Method Report - Logistics Model in the Norwegian National Freight Model System (Version 3)

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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 were lacking logistic elements (such as variation of shipment sizes and frequencies, consolidation of shipments, transhipments at terminals, 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 Norway. A similar, but not identical logistics model was developed for Sweden. This is described in a separate method report (D6B)

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 national model systems for freight transport.

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CHAPTER 1   Introduction

1.1   Background and objectives of the project

The Norwegian 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 Norway, as well as in Sweden, 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 method report describes version 3 of the logistics model, that has been specified and implemented for Norway in 2008, with extensions made in 2009-2012. This module is described in this report. A similar, but not identical logistics module was developed for Sweden; this is described in a companion report (D6B). Apart from this methodological report, there is also a report that describes the computer program and how to apply this as a user (program documentation).

1.2   The ADA model structure

1.2.1   General model structure

The New Norwegian 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 and vehicle 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. These models are commonly based on economic statistics (production and consumption statistics, input-output tables, trade statistics) that are only available at the aggregate level, with zones and zone pairs (e.g. in the case of multi-regional input-output tables) 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. 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 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.

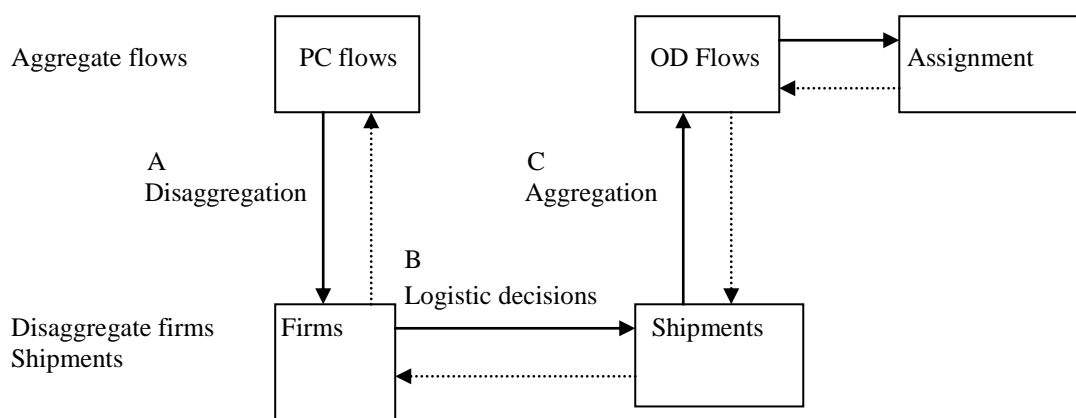Figure 1. ADA structure of the (inter)national/regional freight transport model system

The allocation of flows in tons 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 register of business establishments. 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 3 of the logistics model for Norway 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 tons 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, consolidation centers (CCs), distribution centers (DCs) and/or railway terminals. 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 PWC 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 *P* 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) that could be used for calibration/validation 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 3 of the logistics module for Norway. The previous versions of the logistics module are described in RAND Europe and SITMA (2005, 2006) and Significance (2007).

The logistics module program version 3 consists of six sub-programs:

- A program to generate firm-to-firm flows for Norway:FIRM2FIRM.

- 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; cost output for specific relations (cost log) can also be obtained

- A program to determine the vehicle types and load factors used for consolidated rail and sea transport (CONSOLIDATE)

- Programs to extract OD matrices (EXTRACT).

- Programs to handle capacity constraints in the rail system (constraints)

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 and the transport chain choice program. This includes a description on the determination of shipment size, as well as on 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. The calibration method is explained in chapter 6. In chapter 7, a summary and conclusions are given.

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

For Norway version 3, we used the production and consumption files[1] from version 0 and 1 to generate new firm-to-firm flows starting from the 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. In version 3, these shares were applied to distribute new base matrices for the zone-to-zone (z2z) flows. These new base matrices differ from the ones used in previous model versions in that are more consistent with the data used for establishing the production and consumption shares. In 2009 this will be further improved.

The base matrices 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 there are stereotypes for logistics behaviour of firms (by commodity) in three categories: PC, PW and WC. We therefore aggregated the six categories to three categories, as follows:

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[1] In this step we first assign P and W flows (by commodity type k) leaving zone r to the local units (firms and parts of firms) established in zone r. These will be the sending firms m. The allocation is done proportionally to the share in the production (approximated by the size of the firm in terms of the number of employees) of each firm located in zone r of products that belong to commodity type k. This is the information contained in the production files. Then, we assign W and C flows (by commodity type k) entering zone s to the local units (firms and parts of firms) established in zone s: the receiving firms n. Assignment is done proportionally to the share in consumption of each firm located in zone s of products that belong to commodity type k. For this we use the number of employees of each firm n in zone s in each sector, in combination with national Use tables (the consumption of each sector by commodity type; a sector can consume goods from several commodity classes). The resulting files are the consumption files.

- 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).

Hence the three categories can be written as: PC, PW and WC.

The process for deriving the f2f flows is slightly different between domestic movements (i.e. wholly internal to Norway) and export/import.

Determination of f2f flows for domestic PC relations

For the logistics module version 3 we assume the following number of receivers per sending firm (see Table 1). In the base matrices, the number of z2z flows are overestimated for some of the cargo groups. The estimated number of receivers per sender (Table 1) was deliberately reduced to compensate for this. With revised base matrices in the spring 2009, the number of receivers, and probably also their size distribution, should be re-evaluated.

Table 1. Number of receivers per sender

Commodity	Version 3.0: receivers per sender -domestic
1. bulk food	5
2. consumption food	30
3. beverages	30
4. fresh fish	10
5. frozen fish	10
6. other fish	10
7. thermo input	5
8. thermo consumption	15
9. machinery and equipment	10
10. vehicles	5
11. general cargo: high value goods	35
12. general cargo: live animals	15
13. general cargo: building materials	35
14. general cargo: other inputs	35
15. general cargo: consumption goods	35
16. timber-sawlogs	2

Commodity	Version 3.0: receivers per sender -domestic
17. timber-pulpwood	2
18. pulp	5
19. paper intermediates	10
20. wood products	10
21. paper products	10
22. mass commodities	10
23. coal, ore and scrap	10
24. cement, plaster and cretaceous	10
25. non-traded goods	10
26. chemical products	4
27. fertilizers	2
28. metals and metal goods	20
29. aluminium	2
30. raw oil	1
31. petroleum gas	1
32. refined petroleum products	30

Below the procedure is explained for a hypothetical z2z relation. This example is for a commodity type k, but we drop the subscript 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 10 firms sending k from r (possibly to all s). We also know (Access files) that there are 20 firms receiving k in s (possibly from all r).

