices) whereas RAND Europe provided ideas and comments on the methodology and checked the procedures. A description of the work carried out can be found in Edwards (2007). Below we summarise the key points that refer to step A.

For Sweden, new production and consumption files by firm, commodity type and zone were developed by Henrik Edwards. In version 0 of the program these were based on employment statistics by firm. In version 1 we keep using employment for this, since the turnover statistics would not provide a significant improvement (since the detailed split in turnover is based on employment data). 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 z2z flows to f2f flows, three firm size classes (with thresholds 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:

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

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

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 new 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), but 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 on 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 shipment size 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 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. In the transport chain generation and choice stages of the logistics model, another 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 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, the number of f2f flows is adjusted until the CFS target is reached.

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, where consumption can include wholesale. 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 (besides PC and PW) from the CFS 2004/2005 is currently under investigation. In the Swedish application, intrazonal flows are distinguished, as for Norway. The Swedish commodity types are listed in Table 2.

Table 2. 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

CHAPTER 3 Cost functions and cost parameters

3.1 Norwegian implementation

New cost functions and parameters were received for Norway. These functions give different costs for all the different vehicle/vessel types distinguished. For Norway we use the new 48 vehicle/vessel types (see Table 3), some of which are for unitised transport and some of which are not. For Norway, cost for trailers (on ferries, maybe also for rail) could not be provided for version 1. Therefore, we shall not include trailers on ferries or trains as an alternative; all freight transport using ferries is assumed to involve a road vehicle driving unit and a driver going on-board the ferry together with the cargo.

Table 3. The vehicle/vessel types for Norway.

Mode	Vehicle number	Vehicle name	Capacity (tonnes)
Road	101	LGV	2
	102	Light distribution	8.4
	103	Heavy distribution closed unit	15.6
	104	Heavy distribution, containers	15.6
	105	Articulated semi closed	42
	106	Articulated semi, containers	42
	107	Tank truck distance	39.8
	108	Dry bulk truck	41.8
	109	Timber truck with hanger	32
	110	Thermo truck	32
Sea	201	Lo/lo, 1000dwt	1000
	202	Lo/lo, 2500dwt	2500
	203	Lo/lo, 5000 dwt	5000
	204	Lo/lo, 10000 dwt	10000
	205	Lo/lo 20000 dwt	20000

Mode	Vehicle number	Vehicle name	Capacity (tonnes)
	206	Lo/lo 40000 dwt	40000
	207	Dry bulk 1000 dwt	1000
	208	Dry bulk 2500 dwt	2500
	209	Dry bulk 5000 dwt	5000
	210	Dry bulk 10000 dwt	10000
	211	Dry bulk 20000 dwt	20000
	212	Dry bulk 40000 dwt	40000
	213	Dry bulk 80000 dwt	80000
	214	Container lo/lo 5300 dwt	5300
	215	Container lo/lo 16000 dwt	16000
	216	Container lo/lo 27200 dwt	27200
	217	Ro/ro (cargo) 3600 dwt	3600
	218	Ro/ro (cargo) 6300 dwt	6300
	219	Reefer 5000 dwt	5000
	220	Tanker vessel 3500 dwt	3500
	221	Tanker vessel 9500 dwt	9500
	222	Tanker vessel 17000 dwt	17000
	223	Tanker vessel 40000 dwt	40000
	224	Tanker vessel 100000 dwt	100000
	225	Tanker vessel 300000 dw	300000
	226	Gas tanker, small	28870
	227	Gas tanker, large	48817
Trains	301	Electric combi trains	Wagon: 50
	302	Electric timber trains	Wagon: 35
	303	Electric system trains (bulk)	Wagon: 50
	304	Electric wagon load trains	Wagon: 30
	305	Diesel combi trains	Wagon: 50
	306	Diesel timber trains	Wagon: 35
	307	Diesel system trains (bulk)	Wagon: 50
	308	Diesel wagon load trains	Wagon: 35
Ferries	401	International ferries	
Air	501	Medium sized freight plane	60
	502	Large freight plane	119

Based on the new vehicle/vessel definitions, new restrictions describing which commodities each vehicle/vessel type can carry and which transfers between vehicles are allowed were defined and implemented in the new program.

In the program, the cost function parameters are in separate files to facilitate running policy variants. The new cost functions include a component for waiting time, based on frequency and the cost for mobilisation/positioning the transport unit (e.g. in rail transport).

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:

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

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

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

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

Where:

o : the constant unit cost per order

Q: the annual demand (tonnes per year)

q : the average shipment size.

d: the discount rate (per year)

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

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

t: the average transport time (in hours).

w: the storage costs (in NOK 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 NOK per order, by commodity type.

The transport costs T of:

Link-based cost:

Distance-based costs (given in the cost functions as cost per kilometre per vehicle/vessel, for each of the 48 vehicle/vessel types and for each road vehicle type on the ferry, so effectively we have 57 alternatives here in total); these are calculated using network inputs for distance.

Time-based costs (given in the cost functions as cost per hour per vehicle/vessel for the 57 alternatives); these are based on network input for transport time. 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; for loading at the sender we include half of the mobilisation cost, for unloading at the receiver again we include half of the mobilisation costs, so that a transport chain includes the full mobilisation cost once (the loading/unloading costs are given in the costs functions in two parts: a part per tonne per vehicle/vessel type and a part per shipment per vehicle/vessel type). The part that depends on the tonnage is calculated per transport by multiplying by shipment size in tonnes. Then the part per shipment is added.

