# Calibration and validation of the logistics module in the Norwegian and Swedish national freight model systems decisions

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# Contents

# CHAPTER 1 Introduction

## 1.1 Background and objectives

In Significance (2007), the technical specification of a logistics module for the national freight transport model systems of Norway and Sweden, was presented. Actually there are two logistics models with the same structure, one for Norway and one for Sweden. These models have since been implemented and tested for both countries and calibrated for Norway to aggregate data.

In 2005/2006, a prototype version of the logistics model was developed, that uses Swedish and Norwegian network and cost data and data on the locations of distribution centres. The parameters of this prototype were not calibrated to observed data. The purpose of this version was mainly to show the feasibility of the approach.

After having shown that the approach was feasible, a new and extended version of the logistics model was 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 output of the model consists of flows between origins and destinations (OD-level), where consolidation and distribution centres (including ports, airports and 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.

Key features of the new version of the logistics model are:

- For Norway the model uses all firm-to-firm relations in simulation, for Sweden it is applied for a firm-to-firm relation within sub-cells defined by firm size classes and uses expansion factors to represent the total population.

- The transport chain generation program within the logistics model includes determining the optimal transfer locations within available transport chains for all modes.
- In the determination of shipment size we include the effect of economies of scale in transport (a force leading to larger shipment sizes, because these have lower transport cost).
- 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.

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.

The basic mechanism in the model is minimisation of a deterministic total annual logistics cost function. We have developed a procedure to calibrate parameters in the cost function to available aggregate data.

## 1.2 Content of this report

In chapter 2 of this report we describe the calibration procedure for Norway, as well as the outcomes of the calibration process. For Sweden a calibration has not been carried out. A number of validation test for Norway and Sweden are reported in chapter 3. Further tests have been carried out by both the Norwegian and Swedish client groups. This deliverable 5a only presents the results of tests carried out by Significance (as requested by the clients). Chapter 4 contains a summary and conclusions.

# CHAPTER 2 Calibration for Norway

## 2.1 Calibration procedure

By calibration we mean determining the values of parameters in the logistics models so that the model, will better represent available aggregate data. If parameter values would be based on disaggregate data (e.g. on individual shipments) this is called 'estimation'. Estimation is planned for future versions of the logistics model. The purpose of the calibration of the current model version 1 is:

*To have the model reproduce, as accurately as possible, available aggregate data on modes, transport chains, shipment sizes, etc.*

## 2.2 Calibration data

Calibration data came from existing transport statistics (by mode). The following calibration data were initially requested for Norway:

- Use of modes (road, rail, sea, ferry, air):
    - in terms of shipments, tonnes lifted, tkm, vkm, and
    - by commodity type (32 if possible)
    - as aggregate OD flows (not PC), incl. domestic versus import versus export.
- Shipment size distribution.

For domestic transport we received tonnes and tonne-km for a 10x10 zoning system in Norway (also for a somewhat more detailed zoning system, but these were not used, since that would give too many calibration targets), by aggregate commodity type (10 types, which are aggregates of the 32 commodity types in the model), separately for road, rail and sea transport, from the transport statistics. We interpret these as OD information (observations based on the mode for a leg, a multimodal transport chain from a sender to a received will lead to observation for several modes at the OD level) and the model outcomes that we try to match with the calibration data are also at the OD level. For one of the ten commodity groups (oil, gas, petroleum products) the calibration data are highly incomplete, as the transport statistics delivered do not contain flows of oil and gas.

For export we have received calibration data by mode and aggregate commodity type (no origin and destination zones). The import data have the same distinctions. The calibration data for export and import are for tonnes only, not for tonne-km. In the calibration we make sure than on average the targets for domestic goods flows, export and import receive the same weight per tonne. We calibrate simultaneously for tonnes and tonne-km (which we set as equally important).

Both for domestic flows, export and import, we use the calibration data in the form of shares (e.g. mode shares), in order to preserve the totals that we have at the PWC level, that have been given as inputs to the logistics model.

## 2.3 Calibration method

It has been suggested that for calibration the aggregate logit model could be used, with modes as alternatives and alternative-specific constants to be calibrated to aggregate data. However, for this specific problem this method was not chosen, for the following reasons.

The model input (exogenous variables: X's) and its operation is at the detailed OD/node, commodity, shipment size and transport chain level, whereas the observed calibration data (Y's) are very aggregate.

Also if X would also be at aggregate level (e.g., average transport costs per tonne-km by mode), then aggregate logit models are often problematic, especially because of its restrictive IIA (independence from irrelevant alternatives: uniform cross elasticities) property. To remedy this would also require mixing distributions (as in mixed logit estimation).