So within rs there could be at most 10x20=200 firm-to-firm relations.

As exogenous input (see Table 1) we know that for k there are, say, 30 receivers per sender. Suppose that in the Access files we find 1,000 receivers for k (all zones s, and that we also know the number of senders of k (here: 500) from all zones r. So in total for k there should actually be 30x500=15,000 relations. As a by-product this gives the implied number of senders per receiver: 15,000/1,000 = 15.

The maximum overall number of relations for k is 1,000x500= 500,000. So 15,000/500,000= 3% of the maximum number of relations materialises.

In equation form:

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

> *= ReceiversPerSender/TotalReceivers*

In which:

ReceiversPerSender: average number of receivers per sender (from Table 1).

TotalReceivers: number of receivers in all the zones in the study area.

TotalSenders = number of senders in all the zones in the study area.

Now for rs we assume that this the 3% fraction is applicable. With 200 potential relations there should be 6 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 6 mn relations at random from the 200 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 6 relations proportionally to the share of a mn relation's product in the sum of the products over all 6 mn relations. The sum of the allocated flows over the 6 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.

Extra rules to prevent getting too many small f2f flows were built in for Norway:

- If total z2z flow < 0.5 tonne, then use only one f2f flow

- If total z2z flow > 0.5 tonne and < 1 tonne, then use 1/3 of suggested number (from procedure described above) of f2f flows, rounded down to closest integer higher than zero

- If total z2z flow > 1 tonne and < 2 tonne, then use 2/3 of suggested number of f2f flows, rounded down to closest integer higher than zero

- If total z2z flow > 2 tonne, then use suggested number of f2f flows

Intrazonal flows are included.

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 and 1, 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, as was the case in version 0 and 1.

CHAPTER 3 The cost functions

The cost functions give different logistics cost for all the different vehicle/vessel types distinguished. For Norway we use 49 vehicle/vessel types (see Table 2), some of which are for unitised transport and some of which are not. For semi-trailers (with or without containers), when setting the time cost, it is assumed that 75% of the semis are taken as trailers only, while the remaining 25% is taken with driver and the road vehicle unit as well. For all other road vehicles (not semis), it is assumed that the driver follows the truck. Road trailers on rail vehicles are not allowed in the model. For different commodity groups, different vehicle capacities are used, denoted in Table 2 by 3 profiles. The commodity-profile distribution is in Annex 1.

Table 2. The vehicle/vessel types for Norway (as from 2013).

Mode	Vehicle number	Vehicle name	Capacity (tons)		
			Profile 1	Profile 2	Profile 3
Road	101	LGV	2,2	1,8	1,3
	102	Light distribution	5,7	4,6	3,4
	103	Heavy distribution closed unit	9	7,2	5,4
	104	Heavy distribution, containers	12	9,6	7.2
	105	Articulated semi closed	33	26.4	19,8
	106	Articulated semi, containers	33	26.4	19,8
	107	Tank truck distance	33	26,4	19.8
	108	Dry bulk truck	18	14,7	11,1
	109	Timber truck with hanger	34	27,2	20,4
	110	Thermo truck	33	27,2	19,8
Container vessels, sea	214	Container lo/lo 8500 dwt	8500	6800	5100
	215	Container lo/lo 14200 dwt	14200	11360	13800

		216	Container lo/lo 23000 dwt	23000	18400	13800
Sea (other)		201	Lo/lo, 1000 dwt	1000	800	600
		202	Lo/lo, 2500 dwt	2500	2000	1500
		203	Lo/lo, 5000 dwt	5000	4000	3000

Mode	Vehicle number	Vehicle name	Capacity (tons)		
			Profile 1	Profile 2	Profile 3
	204	Lo/lo, 9000 dwt	9000	7200	5400
	205	Lo/lo 17000 dwt	17000	13600	10200
	206	Lo/lo 40000 dwt	40000	32000	24000
	207	Dry bulk 1000 dwt	1000	1000	1000
	208	Dry bulk 2500 dwt	2500	2500	2500
	209	Dry bulk 5000 dwt	5000	5000	5000
	210	Dry bulk 9000 dwt	9000	9000	9000
	211	Dry bulk 17000 dwt	17000	17000	17000
	212	Dry bulk 45000 dwt	45000	45000	45000
	213	Dry bulk 80000 dwt	80000	80000	80000
	217	Ro/ro (cargo) 8000 dwt	8000	6400	4800
	218	Ro/ro (cargo) 15000 dwt	15000	12000	9000
	219	Reefer 426000 cbf	137000	137000	13700
	220	Tanker vessel 3500 dwt	3500	3500	3500
	221	Tanker vessel 9500 dwt	9500	9500	9500
	222	Tanker vessel 17000 dwt	17000	17000	17000
	223	Tanker vessel 37000 dwt	37000	37000	37000
	224	Tanker vessel 100000 dwt	100000	100000	100000
	225	Tanker vessel 310000 dw	310000	310000	310000
	226	Gas tanker, 35000 cbm	30000	30000	30000
	227	Gas tanker, 57000 cbm	42000	42000	42000
	228	Side port vessel	2530	2530	2530
Wagon load trains	304	Electric wagon load train	65	52	39
	308	Electric car train	24	24	24

Trains	301	Electric combi train	50	40	30
	302	Electric timber train	35	35	35
	303	Electric system train (dry bulk)	100	100	100
	305	Combi trains thermo (el)	50	50	50

Mode	Vehicle number	Vehicle name	Capacity (tonnes)		
			Profile 1	Profile 2	Profile 3
	307	Electric system train (wet bulk)	50	50	50
Ferries	401	International ferry	-	-	-
Air	501	Medium sized freight plane	60	48	36
	502	Large freight plane	119	95,2	71,4
Truck 2525		Truck 2525	41	32,8	24,6
Diesel rail		Diesel combi trains	50	40	30
		Diesel timber trains	35	35	35
		Diesel system trains (dry bulk)	100	100	100
		Diesel combi thermo train	65	65	65
		Diesel system train (wet bulk)	50	50	50

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 program.

In the program, the cost function parameters are in separate files to facilitate running policy variants. The cost functions include a component for waiting time, based on (transport) service 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:

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

Where:

G: total annual logistics costs

O: order costs

T: transport, consolidation and distribution costs

D: cost of deterioration and damage during transit

Y: capital costs of goods during transit

I: inventory costs (storage costs)

K: capital costs of inventory

Z: stockout costs

All the above cost items are defined on an annual basis

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

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

$$(w_k + (d.v_k)).(q_k/2) + Z_{rskq} \qquad (2)$$

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)

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:

Link-based cost:

Distance-based costs (given in the cost functions as cost per kilometre per vehicle/vessel, for each of the 49 vehicle/vessel types and for each road vehicle type on the ferry, so effectively we have 58 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 58 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 cost 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 cost 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:

Cargo fees ("vareavgifter") in Norwegian ports, which are dependent on the type of cargo. They are derived as mean values across several Norwegian ports. These fees are handled in the model as 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 program, 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. Deterioration costs are calculated for the total time in transport, but not for time in the warehouse.

