Advanced skills in CPLEX-based network optimization in anyLogistix

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Additional teaching note to the e-book “Supply Chain Simulation and Optimization with anyLogistix” (2017)

https://www.anylogistix.com/upload/alx-book.pdf

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Foreward

The objective of this teaching note is to explain the principles and techniques on supply chain design and planning analysis using the network optimization tool anyLogistix on the basis of CPLEX. The target audience is management and engineering students and professionals who would like to learn the skills of supply network optimization. anyLogistix is an easy-to-understand tool which students and professionals can use to address a wide range of supply chain management (SCM) problems. This guide explains how to use anyLogistix to create supply chain facility location and planning models, conduct experiments and analyze the results. By reducing technical complexity to a minimum, anyLogistix allows students and professionals without an engineering background to focus on management decision analysis and use KPIs for operational, customer and financial performance measurement and decision-making.

This guide considers three problem statements:

- two-stage capacitated facility location planning,
- three-stage and four-stage supply chains, and
- supply chain-based risk management.

It presents optimization examples by describing how to develop and build models and evaluate KPI. It also discusses how to use these models and optimization results to improve management decision-making.

Because this guide is focused on management issues, it uses simple terms to describe model developments. If you want to import sample models and use them to perform experiments, you can open the anyLogistix's **File** menu and then click **Import**.

Please excuse any errors in the text and formatting. This guide is a work in progress and we welcome any comments and suggestions that may help us improve it.

In this guide, we focus on advanced issues in network optimization in anyLogistix. For introductory notes to anyLogistix and advanced simulation skills, please consult the e-book "Supply Chain Simulation and Optimization with anyLogistix" from the same author (https://www.anylogistix.com/upload/alx-book.pdf).

This guide's author has also co-authored the textbook "Global Supply Chain and Operations Management" by Springer (http://www.springer.com/us/book/9783319242156) and its companion web site *http://global-supply-chain-management.de* where additional AnyLogic and AnyLogistix models can be found. In addition, he has also authored the e-book "Operations and Supply Chain Simulation with AnyLogic" (http://www.anylogic.com/books).

The author is deeply grateful to the AnyLogic Company for their valuable feedback and suggestions for improvement.

Optimization-based decision-making

An optimal decision is the best decision which can be made according to some goal, criteria or objectives. *Optimization* is an analysis method that determines the best possible option for solving a particular supply chain management problem. An optimization model comprises an objective function, a constraint system, and a set of decision variables and input parameters.

The optimization model-based decision-making process is shown in Fig. 1.

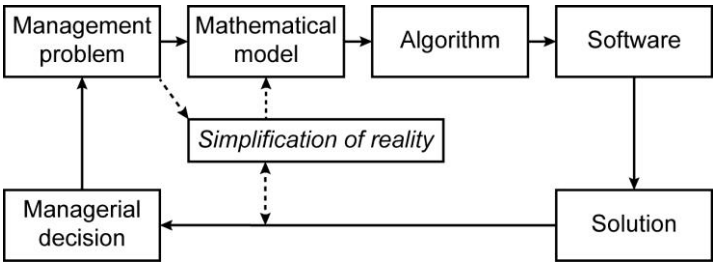


Fig. 1. Optimization model-based decision-making process (Ivanov et al. 2017)

We can observe that a *real management problem* is the initial point of the decision-making process. For example, this could be a facility location problem where we are given demand in some markets, possible locations and capacities of new facilities, fixed costs for having a facility in the supply chain, and transportation costs from each location to each market. We are trying to decide where to locate the facilities and which quantities should be shipped from the facilities to the markets.

The next step is to transform the real problem into a *mathematical model*. For this transformation, we need to reduce the *complexity* of reality. This inevitably results in simplification of reality. For example, we assume deterministic capacity in our facility location model instead of considering fluctuations in demand.

We simplify to make it possible to represent the management problem in the mathematical model in such a way that this model can be solved with the helped of existing *algorithms* in a reasonable time. In our example, we formulate the facility location problem as a mixed-integer linear programming model that can be solved with the help of simplex and branch&bound algorithms.

For implementation of the mathematical model, *software* is needed. The professional solver CPLEX is used in anyLogistix. Software will calculate the *solution*. In our example, the solution would include suggestions on where to open facility locations and which product quantities should be shipped from each opened location to each of the markets so that total production and logistics costs are minimal.

Software calculates this solution. Now, the most important question is as follows: is this solution automatically our *decision*? NO! This is a solution to the mathematical problem. Management expertise is needed to transfer this mathematical solution into managerial decisions. First of all, the simplifications of reality should be reviewed. Second, so called *soft facts* such as risks, flexibility, etc. should be included in the analysis. This need for managerial expertise is why we call these models *decision-supporting quantitative methods*.

Note: The drawback of using optimization is the difficulty in developing a model that is sufficiently detailed and accurate in representing the complexity and uncertainty of the SCM, while keeping the model simple enough to be solved. Optimal decisions are “fragile” and presume certain problem dimensionality, fullness, and certainty of the model. In addition, the optimal solutions are usually very sensitive to deviations. Moreover, decision making is tightly interconnected with dynamics and should be considered as an adaptive tuning process and not as a “one-way” optimization.

Optimization can also be applied as a validation tool for simulation models which can be run using the optimization results (Figure 2).

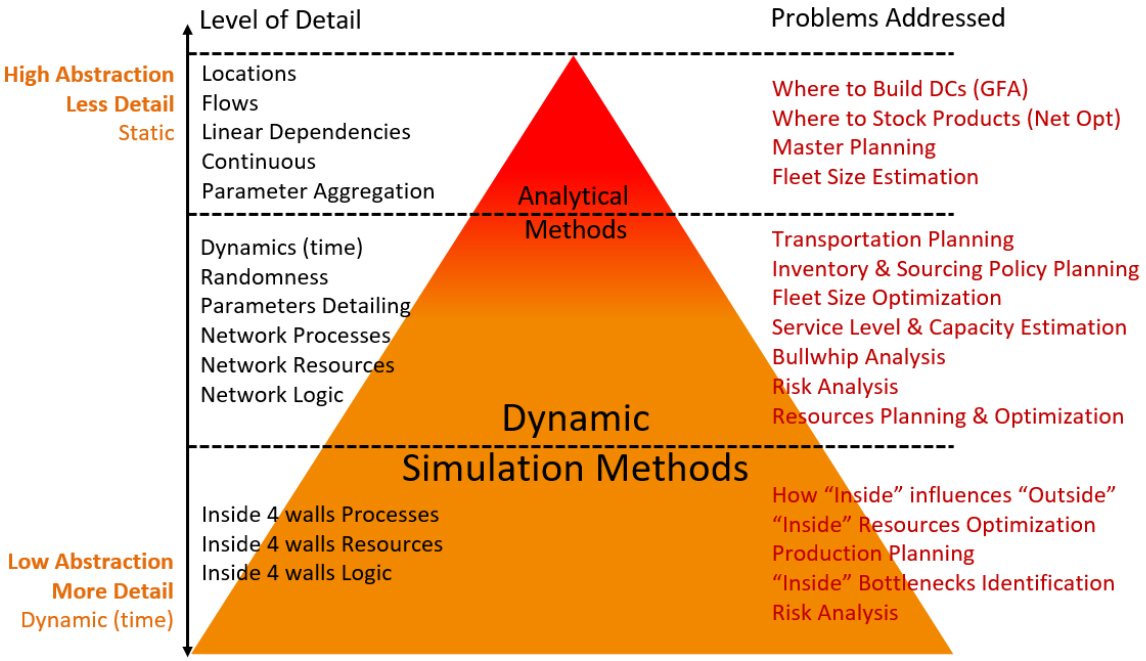


Fig. 2. A pyramid of supply chain design and analysis problems

Analytical optimization methods are used to define the supply chain design with aggregate parameters such as annual capacities, demands, etc. Using a number of parameters such as transportation costs, real routes, and feasible facility locations, it becomes possible to perform network optimization.

By reducing the aggregation and abstraction level, we extend the analytical network optimization models through simulation. In comparison to analytical closed form analysis, simulation has the advantage that it can handle complex problem settings with situational behaviour changes in the system over time. The simulations in anyLogistix can be run using the optimization results and include additional, time-dependant inventory, production, transportation, and sourcing control policies which are difficult to implement at the network optimization level.

Chapter 1 Three-stage, one-period supply network design

You are a supply chain manager at a company that produces beverages. Your task is to design a new supply chain with the highest possible profit. In the reports from different departments at the company you collected the following data:

- Potential locations of your distribution centers (DC) and factories
- Demand in the markets
- Factory production capacities
- Processing capacity at the DCs
- Product price
- Transportation, inventory holding and processing costs at the DCs

