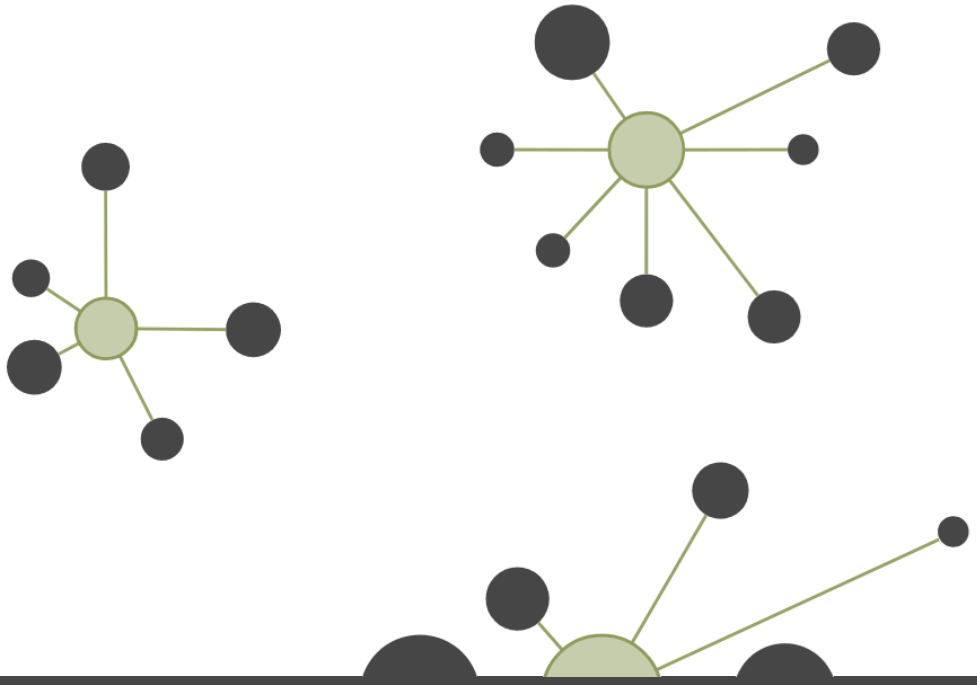
Centers of Gravity Calculator

For advanced Center of Gravity analysis in supply chain network design

User manual

v260620



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Intro

This manual describes how to use Centers of Gravity Calculator and explains all input data and parameters.

For a greenfield analysis, you only need to enter customer locations and demand. Read User input - Customers for a jump-start.

Note
Animations do not play in this file. Please, see those online. Effects become much clearer when animated, and static pictures are sometimes insufficient.

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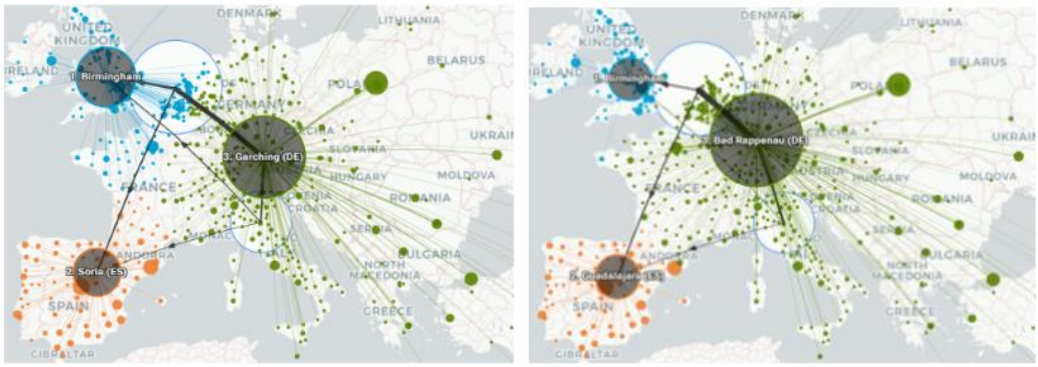
Demo guide

Calculate Centers of Gravity

1. Open section Calculate Centers of Gravity. Press Calculate. See map above, reports, and service level distances. Change the number of Centers of Gravity. Rerun. Review new outcomes.

2. Activate sensitivity analysis, with each demand randomized ±X%. Rerun. Does it still bring similar locations?
   Each rerun demand is randomized again, so rerun and view map a couple of times to check solution robustness thoroughly.

3. You can activate several constraints. But first, deactivate sensitivity analysis, and set the number of Centers of Gravity back to 3.
   a. Activate constraint Predefined warehouses. Rerun. Two predefined warehouses* become part of the solution, one in Birmingham (UK), one in Madrid (Spain) that is allowed to move 200 kilometers and (again) ends up near Guadalajara/Azuqueca. See how this affects the location and size of the 3rd warehouse.
   b. Activate constraint Suppliers as well. Rerun. Each of both suppliers pulls all warehouses (default option). The warehouse in Spain moves northwards to Soria, the 3rd warehouse westwards. Supply flows make the map look more complex. Under map settings you can uncheck their display.
   c. Activate constraint Capacity limits as well. Rerun. Warehouse Birmingham throughput drops from 976,680 to 482,460 (capacity = 482,500). The warehouse in Spain also becomes slightly smaller due to its capacity limit. So, the 3rd warehouse must grow. It takes over customers in the west, so moves westwards, as shown below.



4. Section User input - Constraints explains all (other) constraints and their links to input tables.

Select warehouses

For this part of the demo, 24 predefined warehouses will be created automatically.

4. Deactivate constraints. Open section Select warehouses. Press Read input data, press Select warehouses. The best 3 out of 24 warehouses are selected. Their locations resemble Centers of Gravity (because fixed and variable warehousing cost parameters are kept equal for all warehouses). Total warehousing plus transportation costs are 939676. The transportation costs of 468867 (Output - Reports - Summary) exceed 464757 (Center of Gravity minimum goal value), because the 24 warehouses are not ideally located, and the selection routine does not relocate. The Enumeration solver will have generated a Top X of solutions. The second best solution brings 940735 total costs.

   The more predefined warehouses to select from, the lower transportation costs can become. If loaded with 588 warehouses that have the same geocodes as the 588 customers (bringing 33.7 million possible combinations of 3 warehouses), then transportation costs decrease to 466478. Which is still slightly higher than the minimum goal value of 3 optimized Centers of Gravity. The k-means clustering solver will find the optimal solution within a minute.