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 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.

In the model versions used from 2013, differentiated loading and unloading costs are implemented in the model. These means that different costs and loading/unloading times are used, depending on the terminal. As an approximation, terminals are at present divided into four classes, where class 2 is the default terminal. A class 1 terminal is a simple terminal with efficiency below the class 2 terminals, while class 3 and class 4 representing more efficient terminals, due to technology and scale of operation. The differentiation is per terminal and cargo group. When a terminal has a different class than 2 for a given cargo group, the transfer costs for transfers through that terminal is changed accordingly.

For port charges, the differentiation in port charges are between each port/cargo group combination. This can be set as required and are not limited to defined classes of ports.

In addition, there are also introduced some additional costs for sea transport. One is the charges for piloting the vessels. The piloting charged is depended on expected time used for traffic to/from a given port, additional time for the pilot, and defined minimum charges. The other is the cost paid to control centrals that for safety reasons controls part of the

sea traffic. This cost is dependent on the ports, and which control area they belong to, and to some extent of the cargo the vessels are carrying.

In the model, the charges for pilots, ports and control are allocated as a part of the loading/unloading costs.

CHAPTER 4 The simultaneous determination of shipment size and transport chain

4.1 Role of BuildChain and ChainChoice

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), as well as of shipment size. 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.

The BuildChain module selects the "best" chain per commodity and chain type. By this we mean that it determines the optimum transfer points (including road terminals, ports, railway stations, airports), for each available transport chain that includes transfers between the modes (sea, ferry, rail, road, air) and within road transport (for Sweden also within rail and sea transport). For each leg, BuildChain uses a sub-mode. The sub-modes are aggregations of vehicle/vessel types and include: three types of road transport (see 4.2), sea, rail, ferry and air transport. By aggregating the three sub-modes for road transport, we obtain the modes. The costs of the sub-modes are determined by using commodity-specific typical vehicle and vessel types. So, BuildChain does not use all vehicle and vessel types.

It also determines which transport chain will be available between each specific zone pair, for each commodity type, for use in ChainChoice (Buildchain is the transport chain generation program).

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). They will not necessarily all choose the same transport chain in ChainChoice, because the f2f flows are of a different size. At the zone-to-zone (z2z) level, there is no unique shipment size, because there can be many different shipment sizes between the zones (many f2f flows). The BuildChain procedure uses a different shipment size than the ChainChoice procedure. The latter uses the optimal shipment size for ach f2f flow, q_k, whereas 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 Norway are in Annex 2).

The ChainChoice module calculates the optimal shipment size and selects single 'best' transport chain, in terms of number of legs and specific vehicle and vessel types for each leg. It uses the outcomes of BuildChain as starting point: the set of alternatives considered in ChainChoice is that from BuildChain, and the transfer points are not re-optimised.

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 aggregate modes are evaluated in ChainChoice, not just the typical ones.

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.

The following information is used 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 (with differences in speed between vessel types: eight different speeds)

- Rail (all train types have the same speed, assuming that the actual speeds are restricted by signalling systems)

- International ferry (only one vessel type)

- Air (with different speeds for both types of aircraft).

For all modes, the chosen route is based on minimising the generalised costs. 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 ChainChoice, using data for each terminal (e.g. port) on vessel size restrictions. In BuildChain, this check is only carried out for the 'typical' vehicle/vessel type within each sub-mode (see Table 3). 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 2)
- Road heavy vehicle[2] (the last six road vehicles in Table 2).

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.

Also for rail and sea we distinguish 'sub-modes':

- Rail wagonload
- Other rail

and:

- Sea containerized
- Sea other

These 'sub-modes' have been introduced because certain vehicle types are only allowed in specific terminals.

Together with air and international ferry, these modes are the 'sub-modes' for Norway that are distinguished in the transport chain generation program. Later on, in ChainChoice, we shall distinguish vehicle and vessel types within these sub-modes.

We therefore have the following sub-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 containerised
5. sea other
6. rail wagonload
7. rail other
8. ferry
9. air
A. Large trucks (2525)
B. Diesel rail

The reason for taking the 2525 trucks and diesel rail is that they use to some extent a r limited part of the road network (A) and partly a different network, but with some overlap with electrified network for rail (B).

For rail and sea transport for Norway files are used as inputs that give ports and railway terminals that have direct sea or rail access

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[2] 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.

(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 that will not have direct rail or sea available, there can be road access and egress to/from rail or sea. If there would be 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.

For each one of a set of 27 pre-defined transport chains, BuidChain defines the optimum transfer points and checks whether all chains are actually available for each zone-pair, given network and terminal constraints:

Road system:
Road light (direct)
Road light–road heavy (for export)[3]
Road light-road heavy-road light
Road heavy (unconsolidated)-road heavy (consolidated)-road heavy (unconsolidated)[4]
Road heavy (direct)
Road heavy-road light (for import)[5]

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

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

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[3] 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 been implemented in version 1 or 2.

[4] This chain is only available for commodities where road light is not available, to ensure that there is an option within the road system with consolidation.

[5] 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 been implemented in version 1 or 2.

Road heavy-rail-road heavy
Road light – rail – rail (B) – road light
Road light – rail (B) – rail – road light
Road light – rail (B) – road light
Road heavy – rail (B) – road heavy
Road heavy – rail – rail (B) – road heavy
Road heavy – rail (B) – 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 light-air
Road heavy-air
Air-road light
Air-road heavy

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

Road (A) - 2525, road:
Road (A) (direct)
Road light – road (A) – road light
Road heavy – road (A) – road heavy
Road light – road (A) – road heavy - road light
Road light – road heavy - road (A) – road light

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 sub-mode in the transport chain generation, we use the cost functions and parameters of a specific vehicle /vessel 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 sub-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 sub-mode for Norway are given in Table 3.