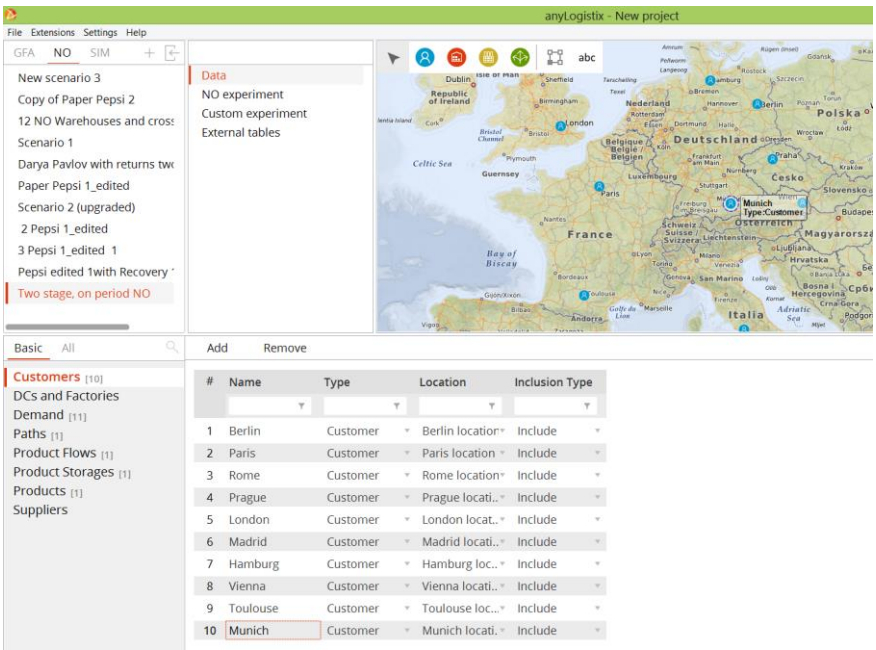
Table 1 Input parameter

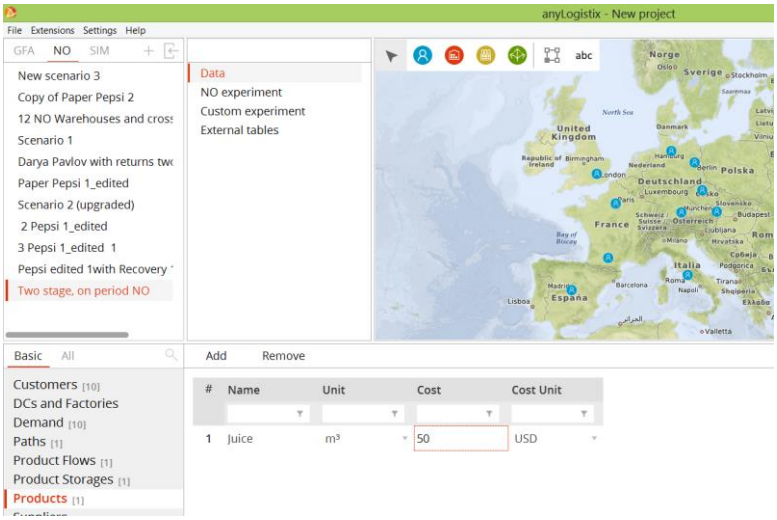
Parameter	**Values**
Demand in the markets, in m^3	730
Transportation distances and time in between supply chain facilities	Determined automatically by actual routes*
Maximum inbound DC processing capacity, in m^3 per day	3,000
Maximum outbound DC processing capacity, in m^3 per day	3,000
Maximum production capacity at own factory, in m^3 per year	3,800
Penalties for overutilization of production capacity, in $	100,000
Unit price, in $ for m^3	3,000
Fixed facility costs, in $ per day	5,000
Transportation costs, in $ per km, per m^3	0.1
Production costs at own factories, per product unit (m^3), in $	250
Inbound processing costs at the DC, in $, per m^3	150
Outbound processing costs at the DC, in $, per m^3	100
Penalty for demand non-fulfillment, in $, per m^3	5,000

* Automated transportation distance and time determination are some advantages of anyLogistix. We do not need to determine a large-scale distance matrix. Both distances and times are determined automatically by the software using real routes and real truck speeds.

Input data

Customers and demand





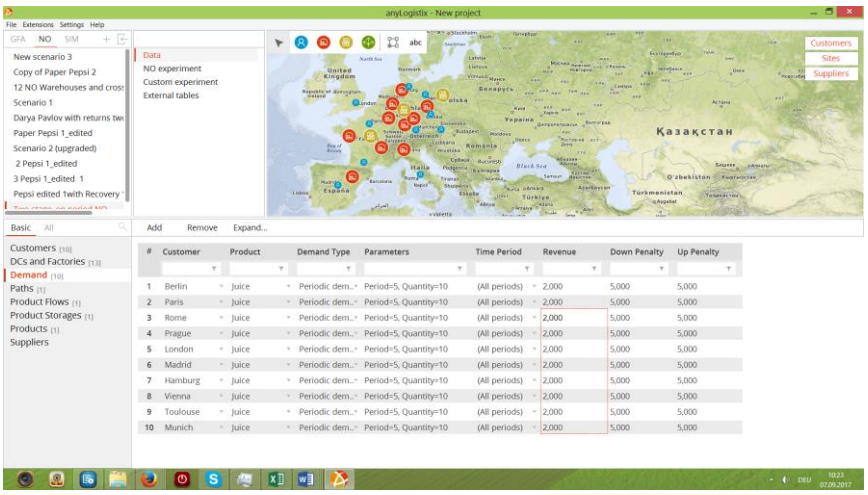
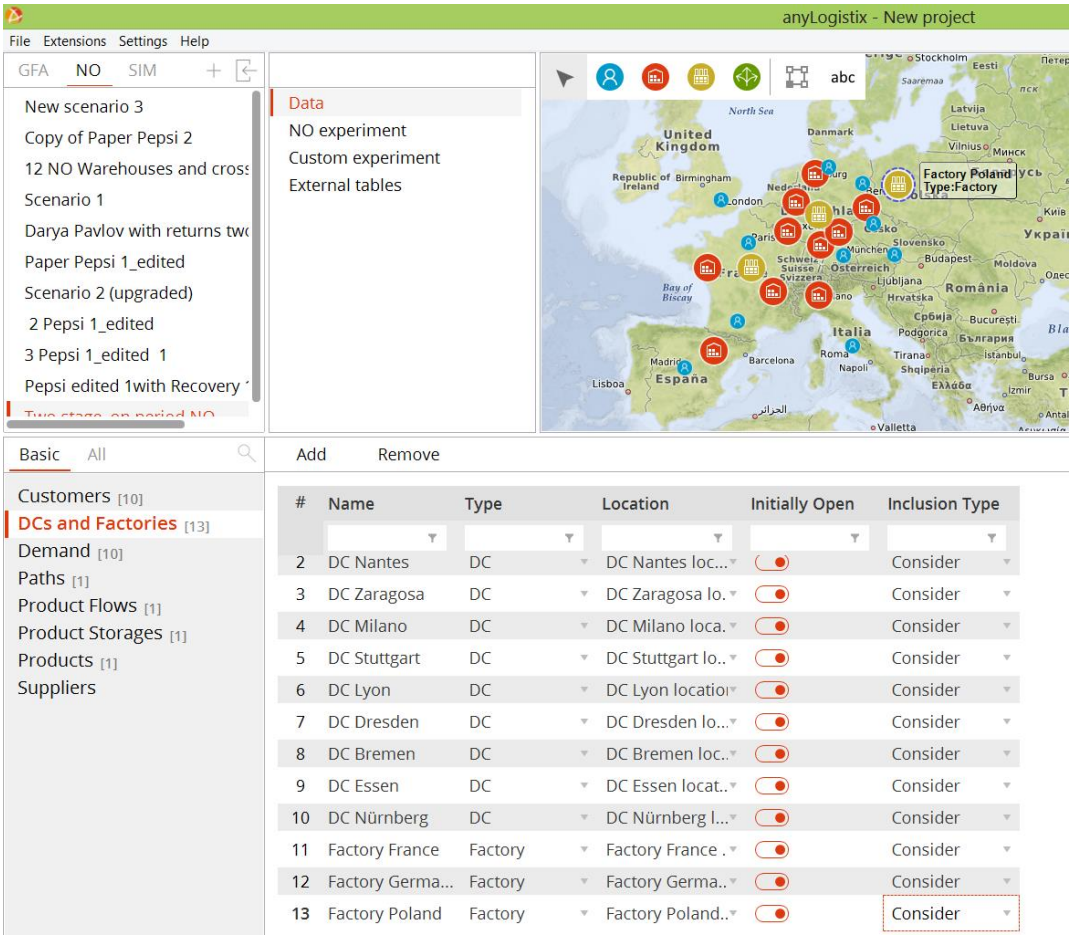