5. The selection changes if warehousing costs become differentiated. Increase fixed costs of Madrid - in table predefined warehouses - to at least 106140 and it will no longer get selected. Differentiated fixed/variable warehousing costs may make the map look less "logical".

Using the software - Logical steps

If your main question is where to locate warehouses, then use Calculate Centers of Gravity

- This routine moves (virtual) warehouses to locations that **minimize transportation costs**, thus determining Centers of Gravity.
- It does not consider warehousing costs.

Go to next page →

If your main question is which warehouses to open/close, then use Select warehouses

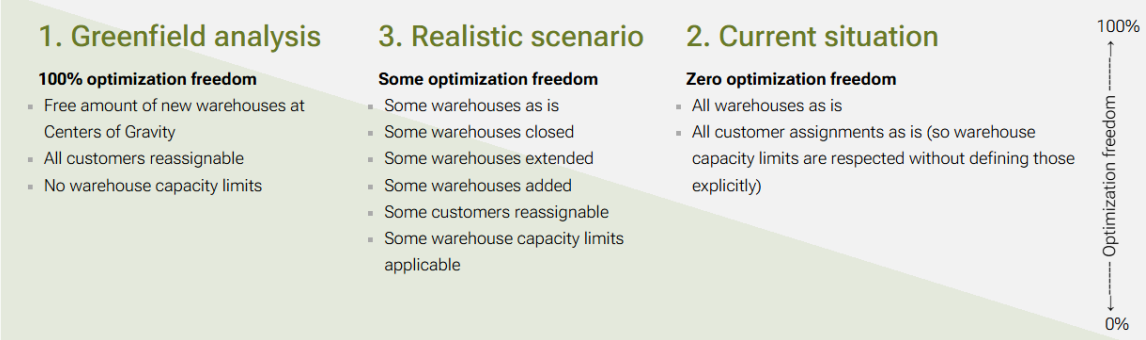
- This routine selects those warehouses that **minimize transportation plus warehousing costs** given a set of warehouses to select from.
- It does not move warehouses.

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Calculate Centers of Gravity - Summary

- **Step 1** is running a greenfield Center of Gravity analysis. You only need to enter demand.
- **Step 2** is replicating the current situation, to get figures to compare scenarios against, such as average customer distance. You enter current warehouses and fix customer assignments.
- **Step 3** is creating a realistic scenario that sits somewhere between the current situation and greenfield. Constraints of step 2 are partly relaxed, like "only some of the current warehouses remain as-is, but others may move to a Center of Gravity".
- **Step 4 (optional)** is adding suppliers to include supplier transportation costs in the optimization.
- **Step 5** is choosing a proper warehouse location for each Center of Gravity, once calculated.



Before setting up your own model, it may be helpful to play around with the demo data first, to get an idea of how the software works, and to check out - for instance - what data relates to what constraint.

Step 1. Run a greenfield Center of Gravity analysis

A first run

- **Fill out table Customers** in section Input tables - Customers.
  - You can start with only the 4 obligatory fields filled: Customer_ID, Latitude, Longitude, Demand. All fields are explained in user manual section Customers.
- **Select the number of Centers of Gravity** in section Calculate Centers of Gravity
- **Press Calculate** to run the greenfield Center of Gravity analysis. That's it! Main output - including Centers of Gravity - is found in report section Output - Reports.

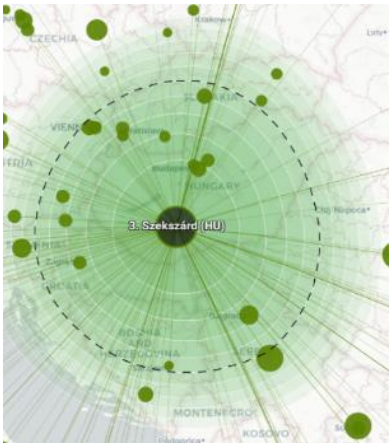
- **Always validate your input data**! For example, does the map show extremely large customers, or large unknown customers, or gaps where you expected to see customers? Invalid input = invalid output!

Assess service levels

- **See service level distance metrics** in report section Output - Service level distances showing percentage of demand and customers reached within a certain distance (estimated road distance between warehouse and customer). This indicates whether more warehouses should be opened, or some could be closed.
- **Activate "distance-based customer coloring"** in section Map settings below map. Customers beyond acceptable **lead time distance** (set in section Parameters & constraints - Service level) become black. Based on this map you may decide to add/relocate warehouses. Or accept that some customers will have a longer lead time - which is probably already the case in reality. A few far-away customers should not be driving your supply chain network design!
- **Activate "Improve service level"** in section Parameters & constraints - Service level and rerun. Service level will be improved at the expense of increased transportation costs.

Run sensitivity analyses

- Go to section Parameters & constraints - Sensitivity analysis.
- **Activate "Display cost-increase-areas"** and rerun. The map will show green areas around each Center of Gravity consisting of 10 bands, each band representing a 1% costs increase range. It also draws a dotted line, representing your selected % (X). If a Center of Gravity were located somewhere on the dotted line, its inbound and outbound transportation costs would increase X%. If a current warehouse falls well within acceptable-costs-increase-range, you may decide to stick with the current warehouse (enter it as a predefined warehouse), instead of opening a new one at the Center of Gravity.



- **Activate "Randomize each demand quantity"** and rerun. Each customer demand temporarily changes between −X% and +X%. Check how much it affects Centers of Gravity.

Step 2. Replicate the current situation

Enter current warehouses

- To **enter current warehouses**:
  - Fill input table Predefined warehouses with current warehouses.
  - Set field Move_limit to 0, to fix the warehouse location.
  - Activate constraint "Predefined warehouses" in section Parameters & constraints - Constraints to include predefined warehouses, and rerun.

Fix customer-warehouse assignments

- To **assign customers to their current warehouse**:
  - Enter field Warehouse_ID in table Customers
  - Activate constraint "Fixed customer warehouse assignments" in section Parameters & constraints - Constraints, and rerun.
  - Displaying current warehouse-customer links may already reveal some room for improvement.
  - Fixing current customer-warehouse assignments automatically means that current capacity limits will be respected, so there is no need to enter field Capacity in Predefined warehouses table, yet.

Step 3. Create a realistic future scenario

Gradually relax some constraints

- **Investigate if current locations are optimal** - given fixed customer assignments:
  - Increase value of field Move_limit of (some) predefined warehouses, and rerun.

- **Investigate if current customer assignments are optimal** - given fixed warehouse locations:
  - Empty field Warehouse_ID of (some) customers, and rerun
  - Or deactivate constraint "Fixed customer-warehouse assignments" in section Parameters & constraints - Constraints, and rerun.