Table 3. Vehicle/vessel type used in transport chain generation program for each sub-mode, by commodity type for Norway

Commodity	Road light	Road heavy	Sea	Rail	Ferry	Air	Road 2525	Rail diesel
Bulk food	n.a.	Dry bulk truck	Dry bulk 2500 dwt	Electric system train	Interna-tional ferry	n.a.	n.a.	Diesel bulk train
Consumption food	Heavy distribution closed unit	Articula-ted semi containers	Lo/lo 2500 dwt	Electric combi train	Interna-tional ferry	Large freight plane	2525 truck	Diesel combi train
Beverages	Heavy distribution closed unit	Articula-ted semi closed	Ro/ro 3600 dwt	Electric wagon load	Interna-tional ferry	n.a.	n.a.	n.a.
Fresh fish	n.a.	Thermo truck	Cont. Lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	Large freight plane	n.a.	Diesel thermo train
frozen fish, other fish, thermo consumption	n.a.	Thermo truck	Cont. Lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	n.a.	n.a.	Diesel thermo train
Machinery & equipment	LGV	Articula-ted semi containers	Lo/lo 2500 dwt	Electric combi train	Interna-tional ferry	n.a.	2525 truck	Diesel combi train
Vehicles	LGV	Articula-ted, semi closed	Ro/ro (cargo) 3600 dwt	Electric combi train	Interna-tional ferry	n.a.	n.a.	n.a.
General cargo: high value goods	LGV	Articula-ted semi containers	Container lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	Large freight plane	n.a.	Diesel combi train

Commodity	Road light	Road heavy	Sea	Rail	Ferry	Air	Road 2525	Rail diesel
Live animals	Heavy distribution closed unit	n.a.	Side port vessel	n.a.	n.a.	n.a.	2525 truck	n.a.
General cargo: building materials & other inputs	Heavy distribution containers	Articula-ted semi containers	Container lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	n.a.	2525 truck	Diesel combi train
General cargo: consumption goods	Heavy distribution containers	Articula-ted semi containers	Container lo/lo 5300 dwt	Electric combi train	Interna-tional ferry	Large freight plan	2525 truck	Diesel combi train

								e		
Timber: sawlogs	LGV	Timber truck with hanger	Lo/lo 2500 dwt	Electric timber train	n.a.	n.a.	n.a.	Diesel timber train
Timber: pulpwood	n.a.	Timber truck with hanger	Lo/lo 2500 dwt	Electric timber train	n.a.	n.a.	n.a.	Diesel timber train
Pulp	n.a.	Articula-ted semi closed	Lo/lo 2500 dwt	Electric combi train	Intern a-tional ferry	n.a.	n.a.	Diesel combi train
Paper inter-mediates Wood products & paper products	Light distribut ion	Articula-ted semi closed	Lo/lo 2500 dwt	Electric combi train	Intern a-tional ferry	n.a.	2525 truc k	Diesel combi train
Mass commoditie s, Cement, plaster & cretaceous,	n.a.	Dry bulk truck	Dry bulk 2500 dwt	Electric system train	n.a.	n.a.	n.a.	Diesel dry bulk train
Coal, ore & scrap	n.a.	Dry bulk truck	Dry bulk 2500 dwt	Electric system train	n.a.	n.a.	n.a.	Diesel dry bulk train
Non-traded goods	n.a.	Dry bulk truck	Dry bulk 1000 dwt	Electric system train	n.a.	n.a.	n.a.	Diesel dry bulk train
Chemical products	n.a.	Tank truck	Tanke r 3500 dwt	Electric system train	n.a.	n.a.	n.a.	Diesel wet bulk train
Fertilizers	Heavy distribut ion closed unit	Articula-ted semi closed	Dry bulk 2500 dwt	Electric combi train	n.a.	n.a.	n.a.	n.a.
Metal & metal goods, aluminium	Heavy distribut ion closed unit	Articula-ted semi closed	Lo/lo 2500 dwt	Electric system train	n.a.	n.a.	n.a.	Diesel combi train

Commodity	Road light	Road heavy	Sea	Rail	Ferry	Air	Road 2525	Rail diesel
Raw oil	n.a.	n.a.	Tanker vessel 100000 dwt[6]	n.a.	n.a.	n.a.	n.a.	n.a.
Petroleum gas	Heavy distribution closed unit	Articulated semi closed	Gas tanker small	n.a.	n.a.	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.	n.a.	Diesel wet bulk train

The BuildChain procedure for Norway searches for 27 typical logistic chains. The search algorithm identifies the optimal chain for each of these 27 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 2 below.

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[6] 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.
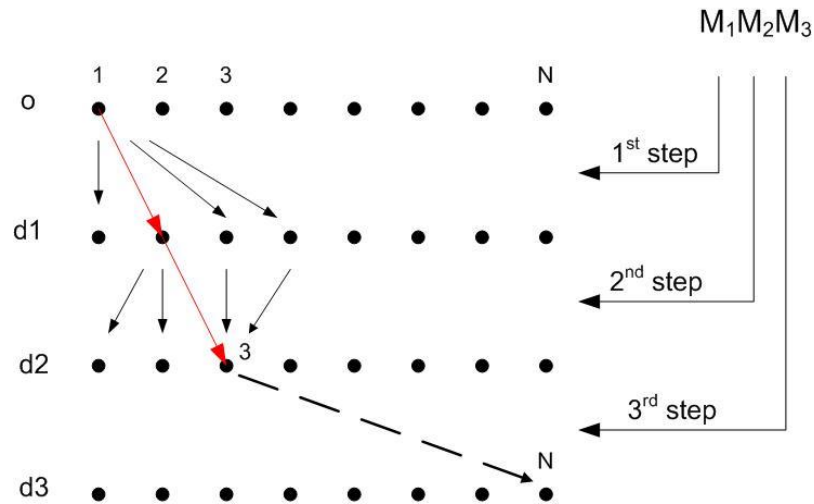
Figure 2: Search algorithm, the optimal two leg chain M1M2 from origin 1 to destination 3 is indicated in red

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 sub-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 2. 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 Norway 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 4). This determines the formula to be used for optimal shipment size.

The outcome will be an average optimal shipment size q for every kmn flow. 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, with a certain weight (its annual frequency to give the total annual kmn flow). We shall work with the situation that all flows in a year for commodity k from m to n are of the same size. In later versions of the program, we may be able to specify and implement a shipment size distribution for the kmn flow and draw shipments of various sizes (each representing some share of the annual flow).