Fig. 3. Input data for customers and demand

DCs and factories



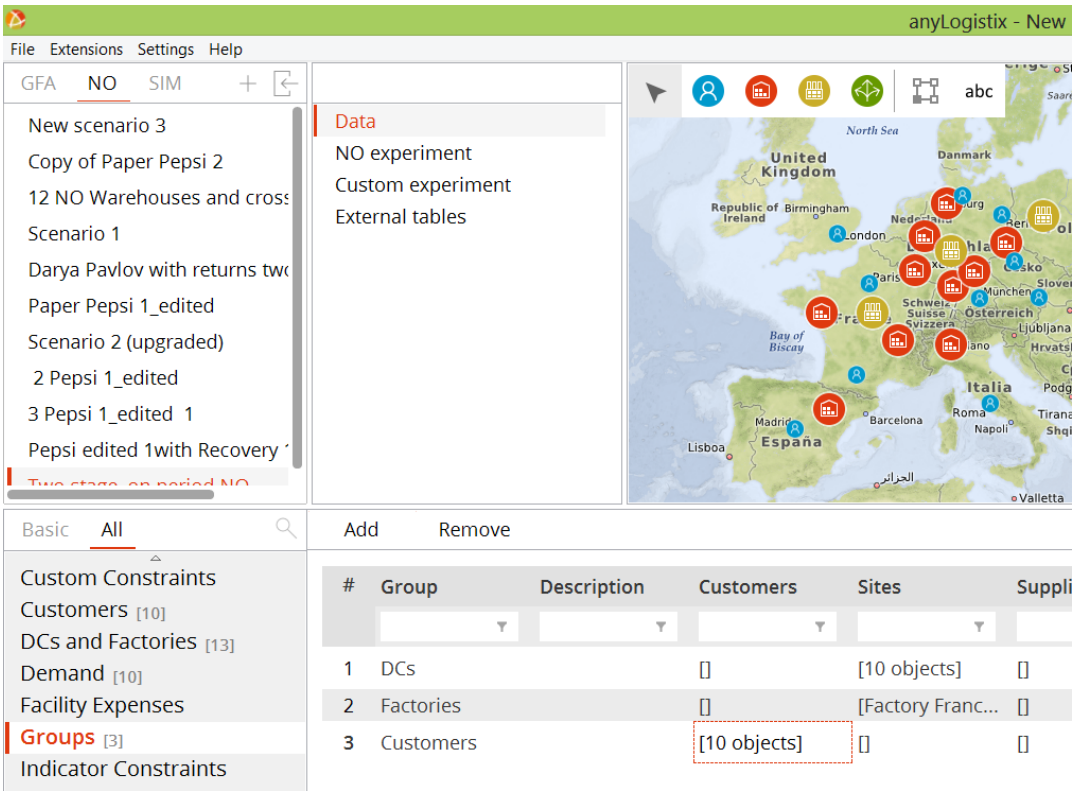


Fig. 4. Setting sites and grouping them

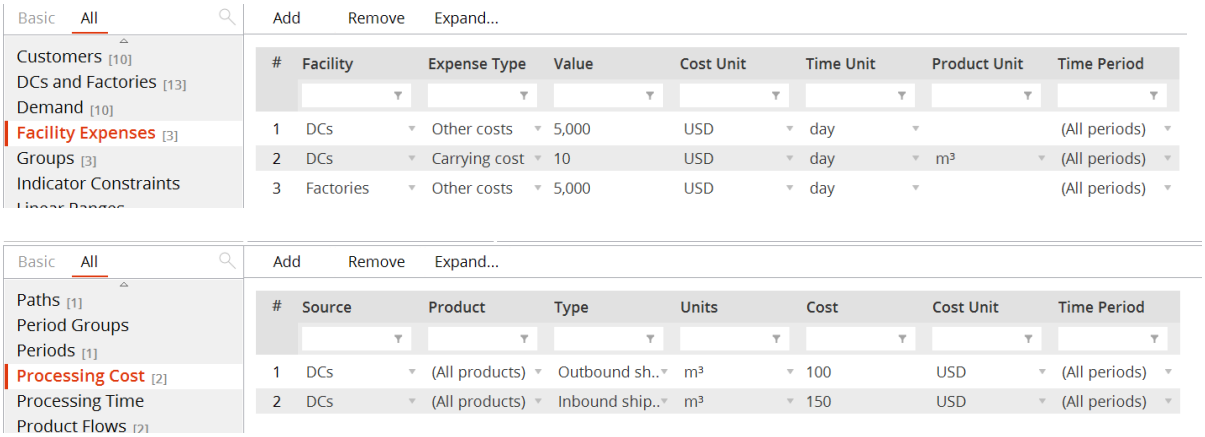


Fig. 5. Costs settings

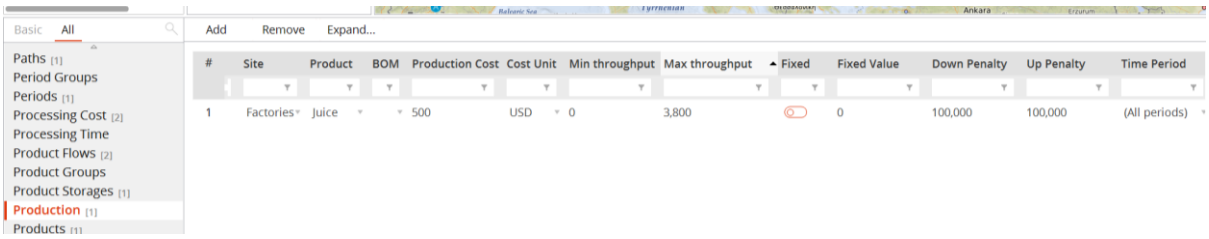


Fig. 6. Production capacity and costs

In Fig. 6, we depict how to set up the production capacity restriction at factories. The production capacity maximum needs to be entered in the column "**Max Throughput**" (if you need to restrict the minimum capacity level, please use the respective column).

Note: In order to activate this constraint, you need to setup any large number in the columns "**down penalty**" and "**up penalty**".

Paths and flows

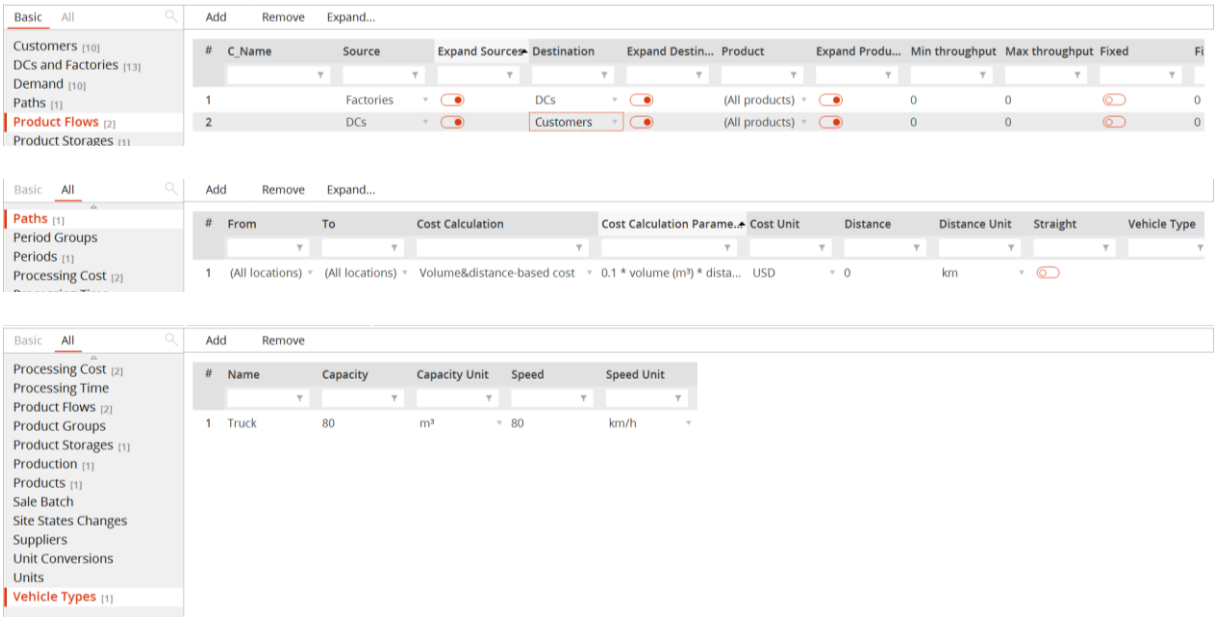


Fig. 7. Path and flow settings

Network optimization experiments

In NO → Experiment, we start the network optimization for the given data:

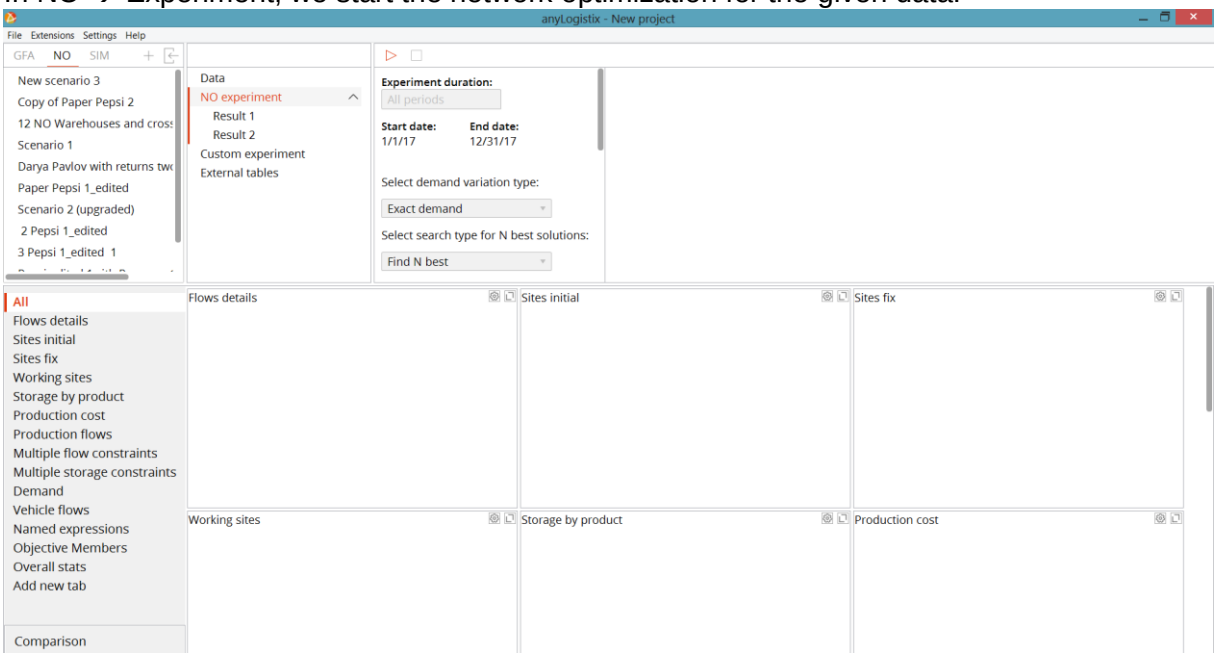
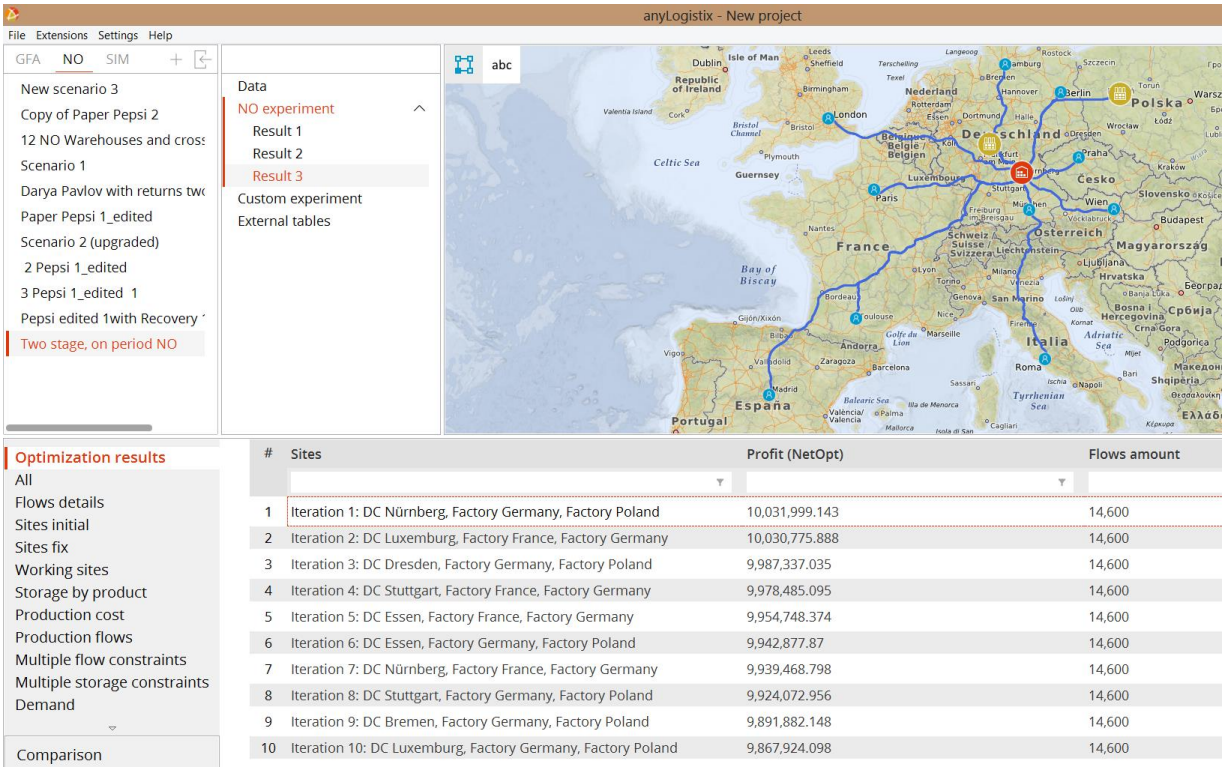