- **Investigate where to open a next new warehouse**:
  - Increase the number of Centers of Gravity beyond the number of predefined warehouses, and rerun.
  - Make sure you allow (some) customers to get (re)assigned to this new warehouse.

Activate other types of constraints

- **Limit warehouse capacities**:
  - Enter field Capacity in the Predefined warehouses table.
  - Activate constraint "Capacity limits" in section Parameters & constraints - Constraints, and rerun.
  - Keep in mind that current limits may not apply in future, if additional space can be rented or the owned facility expanded!

- **Group customers for single sourcing**:
  To force all customers within a group to be assigned to the same, single warehouse:
  - Enter field Group in table Customers.
  - Activate constraint "Customer groups" in section Parameters & constraints - Constraints, and rerun.

Step 4. Add suppliers (optional)

Intro

A Center of Gravity analysis focuses on the demand side with its relatively high transportation costs and lead time requirements. But you can add suppliers to include supply transportation costs. **Adding suppliers becomes more relevant in a Center of Gravity analysis if there are a few dominant supply locations** (such as a large plant or entry harbor), in which case a warehouse should move towards that location. Note that a supplier may pull all warehouses, whereas a customer only pulls one.

Enter suppliers

Enter suppliers - at least obligatory fields Supplier_ID, Latitude, Longitude, Supply - in input table Suppliers.

Enter supplier transportation rate

Supplier shipments are usually larger than customer shipments, on average. This makes supplier transportation relatively cheaper. The lower transportation rate makes suppliers pull Center of Gravity relatively less than customers do.
Enter supplier transportation rate in section Parameters & constraints - Transportation rates.

Activate suppliers

Activate constraint "Suppliers" in section Parameter & constraints - Constraints.

Select supply option

Select 1 out of 4 supply options in section Parameter & constraints - Supply options. It determines how supply flows are constructed.

Non-unique products

1. Option 1: Each supplier delivers to closest warehouse only
   Used for a scenario in which local suppliers supply non-unique products to local warehouses. Closest warehouse (auto-detected) can be overridden by specifying a predefined warehouse in the supplier table. This option will neither create inter-warehouse flows nor rescale supply, to balance supply with demand, as it gives the user full control over supplier-warehouse flows.
2. Option 2: LP optimized supply flows - with auto-sized suppliers
   Used for a scenario in which suppliers supply non-unique products to warehouses. This Linear Programming procedure creates supplier-warehouse flows that minimize supplier-warehouse transportation costs, while adhering to available supply quantities (and fixed supplier-warehouse assignments**). You may give suppliers "infinite" supply, as this LP procedure makes supply match demand exactly. It auto-sizes suppliers.

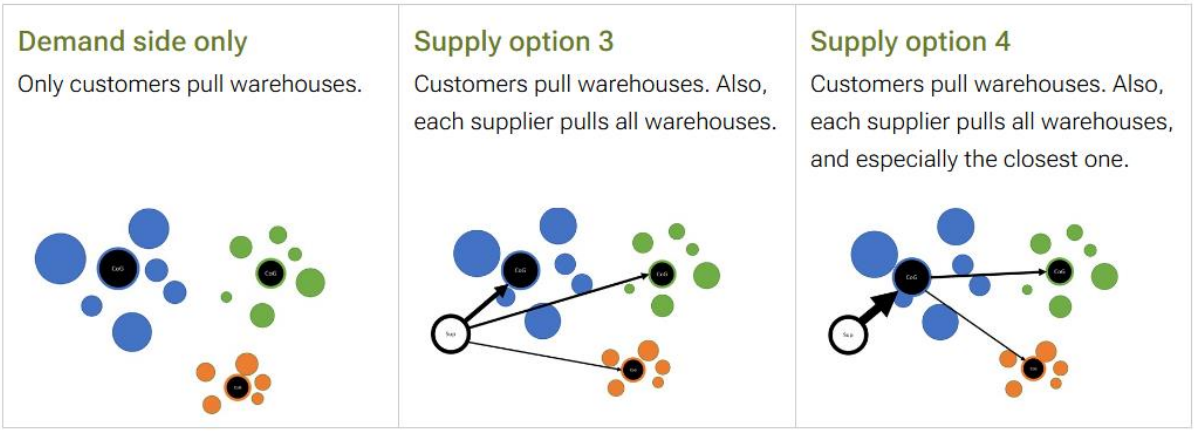
** If fixed supplier-warehouse assignments make it impossible for supply to reach demand, then these assignments are (partly) ignored. A supplier will then also supply warehouses other than the one you assigned it to. This causes a cost penalty. The LP procedure avoids penalties, as long as possible. If a penalty was unavoidable, then you will get a message. Penalties are excluded from costs outcomes as reported.

Unique products

3. Option 3: Each supplier delivers to each warehouse (default option)
   Used for a scenario in which suppliers supply their unique products to each warehouse directly. The supplier volume to each warehouse is pro rata the customer demand assigned to each warehouse.
4. Option 4: Each supplier delivers to each warehouse via closest warehouse
   Used for a scenario in which suppliers supply their unique products to each warehouse - via the closest warehouse (2-echelon) - pro rata demand assigned. Closest warehouse (auto-detected) can be overridden by specifying a predefined warehouse in the supplier table.

Remarks

- **You can specify the supply option at individual supplier level.** It will override the generic setting. This way you can create a mix of options 1/3/4. Option 2 cannot be combined with other options.
- If you have specified a fixed warehouse at a supplier (= supply single warehouse) but also selected option 3 (= supply all warehouses), this causes a logical inconsistency. In that case, option 3 is converted into option 4 'in background'.
- Under options 2/3/4 each supplier - unlike a customer - pulls several/all warehouses.



Revisit step 2 and 3

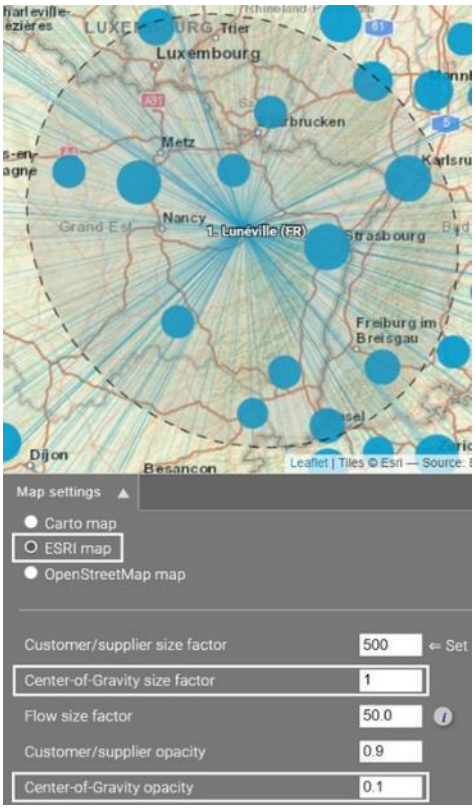
Of course, to keep comparisons apples-to-apples, you need to revisit steps 2 and/or 3 and rerun with suppliers activated in those steps as well.