Table 4. Optimisation logic per commodity type and PW/WC/PC relation

Category:	Logistical implications (model) P-W relationships	Logistical implications W-C relationships	Logistical implications P-C relationships
1. Bulk food	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
2. Consumption food	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
3. Beverages	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
4. Fresh fish	Cost minimisation for transport only	Cost minimisation for transport only	Cost minimisation for transport only
5. Frozen fish	Cost minimisation for transport only	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
6. Other fish	Cost minimisation for transport only	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
7. Thermo input	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
8. Thermo	Optimisation of full	Optimisation of full	Optimisation of full

consumption	logistics costs by W	logistics costs by C	logistics costs by C
9. Machinery and equipment	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by W
10. Vehicles	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
11. General cargo – high value goods	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
12. General cargo – live animals	Cost minimisation for transport only	Cost minimisation for transport only	Cost minimisation for transport only
13. General cargo – building materials	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
14. General cargo – other inputs	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
Category:	Logistical implications (model) P-W relationships	Logistical implications W-C relationships	Logistical implications P-C relationships
15. General cargo – consumption goods	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
16. Timber –saw-logs	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
17. Timber – pulpwood	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
18. Pulp	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
19. Paper intermediates	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
20. Wood products	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
21. Paper products	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
22. Mass commodities	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C

23. Coal, ore and scrap	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
24. Cement, plaster and cretaceous	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
25. Non-traded goods	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
26. Chemical products	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
27. Fertilizers	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
28. Metal and metal goods	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
29. Aluminium	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
Category:	Logistical implications (model) P-W relationships	Logistical implications W-C relationships	Logistical implications P-C relationships
30. Raw oil	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
31. Petroleum gas	Optimisation of full logistics costs by W	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C
32. Refined petroleum products	Cost minimisation for transport only,	Optimisation of full logistics costs by C	Optimisation of full logistics costs by C

For the exports, we have to do the optimisation from the perspective of the sender (in Norway) since we will have no information on the receiving firm abroad.

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

In Table 4, the situations where this optimisation logic applies are called optimisation of full logistics costs. For this category, given the annual flow Q from sender r to receiver s 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:

$$q_k^* = \sqrt{\frac{(o_k * Q_k * 2)}{(w_k + i * v_k)}} \tag{3}$$

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 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[7].

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 $[0.2Q/q^{**}, Q/q^{**}]$.

In all cases there is a further check. For this we calculate the following ratio:

$INT(Q/Cap_{max})$

Where:

INT: operator that takes next higher integer value

Cap_{max}: the capacity of the largest available vehicle/vessel for that commodity group and for the specific transport chain that is evaluated

This ratio gives the minimum possible frequency. If the search for the optimal frequency in either of the two intervals above has not gone down all the way to this minimum frequency, we test another 20 points in the interval $[INT(Q/Cap_{max}), 0.2Q/q^*]$ or $[INT(Q/Cap_{max}), 0.2Q/q^{**}]$.

4.3.2   Optimisation of transport costs only

For optimisation of transport costs only, 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.

Fresh fish (commodity 4) is a commodity with very strict constraints on transport time. We built in a restriction that total transport time for this

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[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.

commodity cannot exceed one week. At the same time, the deliveries are order driven (no inventories) and the choice will be based on minimisation of transport cost only within the time constraint. For this commodity, the small f2f flows should be interpreted as individual orders, and for example one shipment per year will mean that there is one order delivered in a year.

4.4   Consolidation

4.4.1   The three iterations

To calculate the total logistics cost of transport chains that use rail, sea, airplane or consolidated road vehicles (which are shared with other shipments), 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 will be 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 3).
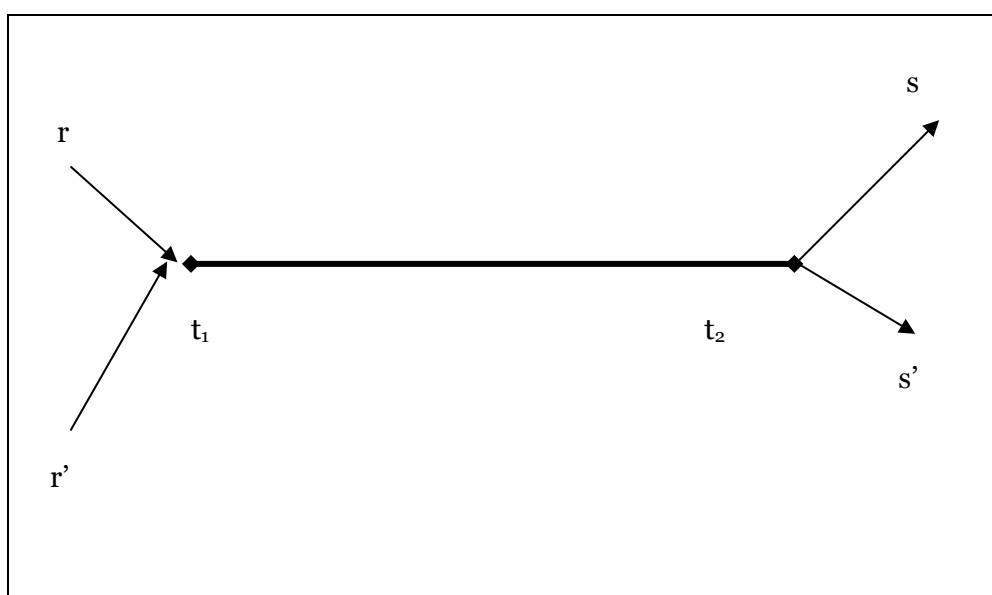

Figure 3. Different f2f flows using the same pair of transfer locations

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. Only in the first iteration transport chains are generated by the BUILDCHAIN program, using fixed load factors supplied to the program in an input file. These transport chains are used in all model iterations. The same load factors are used for CHAINCHOI in the

first iteration. In subsequent iterations load factors are used that have been generated by the model itself.

Each iteration consists of running ChainChoice first and CONSOLIDATE after that, to determine the new rail and sea consolidation factors.

Consider an O-D leg between two transfer points (terminals) 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 (load factor) is φ, defined as vehicle load divided by vehicle capacity. 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 per tonne for the consolidated transport are then:

q/(φ * Cap) * vehicle/vessel cost

In the first iteration the values for $\varphi_{t1-t2, h, k}$ are provided in an input file.

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

The Buildchain process produces the optimum transfer points t_1- t_2 for each chain type [ℓ] between r and s, separately by commodity k. ChainChoice determines the optimal vehicle/vessel type for each leg. Thus, as a result of the program, we will know, for flow between each r and s, which chains ℓ are predicted to use the leg. 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 chosen for this f2f flow mn that includes the leg t_1- t_2. This is used in iteration 2 and 3; so the amount of other cargo available for consolidation with a given shipment is based on the predicted OD flows from the previous iteration of the model.

In the second and third (and currently final) iteration of the model, the process is repeated, but, based on the previous iteration, the actual chain chosen (the chain predicted to be selected in iteration 1 or 2) is used in calculating the OD flow for t_1- t_2. Hence the OD flow Π' is calculated as:

$$\Pi'_{t_1 - t_2, h, k} = \sum_{mn} Q_{mn}^k . \delta_{[mn], optimal\ chain\ has\ t_1 - t_2\ using\ h} \qquad (4)$$

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

In the next paragraphs the methods to calculate the consolidation factors are described in detail. Different methods are used for road transport on the one side and road/sea on the other side.