Vehicle/vessel pair specific costs:

Transfer costs at a consolidation or distribution centre, including ports, railway terminals and airports (the transfer costs are given in the costs functions in two parts: a part per tonne per vehicle/vessel type and a part per shipment per vehicle/vessel type; the costs of stuffing or stripping a container when the cargo transfers between a container and a non-container vehicle are included). The part that depends on the tonnage is calculated per transport by multiplying by shipment size in tonnes. Then the part per shipment is added.

Commodity type specific costs:

Additional costs for loading/unloading or transferring to/from a sea vessel (these are given in the cost functions per tonne); these costs are used once for transport chains that start with sea transport (loading at sender), once for chains that end with sea transport (unloading at receiver) and once for every transfer to or from sea transport. For a direct sea chain between sender and receiver, they are used twice. Here too, multiplication by the shipment size takes place.

All these transport costs (from link-based to commodity type specific 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.

For the costs of deterioration and damage, the firm-to-firm flows Q come from the programme, t comes from the networks and for the value v of the goods per tonne we have received information for both Norway and Sweden per commodity class. For j assumptions had to be made. The decline in the value if the goods per tonne-hour was set at 0.1-0.3% of the value of the goods (depending on the commodity type) for the commodity types 2 (consumption food), 4 (fresh fish), 7 (thermo input), 8 (thermo consumption), 9 (machinery and equipment), 11 (general cargo, high value) and 21 (paper products and printed matter). For the other commodity groups the assumption made is that there is no decline in the value of the goods during transport.

The capital costs of the goods in transit Y are calculated using commodity group specific average monetary values (NOK/tonne/hour) for export and domestic trade (which we also use for imports), that are multiplied by the total transport chain time. The effective interest rate used here is 11% per year (market rate of 4% plus 7% for the cargo owners' requirements). 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. The latter is based on frequency information for liner shipping. We received frequencies at the link level for situations where there are fixed frequencies and for which information is available (ferries, liner shipping). This was used to calculate waiting time (as a fraction between 0 and 1 of half-headway), which was included in the costs functions (as part of the costs for the inventory in transit). For other vehicles/vessels than liners and ferries, we are using assumptions instead of real-world data on the average frequency per vehicle/vessel type.

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.

Cost for stockouts (or safety stock costs) are not used due to lack of information on these items.

3.2 Swedish implementation

For Sweden the structure of the cost function is principally the same as for Norway. The difference is that for Sweden the costs functions are given for a different set of vehicle/vessel types (and also for a different commodity type classification).

The new Swedish vehicle/vessel type classification (see Table 4) 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, ferries and airplane in Table 4 cannot be used for container transport; the Kombi train and the container vessels in Table 4 are for container transport only). This means that in the program for Sweden for most vehicle/vessel types we shall 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 may be differences in the transfer costs (generally speaking

Table 4. The vehicle/vessel types for Sweden

Mode	Vehicle number	Vehicle name	Capacity (tonnes)
Road		Lorry light LGV, ≤ 3,5 ton	2
		Lorry medium 3,5-16 ton	9
		Lorry medium16-24 ton	15
		Lorry HGV 25-40 ton	28
		Lorry HGV 25-60 ton	47
Rail		Kombi train	Wagon: 32
		Feeder/shunt train	Wagon: 30
		Wagon load train	Wagon: 27
		System train STAX 22,5	Wagon: 50
		System train STAX 25	Wagon: 72
		System train STAX 30	Wagon: 80
Sea		Container vessel 5 300 dwt	5300
		Container vessel 16 000 dwt	16000
		Container vessel 27 200 dwt	27200
		Container vessel 100 000 dwt	100000
		Other vessel 1 000 dwt	1000
		Other vessel 2 500 dwt	2500
		Other vessel 3 500 dwt	3500
		Other vessel 5 000 dwt	5000
		Other vessel 10 000 dwt	10000
		Other vessel 20 000 dwt	20000
		Other vessel 40 000 dwt	40000
		Other vessel 80 000 dwt	80000
		Other vessel 100 000 dwt	100000
		Other vessel 250 000 dwt	250000
		Ro/ro vessel 3 600 dwt	3600
		Ro/ro vessel 6 300 dwt	6300
		Ro/ro vessel 10 000 dwt	10000

Mode	Vehicle number	Vehicle name	Capacity (tonnes)
Ferry		Road ferry 2 500 dwt	3600
		Road ferry 5 000 dwt	6300
		Road ferry 7 500 dwt	10000
		Rail ferry 5 000 dwt	3600
Air		Freight aeroplane	50

container transfers are cheaper than other transfers at consolidation and distribution centres).

In the cost functions for Sweden, the time-based cost not only apply to the time on the link, but also to the time in the nodes (wait time, loading and unloading time). In the Norwegian model, the time in the nodes was only used for the capital cost on the inventory in transit.

For Sweden we use an interest rate of 10% in total. Deterioration/damage of the goods is not included in version 1 of the Swedish model. In the version of the Swedish model that was delivered in April 2007, the service frequency of the modes (e.g. of liners), which has an impact on the capital cost of the goods in transit, is not used. This was included in the version that was delivered in June 2007.

In version 1 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 modes. This is not what happens in reality with trailers, which are truck and trailer within road transport, but trailer only on the ferry. Therefore, we have not included trailers on ferries or trains as an alternative for the Swedish model.

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).

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 is not commodity specific.