The calibration method works as follows. It is a form of generalised least squares. The objective function is:

$$\text{Min } [P(\theta)-O]' V^{-1} [P(\theta)-O] \qquad (1)$$

Subject to $P(\theta)=L(X, \theta)$, and range for $\theta$

Where:

P=predicted

O=observed (calibration targets)

V=variance-covariance matrix (inverse is general weighting matrix)

L=logistics model, aggregated to OD level.

X: inputs

θ: coefficients (calibration parameters) to be calibrated.

To do the calibration, the following calibration parameters were added to the (highly nonlinear) logistics costs functions (between brackets: the number of parameters):

- Order costs (1)
- Mode-specific constants (5-1=4)
- Constant for direct transport (1)
- Implied discount rate for small, medium and large firms (3)
- Trade-off of transfer to link-based costs (1).

These are all multiplicative parameters. There is only one set of the above parameters: these serve to improve the match between model outputs and observed data for both tonnes and tonne-km, for domestic, import and export.

The calibration algorithm is the Box-Complex method (Box, 1965, Balakrishna, 2006)). This method belongs to the class of direct search methods, that do not require derivative methods (unlike gradient search), which is convenient given our highly nonlinear logistics cost function (which is a step function). In this application, it works as follows:

1. Start with randomly selecting 20 points (with as many dimensions as coefficients) that span the search space.
2. Each iteration: the worst point is replaced by its reflection about the centroid of the remaining points. If the new point is worse than the old, it is moved closer to the centroid.

Each iteration involves at least one (possibly more than one) complete run of the logistics model (which itself is iterative, using three iterations to determine the degree of consolidation) and an aggregation of the model results to 10x10 zones and to 10 aggregate commodities. Therefore, each iteration takes at least as long as a model run (which now takes about two hours for all commodities). Because of this runtime, the calibration was done by commodity (the commodities are independent) on multiple computers at the same time.

We stop the calibration after 35 iterations. Initial experience has shown that after 35 iterations the calibration parameters and function value for the objective function only change marginally (also see section 2.4).

## 2.4 Calibration results

### Aggregate commodity 1

Since the optimisation that we did for calibration was in terms of (mode) shares (in tonnes and tonne-km), we judge the results of the calibration in terms of shares, not in number of tonnes or tonne-km. For aggregate commodity 1 (commodity groups 1, 2 and 3: bulk food, consumption food and beverages) the uncalibrated model had for domestic tonnes a sum of squared differences in the mode shares between target and model output of 16.4 and after calibration (35 calibration iterations) this was 14.2. For tonne-kilometres there also was an improvement: from 18.8 (uncalibrated) to 15.9 (calibrated). This already indicates that the calibration improved the fit to the observed data, but that substantial differences remain after calibration (due to the complexity and multidimensionality of the calibration task). For import and export, the calibration for commodity 1 was more successful: see Table 1. Here the shares of the four modes in tonnes were substantially different from the target shares before calibration and almost equal to the target shares after calibration.

Table 4. Mode shares (in %) in the calibration data and in the logistic model results.

| Aggregate commodity | segment | Source | Road | Sea | Rail | Ferry | Total |
|---|---|---|---|---|---|---|---|
| 1 | Domestic tonnes | Observed | 96 % | 3 % | 1 % | - | 100 % |
| 1 | Domestic tonnes | Uncalibrated model | 88 % | 6 % | 6 % | - | 100 % |
| 1 | Domestic tonnes | Calibrated model | 90 % | 9 % | 1 % | - | 100 % |
| 1 | Domestic tonne-km | Observed | 79 % | 11 % | 10 % | - | 100 % |
| 1 | Domestic tonne-km | Uncalibrated model | 69 % | 15 % | 16 % | - | 100 % |
| 1 | Domestic tonne-km | Calibrated model | 62 % | 28 % | 10 % | - | 100 % |
| 1 | Export tonnes | Observed | 20 % | 73 % | 0 % | 7 % | 100 % |
| 1 | Export tonnes | Uncalibrated model | 33 % | 60 % | 7 % | 0 % | 100 % |
| 1 | Export tonnes | Calibrated model | 22 % | 71 % | 2% | 5 % | 100 % |
| 1 | Import tonnes | Observed | 16% | 72% | 2% | 10% | 100 % |
| 1 | Import tonnes | Uncalibrated model | 26% | 60% | 10% | 4% | 100 % |
| 1 | Import tonnes | Calibrated model | 16% | 73% | 4% | 7% | 100% |

In Figure 1 is the change in function value (the objective function that is minimised in the calibration) by iteration for aggregate commodity 1. We can see that most of the progress is made in the first 10 iterations and that after iteration 20 and certainly after 32, the total function value does not change much anymore.