Step 5. Choose a proper warehouse location for each Center of Gravity

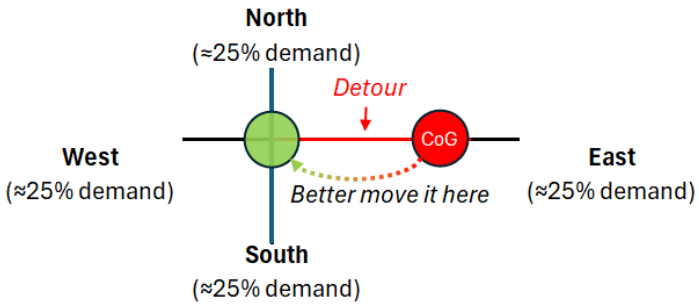
Once calculated, choose a proper warehouse location for each Center of Gravity (that may have ended up on top of a mountain or in the middle of a lake).

Under Map settings, select ESRI map and decrease Center of Gravity size factor or opacity to see the road network.

Consider locations within the 1%-costs-increase-range around the Center of Gravity - the visual outcome of the sensitivity analysis as described under step 1.



If the Center of Gravity sits on top of a dominant customer or supplier, then search for a highway/expressway junction close by. In this case, the 1%-costs-increase-range will be relatively small.
Else, search for a location where two expressways cross each other. At such crossing, transportation in any direction will not cause a detour. Whereas if a location is only near an east-west expressway, then transportation to the north or south means a detour to reach the north-south expressway. Moving the location to the crossing will remove that detour for 3 directions, but add it to 1 direction (east). If demand is equally divided across all 4 directions, this move lowers the sum of weighted road distances.



If you want to check your location with actual road distances, then you can use Batch Driving Distances Caclulator.

Select warehouses

Mandatory

- Enter your data into the input tables. Predefined warehouses are no longer optional, but mandatory.
- Open section Select warehouses: Press button "Read input data". Specify the number of warehouses to be selected (per group) and select solvers. Press button "Select warehouses".

Optional

- Enter warehouse capacity limits. Keep in mind that current limits may not apply in future, if additional space can be rented or the owned facility expanded!
- Enter fixed customer-warehouse assignments, if some customers need to be delivered from a specific warehouse.
- You may override the transportation costs matrices as calculated by the software with your own transportation costs input based on your own costing method / actual rate tables / actual road distances that can be retrieved using **Batch Driving Distances Calculator**. Transportation rates for new warehouses may be unknown. Or transportation rates from a current warehouse to customers that are currently delivered from another warehouse may be unknown. Rates being unknown is often a cumbersome part in supply chain network design, and reason to use a simpler costing method like the one embedded in this software.
- Enter warehouse fixed/variable costs, so these are taken into account as well in the optimization.

How to activate constraints

Constraint	How to activate
Predefined warehouses	Always active, regardles constraint setting.
Fixed customer-warehouse assignments	By checking constraint in section Constraints
Fixed supplier-warehouse assignments	Not supported
Capacity limits	By using Greedy solver or LP solver (not by checking constraint).
Customer groups	Not supported
Suppliers	By checking constraint in section Constraints. Supply option 3 is activated in background, other options are not supported.
Border crossing points	By checking constraint in section Constraints.

User input

Customers

Mandatory fields

- **Customer_ID** is a free format identifier.
- **Latitude** and **Longitude** are both decimal numbers and the result of converting a textual **ship-to address** (not sold-to address) into geographic coordinates - a process called geocoding. You can use:
  - Batch Geocoder - Free (OpenStreetMap based)
  - Batch Geocoder - Paid (Google Maps based)
  - Excel interfaces with Google Maps / TomTom / BING geocoding api
  - or any other geocoder

  - **City names may not be unique (or misspelled), so use postal codes as well** to geocode as otherwise you may end up with demand at the wrong location.
  - **Double check postal codes on missing leading zeroes.** For example, if you see German postal codes with only 4 digits, then a leading zero is missing. **If working in Excel: do not forget to set the column to type "text" before loading postal codes into it** otherwise leading zeroes get lost! Batch Geocoder - Paid (based on Google Maps api) autocorrects if a proper city name has been supplied as well, and reports the corrected postal code.
  - **Put aggregated demand of far-away-customers** delivered by sea/air (on overseas island) **on exit harbor/airport** (latitude/longitude), to ensure that Centers of Gravity are pulled in the right direction, and to avoid that a Center of Gravity ends up in such remote area. **Or simply delete them**, if their demand is marginal. Or activate remote filter under initialization options.



  - **Try to keep your model small**. If you have more than 5,000 customers, then - most likely - this number can be (significantly) reduced by aggregation, while keeping the model valid. It makes your model run (much) faster. Of course, you can always run it first without aggregating data. See Customer aggregation suggestions in the appendix.

- **Demand** = total yearly **future demand** of a customer (as you are designing for the future), ideally expressed in your transportation cost driver: volume or (volumetric) weight.
  - Collect a full year of demand data if your business is highly seasonal. Otherwise, one month × 12 may do.
  - Design for the future: include demand growth percentages.
  - If available, then use shipment data with volumes or weights. Otherwise, demand can be calculated based on sales order quantities × item dimensions. But beware: item masters are often not 100% clean, which may cause large calculation errors. Check at least for shipments that exceed truck capacity or that are extremely small.
  - If a sales budget is the only info (new market entry), then use demographics to create a geographical demand proxy.
  - Though not obligatory, it is advised to enter demand figures as whole numbers, as these are easier to read.
  - If shipment volumes/weights are impossible to obtain, then use financial sales per customer as demand.
  - To model demand at **product group level**: split a customer into sub-customers, and link each sub-customer to the subset of warehouses holding the applicable product group. See field Warehouse_IDs.