Fig. 8. Start of network optimization experiment

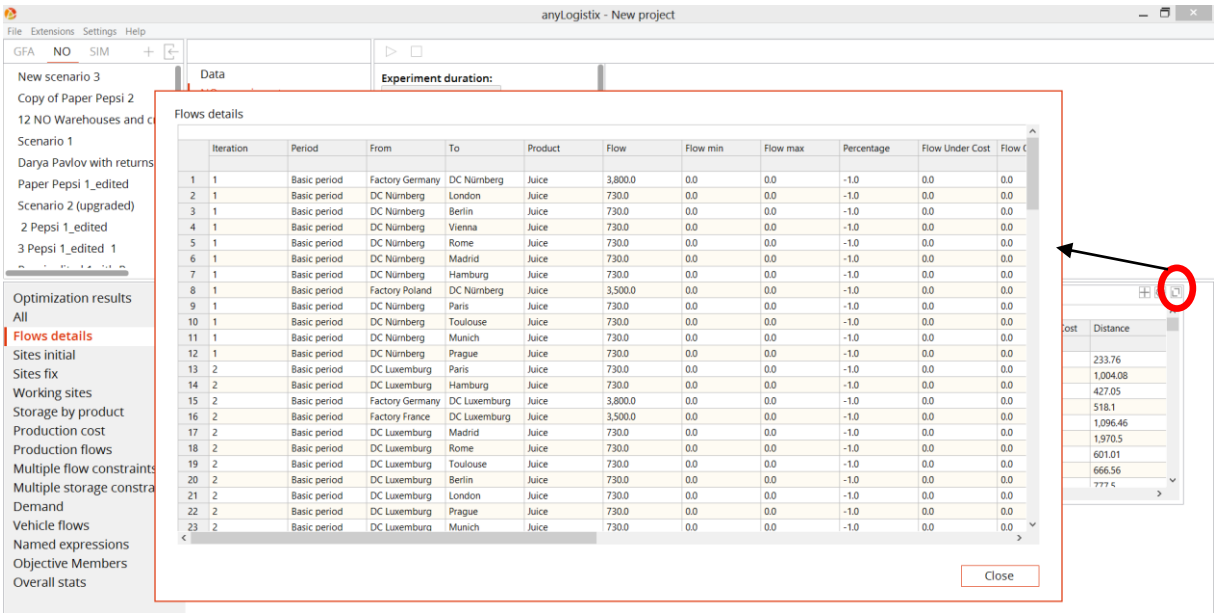
The results are shown in Figs 9-12.



#	Sites	Profit (NetOpt)	Flows amount
1	Iteration 1: DC Nürnberg, Factory Germany, Factory Poland	10,031,999.143	14,600
2	Iteration 2: DC Luxemburg, Factory France, Factory Germany	10,030,775.888	14,600
3	Iteration 3: DC Dresden, Factory Germany, Factory Poland	9,987,337.035	14,600
4	Iteration 4: DC Stuttgart, Factory France, Factory Germany	9,978,485.095	14,600
5	Iteration 5: DC Essen, Factory France, Factory Germany	9,954,748.374	14,600
6	Iteration 6: DC Essen, Factory Germany, Factory Poland	9,942,877.87	14,600
7	Iteration 7: DC Nürnberg, Factory France, Factory Germany	9,939,468.798	14,600
8	Iteration 8: DC Stuttgart, Factory Germany, Factory Poland	9,924,072.956	14,600
9	Iteration 9: DC Bremen, Factory Germany, Factory Poland	9,891,882.148	14,600
10	Iteration 10: DC Luxemburg, Factory Germany, Factory Poland	9,867,924.098	14,600

Fig. 9. Network optimization results

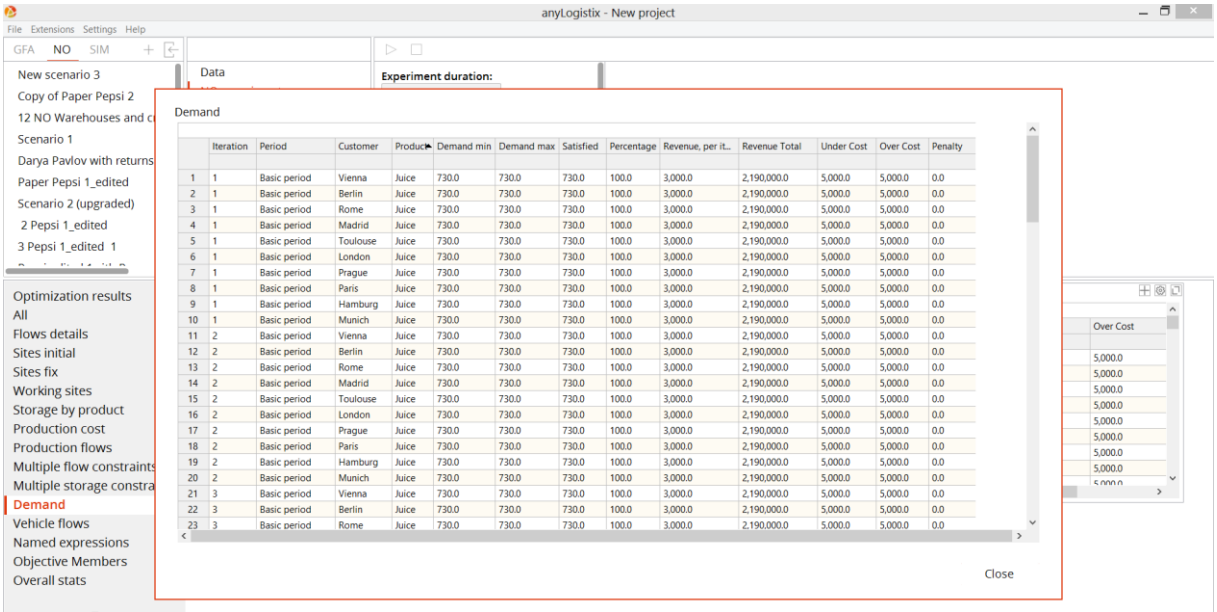
It can be observed in Fig. 9 that the supply chain design with two factories in Germany and Poland and a DC in Nuernberg earns the highest profit.



	Iteration	Period	From	To	Product	Flow	Flow min	Flow max	Percentage	Flow Under Cost	Flow C
1	1	Basic period	Factory Germany	DC Nürnberg	Juice	3,800.0	0.0	0.0	-1.0	0.0	0.0
2	1	Basic period	DC Nürnberg	London	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
3	1	Basic period	DC Nürnberg	Berlin	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
4	1	Basic period	DC Nürnberg	Vienna	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
5	1	Basic period	DC Nürnberg	Rome	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
6	1	Basic period	DC Nürnberg	Madrid	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
7	1	Basic period	DC Nürnberg	Hamburg	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
8	1	Basic period	Factory Poland	DC Nürnberg	Juice	3,500.0	0.0	0.0	-1.0	0.0	0.0
9	1	Basic period	DC Nürnberg	Paris	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
10	1	Basic period	DC Nürnberg	Toulouse	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
11	1	Basic period	DC Nürnberg	Munich	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
12	1	Basic period	DC Nürnberg	Prague	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
13	2	Basic period	DC Luxemburg	Paris	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
14	2	Basic period	DC Luxemburg	Hamburg	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
15	2	Basic period	Factory Germany	DC Luxemburg	Juice	3,800.0	0.0	0.0	-1.0	0.0	0.0
16	2	Basic period	Factory France	DC Luxemburg	Juice	3,500.0	0.0	0.0	-1.0	0.0	0.0
17	2	Basic period	DC Luxemburg	Madrid	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
18	2	Basic period	DC Luxemburg	Rome	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
19	2	Basic period	DC Luxemburg	Toulouse	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
20	2	Basic period	DC Luxemburg	Berlin	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
21	2	Basic period	DC Luxemburg	London	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
22	2	Basic period	DC Luxemburg	Prague	Juice	730.0	0.0	0.0	-1.0	0.0	0.0
23	2	Basic period	DC Luxemburg	Munich	Juice	730.0	0.0	0.0	-1.0	0.0	0.0

Fig. 10. Optimal flows

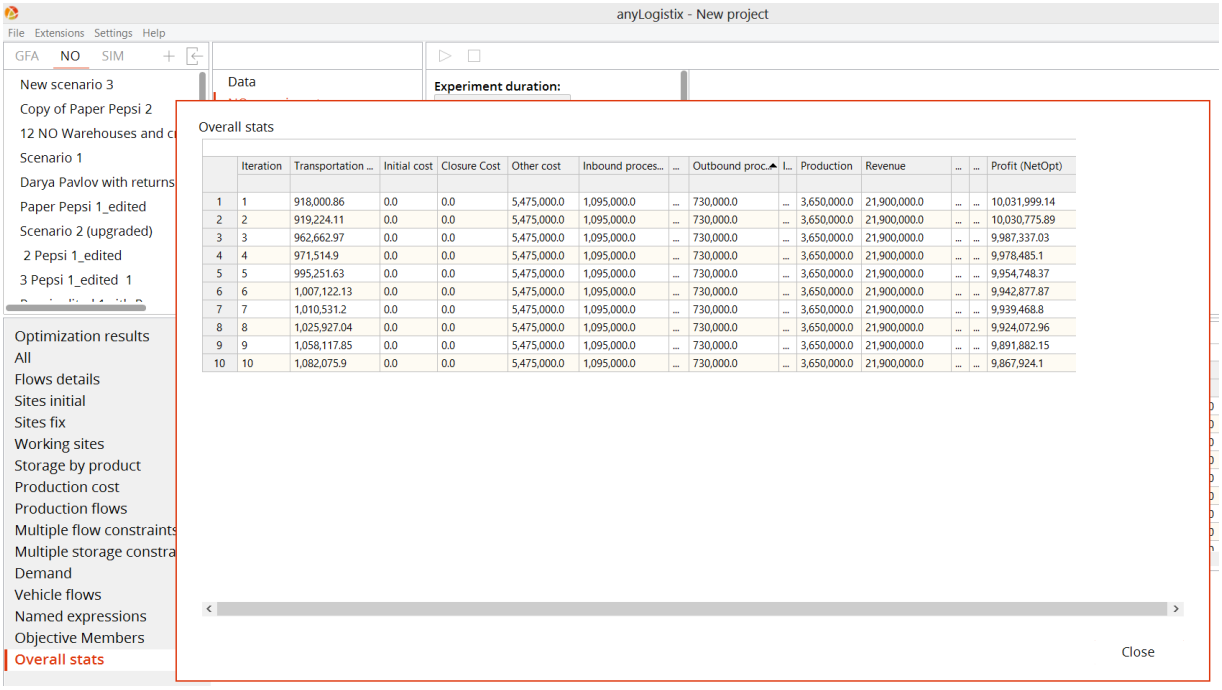
In Fig. 10, supply chain material flows for the optimal and other possible design are presented.