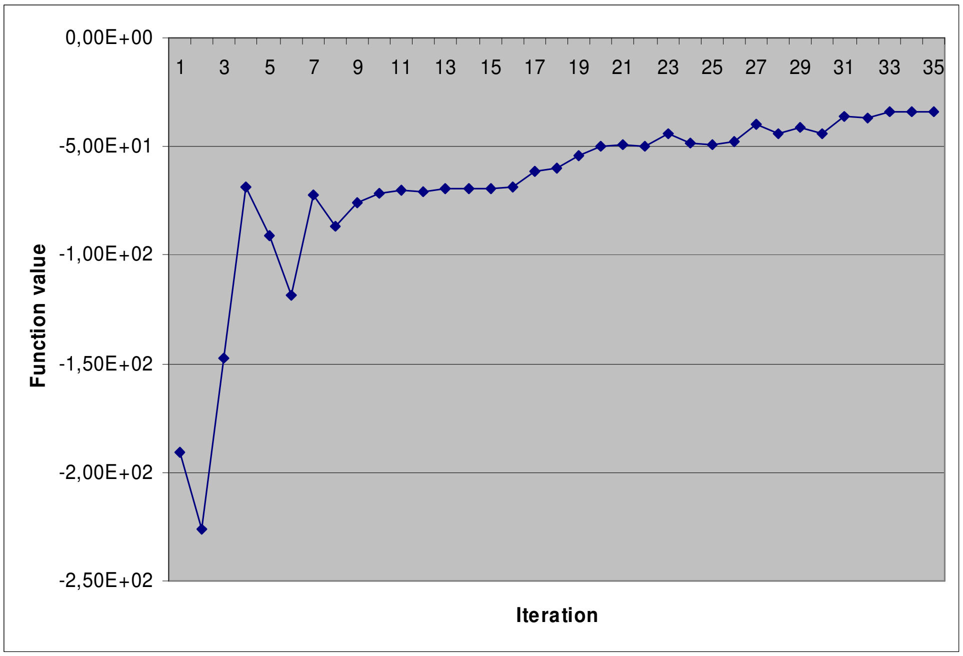


Figure 1. Calibration function value by iteration for aggregate commodity 1.

### Aggregate commodity 2-10

Here follows the same analysis for the other commodities.

# CHAPTER 3 Validation for Sweden

## 3.1 Validation of shipment sizes

In Table 2 is a comparison of the number of shipments calculated (by Henrik Edwards) from the CFS and the output from the logistics model for Sweden. This model gives 18 mln f2f flows for Sweden and 25 mln shipments now (domestic, import and export). This does not include the shipments in f2f flows that do not have a transport chain (especially intrazonal flows). The CFS total number of shipments is 78 mln (also in the sheet). Part of the difference may have to do with the fact that mode run reported here does not yet include intrazonal flows (has been included in a later version).

In the Table one can see for which commodities the biggest discrepancies between the calculation based on the CFS and our model output occur. In relative terms this is for commodity 4 (sugar beet) and 35 (air freight). In absolute terms for commodities 10 (foodstuffs), 29 (leather, textile, clothing, …) and 32 (machinery).

For commodity 4, the CFS number of 50 shipments seems rather unlikely to for sugar beet. For 10, 29 and 35 we use the shipment size rule for minimisation of inventory and transport costs with the [0.2Q/q*, Q/q*] interval (see Significance, 2007, chapter 5). These commodities are all general cargo. Maybe we should use a different rule for general cargo which would make high frequencies and small shipment sizes more likely. For other general cargo commodities we have discrepancies in the same direction. Increasing the number of f2f flows for general cargo commodities might also help to get a better number of shipments.

For commodity 32 we use transport costs minimisation only. This starts at a frequency of 1, and apparently this is where it stopped for this commodity (see the frequency columns for 32). We need a different rule here to determine shipment size, which could be the inventory and transport costs minimisation on the the [0.2Q/q*, Q/q*] interval, or a new rule for general cargo.