CHAPTER 4 The transport chain generation program

4.1 Norwegian implementation

In the logistics model there is a choice between a number of transport chains (with one to four legs and with different aggregate modes and different vehicle/vessel types for each leg). The transfer locations between the legs are determined in a separate earlier step: the transport chain generation program. For transfers within road chains, this already took place in version 0 in a program developed by RAND Europe. For transfers between road, sea, rail and air transport, the optimal transfer locations in version 0 were determined in a program developed by Henrik Edwards. For version 1, RAND Europe/Significance extended its own program for the determination of optimal transfer location within road transport to all modes. This 'pre-program' now produces the choice set of available transport chains. Then the logistics costs optimisation in the main program will determine the transport chain choice from this choice set. The transport chain generation program use unimodal distance and time information from the networks as inputs. The optimal transfer location program was also extended to include all possible multi-modal transfer nodes in addition to the zone centroids that it currently uses. The terminals are coded as separate nodes and we received unimodal network information on times and distances between all the centroids and all the nodes for all available modes.

We received from the networks as information on links: unimodal distance (km), time (minutes) and non-time and distance related costs (Kroner) between any pair of zones or terminals for the following modes for Norway:

- Road (with different routes for ten different vehicle types)
- Sea (the same route for all vessel types, but with differences in speed between vessel types: eight different speeds)
- Rail (same route for all train types and, assuming that the actual speeds are restricted by signalling systems, all train types have the same speed)

- International ferry (only one vessel type)
- Air (the same route for both types of aircraft, but different speeds).

Whether a certain 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. The fact that some ports cannot handle large vessels (maximum draught), is accounted for later on in the main program, using data for each terminal (e.g. port) on vessel size restrictions. In the chain generation program this check is only carried out for the 'typical' vehicle/vessel type within each mode (see Table 5), so that 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).

In the transport chain generation program for Norway we split the road modes into:

- Road light vehicle (the first four road vehicles in Table 3)
- Road heavy vehicle[1] (the last six road vehicles in Table 3).

This was done to generate chains with consolidation and distribution within the road transport system (such as light road first, then consolidation on to a heavy road vehicle, then de-consolidation onto a light road for distribution). Furthermore, this gives the possibility to account for different paths through the network for heavy and light vehicles (e.g. because of weight restrictions for certain bridges or roads, bans on heavy vehicles) and their impact on the optimal transfer locations.

Together with rail, sea, air and international ferry, road light and road heavy are the 'aggregate modes' for Norway that are distinguished in the transport chain generation program. Later on, in the main program we shall distinguish vehicle and vessel types within these aggregate modes. The reason for not doing this already in the transport chain generation program is that this would lead to an explosion in the number of transports chains that have to be evaluated. For instance with two aggregate road modes, we can have four road-sea-road chains, but with ten road modes, there would be 100 such chains.

We therefore have the following aggregate modes for Norway (with the numbering used in the program and its outputs):

1. road light
2. road heavy
3. consolidated road heavy
4. sea
5. train
6. ferry
7. air,

[1] Inside the transport chain generation program itself we also distinguish between 'consolidated heavy vehicle' and 'unconsolidated heavy vehicle', so internally there are three vehicle types for road transport.

For rail and sea transport we received for Norway files that give ports and railway terminals that have direct sea or rail access (distinguishing flows in and out) for specific commodity types. In the transport chain generation program we use these as input, assuming that all firms in the zone of the port or railway terminal have direct access for these commodities. For senders and receivers in Norway and Sweden that will not have direct rail or sea available, there can be road access and egress to/from rail or sea. If we would receive similar data for direct air transport, we could use the same procedure for air transport too. For overseas locations (e.g. Africa, Far East, North-America) we have assumed that direct sea access is available (both into and out of these zones), because there are no land-based network links in the Norwegian model for these zones. Otherwise these zones in the model would not be connected to Norway.

The transport chain generation program then builds the following transport chains, in principle for each zone-pair (but some transport chains my be unavailable, see above):

Road system:
Road light (direct)
Road light–road heavy (for export)[2]
Road light-road heavy-road light
Road heavy (unconsolidated)-road heavy (consolidated)-road heavy (unconsolidated)[3]
Road heavy (direct)
Road heavy-road light (for import)[4]

Sea:
Sea (if sender and receiver have direct sea access)

Road and sea:
Road light-sea-road light
Road light-sea-road heavy
Road heavy-sea (if receiver has direct sea access)
Road heavy-sea-road light
Road heavy-sea-road heavy
Sea-road heavy (if sender has direct sea access)

Rail:
Rail (if sender and receiver have direct rail access)

Road and rail:
Road light-rail-road light

[2] As in version 0 we might make this transport chain available also for transports to domestic receivers that receive more than 100,000 tonnes of a commodity type on an annual basis. This has not (yet) been implemented in version 1.0.

[3] This chain is only available if road light is not available, to ensure that there is an option within the road system with consolidation.

[4] Similarly, we might make this transport chain available also for transports from domestic senders that send more than 100,000 tonnes of a commodity type on an annual basis. This has not (yet) been implemented in version 1.0

Road heavy-rail (if receiver has direct rail access)
Road heavy-rail-road heavy
Rail-road heavy (if sender has direct rail access)

Road and international ferry:
Road heavy-ferry-road heavy

Road and air:
Road light-air-road light
Road heavy-air-road heavy

Road, sea and rail:
Heavy road-sea-rail-heavy road
Heavy road-rail-sea-heavy road

In the calculations within the transport chain generation program we use the same total logistic costs function and the same cost input parameters as for the main program. For each aggregate mode in the transport chain generation, we use the costs functions and parameters of a specific vehicle /vessel type. Which vehicle/vessel type is used, differs by commodity type. The transport chain generation program 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), we also received information on location, which commodities can be handled, which aggregate modes can be handled and maximum draught (for three broad commodity groups). Network restrictions for sea (size of vessel that a port can handle) are thus handled in the terminal file, not in the link output.