	Iteration	Period	Customer	Product	Demand min	Demand max	Satisfied	Percentage	Revenue, per it...	Revenue Total	Under Cost	Over Cost	Penalty
1	1	Basic period	Vienna	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
2	1	Basic period	Berlin	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
3	1	Basic period	Rome	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
4	1	Basic period	Madrid	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
5	1	Basic period	Toulouse	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
6	1	Basic period	London	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
7	1	Basic period	Prague	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
8	1	Basic period	Paris	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
9	1	Basic period	Hamburg	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
10	1	Basic period	Munich	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
11	2	Basic period	Vienna	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
12	2	Basic period	Berlin	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
13	2	Basic period	Rome	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
14	2	Basic period	Madrid	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
15	2	Basic period	Toulouse	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
16	2	Basic period	London	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
17	2	Basic period	Prague	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
18	2	Basic period	Paris	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
19	2	Basic period	Hamburg	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
20	2	Basic period	Munich	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
21	3	Basic period	Vienna	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
22	3	Basic period	Berlin	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0
23	3	Basic period	Rome	Juice	730.0	730.0	730.0	100.0	3,000.0	2,190,000.0	5,000.0	5,000.0	0.0

Fig. 11. Demand fulfillment analysis

Fig. 11 shows that the demands in all the markets are 100% covered in the optimal solution.



	Iteration	Transportation ...	Initial cost	Closure Cost	Other cost	Inbound proces...	...	Outbound proc...	I...	Production	Revenue	...	...	Profit (NetOpt)
1	1	918,000.86	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	10,031,999.14
2	2	919,224.11	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	10,030,775.89
3	3	962,662.97	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,987,337.03
4	4	971,514.9	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,978,485.1
5	5	995,251.63	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,954,748.37
6	6	1,007,122.13	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,942,877.87
7	7	1,010,531.2	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,939,468.8
8	8	1,025,927.04	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,924,072.96
9	9	1,058,117.85	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,891,882.15
10	10	1,082,075.9	0.0	0.0	5,475,000.0	1,095,000.0	...	730,000.0	...	3,650,000.0	21,900,000.0	...	...	9,867,924.1

Fig. 12. Start of network optimization experiment

Finally, the financial performance report on the optimal and other possible supply chain designs is shown in Fig. 12.

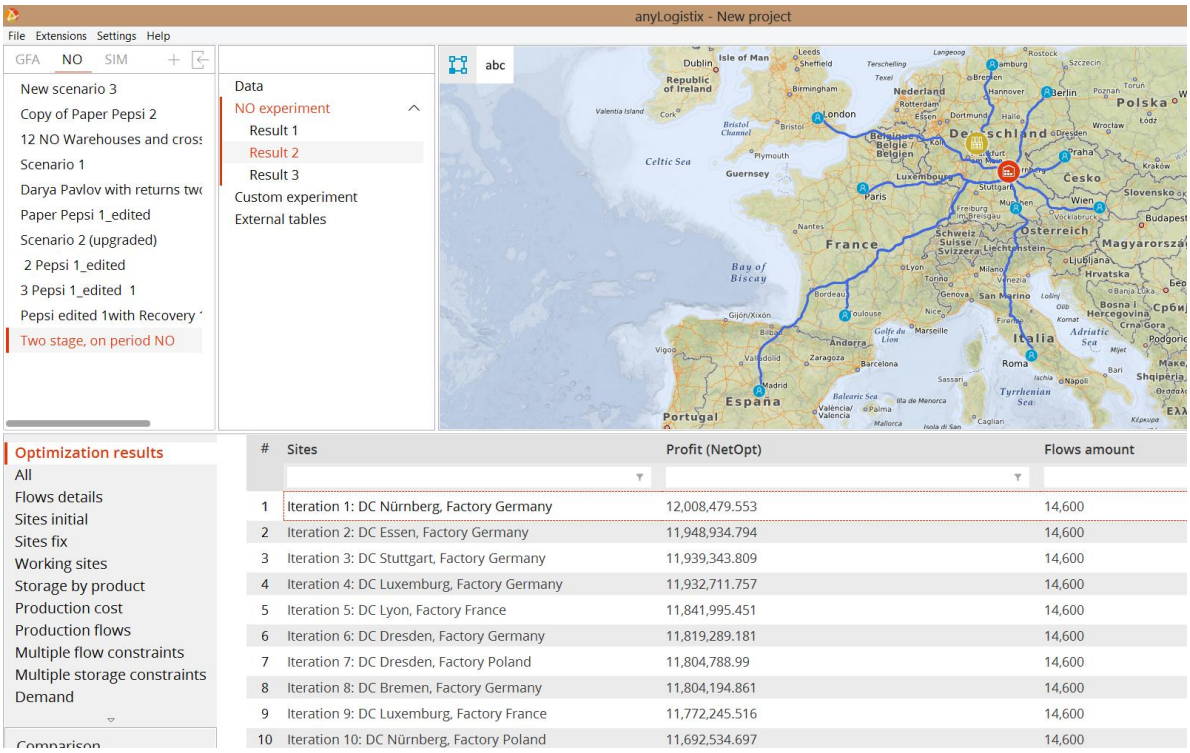
How to analyze the optimization results and make a management decision

Is the mathematically optimal solution automatically the right decision?

The optimal solution to our problem is to open factories in Germany and Poland and a DC in Nuernberg. Imagine you need to report your results to the CEO. She may ask you some questions such as e.g.:

- is it possible to find a better supply chain design with an even higher profit?
- what happens if the demand in particular markets changes?
- what happens if facility costs grow and transportation costs decrease?
- what about disruption risks: if anything happens at the DC in Nuernberg, is there no second source or backup DC in the supply chain design?

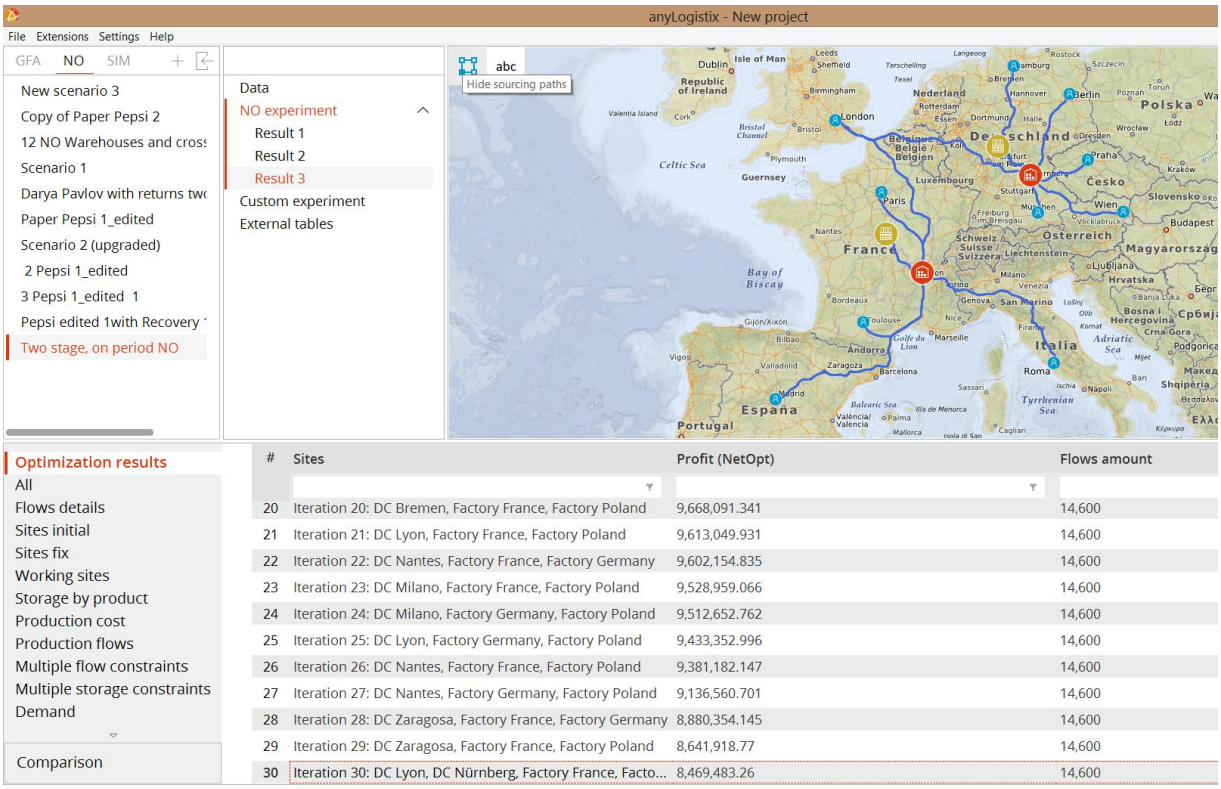
Indeed, you would answer that, for the given set of parameters and their values, this is the best solution in terms of profit maximization. However, the changes in input parameters, e.g., in demand, fixed facility or variable transportation costs, or even in the production capacities may change the solution. For example, the solution changes if you assume a maximum production capacity of factories 8,000 m^3 a year instead of 3,500 m^3. The optimization result is shown in Fig. 13.



#	Sites	Profit (NetOpt)	Flows amount
1	Iteration 1: DC Nürnberg, Factory Germany	12,008,479.553	14,600
2	Iteration 2: DC Essen, Factory Germany	11,948,934.794	14,600
3	Iteration 3: DC Stuttgart, Factory Germany	11,939,343.809	14,600
4	Iteration 4: DC Luxemburg, Factory Germany	11,932,711.757	14,600
5	Iteration 5: DC Lyon, Factory France	11,841,995.451	14,600
6	Iteration 6: DC Dresden, Factory Germany	11,819,289.181	14,600
7	Iteration 7: DC Dresden, Factory Poland	11,804,788.99	14,600
8	Iteration 8: DC Bremen, Factory Germany	11,804,194.861	14,600
9	Iteration 9: DC Luxemburg, Factory France	11,772,245.516	14,600
10	Iteration 10: DC Nürnberg, Factory Poland	11,692,534.697	14,600

Fig. 13. Optimization result for new production capacity maximum

It can be observed in Fig. 13 that the new optimal solution is now a supply chain design with a factory in Germany and a DC in Nuernberg. This solution is even more profitable than the previous one. Why do you think this change occured? Using the optimization results, you might also quickly answer the CEO's question about what the highest profit is that could be achieved in a supply chain design with two DCs (risk management!), see Fig. 14.