Optional fields

- **Warehouse_IDs** is used to assign a customer to a predefined warehouse, so it should match to a Warehouse_ID as defined in table Predefined warehouses. If left empty, then no fixed assignment applies.
  - Create a fixed assignment by entering a **single warehouse_ID**.
  - Create a semi-fixed assignment by entering a **subset of warehouse_IDs** that the solver is allowed to select from. Use / as separator between warehouse_IDs. For example, Birmingham/Madrid/WH05.

  Activate constraint "Fixed customer-warehouse assignments" in section Parameters & constraints - Constraints

- **Group** - free format - is used to force all customers within the same group to be delivered by the same single warehouse only (single-sourcing). What group stands for, is for you to decide. For example, a country. The group is assigned to the warehouse that comes with the lowest sum of weighted distances for this group of customers. Underlying cost calculation is still done at individual customer level. Read user manual section Center of Gravity algorithms - Customer grouping for more info.
  A fixed customer-warehouse assignment takes precedence over a customer group. Warehouse capacity limits may cause a customer group to 'break'.

  Activate constraint "Customer groups" in section Parameters & constraints - Constraints.

- **Shipment_size** translates into an individual customer transportation rate. If specified, then it overrides the general customer shipment size. Read user manual section Transportation rates for more info. Make sure it does not exceed truck capacity. Shipment size can be expressed in KG, M3, pallets, loading meters, ... which - of course - should relate to how you have expressed demand.
- **Lead_time_distance** is the individual maximum allowed distance from the warehouse. If specified, then it overrides the general lead time distance as set in section Parameters & constraints - Service level. Customers are colored black if the lead time distance is exceeded, showing where service is compromised. Enter the distance in the correct distance unit, miles or kilometers, as you have selected in section Parameters & constraints - Distance.
- **Border_group** links the customer to a border group. A border group has specific border crossing points to enter or exit the bordered area. Those border crossing points are defined in table Border Crossing Points. A flow from a warehouse to a customer will go via one of the border crossing points, unless the warehouse and customer are both inside the bordered area.

  Activate constraint "Border crossing points" in section Parameters & constraints - Constraints.

Optional fields for "Select warehouses" functionality only

- **Qty_1 to 5** are the warehouse cost driver quantities of a customer, such as #orders, #order lines, #unit_picks, #carton_picks, #pallet_picks. You may decide for yourself what each qty stands for.

Various remarks

- After having entered 4 obligatory fields you can run a first Center of Gravity analysis. Go to Calculate Centers of Gravity and press Calculate.
- **Always validate your data**! Check top-X customers list. Are major customers missing? Or do unknown customers appear? Check the demand map. Are gaps seen? Or do large unknown locations appear?
- Default customer opacity is 0.9 to make customers behind each other visible. Small customers are plotted on top of large. But still. Customers with the same latitude/longitude are plotted on top of each other. Only a relatively small dot will be seen that does not reflect total demand. **By aggregating demand, you might get a more insightful demand map.**

Try to keep your model small

If you have more than 5,000 customers, then - most likely - this number can be (significantly) reduced by aggregation, while keeping the model valid, as can be seen in the case examples section below. It makes your model run (much) faster. Of course, you may always run it first without aggregating data, to check if run time

is an issue at all. The **aggregation tool** aggregates customers and its output can easily be imported into table Customers.

Tight warehouse capacity limits might be a valid reason for not aggregating data. It is easier to match those limits more closely having many small customers that can be (re)assigned than having only a few big aggregated customers.

Predefined warehouses (optional)

Mandatory fields

- **Activate constraint "Predefined warehouses"** in section Parameters & constraints - Constraints to include predefined warehouses in the solution.

- **Warehouse_ID** - free format, for example "Birmingham" - is used in the Customers and Suppliers table to assign customers or suppliers to this warehouse (instead of having the software assign customers and suppliers).
- **Latitude, Longitude** is the result of converting a textual address into geographic coordinates - a process called geocoding. For more info, read the help text for fields Latitude, Longitude of Customers.

Optional fields

- **Move_limit** = 0 (default) means a fixed location, > 0 means a location that may move away from its initial coordinates but no further than its move limit. To be expressed in either miles or kilometers, as you have selected in section Parameters & constraints - Distance.
- **Capacity** is used to limit warehouse throughput, with throughput being demand assigned to the warehouse (in case of a main warehouse not including demand assigned to its satellites). It is not storage capacity. Warehouse capacity limits may cause customer groups to 'break'.

  Activate constraint "Capacity limits" in section Parameters & constraints - Constraints.

- **Transport_rate_index** is used to adjust customer transportation rates of all customers supplied from this warehouse. An index below 100 means transportation from this warehouse to customers is relatively cheaper, an index larger than 100 means more expensive. Customer transportation rates are multiplied by the warehouse Transportation rate index/100, for all customers assigned to the warehouse. The lower this index, the more customers a warehouse will get assigned (unless other constraints prevent this).
- **IsSatellite** = 0 (no) or 1 (yes) and is used to distinguish main warehouses from satellite warehouses. This is relevant if suppliers are activated and parameter "Link supplier to closest Main warehouse" is checked. Even in a demand-only model main→satellite warehouse flows are generated.
- **MainWarehouse_ID** is used to assign a satellite warehouse to a main warehouse. If left empty, then the satellite warehouse gets linked to its closest main warehouse.
- **Color** overwrites the default warehouse color. Format: #rrggbb (red, green, blue hexadecimal values)

Optional fields for "Select warehouses" functionality only

- **Whs_group (opt)**
  - Valid entries are 'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', or 'j'. If left empty, default 'a' is used.
  - Group 'j' is a special 'must-be-included' group. **All warehouses in group 'j' will always be included in the selection** (which of course may affect the selection of warehouses from other groups).
  - Group can be interpreted as geographical region. By grouping warehouses per region, you can ensure that each region gets a warehouse, if you set the number to be selected from that group higher than 0.
- **Fixed_costs** are in fact binary-fixed costs, the fixed costs apply if a warehouse is selected.
- **Rate_1 to 5** are the warehousing cost per unit for up to 5 cost drivers (and linked to your customer table). Example: if customer X has Qty_1 = 10 and Qty_2 = 5, and warehouse Y has Rate_1 = 2.50, and Rate_2 = 3.75, then the variable costs of this customer X at warehouse Y are 10×2.50 + 5×3.75.

Suppliers (optional)

Mandatory fields

- **Activate constraint "Suppliers"** in section Parameters & constraints - Constraints to include suppliers.