The vehicle/vessel types used in the transport chain generation for each aggregate mode for Norway are given in Table 5.

Table 5. Vehicle/vessel type used in transport chain generation program for each aggregate mode, by commodity type for Norway

Commodity	Road light	Road heavy	Sea	Rail	Ferry	Air
Bulk food	n.a.	Dry bulk truck	Dry bulk 2500 dwt	Electric system train	Interna-tional ferry	n.a.
Consumption food	Heavy distribution closed unit	Articula-ted semi containers	Lo/lo 2500 dwt	Electric combi train	Interna-tional ferry	Large freight plane
Beverages	Heavy distribution closed unit	Articula-ted semi closed	Ro/ro 3600 dwt	Electric wagon load	Interna-tional ferry	n.a.

Commodity	Road light	Road heavy	Sea	Rail	Ferry	Air
Fresh fish, frozen fish, other fish, thermo consumption	n.a.	Thermo truck	Reefer 5000 dwt	Electric combi train	Interna-tional ferry	Large freight plane
Machinery & equipment	LGV	Articula-ted semi containers	Lo/lo 5000 dwt	Electric combi train	Interna-tional ferry	n.a.
Vehicles	LGV	Articula-ted, semi closed	Ro/ro (cargo) 3600 dwt	Electric combi train	Interna-tional ferry	n.a.
General cargo: high value goods	LGV	Articula-ted semi containers	Contain er lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	Large freight plane
Live animals	Heavy distribution closed unit	n.a.	n.a.	n.a.	n.a.	n.a.
General cargo: building materials & other inputs	Heavy distribution containers	Articula-ted semi containers	Contain er lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	n.a.
General cargo: consumption goods	Heavy distribution containers	Articula-ted semi containers	Contain er lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	Large freight plane
Timber: pulpwood and sawlogs	n.a.	Timber truck with hanger	Lo/lo 5000 dwt	Electric timber train	n.a.	n.a.
Pulp	n.a.	Articula-ted semi closed	Lo/lo 5000 dwt	Electric combi train	Interna-tional ferry	n.a.
Paper inter-mediates Wood products & paper products	Light distribution	Articula-ted semi closed	Lo/lo 5000 dwt	Electric combi train	Interna-tional ferry	n.a.
Mass commodities, Cement, plaster & cretaceous, chemical products	n.a.	Dry bulk truck	Dry bulk 5000 dwt	Electric system train	n.a.	n.a.

Commodity	Road light	Road heavy	Sea	Rail	Ferry	Air
Coal, ore & scrap	n.a.	Dry bulk truck	Dry bulk 10000 dwt	Electric system train	n.a.	n.a.
Non-traded goods	n.a.	Dry bulk truck	Dry bulk 1000 dwt	Electric system train	n.a.	n.a.
Fertilizers	Heavy distribution closed unit	Articula-ted semi closed	Lo/lo 2500 dwt	Electric combi train	n.a.	n.a.
Metal & metal goods, aluminium	Heavy distribution closed unit	Articula-ted semi closed	Lo/lo 5000 dwt	Electric system train	Interna-tional ferry	n.a.
Raw oil	n.a.	n.a.	Tanker vessel 100000 dwt[5]	n.a.	n.a.	n.a.
Petroleum gas	Heavy distribution closed unit	Articula-ted semi closed	Gas tanker small	n.a.	n.a.	n.a.
Refined petroleum products	n.a.	Tank truck distance	Tanker vessel 3500 dwt	Electric system train	n.a.	n.a.

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

To explain the algorithm used to build the chains we will, as an example, consider the determination of chains of type 131 (road light – consolidated road heavy – road light). To create these chains the program takes the best chains of type 13 (road light-consolidated road heavy) to all nodes (not only the zones) as a starting point. These chains are extended with a leg of type 1 (road light). While evaluating all available extensions of type 1, for all origin nodes, the program keeps track of the best (extended) chain arriving at any destination node. These best (extended) chains are the ones that are listed in the chain output file.

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

[5] For raw oil only sea transport is available. To avoid a situation in which zones are unconnected for this commodity type, domestic and foreign ports that can handle oil tankers were given direct access (in and out) by sea transport.

4.2 Swedish implementation

The transport chain generation model for Sweden uses the following aggregate modes:

- Two road modes: road light (the first two road vehicles in Table 4) and road heavy (the last three road vehicles in Table 4), to account for vehicle weight restrictions on the network
- Four rail modes: feeder trains, wagonload trains, combi-trains and system trains; feeder and wagonload train will be used in combination in a transport chain. Combi-trains are only fore container transport and system trains only for non-container transport; the latter requires direct access/egress at the sender, receiver or the port.
- Three sea modes: feeder ships, long-haul ships and direct sea vessels. The first two need to be combined in a transport chain, unlike the third one.
- Air.

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

For Sweden, the transport chain generation program itself consists of two stages:

- Stage 1: a pre-program for transfers within the rail system and a pre-program for transfers within the sea system;
- Stage 2: generation of available transport chains with transfer locations within road transport and between road, sea, rail and air transport.

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

- Feeder - wagonload
- Wagonload - feeder

Both can be used for containerised and non-containerised transport. We then keep these within-rail transfer locations and use the full train system costs (all train sub-legs) in our transport chain choice model.

Furthermore for Sweden we have a pre-program with two vessel types, feeder vessels, and long-haul (e.g. intercontinental) vessels, so that we can have transfers within the maritime system. The options are (both for containerized and non-containerised):

- Feeder vessel - long-haul vessel
- Long-haul vessel - feeder vessel.