Table 2. Comparison of number of shipments in model output for Sweden and CFS

| Com-modity | Relations Domestic | Relations Export | Relations Import | Shipments Domestic | Shipments Export | Shipments Import | shipments All | Frequency Domestic | Frequency Import | Frequency Export | Shipments CFS | Shipments model/CFS | Shipments CFS-model |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 184456 | 3347 | 2286 | 213447 | 8846 | 4441 | 226734 | 1,16 | 2,64 | 1,94 | 102556 | 2,21 | -124178 |
| 2 | 187359 | 10972 | 28242 | 285529 | 11653 | 41129 | 338311 | 1,52 | 1,06 | 1,46 | 1073046 | 0,32 | 734735 |
| 3 | 30712 | 1587 | 1404 | 30918 | 1587 | 1404 | 33909 | 1,01 | 1,00 | 1,00 | 129530 | 0,26 | 95621 |
| 4 | 28904 | 4221 | 548 | 28928 | 4285 | 562 | 33775 | 1,00 | 1,02 | 1,03 | 50 | 675,50 | -33725 |
| 5 | 279724 | 9258 | 5145 | 722914 | 30005 | 71251 | 824170 | 2,58 | 3,24 | 13,85 | 633132 | 1,30 | -191038 |
| 6 | 464127 | 5805 | 3989 | 561239 | 47380 | 7073 | 615692 | 1,21 | 8,16 | 1,77 | 755261 | 0,82 | 139569 |
| 7 | 211724 | 3605 | 3719 | 221188 | 4402 | 5403 | 230993 | 1,04 | 1,22 | 1,45 | 110437 | 2,09 | -120556 |
| 8 | 12071 | 2810 | 2745 | 15993 | 2832 | 2942 | 21767 | 1,32 | 1,01 | 1,07 | 100000 | 0,22 | 78233 |
| 9 | 722582 | 5106 | 26340 | 786847 | 25148 | 80596 | 892591 | 1,09 | 4,93 | 3,06 | 2019840 | 0,44 | 1127249 |
| 10 | 1825349 | 7595 | 140902 | 3564084 | 73721 | 473199 | 4111004 | 1,95 | 9,71 | 3,36 | 11497301 | 0,36 | 7386297 |
| 11 | 117948 | 4252 | 4314 | 119820 | 4362 | 4490 | 128672 | 1,02 | 1,03 | 1,04 | 846265 | 0,15 | 717593 |
| 12 | 20795 | 1811 | 2608 | 29864 | 3532 | 7540 | 40936 | 1,44 | 1,95 | 2,89 | 36394 | 1,12 | -4542 |
| 13 | 647 | 38 | 238 | 939 | 38 | 6931 | 7908 | 1,45 | 1,00 | 29,12 | 960 | 8,24 | -6948 |
| 14 | 57906 | 3487 | 43173 | 198109 | 20661 | 105545 | 324315 | 3,42 | 5,93 | 2,44 | 594675 | 0,55 | 270360 |
| 15 | 24476 | 275 | 2298 | 38471 | 4190 | 3756 | 46417 | 1,57 | 15,24 | 1,63 | 73328 | 0,63 | 26911 |
| 16 | 1893 | 1468 | 804 | 17110 | 10282 | 11728 | 39120 | 9,04 | 7,00 | 14,59 | 17619 | 2,22 | -21501 |
| 17 | 501031 | 2854 | 23083 | 593708 | 61676 | 94611 | 749995 | 1,18 | 21,61 | 4,10 | 2178123 | 0,34 | 1428128 |
| 18 | 610025 | 2827 | 5632 | 924105 | 20965 | 25758 | 970828 | 1,51 | 7,42 | 4,57 | 2251411 | 0,43 | 1280583 |
| 19 | 82335 | 1522 | 8319 | 191930 | 11211 | 18036 | 221177 | 2,33 | 7,37 | 2,17 | 785106 | 0,28 | 563929 |
| 20 | 149620 | 3093 | 2825 | 215330 | 22196 | 10384 | 247910 | 1,44 | 7,18 | 3,68 | 339577 | 0,73 | 91667 |
| 21 | 30239 | 800 | 3285 | 38465 | 2396 | 10740 | 51601 | 1,27 | 3,00 | 3,27 | 43084 | 1,20 | -8517 |