- **Supplier_ID**: free format identifier.
- **Latitude, Longitude** is the result of converting a textual address into geographic coordinates - a process called geocoding. For more info, read the help text for fields Latitude, Longitude of Customers.
- **Supply** is the total yearly future supply of a supplier. Usually, the supply of all suppliers should - more or less - match the demand of all customers. Unless supply is about the dry ingredients of liquid finished products, for example.

Optional fields

- **Warehouse_IDs** (= link to table Predefined warehouses) is used to assign a supplier to a warehouse or subset of warehouses (similar to assigning a customer to a warehouse or subset of warehouses). If left empty, the software decides which Center(s) of Gravity is/are supplied by the supplier. If specified, then this supplier will not supply all warehouses directly, even if supply option "Each supplier delivers to each warehouse directly" has been selected.

  Activate constraint "Fixed customer-warehouse assignments" in section Parameters - Constraints.

- **Shipment_size** translates into an individual supplier transportation rate.
- **Supply_option** (1, 3, or 4) can be set to override the general supply option (1, 3, or 4) as selected in section Parameters - Supply options. General supply option 2 (LP optimized supply flows) can not be overridden at individual supplier level (individual settings are ignored).
- **Border_group** links the supplier to a border group. A border group has specific border crossing points to enter or exit the bordered area. Those border crossing points are defined in table Border Crossing Points. A flow from a supplier to a warehouse will go via one of the border crossing points, unless the warehouse and supplier are both inside the bordered area. Leave field empty if you want this functionality to be ignored for a particular supplier. **Border crossing points for suppliers only work with default supply option 3.**

  Activate constraint "Border crossing points" in section Parameters - Constraints.

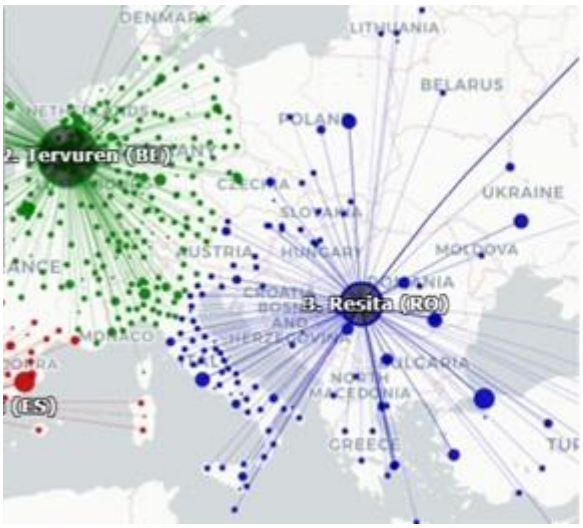
  For more info about suppliers, transportation rates, and supply options, read user manual section Logical steps - Step 4. Add suppliers

Border crossing points (optional)

Mandatory fields

- **Activate constraint "Border crossing points"** in section Parameters - Constraints.

- The use of border crossing points may improve distance accuracy and direction in which a Center of Gravity is pulled.
- If an area can only be entered/exited at some specific points, you may enter these border crossing points.
- A transportation flow must go via a border crossing point if
  - a warehouse is outside the bordered area and the customer inside ("entry")
  - a warehouse is inside the bordered area and the customer outside ("exit")
- A flow via a border crossing point means a detour. The border crossing point causing the smallest detour is auto-detected. It also means that the warehouse is pulled towards this point instead of the customer, until the border has been crossed.
- **Border_group** - free format - is the name of the bordered area with all its crossing points (latitude, longitude) entered in this table. Field border_group is also found in the customers table and used to specify which customers belong to the border group (thus defining its geographic shape). **To function properly at least some customers of a bordered area should be located close to the border point** (within a 50 km range).
- In the picture on the right the border crossing points in the northern part of Italy prevent shortcuts across the Adriatic Sea. If ferries are a valid transportation option, then you may remove all border crossing points or add ferry harbors as points.
- Current implementation handles only one border crossing point per flow, not multiple. A warehouse area exit point takes priority over a customer area entry point: "exit before entry". A warehouse area entry point takes priority over a supplier area exit point.





Border crossing points are not meant for modeling flows via sea/airports

As described in section Customers, demand of far away regions reached by air/sea should be put at exit port, instead of far away region itself (and especially if no warehouse should end up in that region). Similarly, supply coming from far away regions should be put at entry port. Sea/air lanes can neither be entered nor optimized with the software (not its purpose), hence these lanes should be excluded. Any sea/air lane would be considered trucking lane, and the selected border crossing point would be (partly) based on sea/air lane distance. This would make no sense, as truck rates do not compare to sea/air rates. **It would cause false optimization.**

The only valid reason for wanting to include sea/air lanes would be for "picture only". For "picture only": see also Map Maker, a free app providing full manual control over locations and flows to be depicted.

Constraints

Intro

By (de)activating **constraints (optional)** in section Parameters - Constraints you (de)activate parts of your input data, so you can quickly investigate how a constraint affects goal value and supply chain network structure.

The following explains the links between constraints and input tables. Similar info is provided in previous sections. But this section is more focused. It also describes demo data, so you can check how a constraint is set up.

1. ☐ Predefined warehouses
2. ☐ Fixed customer-warehouse assignments
3. ☐ Fixed supplier-warehouse assignments
4. ☐ Capacity limits
5. ☐ LP optimization
6. ☐ Customer groups
7. ☐ Suppliers → Also select a supply option
8. ☐ Border crossing points

Predefined warehouses table

- **Ad 1.** Activate **constraint "Predefined warehouses"** to include predefined warehouses in the solution.
  Demo: contains one predefined warehouse in Birmingham (UK) and one in Madrid (Spain), with **field Move_limit** set to 0 for the Birmingham warehouse (it cannot move), and set to 200 for the Madrid warehouse (it can move within a 200 km range). If the number of Centers of Gravity is set higher than two, then these two locations will be part of the solution (Birmingham remains Birmingham, Madrid is moved to Guadalajara if running for 3 Centers of Gravity). If you make Madrid's Move_limit 0, it will remain Madrid.

  Note
  In fact, the demo contains 22 more warehouses. As these can all move freely around (9999 km), they can not really be considered predefined for the Centers of Gravity calculation, and they might just as well have been left out. They have been added to demonstrate the "Select warehouses" functionality (that selects only, and does not relocate warehouses).

- **Ad 4.** Activate **constraint "Capacity limits"** to limit total customer demand that can be assigned to the warehouse.
  Demo: **field Capacity** is set for both predefined warehouses Birmingham and Madrid.