Transfers between sea vessels in version 1 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).

The resulting transfer information from the sea system pre-program is kept fixed in the subsequent transport chain generation and choice.

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 as for Norway on the basis of a list of zone-commodity combinations. We assume that al firms within the eligible zone-commodity combination have the direct transport chain available, and also assume that no other zone-commodity combinations have such direct access. For overseas locations (e.g. Africa, Far East, North-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.

Table 6. Aggregate modes (1-7) and vehicle types for container transport and aggregate modes (8, 9, A-I) and vehicle types for non-container transport for Swedish model

Aggregate mode		ModeNr	VhclNr	Vehicle type
Containers	Heavy lorry	A	104	Lorry HGV 25-40 ton
			105	Lorry HGV 25-60 ton
	Kombi train	D	201	Kombi train
	Feeder train	E	202	Feeder/shunt train
	Wagonload train	F	203	Wagon load train
	Direct Sea	J	301	Container vessel 5 300 dwt[1]
			302	Container vessel 16 000 dwt[1]
			303	Container vessel 27 200 dwt[1]
			304	Container vessel 100 000 dwt[1]
			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

Aggregate mode		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[6]	104	Lorry HGV 25-40 ton
			105	Lorry HGV 25-60 ton
	Feeder train	G	202	Feeder/shunt train
	Wagonload train	H	203	Wagon load train
	System train	I	204	System train STAX 22,5
			205	System train STAX 25
			206	System train STAX 30
	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

[6] Consolidated heavy lorry is coded as mode S in the chains file.

For Sweden the following 73 transport chains will be used (see Table 7). The typical vehicle/vessel types to be used for each of the Swedish commodity types is in Table 8.

Table 7. Road chains used for Sweden

Aggregate modes in transport chain	Mode number in Table 6				
Road light	B				
Road heavy	AC	C			
Road light-heavy	BC				
Road heavy-light	CB				
Road light-heavy-light	BCB				
Direct Rail	W	I	X		
Road heavy-Rail	AW	CX			
Rail-road heavy	WA	XC			
Road heavy-Rail-road heavy	AWA	CXC			
Road heavy-combi-road heavy	ADA				
Direct Sea	J	Y	M	Z	
Road heavy-sea	AJ	AY	CM	CZ	
Sea-road heavy	JA	YA	MC	ZC	
Road heavy-sea-road heavy	AJA	AYA	CC	CZC	
Rail-sea	WJ	WY	XM	XZ	IM
Sea-Rail	JW	YW	MX	ZX	MI
Rail-sea-Rail	WJW	WYW	XMX	XZX	IMI
Road heavy-rail-sea	AWJ	AWY	CXM	CXZ	
Sea-rail-road heavy	JWA	YWA	MXC	ZXC	
road heavy-rail-sea-rail-road heavy	AWJWA	AWYWA	CXMXC	CXZXC	
Road heavy-rail-sea-rail	AWJW	AWYW	CXMX	CXZX	
Road heavy-combi-sea-combi-road heavy	ADJDA	ADYDA			
Road heavy-road ferry-road heavy	CPC				
Rail-sea-road heavy	IMC				
Road heavy-sea-rail	CMI				
Rail-rail ferry-Rail	XQX				
Road heavy-Rail-ferry-Rail	CQX				
Rail-ferry-Rail-road heavy	XQC				
Road heavy-Rail-ferry-Rail-road heavy	CQXC				
Road light-air	BR				
Air-road light	RB				
Road light-air-road light	BRB				

W=feeder - wagonload or wagonload - feeder container

X=feeder - wagonload or wagonload - feeder non-container

Y=feeder vessel - long-haul vessel or long-haul vessel – feeder vessel container

Z= feeder vessel - long-haul vessel or long-haul vessel – feeder vessel non-container

Table 8. Vehicle type in transport chain generation program for each mode by commodity type for Sweden (see Table 2 for commodity group numbers and Table 6 for mode and vehicle numbers)

Commodity	A	D	E	F	J	K	L	B	C	G	H	I	M	N	O	P	Q	R
1	105	201	202	203	-	-	-	102	105	202	203	204	314	307	314	319	321	401
2	105	201	202	203	-	-	-	102	105	202	203	204	314	305	314	319	321	401
3	105	201	202	203	-	-	-	102	105	202	203	204	314	305	314	319	321	401
4	105	201	202	203	-	-	-	102	105	202	203	204	314	308	314	319	321	401
5	105	201	202	203	303	301	303	102	105	202	203	204	314	307	314	319	321	401
6	105	201	202	203	303	301	303	102	105	202	203	204	314	305	314	319	321	401
7	105	201	202	203	303	301	303	102	105	202	203	204	314	307	314	319	321	401
8	105	201	202	203	-	-	-	102	105	202	203	204	314	306	314	319	321	401
9	105	201	202	203	-	-	-	101	105	202	203	204	314	306	314	319	321	401
10	105	201	202	203	303	301	303	101	105	202	203	204	314	306	314	319	321	401
11	105	201	202	203	-	-	-	102	105	202	203	204	314	306	314	319	321	401
12	105	201	202	203	303	301	303	102	105	202	203	204	314	310	314	319	321	401
13	105	201	202	203	-	-	-	102	105	202	203	204	314	313	314	319	321	401
14	105	201	202	203	303	301	303	102	105	202	203	204	314	309	314	319	321	401
15	105	201	202	203	303	301	303	102	105	202	203	206	314	310	314	319	321	401
16	105	201	202	203	303	301	303	102	105	202	203	204	314	308	314	319	321	401
17	105	201	202	203	303	301	303	101	105	202	203	205	314	306	314	319	321	401
18	105	201	202	203	303	301	303	102	105	202	203	204	314	308	314	319	321	401
19	105	201	202	203	303	301	303	102	105	202	203	204	314	307	314	319	321	401