| Com-modity | Relations Domestic | Relations Export | Relations Import | Shipments Domestic | Shipments Export | Shipments Import | shipments All | Frequency Domestic | Frequency Import | Frequency Export | Shipments CFS | Shipments model/CFS | Shipments CFS-model |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 8821 | 2786 | 2597 | 48960 | 36018 | 29140 | 114118 | 5,55 | 12,93 | 11,22 | 280660 | 0,41 | 166542 |
| 23 | 524669 | 28948 | 223318 | 741793 | 124449 | 380584 | 1246826 | 1,41 | 4,30 | 1,70 | 4596203 | 0,27 | 3349377 |
| 24 | 40544 | 1127 | 976 | 76011 | 12370 | 7010 | 95391 | 1,87 | 10,98 | 7,18 | 100755 | 0,95 | 5364 |
| 25 | 295887 | 14542 | 97503 | 295957 | 14974 | 97715 | 408646 | 1,00 | 1,03 | 1,00 | 2208949 | 0,18 | 1800303 |
| 26 | 1711122 | 40582 | 97048 | 1901683 | 60557 | 115018 | 2077258 | 1,11 | 1,49 | 1,19 | 5522213 | 0,38 | 3444955 |
| 27 | 247357 | 1831 | 8421 | 283890 | 11135 | 18850 | 313875 | 1,15 | 6,08 | 2,24 | 1018474 | 0,31 | 704599 |
| 28 | 61548 | 1342 | 5319 | 90526 | 32455 | 14529 | 137510 | 1,47 | 24,18 | 2,73 | 266010 | 0,52 | 128500 |
| 29 | 3985615 | 19578 | 158491 | 4791985 | 79957 | 271623 | 5143565 | 1,20 | 4,08 | 1,71 | 16934665 | 0,30 | 11791100 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | 100000 | | 100000 |
| 31 | 119266 | 701 | 1687 | 148677 | 701 | 2670 | 152048 | 1,25 | 1,00 | 1,58 | 275169 | 0,55 | 123121 |
| 32 | 2106705 | 150512 | 521452 | 2107235 | 151084 | 521602 | 2779921 | 1,00 | 1,00 | 1,00 | 14215983 | 0,20 | 11436062 |
| 33 | 1447057 | 14744 | 59914 | 1868009 | 43989 | 99336 | 2011334 | 1,29 | 2,98 | 1,66 | 6425954 | 0,31 | 4414620 |
| 34 | 204997 | 4700 | 2785 | 231738 | 6666 | 4272 | 242676 | 1,13 | 1,42 | 1,53 | 143186 | 1,69 | -99490 |
| 35 | 12162 | 9856 | 26180 | 39577 | 25425 | 41213 | 106215 | 3,25 | 2,58 | 1,57 | 2630000 | 0,04 | 2523785 |
| | 16309673 | 367982 | 1517590 | 21424979 | 971148 | 2591081 | 24987208 | 1,31 | 2,64 | 1,71 | 78305916 | 0,32 | 53318708 |

## 3.2 Validation for specific test cases

For Sweden, the client specified seven test cases (the same as in 2006) to be illustrated in more detail. These relate to actual PWC-matrix relations that use a number of different solutions in the delivered logistics model. They cover three different commodity groups and both large and small shipment sizes.

1. Sawn wood (commodity 6) between 916100 and 918000 (domestic flow 182 km).
2. Sawn wood (commodity 6) between 788100 and 625 (export 1721 km).
3. Sawn wood (commodity 6) between 918200 and 556 (export 2534 km).
4. Paper, pulp, waste (commodity 24) between 808200 and 758100 (domestic 593 km).
5. Paper, pulp, waste (commodity 24) between 768200 and 828700 (domestic 311 km).
6. Glassware and ceramic products (commodity 27) between 825700 and 742800 (domestic 493 km).
7. Glassware and ceramic products (commodity 27) between 517 (Fredrikstad) and 719100 (Sigtuna) (Import 1384 km).

### Test case 1

The detailed model outcomes of the chosen transport chain for this flow are given below. These outcomes relate to one of the subcells (firm size class to firm size class) for this PWC relation. This subcell has 1534 tonnes, which are transported in 33 shipments of 46.5 tonnes each, as a direct transport by heavy lorry (1 vehicle per shipment).

Tonnes: 1534.0000

Freq: 33

Shipment size: 46.4848

Chain type: 9

> Leg: 9
>
> Orig: 916100
>
> Dest: 918000
>
> Dist: 179.2000
>
> Time: 0.1789
>
> Vehicle type: 105
>
> Nr. vehicles: 1.0000
>
> Wait Time: 0.0000

Time costs: 723.5686

Dist costs: 930.6035

Infra costs: 0.0000

Loading costs: 1301.5758

Fairway dues: 0.0000

Pilot fees: 0.0000

Transport costs: 97539.6798

Order costs: 18942.0000

Holding costs: 45757.8255

We noticed that the transport time, read in from the level-of-service matrices (network input) for vehicle type 105 (HGV 25-60 tonnes) is not correct. The time costs are still substantial because of the loading time.

The last three items (transport costs, order costs and holding costs) are per year).

Other test cases have not been investigated yet, because the link time inputs for vehicle type 105 (which is used in many chains) need to be corrected first

# References

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