- **Ad 5.** For more info about capacity limits and **LP optimization**, read user manual section Center of Gravity algorithms - Warehouse capacity limits.

Customers table

- **Ad 2.** Activate **constraint "Fixed customer-warehouse assignments"** to assign customers to a predefined warehouse (or subset of predefined warehouses).
  Demo: **field Warehouse_IDs** is set to "Birmingham" for all customers in UK/Ireland to assign them to the predefined Birmingham warehouse. It is set to "Madrid" for all customers in Spain/Portugal.

- **Ad 6.** Activate **constraint "Customer groups"** to have all customers within the same group delivered by the same single warehouse that can deliver to the group against lowest transportation costs. These costs are still calculated at individual customer level, see example in user manual section Center of Gravity algorithms - Customer grouping.
  Demo: **field Group** is filled with the applicable ISO 3166-1 alpha-2 country code for all customers. So - in the demo - group stands for country. This prevents customers in Western France to get delivered by the UK warehouse.

- **Ad 8.** Activate **constraint "Border crossing points"** to include border crossing points.
  Demo: **field Border_group** is filled for customers in UK, IE, Italy, and Iberia.

Suppliers table

- **Ad 7.** Activate **"Suppliers"** to include suppliers. **Also select a** supply option.
  Demo: contains one supplier in Rotterdam (The Netherlands - Entry harbor supplying 71% total demand), and one in Bologna (Italy).

- **Ad 3.** Activate **constraint "Fixed customer-warehouse assignments"** to assign suppliers to a predefined warehouse. It links to **field Warehouse_ID**. If filled, then the supplier will only supply this warehouse. And via this warehouse to each other warehouse, if supply option "Each supplier delivers to each warehouse via closest warehouse" is selected.
  Note that if field Warehouse_ID is filled, then a supplier will never supply all warehouses directly, even if supply option "Each supplier delivers to each warehouse directly" has been selected.

Border crossing points table

- **Ad 8.** Activate **constraint "Border crossing points"**.
  Demo: **field Border_group** relates to the same field found in the customer table and specifies which border crossing points (if any) are applicable for which customers. The demo contains a limited number of border crossing points in Italy, Iberia, UK/Ireland, just to show you how this concept works.

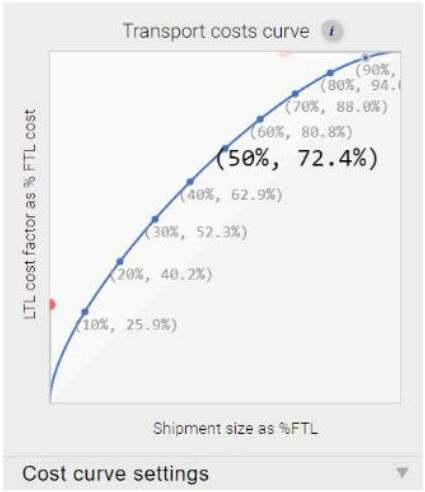
Transportation rates

Intro

In section Parameters - Transportation rates you set transportation rates to differentiate between customer and supplier transport. You may also adjust the cost curve that expresses how much - relatively - more expensive smaller shipments (LTL-like transport) are compared to larger shipments (FTL-like transport).

Transportation costs curve

Smaller shipments being relatively more expensive than larger shipments is expressed in the transportation costs curve. The default cost curve shows that a shipment size of 50% FTL brings 72.4% FTL costs, meaning that - per each unit transported - it is 1.45 times more expensive than FTL transport. You can **adjust the curve by dragging control point handles** or entering control point values in the cost curve settings below the chart.



Small customer shipments versus large supplier shipments

In logistics, smaller shipments to customers are relatively more expensive than larger shipments from suppliers. **Average customer and supplier shipment sizes** - as set in the transportation rates table - are translated into rates by applying the cost curve.

Shipment size can be expressed in KG, M3, pallets, loading meters, ... It should relate to how you have expressed customer demand, as a single transportation unit of measurement applies to the whole model.

	Shipment size	% FTL	See curve % FTL costs	Cost ratio	Cost/km	Cost/km/qty
Full Truck Load	25000	100.00%	100.00%	1.000000	1.25	0.000050000
Customer	800	3.20%	12.95%	4.046175	0.161847	0.000202308
Supplier	20000	80.00%	93.96%	1.174459	1.174459	0.000058722
Inter-warehouse	20000	80.00%	93.96%	1.174459	1.174459	0.000058722

Centers of Gravity depend on **ratio supplier rate/customer rate =** 0.290264

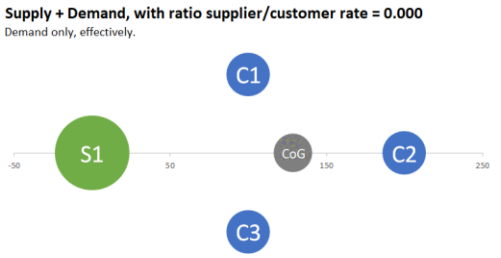
The ratio supplier/customer rate is important as it expresses how relatively less suppliers pull warehouses than customers do. This ratio is independent of cost/km. Therefore, **high accuracy of cost/km is of lesser importance**.

Ratio supplier rate/customer rate

The ratio supplier rate/customer rate expresses how relatively less suppliers pull warehouses than customers do. To minimize transportation costs, a Center of Gravity should move closer towards a customer than towards a supplier, if their total transportation volumes would be equal, regardless of distance!

Keep in mind that a supplier is not just a small customer as they can pull all warehouses. Read user manual section Logical steps - Step 4. Add suppliers for more info.

Animated calculation of how ratio affects Center of Gravity



Location	X	Y	Quantity	Rate	Distance	Costs *
Customer C1	100	50	1	$ 1.00	57.73	$ 57.73
Customer C2	200	0	1	$ 1.00	71.13	$ 71.13
Customer C3	100	-50	1	$ 1.00	57.74	$ 57.74
Supplier S1	0	0	3	$ -	128.87	$ -
Center-of-Gravity	**128.87**	**0.00**			**Total costs**	**$ 186.60**

* Costs = Quantity x Rate x Distance

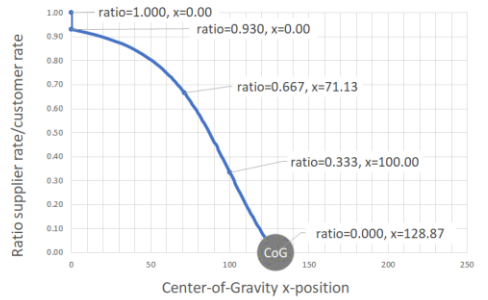


Chart can be verified by geometry that brings the following formula for the Center of Gravity x-position = max(0, 100 + 50 × F / √(1 - F²)), with F = (1 - 3 × ratio)/2. F stands for pull force in horizontal direction - of both customer C1 and C3 - required to reach an equilibrium state.