Commodity	A	D	E	F	J	K	L	B	C	G	H	I	M	N	O	P	Q	R
20	105	201	202	203	-	-	-	102	105	202	203	204	314	306	314	319	321	401
21	105	201	202	203	-	-	-	102	105	202	203	204	314	306	314	319	321	401
22	105	201	202	203	-	-	-	102	105	202	203	204	314	309	314	319	321	401
23	105	201	202	203	303	301	303	102	105	202	203	204	314	308	314	319	321	401
24	105	201	202	203	303	301	303	102	105	202	203	204	314	307	314	319	321	401
25	105	201	202	203	303	301	303	101	105	202	203	204	317	315	317	319	321	401
26	105	201	202	203	-	-	-	101	105	202	203	204	314	308	314	319	321	401
27	105	201	202	203	303	301	303	101	105	202	203	204	314	306	314	319	321	401
28	105	201	202	203	303	301	303	102	105	202	203	204	317	315	317	319	321	401
29	105	201	202	203	303	301	303	101	105	202	203	204	314	305	314	319	321	401
30	105	201	202	203	303	301	303	101	105	202	203	204	317	315	317	319	321	401
31	105	201	202	203	303	301	303	102	105	202	203	204	314	307	314	319	321	401
32	105	201	202	203	303	301	303	101	105	202	203	204	317	315	317	319	321	401
33	105	201	202	203	303	301	303	101	105	202	203	204	317	315	317	319	321	401
34	105	201	202	203	303	301	303	102	105	202	203	204	317	315	317	319	321	401
35	-	-	-	-	-	-	-	101	-	-	-	-	-	-	-	-	-	401

CHAPTER 5 Shipment sizes

5.1 Norwegian implementation

For products and type of relations (P-C, P-W, W-C) with joint optimization of inventories and transport, version 1 includes the influence of transport costs on shipment size. By moving to a larger vehicle/vessel, lower transport costs per tonne can be obtained (economies of scale in transport). This is a force that will work to increase shipment size, which we combine with the influence of order costs (working in the same direction) and capital and storage costs of the inventory (working in the opposite direction: reducing shipment size).

The transport chain generation program for Norway generates up to 23 different transport chains for every z2z relation, by commodity type. These 23 transport chains encompass a considerably larger number of vehicle/vessel type sequences, which represent all the vehicle/vessel types used for each leg of the transport chain. We first determine the optimal shipment size q* without the influence of transport costs, using the economic order quantity formula (see D4 of December 2005, p. 108) to get a starting point. 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*], by drawing form a uniform distribution. 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[7].

For the other stereotypes of logistic optimisation we use the following procedures:

- 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

[7] 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.

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. For the commodity type fresh fish we also built in the restriction that the total transport time cannot exceed one week.

- 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.

5.2 Swedish implementation

The shipment size determination for Sweden is done in the same way as for Norway (but only distinguishing P-C and W-C flows). The outcomes can be compared to shipment sizes and numbers of shipments calculated from the CFS.

CHAPTER 6 Consolidation

6.1 Norwegian implementation

In the first iteration of the model, that also includes generating the available transport chains, we use a load factor of 75% (this is just a starting point): for all consolidated legs of a transport chains (that is legs coming after a consolidation centre) we 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. This is needed to calculate the total logistics cost of transport chains that use rail, sea, airplane or consolidated road vehicles. In the second iteration, the load factor is based on the potential for consolidation and observed terminal throughput data, as described below. In the third iteration, we use the OD legs from the previous model run as starting point for the level of consolidation between terminal pairs.

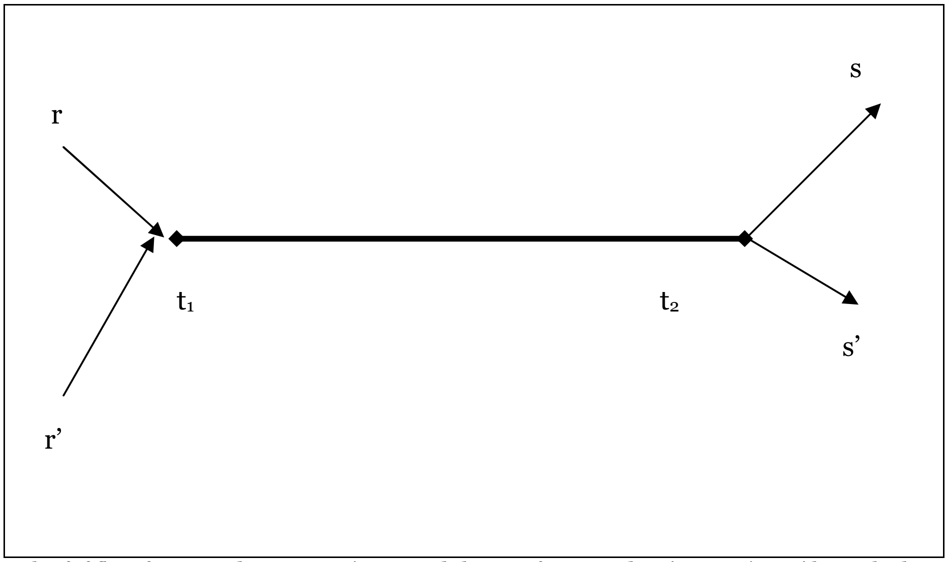
The consolidation depends –among other things- on whether there will be sufficient other cargo on an OD leg (especially a CC-DC leg, such as port-port). The issue of whether at some transfer location there will be sufficient other cargo (going in the right direction) for consolidation will be treated initially by looking at the (potential and/or observed) total amount of goods by commodity type that will be sent from a transfer point (e.g. a port) to another transfer point. For the largest transfer point to transfer point (e.g. port-to-port) flows, we can assume near-perfect consolidation (but only for shipment sizes that exceed a certain size, e.g. a truckload), for small ports (by commodity type), consolidation might be very limited. This leads to a decreasing function of the consolidation probability with decreasing total amounts of goods by commodity type being moved between the two transfer locations. This function is a simplification and different from what John Bates suggested for consolidation (the idea to start from the potential amount of goods between transfer locations is used in the same way in both our approaches).