4.4.2   Road consolidation method

For road transport the consolidation factors are calculated within the Chainchoi-program. In the first model iteration, the Chainchoi program uses the same utilization levels as the Buildchain program. These levels are read from a (user defined) input file. After all firm-to-firm have been processed, the Chainchoi program calculates updated road utilization levels φ, that will be used in the next model iteration.

To update the road utilization levels, the Chainchoi program uses a method proposed by John Bates. The OD flows Π' calculated from formula 4, are ranked according to the calculated potentials and allocated values of φ in the range [0.05, 0.95]. These updated utilization levels φ are saved to a file, in order to be used as input for the next Chainchoi model iteration.

4.4.3   Rail and Sea consolidation method
In order to extend consolidation to include different commodity types in the same transport unit, a procedure from Grønland (2008) was implemented for rail and sea. Below is a more mathematical representation of the implementation of these ideas.

For consolidation at consolidation centres within a commodity type, the procedure would be:

1) In iteration 1 we use fixed consolidation factors provided in an input file.

2) At the end of iteration 1, we calculate the OD flows Π', using eq. (4)), in tonnes (absolute level, based on chosen chains only), for each leg from terminal (consolidation centre) t_1 to terminal t_2, by aggregate mode h and by commodity type k.

3) Then there is a sub-module that operates on the outputs of iteration 1 and prepares inputs for iteration 2. It also reads in the minimum service frequency ($f_{min,h,k}$) by sub-mode h (and sometimes also OD) and commodity type. These are exogenous to the model. Then it calculates the vehicle/vessel load for sub-mode h as:

$$\Pi'_{t_1-t_2,h,k,pervehicle} = \frac{\Pi'_{t_1-t_2,h,k}}{f_{min,h,k}} \tag{5}$$

For each OD and commodity type, this load is compared to the capacities $Cap_{v \in h}{}^k$ of the available vehicles/vessels within the aggregate sub-mode h. The smallest vehicle/vessel type v within the sub-mode h that is big enough to carry the load from eq. (5) is selected.

If the OD volume in the numerator of (5) exceeds the capacity of the largest vehicle type within the sub-mode, the exogenous

frequency (denominator of (5)) is increased until we find a vehicle type that is large enough. If there is no exogenous service frequency, this indicates that there is no service (e.g. no liner vessels) that can be used in a consolidated way. But we do allow unconsolidated vehicles/vessels in such cases (using default frequency values).

Then we calculate the load factor for the selected vehicle/vessel type as

$$\varphi_{t_1-t_2,v,mn}^k = \frac{\Pi'_{t_1-t_2,h,k,pervehicle}}{Cap_v^k} \quad (6)$$

The selected vehicle/vessel type and the load factor (by OD, sub-mode, commodity type) are carried over to iteration 2. This means that in iteration 2 for the OD leg between t_1 and t_2, we no longer compare different vehicle/vessel types within sub-mode h, but instead we use the vehicle/vessel type v selected in the new sub-module following iteration 1.

4) Now we do iteration 2 of the model, working at the level of individual f2f flows (mn), not OD flows (which was the level used in step 3). The selected vehicle/vessel from step 2 above is used as the vehicle/vessel type for that specific OD and sub-mode h when using consolidation in ChainChoi. Other consolidation on this OD and sub-mode is not allowed. The load factors from the new sub-module (eq. 6) are used to calculate the cost of the consolidated legs (cost sharing of distance and time based link cost).

5) Then we do the new sub-module again, and after this iteration 3.

The extension to consolidation of several commodity types in the same vehicles/vessels works as follows.

We calculate the factor α from the base matrices, which are not mode-specific:

$$\alpha_k = \frac{Q_k^B}{\sum_{j \in C} Q_j^B} \quad (7)$$

Where the superscript B denotes that the annual tonnes Q come from the base matrices, and that they are summed over all zone pairs.

C is a set of commodity types j that includes k, as well as other commodity types that can be consolidated with k (if any). Grønland (2008) has provided suggestions about which commodity groups can be consolidated only within the group, which commodity types can be grouped with others and which cannot be consolidated at all (see Annex 3). For commodity types that can be consolidated with other groups, eq. (5) from the above procedure is replaced by:

$$\Pi'_{t_1-t_2,h,k,pervehicle} = \frac{\Pi'_{t_1-t_2,h,k}}{\alpha_k f_{\min,h,k}} \qquad (8)$$

This means that we increase the OD flow for commodity k between t_1 and t_2 to take into account that commodity k can be consolidated with other commodities.

All other steps remain the same.

4.4.4   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: shipments with direct access or egress to sea and rail cannot consolidate, 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.

4.4.5   Cost calculation for consolidated and unconsolidated legs

After having determined the load factor or utilisation rate φ (within one of the iterations), 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$_v$)

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

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 $load_v = \varphi * Cap_v$ (on an OD basis)

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

If $load_v < q < Cap_v$, then the shipment size exceeds the assumed load of the consolidated vehicle, but not its unconsolidated capacity; in this case we 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)

4.4.6   Consolidation along the route

Consolidation along the route (collection round or milk round) is included as an additional road-based transport chain (so we get 27+1=28 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 versions 1 and 2 this is limited to consolidation in a single production zone (pick up from several senders) and a single consumption zone (deliver to several receivers). 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. As soon as the vehicle is 50% full, it will stop searching for more cargo in zone r and start the main haul from zone r to zone s. 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.

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:

PWC-flows

PWC<commodity>.dat	PWC flows
production.txt	Production per firm per commodity
consumption.txt	Consumption per firm per commodity

LOS

<mode>_distance.csv	Distance matrix
<mode>_dom_distance.csv	Domestic distance matrix
<mode>_time.csv	Time matrix
<mode>_toll.csv	Cost matrix
<mode>_freq.csv	Service frequency matrix

Nodes

nodes<commodity>.dat	Available nodes, allowed transfers, direct access, draughts

Costs

vehicles.txt	Capacity, time, distance, loading costs, default frequency, draught per vehicle type
Terminal<class>.txt	(Un)Loading costs per vehicle type for terminal class <class>[8]
transfer<class>.dat	Transfer costs per vehicle types for terminal

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[8] (Un)Loading costs for default terminal class 2 are read from vehicles.txt

	class <class>[9]
TransferProhibition.txt	Transfer prohibitions per vehicle types
cargocosts.dat	Product value, inventory costs, order costs per commodity type
Consolfac.txt	Consolidation factors per commodity and vehicle type
controlfeecost.txt	Sea control fees per vessel type and terminal category

The programme then builds a firm-to-firm database of annual commodity flows, 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:

FIRM2FIRM

f2f<commodity>.dat	f2f flows

BUILDCHAIN

Chains<commodity>.dat	available chains per od

CHAINCHOI

chainchoi<commodity>.out	best chain (route, costs) per f2f relation
chainchoi.out	Aggregated files of chainchoi<commodity>.out
chainchoi<commodity>.log	Totals summary (
chainchoi<commodity>.cst	detailled cost log
chainchoi<commodity>.rep	Aggregated totals (tonnes, tkm, costs), input for report.exe
consol_<commodity>_<mode>.314	od-matrix with consolidation factors (output of ranking)
tonnes_<commodity>_<mode>.314	od-matrix with tonnes per mode and commodity

CONSOLIDATE

consol<commodity>_,mode>.dat	od-matrix with consolidation factors
vhcl<commodity>_,mode>.dat	od-matrix with vehicle types
freq<commodity>_,mode>.dat	od-matrix with frequenties

Report

summary.rep	merged Domestic and International Relations, Shipments, Vehicles, Tonnes and TonneKms per commodity
vehicles.rep	merged nr vehicles, tonnes, tonnekms per

---

[9] For the default terminal class 2 the <class> index is omitted

vehicle type
per commodity type

EXTRACT

od_tonnes<vehicletype>.314   od-matrix with tonnes per vehicle type
od_vhcl<vehicletype>.314   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. These can be calculated using the information on the loaded vehicle flows (as return flows, some of which will be empty), as derived above. The idea here is that overcapacity always has to return empty to the starting point.

Below the equations for road are worked out in more detail, with coefficients fixed a priori. For the moment the logistics model only calculates the empty vehicle flows for road transport because input (as in eq. 16) is missing for other modes. Similar equations could be used for sea vessels, trains and airplanes as well.

According to the Swedish road statistics, 24-25% of all domestic vehicle kilometres of lorries registered in Sweden is driven empty (SIKA and SCB, 2005). We assume that this percentage will be higher for trips zones that are close to each other and will decline (but not become zero) if distance increases. We distinguish between:

- Zones with an OD distance of less than .

- Zones that are more than 50 km apart.

For vehicles travelling between zones in the first category, we initially assume that empties are half of the full flows. We use this relationship, as a first approximation, for both countries, but only for nearby zones. Transport to nearby zones concerns to a large extent distribution transport, and is based on a fairly low utilisation. For zones with an OD distance of less than 50 km, the number of empties for each vehicle category k in sub-mode h between zone s and zone r is calculated as:

$$V_{h,k=empty,sr} = 0,5 * \sum_{k=1,32}V_{hkrs} \tag{11}$$

For non-neighbouring zones and OD-combinations with a longer distance than 50 km, the calculations are based on a vehicle balance approach:

Take the total number of arriving and loaded vehicles for a given mode/vehicle type h to be:

$$V^a_{hs} = \Sigma_r (\Sigma_{k=1,32} V_{hkrs}) \tag{12}$$

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

$$V^L_{hs} = \Sigma_r (\Sigma_{k=1,32} V_{hksr}) \tag{13}$$

Overcapacity in terms of more vehicles available than needed is:

$$\theta_{hs} = V^a_{hs} - V^L_{hs} \; (\text{If } V^a_{hs} - V^L_{hs} > 0)$$
$$= 0 \text{ (otherwise)} \tag{14}$$

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

$$\text{If } \theta_{hs} > 0, V_{s, k=empty} = \theta_{hs} + P(E)\Sigma_r x_{sr} = \theta_{hs} + (\Sigma_{k=1,32}\alpha_s (\Sigma_{hr}V_{hksr}))$$

$$\text{If } \theta_{hs} = 0, T_{s, k=empty} = (0 +) P(E)\Sigma_r x_{sr} = (\Sigma_{k=1,32}\alpha_s (\Sigma_{hr}V_{hksr})) \tag{15}$$

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. As a preliminary approximation (before acquiring empirical data), we use the following values:

A $\alpha_{sr} = 0.58 - (0.0016*\text{distance}(r,s))$,   if distance(r,s) ≤ 300 km

   $= 0.1$ if distance(r,s) > 300 km (16)

This gives:

$$\text{If } \theta_{hs} > 0, V_{s, k=empty} = \theta_{hs} + P(E)\Sigma_r x_{sr} = \theta_{hs} + \alpha(\Sigma_{k=1,32}\alpha_{sr} (\Sigma_{hr}V_{hksr}))$$

$$\text{If } \theta_{hs} = 0, V_{s, k=empty} = (0 +) P(E)\Sigma_r x_{sr} = (\Sigma_{k=1,32}\alpha_{sr} (\Sigma_{hr}V_{hksr}))$$

$$V_{h,k=empty,sr} = [(\Sigma_{k=1,32}V_{h,k,rs})/(\Sigma_r(\Sigma_{k=1,32}V_{hksr}))]* V_{s, k=empty} \tag{17}$$

CHAPTER 6 Capacity constraints in rail system

A separate program has been developed for calculating the impact of capacity constraints in the rail system, both in line capacities as well as in terminal capacities. The principles used are described as follows:

We will basically deal with two categories of constraints in the rail system:

- Capacity limitations on lines ("line capacity")
- Capacity limitations on terminals ("terminal capacity")

Line capacity is expressed as number of trains possible per day (24 hours) on a weekday. The capacity will in practice be a function of several factors:

- Number of x-tracks on the line
    - Number, dispersion, length
- The train schedule
    - Distribution of trains over the day
    - Relative priority for freight trains versus passenger trains
    - Length of blocks and control and signal system
    - Adaption between infrastructure and schedule

To simplify, the capacity of lines between main cities is expressed as maximum number of trains possible on a working day. The capacity will be adjusted to yearly capacity (trains) by multiplying by 5,5 days per week, and 48 weeks per year.

Yearly train capacity (number of trains) = (Daily train capacity) * 264

The capacity will be transformed to wagon capacity ("vehicle capacity") by multiplying the number of trains by the average number of wagons in a train specified in the cost model:

Vehicle capacity per year = (Yearly train capacity)*(Average number of wagons per train)

Ton capacity = (Vehicle capacity per year)*(Average number of tons per wagon)

Line capacity will be given in a table defined with lines, overlapping lines, and capacities in each direction (input file).

Terminal capacity is the capacity that can be transferred, loaded and unloaded on a terminal in a year. The capacity can be expressed in terms of tons per year. Terminal capacity is given in an exogenous file with terminals listed with defined maximum capacity for each line.