#	Sites	Profit (NetOpt)	Flows amount
20	Iteration 20: DC Bremen, Factory France, Factory Poland	9,668,091.341	14,600
21	Iteration 21: DC Lyon, Factory France, Factory Poland	9,613,049.931	14,600
22	Iteration 22: DC Nantes, Factory France, Factory Germany	9,602,154.835	14,600
23	Iteration 23: DC Milano, Factory France, Factory Poland	9,528,959.066	14,600
24	Iteration 24: DC Milano, Factory Germany, Factory Poland	9,512,652.762	14,600
25	Iteration 25: DC Lyon, Factory Germany, Factory Poland	9,433,352.996	14,600
26	Iteration 26: DC Nantes, Factory France, Factory Poland	9,381,182.147	14,600
27	Iteration 27: DC Nantes, Factory Germany, Factory Poland	9,136,560.701	14,600
28	Iteration 28: DC Zaragosa, Factory France, Factory Germany	8,880,354.145	14,600
29	Iteration 29: DC Zaragosa, Factory France, Factory Poland	8,641,918.77	14,600
30	Iteration 30: DC Lyon, DC Nürnberg, Factory France, Facto...	8,469,483.26	14,600

Fig. 14. Selection of the best result with two DCs

We can observe in Fig. 14 that the most profitable supply chain design with two DCs is the option with two factories in Germany and France and two DCs in France and Germany. However, the profit from this supply chain design would be lower than that of the optimal supply chain design. We call this the “costs of robustness” (Ivanov 2018).

Variation experiment

In order to answer the CEO’s questions about what happens if demands change, facility costs grow and transportation costs decrease, you can run the variation experiment (see details in Ivanov 2017). You might want to let the transportation costs range from 0.05 to 0.5, the fixed facility costs range from 50 to 300, and demand be changed by 20% up or down.

Note: the variation experiment is possible in the SIM mode of anyLogistix. There you will need to define additional policies, e.g., the inventory control policy.

Chapter 2 Four-stage, multi-period supply chain planning with capacity disruptions, inventory, and transportation constraints

Problem statement

Additional features that will be added in this Chapter:

- Limited transportation capacity
- Many periods
- Capacity disruptions
- Inventory holding costs
- Limited storage capacity

Assume the following problem statement based in Ivanov et al. (2014). We investigate a multi-stage distribution network (DN) that displays the following characteristics: (i) system performance depends on the ability to operate despite perturbations; (ii) some system elements may become unavailable due to disruptions in the DN, and (iii) the system experiences performance degradation if some of its elements fail.

Consider the following supply chain design (Fig. 15).

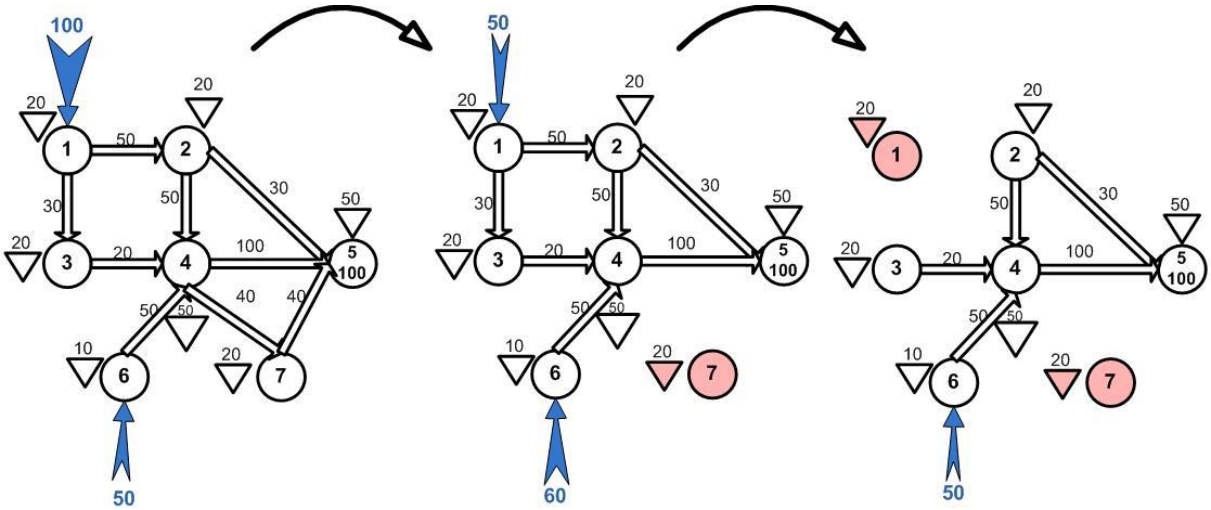


Fig. 15. Supply chain design (Ivanov et al. 2014)

The DN is composed of two seaports (nodes 1 and 6), a central distribution hub (node 4), two intermediate warehouses (nodes 2 and 3), an outsourced warehouse (node 7), and a regional distribution centre as a strategic inventory holding point (node 5). Execution in each of the nodes and transportation arcs is limited by maximal warehouse capacity, processing throughput, and transportation throughput, respectively.

The triangles represent warehouse capacity, and numbers on the arcs refer to maximal transportation throughput. Suppliers deliver certain order quantities at the beginning of each period at seaports 1 and 6. Then, the goods are processed in central distribution hub 4. The goods from hub 1 are additionally processed at intermediate terminals 2 and 3. From hub 4, the goods are moved to the regional distribution center 5, which has a demand in each of the periods (i.e., 100 units per period). We consider three periods. Inventory from previous periods may be used in the following periods. Profit is computed as revenue from goods delivered at node 5 minus the sum of sourcing, transportation, processing, fixed, and inventory holding costs which are assumed to be a linear function of the quantities.

The primary problem is to find the aggregate product flows to be moved from suppliers through the intermediate stages to the strategic inventory holding point subject to maximizing

the service level and minimizing the total cost under (i) constrained capacities and processing rates and (ii) varying demand, supply, and DN structure for a multi-period case. In addition, the calculated plans should suggest ways to reconfigure product flows in the event of capacity disruptions. As shown in Fig. 15, in period 2, node 7 becomes unavailable, and in period 3 we have disruptions at seaport 1 and node 7.

Setting the management problem in anyLogistix Network Optimizer

In Figs 16-21, the input settings and parameters for the problem considered are defined.

Supply chain design

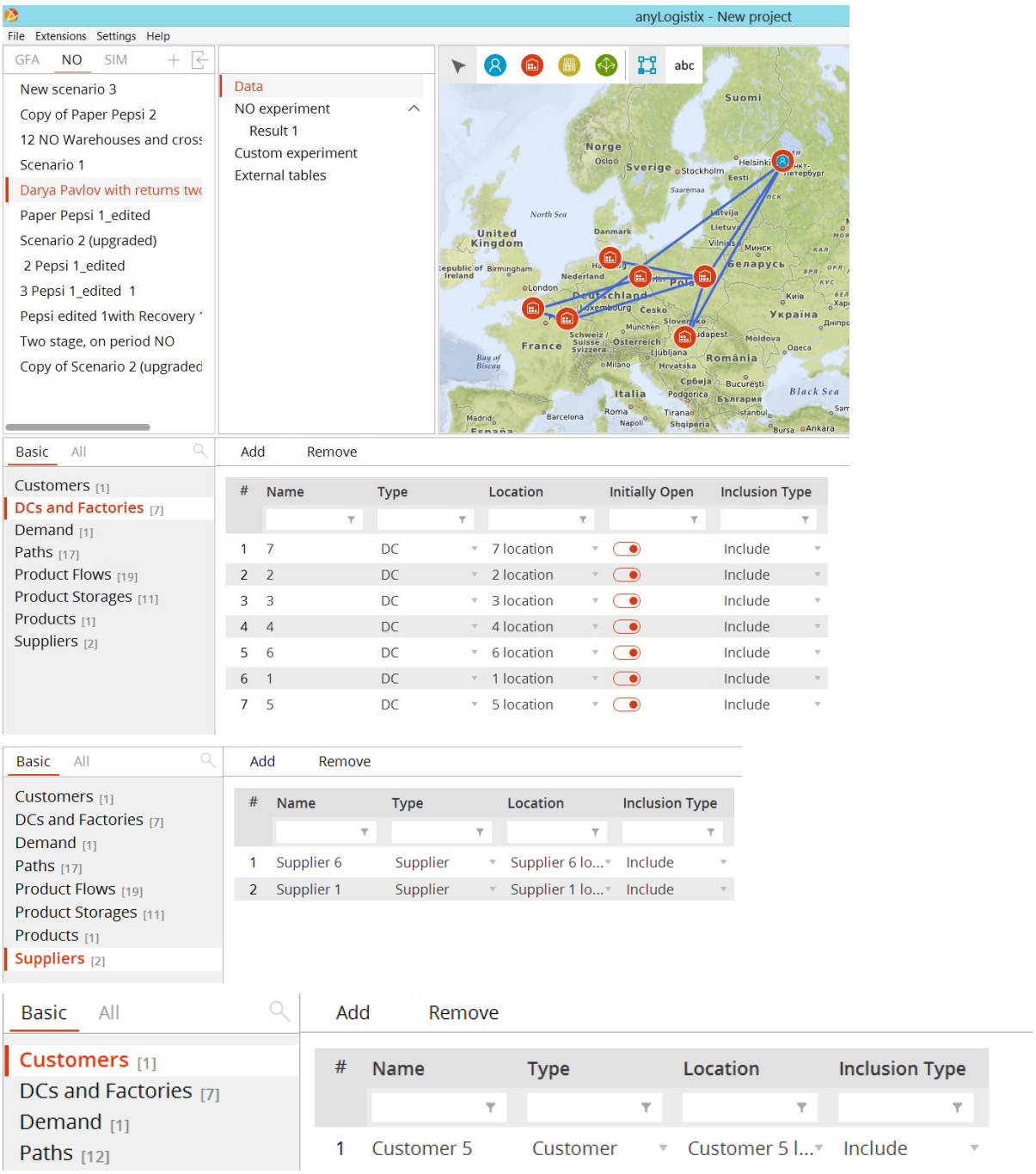


Fig. 16. DN design

Note: In order to set up storage capacity at the customer, we define an auxiliary DC in the same location. This allows setup of storage capacity without any transportation costs or time. In order to setup the incoming flows to seaports 1 and 6 we set up auxiliary suppliers at the same locations as seaports 1 and 6.