For ports there is information on port throughput from port statistics, which also distinguishes between flows into the port (‘input’) and flows leaving the port (‘output’). There might be similar information for air freight terminals (but this is not used presently). From the transport chain generation program we know for each terminal t which PC relations might be using it (for which PCs this transfer location is optimal in some transport chain)[8]. So we can accumulate the volume of f2f flows that has a certain port-to-port leg [t_1,t_2] available. In the formulation of John Bates in his comments on PM06):

'In terms of any given mode chain, each rs movement (with variations by commodity; the word 'possible; was deleted here, GdJ*) is uniquely allocated to a particular set of transfer points. It therefore becomes possible to identify the* ***set*** *of {rs} which are allocated to the same transfer points, and this defines the* ***maximum*** *possibilities for consolidation.'*

This is the 'potential for consolidation'.

Figure 1. 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 the potential for consolidation.

It would be best to use this together with the throughput, which is the observed overall volume for a transfer location (not OD specific). What we did was to multiply for each pair of transfer locations the potential for consolidation on this pair with the output for the first transfer location of the pair. For different pairs of transfer locations we then get different products, each of which we divide by the biggest of these products (so that we get values between 0 and 1 for every pair of locations). These values between 0 and 1 are then used to determine the above-mentioned

[8] Since the transport chain generation calculates optimal transfer locations for a number of pre-defined chains, some of these chains might be very unattractive (e.g. large detours). We therefore built in an extra filter in which we compare the logistic costs of an indirect transport chain with the direct costs, and delete chains from the potential if they exceed the costs of direct transport by some factor (currently a factor 5). However, the direct road chain is never made unavailable because of its costs (it can be unavailable because there is no land connection). Also air transport is never dropped because of cost reasons (but only available for four commodity types). This brings our approach more in line with that of John Bates.

consolidation factor (ranging from almost 1 for perfect consolidation for the largest OD flows to almost 0 for the smallest OD flows). The pair of transfer locations with the highest product gets a 95% consolidation (vehicles/vessels from t_1 to t_2 95% loaded, costs shared with other users), the pair with the lowest product gets 5% consolidation (load factor of 5%, unless the f2f flow between m and n itself already constitutes a bigger load). This allocation of consolidation factors between 5 and 95% takes place separately for the OD flows for each commodity type and aggregate mode (e.g. sea).

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. For Norway, we have no information on road terminals abroad and therefore we allow transport chains road light – consolidated road heavy for export (no explicit deconsolidation abroad) and consolidated road heavy – road light for import (no explicit consolidation abroad). For overseas zones we allow direct access to consolidated ships for Norwegian import and export.

For modes for which we have no throughput information (road, rail), we only use the potential for consolidation from the transport chain generation program, to define the percentage of consolidation (in the same way as above).

In the longer run, the logistics optimisation determines the amount of goods that will go from a port or other transfer point to another transfer point or final destination: the logistics model produces the OD patterns between nodes and centroids. This means that whereas the initial model run needs to take exogenous information on the amount of goods from/to a transfer point, the model can in principle be used iteratively to generate endogenously determined –equilibrium- rates of consolidation at the OD (not PC) level. Version 1 of the logistics model uses the above information on observed outputs of consolidation centres (e.g. ports) in a second iteration and in the third and final iteration, it uses the OD patterns of the second iteration as input to determine the degree of consolidation. In the third iteration we also use the 5-95% method, but now based on the OD flows from the second run. In future versions of the model, one could run further iterations, in which one would also adjust the frequency of the transport services e.g. the liners), leading to differences in waiting time, assuming that there is no limit on the number of vehicles/vessels that can be made available (at a certain frequency) and no maximum on the frequency of transport service. In principle it is also possible to adjust the vehicle capacity (use bigger/smaller vehicles or vessels or use longer/shorter trains). We can also allow for runs in which the equilibration will not be by frequency, but by vehicle/vessel capacity (e.g. longer trains). Changing both frequency and capacity in the same iterative process would probably overburden the model and could lead to unstable results..

Consolidation along the route (collection round or milk round) is included as an additional road-based transport chain (so we get 23+1=24 transport chains in total). This chain, and its logistics cost, is not generated in the transport chain generation program, but is included afterwards in the main logistics program, as direct road transport with an extra waiting time and distance (detour). In version 1 this is limited to consolidation in a single zone. The rule of the thumb that Inge Vierth provided (drive 10 km to get another tonne) is 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 is 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 is 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) is selected.

For convoys in road transport, consolidation is not allowed, except when there would be vehicle size constraints at the origin or destination (e.g. heavy vehicle bans in city centres).

Consolidation in version 1 is within a commodity group only, even for containers.