For terminals where we have no specified maximum capacity, the default value is no capacity limitations

The line capacity calculations are used in the following way:

1. The model is first run without any constraints. Make a summary report of traffic flows in the unconstrained case that is kept for further comparisons later on. The traffic flows should be related to traffic in and out of the end terminals for the defined main lines.
2. A table of shadow prices (cost per ton) for traffic is defined for each direction on each main line (P_{ij}). Initial values for each shadow price are set to 0. For each main line, a table of dimensioning traffic flow is made. Initial values are set to 0. We will also need an entry in the table (M_{ij}) which is set to 1 if the capacity limit is violated in the last iteration, and 0 otherwise.
3. Perform then for each of the main lines (based on end of line terminals) the following procedure:
    a. For each of the main lines, the train traffic going in and out of the terminals is calculated. This is done as follows: Traffic into a terminal (X) is summed across traffic from all terminals on the line going from the terminals to X (for the direction going into the terminal) and summed across traffic going to all terminals on the line going to the terminals from X (for the direction going from the terminals). The summation is across all train vehicle types.
    b. For each line (and direction), the dimensioning traffic is defined as the maximum of the values for the two end terminals calculated in a).

4. Perform for each of the defined main lines the following procedure:
    a. Compare the dimensioning traffic (T_{ij}) with the line capacity (C_{ij}).
       If ($T_{ij} \leq C_{ij}$), set $P_{ij} = 0$.
       Go to c.
    b. Set $P_{ij} = (T_{ij}/C_{ij})-1$ and $M_{ij} = 1$
    c. If $P_{ij} = 0$ and $M_{ij}=1$, set $P_{ij} = max(((T_{ij}/C_{ij})-1);-1)$ (negative value).[1]

      d.   If all P_{ij} = 0, go to 6. (Alternatively, P_{ij} is compared with a predefined value y, and the criteria becomes all P_{ij} < y).

5. Recalculate with the logistics model, with the following adjustment:
      a.   The rail cost pr km used for each line is set as:
          (Previous km cost for the line) * (1+P_{ij})
      b.   Go to 3.

All calculations are doing changes in the chainchoice files, with buildchain files kept unchanged. No capacity calculations are possible before the model is run and buildchain files are established.

The terminal capacity is calculated according to the following rules:

- If the terminal is not listed in the input file with a defined capacity, no limitations in implemented
- Otherwise, the terminal capacity applies to the sum of all cargo going through the terminal (all train vehicle types and all directions)
- If possible, we should be able to use separate capacities for wagon load trains and for other trains.

In principle, the termilnal constraints will be used in the model (for rail) as follows:

1. The model is first run without any terminal constraints, either with or without using the line constraints.

2. The following procedure is done for all terminals:

      a.   Establish a table with a dimensioning volume (T_k) calculated as the sum of all tonnage going in and out of the terminal for all train vehicle types. Further make an entry (M_k) for each terminal that is 1 if the capacity constraint was violated in the last iteration, and 0 otherwise. Further, establish a table of shadow price adjustments for terminal loading/unloading cost per ton (P_k) for each constrained terminal.

3. Perform for each of the terminals with a defined capacity constraint the following procedure:
      a.   Compare the dimensioning traffic (T_k) with the terminal capacity (C_k).
          If ($T_k \leq C_k$), set P_k = 0 .
          Go to c.
      b.   Set P_k = (T_k/C_k)-1 and M_k = 1

   c. If $P_k = 0$ and $M_k=1$, set $P_k = \max(((T_k/C_k)-1);-1)$ (negative value).

4. If all $P_k = 0$, go to 6. (Alternatively, P_k is compared with a predefined value z, and the criteria becomes all $P_k < z$). Otherwise, go to 5.[1]

5. Recalculate with the logistics volume with the following adjustment: The loading/unloading cost for each terminal with $M_k=1$ is set as:
(Previous (un)loading cost) * $(1+P_k)$.
Go to 3.

6. Set up adjusted reports of traffic flows and compare with traffic flows without constraints. Set up table of calculated cost adjustments (P_{ij} and P_k) for all active constraints.

Both line capcities and terminal capacities are compaired with total rail volumes over terminals and lines (other rail, wagonload rail and diesel rail).

CHAPTER 7 Summary and conclusions

A new version (version 3) of the logistics model has been specified and implemented for Norway (a similar model exists for Sweden) within the framework of its 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.

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 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 3 uses a deterministic logistics cost function and can be calibrated to data on mode shares between aggregate zones for Norway (as was done for version 1).

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. Vehicle capacity profiles by commodity

	Commodity	Vehicle capacity profile (see Table 2)
1	Bulk food	1
2	Consumption food	2
3	Beverages	1
4	Fresh fish	1
5	Frozen fish	2
6	Other fish (conserved)	2
7	Thermo input	2
8	Thermo consumption	2
9	Machinery and equipments	1
10	Vehicles	2
11	Gen cargo, high value	2
12	Gen cargo, living animals	3
13	Gen cargo, building materials	1
14	Gen cargo, inputs	2
15	Gen cargo, consumption	3
16	Sawlogs	1
17	Pulpwood	1
18	Pulp and chips	1
19	Paper intermediates	1
20	Wood products	2
21	Paper products and printed matters	1
22	Mass commodity	1
23	Coal, ore and scrap	1

	Commodity	Vehicle capacity profile (see Table 2)
24	Cement, plaster and cretaceous	1
25	Non-traded goods	1
26	Chemical products	2
27	Fertilizers	1
28	Metals	1
29	Aluminium	1
30	Raw oil	1
31	Petroleum gas	1
32	Refined products	1

Annex 2. Average shipment sizes used in BuildChain

Commodity	Typical shipment Size Norway (tonnes)[10]
1	37.62
2	14.04
3	14.04
4	28.8
5	28.8
6	28.8
7	28.8
8	28.8
9	1.8
10	1.8
11	1.8
12	14.04
13	14.04
14	14.04
15	14.04
Commodity	Typical shipment Size Norway (tonnes)

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[10] At the moment (December 2008) in runs of the logistics model for Norway, a typical shipment size of 500 tonnes is used for every commodity. Small shipment sizes lead in some cases to shorter sea- and rail legs than what would be realistic.

16	28.8
17	28.8
18	37.8
19	7.56
20	7.56
21	7.56
22	37.62
23	37.62
24	37.62
25	37.62
26	35.82
27	14.04
28	14.04
29	14.04
30	90000
31	14.04
32	35.82

Annex 3. Consolidation clusters of commodity groups

Category	commodity groups
1 (no consolidation)	71, 74, 81, 101,102
2 (only consolidation within cargo group)	11,21,51,52,63,64,66,91,92,103
3 (consolidation across groups, but limited to within predefined clusters of groups)	Consolidation cluster (I): 22,31,32 Consolidation cluster (II): 61,62 Consolidation cluster (III): 12,13,23,41,53,54,55,65