Demand and periods

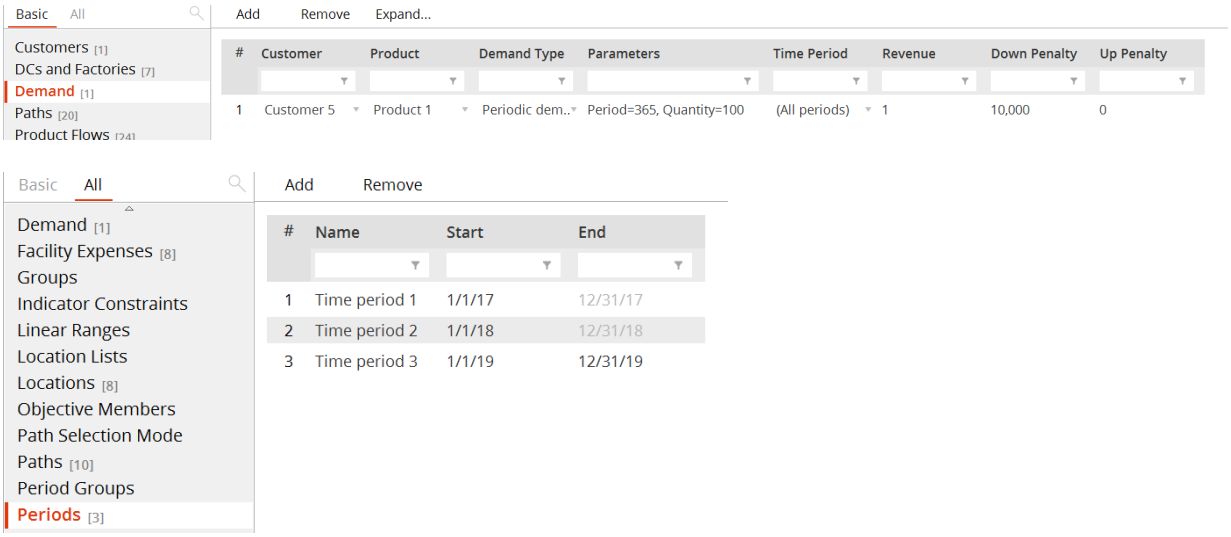


Fig. 17. Demand and periods

Transportation capacities and disruptions

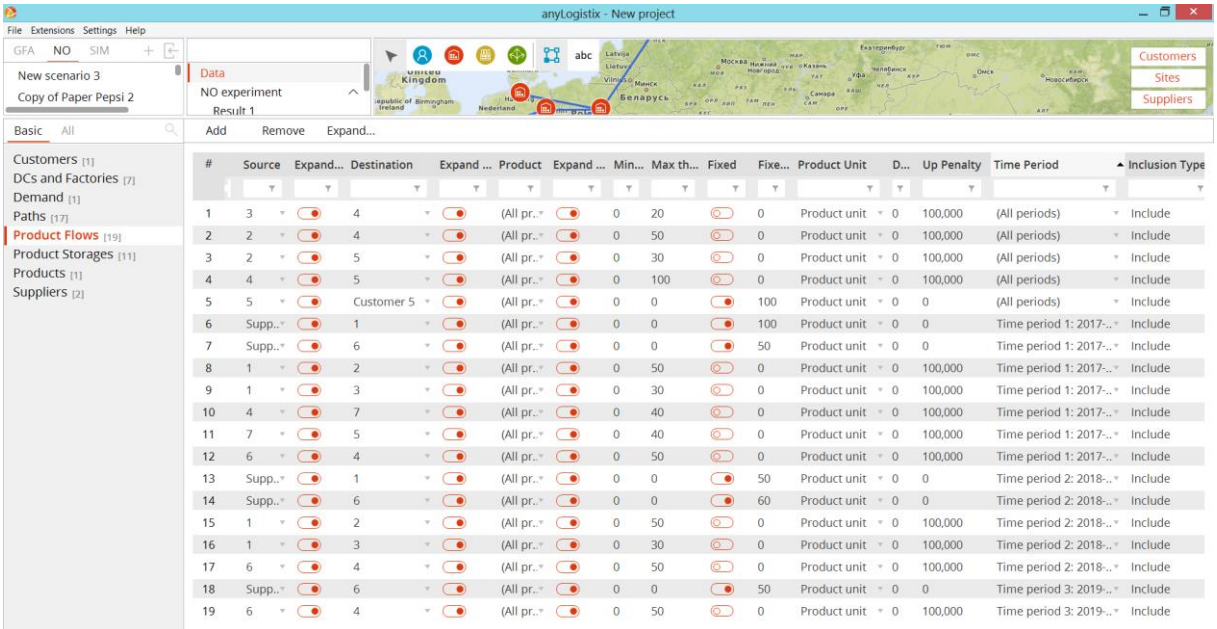


Fig. 18. Product flows

In "**Product flows,**" we set up the constraint on the limited transportation throughput in the column "**Max Throughput.**" Moreover, here we also set up the conditions of the incoming flows from suppliers at seaports 1 and 6. Finally, the disruptions in the supply chain are set up here by explicitly entering and not entering product flows in different periods.

Note: the constraints are activated by setting the **Up Penalty** as a large number. If the penalty is not set up, then two situations are possible:

1. Max >= min and min > 0, down penalty = up penalty = 0, then max throughput is considered fixed, i.e., the flows will exactly equal the value in the column “**max throughput**”. Fixed is the value that cannot be violated.
2. Max >= min and min = 0, down penalty = up penalty = 0, then the throughput constraint is ignored.

Note: In "**Product Storages,**" you need to define data separately for "DCs" and “Factories”; do not use the default setting "All sites". Do not forget to activate "**Expand sources.**" Do not use penalties if min and max throughputs are not defined.

In Fig. 19, paths setting is illustrated.