The starting point of 75% for consolidation has been tested by SIKA by trying out different starting values. This did not have substantial effects at the level of aggregate outcomes, but for specific individual flows there could be large differences. This actually is a rather satisfactory outcome, since the model (as any micro-model), though it works with individual flows, was not designed to forecasts individual flows, but aggregates of these. However, solution might be to repeat the third iteration several times (each time using the OD pattern from the previous run to determine the amount of consolidation in the present run). That should make the final outcome les dependent on the starting point.

6.2 Swedish implementation

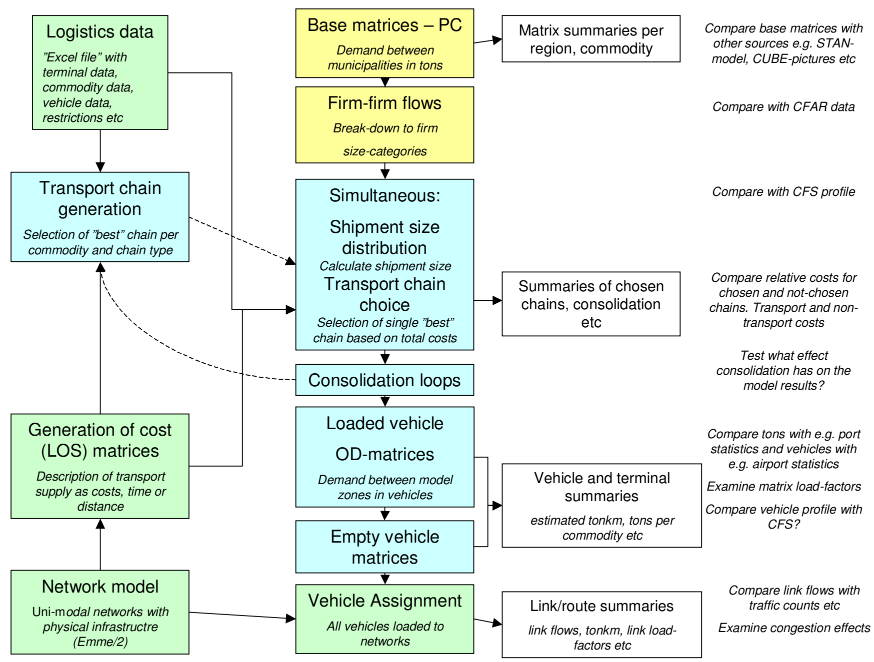
For Sweden consolidation is treated basically the same as for Norway, except that in the version of the program for Sweden that was delivered in April 2007 consolidation en-route had not been implemented. This was included in the version that was delivered in June 2007.

CHAPTER 7 Production of matrices of vehicle flows and logistics costs

Once we have the outputs at the level of the individual f2f flows (frequency/shipment size, detailed transport chains and costs), these can be aggregated in different ways. As for versions 0, version 1 includes the possibility to produce OD matrices of tonnes and tonne-kilometres by mode and commodity type (but also more aggregate –non-OD- statistics on the total number of tonnes and tonne-kilometres by mode and commodity type), as well as OD matrices of loaded vehicles, and of loaded and empty road vehicles. The procedures to calculate these outputs have remained the same as versions 0 (see D4, RAND Europe and SITMA (2005). This also goes for the calculation of empty vehicles flows. Furthermore, total logistics costs per PWC flow can be produced, for use in the future determination of PWC flows.

Figure 2 gives an overview of the overall model structure.

Figure 2. Overview of overall model structure (column on the right: tests to be carried out)



CHAPTER 8 Summary and conclusions

A new version (version 1) of the logistics model has been specified, and applied for both Norway and Sweden within the framework of their national freight transport forecasting systems. The Norwegian model takes as inputs commodity flows from production to consumption zone (that also include the wholesale function). The logistics model then disaggregates these flows to firm-to-firm flows. For Sweden the disaggregation to firm-to-firm flows is done as part of the base matrix calculation, outside the logistics model, and the logistics model takes these as given.

After this disaggregation, for both countries, 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 key differences between this version 1 and previous prototype versions of the logistics model are:

- For Norway the model distinguishes between production-consumption, production-wholesale and wholesale-consumption flows. For Sweden there is the distinction between production-consumption and production-wholesale flows. For Norway version 1 uses all firm-to-firm relations in simulation (as in version 0), for Sweden the model is now applied for a firm-to-firm relation within sub-cells defined by firm size classes and uses expansion factors to represent the total population. For both countries, the run time has been reduced by reducing the number of firm-to-firm flows to be evaluated.
- New vehicle/vessel types were defined for both Norway and Sweden and the cost functions were updated and refined. Waiting time was included, based on frequency information/assumptions.
- The transport chain generation program within the logistics model was extended to determine the optimal transfer locations within available transport chains for all modes (in version 0 this could

only handle road modes; transfer locations for the other modes were handled outside the model). For Sweden, the program also handles rail-rail transfers and sea-sea transfers.

- The number of transport chains that are evaluated in the transport chain generation module was extended.
- In the determination of shipment size we now include the effect of economies of scale in transport (a force leading to bigger shipment sizes, because these have lower transport costs).
- The degree of consolidation (or the load factor of the vehicles) between consolidation centres and distribution centres is determined in an iterative procedure which starts with an assumed average load factor, but in a subsequent iteration includes information on the availability of other cargo (based on the available transport chains and port statistics), and in an even further iteration uses the flows between consolidation centres predicted in the previous model iteration.
- Version 1 uses a deterministic logistics cost function and has been calibrated to data on mode shares between aggregate zones for Norway. Calibration of the Swedish model has not yet been undertaken.

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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