It is easy to understand that x-position becomes exactly 100 at ratio 1/3, as supply quantity of 3 × 1/3 balances with C2 quantity of 1, and C1 and C3 then pull it to 100.

For a ratio ≥0.93 the supplier pull force outweighs customer pull forces, so the Center of Gravity ends up on top of the supplier. This 0.93 is in fact (1+2×1/√(1²+0.5²))/3 = (1+4/√5)/3 = 0.9296...

Small customer shipments versus large customer shipments

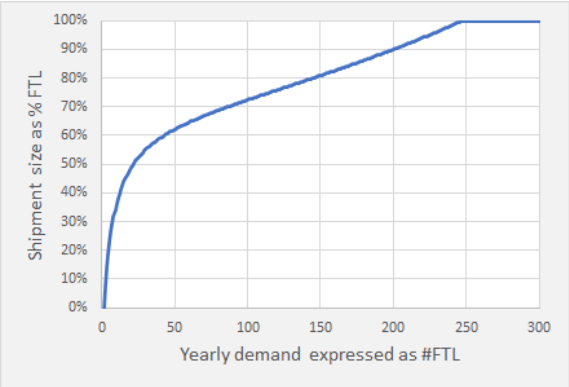
Similarly, in logistics, shipments to small customers are relatively more expensive than shipments to large customers. To differentiate you can enter **individual shipment sizes** at individual customer (and also at individual supplier level). The impact of individual shipment size on Centers of Gravity may be small, if smaller and larger customers are scattered all around.

	Shipment size	% FTL	See curve % FTL costs	Cost ratio	Cost/km	Cost/km/qty
Full Truck Load	25000	100.00%	100.00%	1.000000	1.25	0.000050000
Customer	800	3.20%	12.95%	4.046175	0.161847	0.000202308
Supplier	20000	80.00%	93.96%	1.174459	1.174459	0.000058722
Inter-warehouse	20000	80.00%	93.96%	1.174459	1.174459	0.000058722

Centers of Gravity depend on **ratio supplier rate/customer rate =** 0.290264

Auto-sizing shipments per individual customer

Calculates individual shipment sizes, replacing the average customer shipment size as set in transportation costs table, assuming shipments to larger customers are larger and shipments to smaller customers are smaller. The chart shows the assumed relation between demand volume and shipment size.



As this method is rough, **it is better to enter actual individual shipment sizes in the customer table than to activate auto-sizing.**

Displaying transport-rated volumes on the map

In section Map settings you can choose to display location sizes as transport-rated volumes (volume × rate ratio), instead of plain volumes (default setting). Suppliers will then appear relatively smaller than customers, which better reflects the Center of Gravity 'pull forces' of suppliers and customers.

Inter-warehouse flows

A default model looks like: (suppliers →) warehouses → customers
But you can also model: (suppliers →) warehouses → warehouses → customers

There are two options to model inter-warehouse flows.

1. **In a model with suppliers: Select supply option "Each supplier delivers to each warehouse via closest warehouse".**
   Closest warehouse can be overridden by specifying a predefined warehouse in field Warehouse_IDs of the supplier table. Supply quantities (that are related to demand quantities) determine warehouse-warehouse flow quantities.

2. **In a model without suppliers: Set up predefined warehouses, some as main warehouse (field IsSatellite=0), some as satellite (IsSatellite=1).**
   Each satellite gets supplied by its closest warehouse. Satellite demand quantities determine warehouse-warehouse flow quantities.

You can combine it with forcing a link between a customer/supplier and a (subset of) warehouse(s) by entering field Warehouse_IDs.

In general, **try to keep your model simple**. Its purpose is to help answer questions. That does not necessarily mean it should reflect reality as closely as possible. For example, if all suppliers deliver to a single plant (main warehouse), and the plant delivers to warehouses that deliver to customers, you can create a 2-echelon model with plant (main warehouse) → warehouses. But if that plant location is fixed, then there is no possibility to optimize suppliers→plant flows. So, you may consider replacing all suppliers and plant with a single fake supplier at (previously) plant location, and revert to a simple 1-echelon model.

Note: "Select warehouses" routine does not support inter-warehouse flows.

Appendix: customer aggregation suggestions

- **You may round customer latitudes and longitudes to two decimals, then aggregate demand per rounded-latitude-and-longitude-category.** By rounding a customer may shift 0.78 km (0.5 mile) from its original position, at most. This 0.78 km is the as-the-crow-flies distance between (latitude, longitude) point (0.000, 0.000) and (0.005, 0.005). The further away from the Equator, the smaller this maximum shift becomes. At a 'European' latitude of 44.000 it is 0.68 km, at most. On average, customers shift approx. 0.37 km, which is unnoticeable on the map. Moreover, all customer shifts together will largely counterbalance each other, **so Centers of Gravity shift a negligible 0.0-0.1 km.**

  The built-in **aggregation tool** applies a more precise variant. It calculates the weighted average latitude and longitude of customers within each aggregation category as aggregated customer coordinates. (It also calculates cost neutral aggregated shipment sizes, which requires reversed interpolation of the transport cost curve.)

- **You may aggregate demand per 2-digit postal code, per country** if creating a supply chain model for total Europe. Each country becomes 100 customers, at most. For example, customer DE-13 stands for all German customers with postal code 13XXX (ISO 3166-1 alpha-2 country code for Germany is DE). On a side note: transportation rate tables often use aggregated postal code zones, so they are only accurate to that level as well.
  Add 2-digit postal code to each customer. Create a pivot table to sum demand per 2-digit postal code. Use geocodes of largest customer with that 2-digit postal code to locate aggregated demand (no need to geocode all customers). Or use geocodes from geocodes of EU countries 2-digit postal codes (use file at your own risk).

  If your case is about a single country, then aggregating at 3-digit postal code level may be more appropriate. This will result in a model with 1000 customers, at most.

- The appropriate level of aggregation depends on geographical scale and average warehouse-customer distances. The larger the scale, the longer the distance, the larger the aggregation range may become. And vice versa.

- The software itself contains two subsections that explain how the built-in **aggregation tool** works, and a subsection showing three aggregation case examples. You can check the last case for yourself, as it is based on demo data.