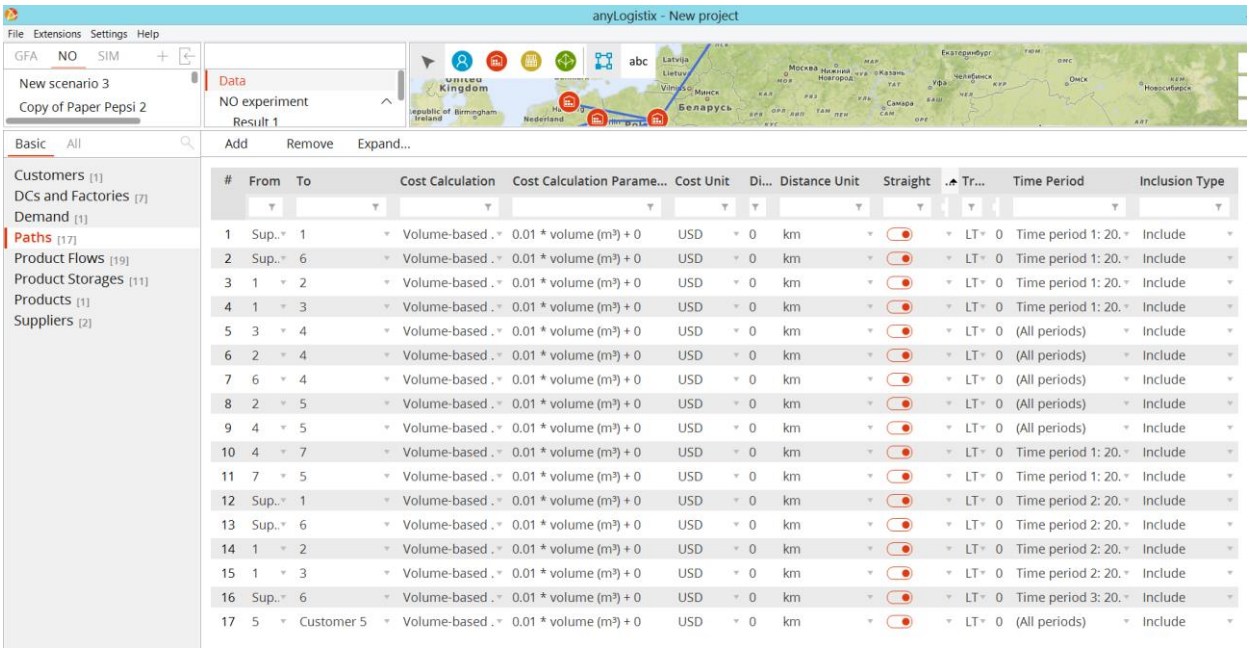


Fig. 19. Paths

Warehouse storage capacities

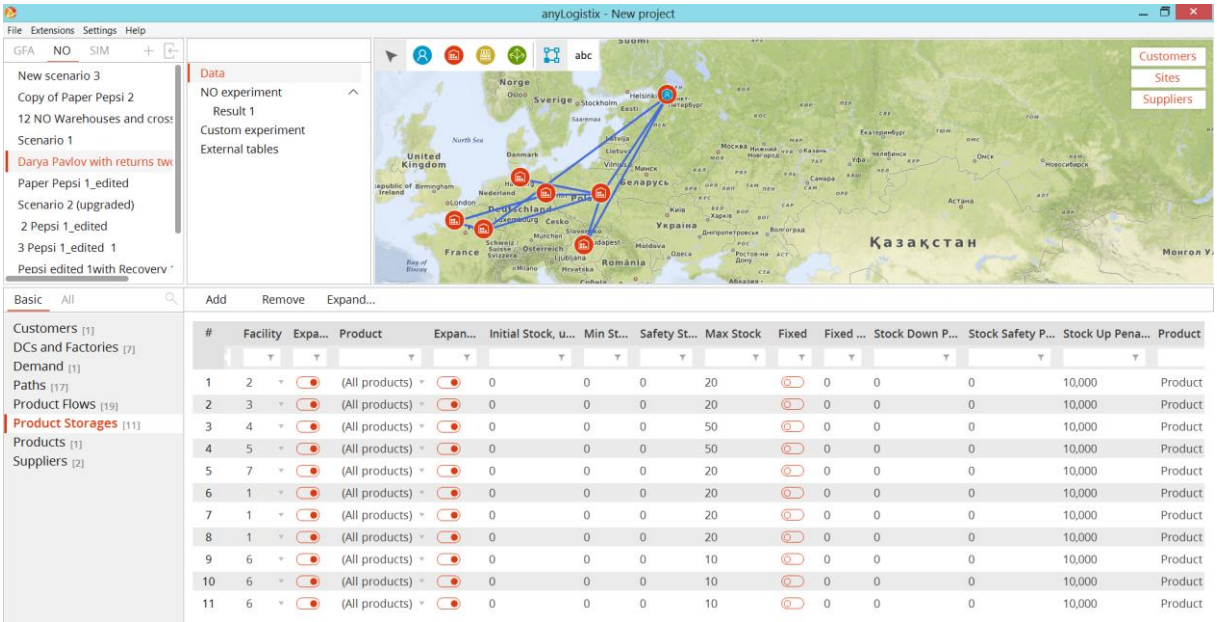


Fig. 20. Storage capacity setup

Costs and profits

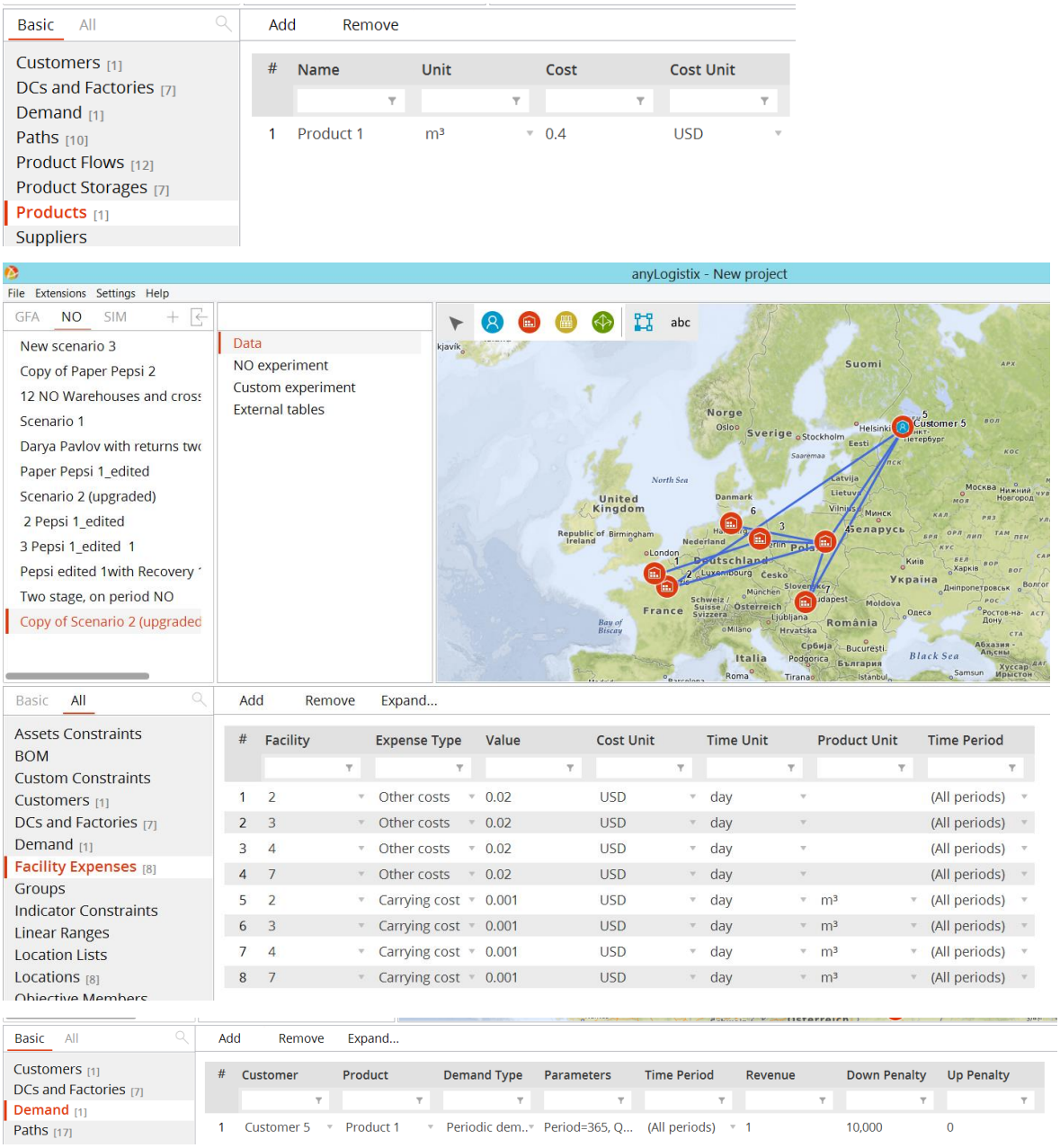


Fig. 21. Costs and profits

Network optimization results

Fig. 22 presents network optimization results.

Flows details

	I...	Period	From	To	Product	Flow	Flow min	Flow max	Percentage	Flo...	Flow Over Cost	Distance	...	O...	Transportation ...	Transportation ...	I...	I...	Flow Cost, per i...	Penalty
1	1	Time period 1	5	Customer 5	Product 1	100.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	1.0	...	...	0.01	0.0
2	1	Time period 1	4	5	Product 1	90.0	0.0	100.0	90.0	0.0	100,000.0	1,019.26	...	0.0	0.01	0.9	...	...	0.01	0.0
3	1	Time period 1	2	4	Product 1	20.0	0.0	50.0	40.0	0.0	100,000.0	1,200.56	...	0.0	0.01	0.2	...	...	0.01	0.0
4	1	Time period 1	3	4	Product 1	20.0	0.0	20.0	100.0	0.0	100,000.0	517.53	...	0.0	0.01	0.2	...	...	0.01	0.0
5	1	Time period 1	Supplier 1	1	Product 1	100.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	1.0	...	...	0.01	0.0
6	1	Time period 1	1	2	Product 1	50.0	0.0	50.0	100.0	0.0	100,000.0	305.51	...	0.0	0.01	0.5	...	...	0.01	0.0
7	1	Time period 1	6	4	Product 1	50.0	0.0	50.0	100.0	0.0	100,000.0	764.61	...	0.0	0.01	0.5	...	...	0.01	0.0
8	1	Time period 1	2	5	Product 1	30.0	0.0	30.0	100.0	0.0	100,000.0	2,020.77	...	0.0	0.01	0.3	...	...	0.01	0.0
9	1	Time period 1	Supplier 6	6	Product 1	50.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	0.5	...	...	0.01	0.0
10	1	Time period 1	1	3	Product 1	30.0	0.0	30.0	100.0	0.0	100,000.0	928.16	...	0.0	0.01	0.3	...	...	0.01	0.0
11	1	Time period 2	3	4	Product 1	20.0	0.0	20.0	100.0	0.0	100,000.0	517.53	...	0.0	0.01	0.2	...	...	0.01	0.0
12	1	Time period 2	4	5	Product 1	90.0	0.0	100.0	90.0	0.0	100,000.0	1,019.26	...	0.0	0.01	0.9	...	...	0.01	0.0
13	1	Time period 2	Supplier 1	1	Product 1	50.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	0.5	...	...	0.01	0.0
14	1	Time period 2	Supplier 6	6	Product 1	60.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	0.6	...	...	0.01	0.0
15	1	Time period 2	5	Customer 5	Product 1	100.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	1.0	...	...	0.01	0.0
16	1	Time period 2	6	4	Product 1	50.0	0.0	50.0	100.0	0.0	100,000.0	764.61	...	0.0	0.01	0.5	...	...	0.01	0.0
17	1	Time period 2	1	2	Product 1	50.0	0.0	50.0	100.0	0.0	100,000.0	305.51	...	0.0	0.01	0.5	...	...	0.01	0.0
18	1	Time period 2	2	5	Product 1	30.0	0.0	30.0	100.0	0.0	100,000.0	2,020.77	...	0.0	0.01	0.3	...	...	0.01	0.0
19	1	Time period 2	1	3	Product 1	20.0	0.0	30.0	66.67	0.0	100,000.0	928.16	...	0.0	0.01	0.2	...	...	0.01	0.0
20	1	Time period 2	2	4	Product 1	20.0	0.0	50.0	40.0	0.0	100,000.0	1,200.56	...	0.0	0.01	0.2	...	...	0.01	0.0
21	1	Time period 3	3	4	Product 1	10.0	0.0	20.0	50.0	0.0	100,000.0	517.53	...	0.0	0.01	0.1	...	...	0.01	0.0
22	1	Time period 3	Supplier 6	6	Product 1	50.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	0.5	...	...	0.01	0.0
23	1	Time period 3	6	4	Product 1	50.0	0.0	50.0	100.0	0.0	100,000.0	764.61	...	0.0	0.01	0.5	...	...	0.01	0.0
24	1	Time period 3	5	Customer 5	Product 1	100.0	0.0	0.0	-1.0	0.0	0.0	0.0	...	0.0	0.01	1.0	...	...	0.01	0.0
25	1	Time period 3	4	5	Product 1	60.0	0.0	100.0	60.0	0.0	100,000.0	1,019.26	...	0.0	0.01	0.6	...	...	0.01	0.0

Optimization results
All
Flows details
Sites initial
Sites fix
Working sites
Storage by product
Production cost
Production flows
Multiple flow constraints
Multiple storage constraints
Demand
Vehicle flows

Demand

	Iteration	Period	Customer	Product	Demand min	Demand max	Satisfied	Percentage	Revenue, per it...	Revenue Total	Under Cost	Over Cost	Pe
1	1	Time period 1	Customer 5	Product 1	100.0	100.0	100.0	100.0	1.0	100.0	10,000.0	0.0	0.
2	1	Time period 2	Customer 5	Product 1	100.0	100.0	100.0	100.0	1.0	100.0	10,000.0	0.0	0.
3	1	Time period 3	Customer 5	Product 1	100.0	100.0	100.0	100.0	1.0	100.0	10,000.0	0.0	0.

Sites fix
Working sites
Storage by product
Production cost
Production flows
Multiple flow constraints
Multiple storage constraints
Demand
Vehicle flows
Named expressions
Objective Members
Overall stats
Add new tab

Overall stats

	I...	Transportation cost	I...	...	...	Other cost	I...	Carrying cost	...	Inventory purch...	...	Revenue	Penalties	Objective custo...	Profit (NetOpt)
1	1	13.0	...	...	...	87.6	...	7.3	...	124.0	...	300.0	0.0	0.0	68.1

Fig. 22. Network optimization results

It can be observed from Fig. 22 that a total profit of 68.1 monetary units can be achieved whereby the demand is 100% met. The network optimal distribution plan has also been computed subject to the considered disruption scenario. This plan can be used as a contingency/recovery plan in the event of the real disruptions.

Additional features

In the given example, we applied some of the network optimization functionality of anyLogistix. Indeed, anyLogistix network optimizer can do much more. For example, you may extend the problem statements by adding new parameters or constraints in terms of processing time and costs at the DCs, considering demand and lead times not as fixed parameters but rather as stochastic variables, or by including sales batches. For more advanced application, custom constraints, indicator constraints, and linear ranges can be used to develop specific control policies, e.g., return flows in the supply chain. Moreover, it is always possible to customize the factory, warehouse, supplier, and customer agents in Any Logic and create any kind of network optimization model.

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4. Ivanov D. (2018). *Structural Dynamics and Resilience in Supply Chain Risk Management*. Springer, New York.