Supply Chain Simulation and Optimization with AnyLogistix

Decision-oriented teaching notes for model-based management decision-making

Prof. Dr. Dmitry Ivanov

Berlin School of Economics and Law

Professor of Supply Chain Management

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About the author

Prof. Dr. habil. Dr. Dmitry Ivanov is professor of Supply Chain Management at Berlin School of Economics and Law (BSEL). He has been *teaching* for more than15 years the courses in operations management, production and supply management, supply chain management, logistics, management information systems, and strategic management at undergraduate, master's, PhD, and executive MBA levels at different universities in Germany, Russia, UK, US, and China.

Prior to becoming an academic he was mainly engaged in *industry and consulting*, especially for process optimization in manufacturing and logistics and ERP systems. His practical expertise includes numerous projects on application of operations research and process optimization methods for operations design, logistics, scheduling and supply chain optimization.

His *research* explores supply chain structure dynamics and control, with an emphasis on global supply chain design with disruption management consideration, distribution planning, and dynamic (re)-scheduling. He is (co)-author of structure dynamics control method for supply chain management. He applies mathematical programming, simulation and control theoretic methods. Based on the triangle “process-model-technology” he investigates the dynamics of complex networks in production, logistics, and supply chains. Most of his courses and research are placed at the interface of supply chain management, operations research, industrial engineering, and information technology.

He is the (co)-author of more than 260 *publications*, including textbook “Global Supply Chain and Operations Management” and a monograph “Adaptive Supply Chain Management”. Professor Ivanov’s research has been published in various academic journals, including International Journal of Production Research, European Journal of Operational Research, Journal of Scheduling, Transportation Research, International Journal of Production Economics, Computers and Industrial Engineering, International Journal of Systems Science, Annual Reviews in Control, etc. He has been guest-editor of special issues in different journals, including International Journal of Production Research and International Journal of Integrated Supply Management. He is an associate editor of International Journal of Systems Science and Editorial Board member of several international and national journals, e.g., International Journal of Systems Science: Operations and Logistics. He is Chair of IFAC Technical Committee 5.2 “Manufacturing Modelling for Management and Control”. He is General Conference Chair of 9th IFAC Conference MIM 2019 “Manufacturing Modelling, Management and Control”. He regularly presented his research results and has been co-chair and IPC member of many international conferences where he has organized numerous tracks and sessions (including INCOM, EURO, INFORMS, OR, MIM, MCPL, IFAC World Congress, PRO-VE, ICINCO).

Contact:

Prof. Dr. habil Dr. Dmitry Ivanov
Berlin School of Economics and Law
Professor of Supply Chain Management

E: dmitry.ivanov(at)hwr-berlin.de

Introduction to the book

This introductory note was created in order to support instructors in supply chain (SC) and operations management courses involved with simulation and optimization. The objective of this teaching note is to provide some guidelines of how to teach SC simulation and optimization course with the use of anyLogistic (ALX) software. Without relying heavily on statistics and mathematical derivations, this guideline offers applied models and a simple, predictable format to make it easy to understand for people without engineering background.

The idea behind this teaching note is to enhance SC, logistics and operations management courses by using decision-support software. ALX is a unique tool for SC and logistics simulation and optimization in regard to management decision-making support. In practice, it is a challenging task to combine modelling and management decision-making views. On one hand, application of optimization and simulation software implies some background in programming. On the other hand, technical issues in development of optimization and simulation models may distract the attention and time from the real objective, i.e., management decision analysis and decision-making support with the help of simulation and optimization software. AnyLogistix is an easy-to-understand tool that can be used by management students and professionals.

The focus of this teaching note is to introduce professionals and students into the basic principles of decision-support using simulation and optimization in SCs and logistics. It shows the range of SC management (SCM) problems that can be addressed by ALX. It also explains how to create SC models in ALX, conduct experiments, and analyse the results. In reducing technical complexity to the necessary minimum, the main attention is paid to management decision analysis and using KPI for operational, customer and financial performance measurement for decision-making.

The material is grouped into three parts that correspond to three basic process structures as well risk management in the SC:

- Two-stage SC, Three-stage SC, Four-stage SC, and
- Risk management in the SC

For these system structures, simulation and optimization examples are presented. First, technical development of the models is described. Step-by-step, the model building and KPI evaluation techniques are introduced and illustrated. Second, the developed models are discussed in regard to the usage of simulation and optimization results for decision-making.

Being focused on the management issues, the model developments are described as easily as possible. It can be advisable to import example models in "File → Import" and perform some experiments with them.

Since this guide is just at the beginning of its development, we excuse some possible errors in the texts and formatting. We consider this guide rather as a working material and are grateful to any comments and suggestions that may improve this material in future.

The author of this guide 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. I addition, the author of this guide has also authored the e-book "Operations and Supply Chain Simulation with AnyLogic" (http://www.anylogic.com/books). The author deeply thanks The AnyLogic Company for valuable feedbacks and improvement suggestions.

Introduction to ALX

A *supply chain (SC)* is a network of organizations and processes wherein a number of various enterprises (suppliers, manufacturers, distributors and retailers) cooperate and coordinate along the entire value chain to acquire raw materials, to convert these raw materials into specified final products, and to deliver these final products to customers (Ivanov et al. 2017).

SC management (SCM) is a cross-department and cross-enterprise integration and coordination of material, information and financial flows to transform and use the SC resources in the most rational way along the entire value chain, from raw material suppliers to customers. SCM is one of the key components of any organization and is responsible for balancing demand and supply along the entire value-adding chain (Ivanov et al. 2017).

SCM integrates production and logistics processes. The decision-making area in SCM ranges from strategic to tactical and operative levels. *Strategic* issues include determination of the size and location of manufacturing plants or distribution centres, decisions on the structure of service networks, factory planning, and designing the SC. *Tactical* issues include such decisions as production or transportation planning as well as inventory planning. *Operative* issues involves with production scheduling and control, inventory control, and vehicle routing.

Decision-making in SCM implies the usage of both qualitative and quantitative methods. Quantitative methods are typically based on optimization or simulation. In order to understand the application of quantitative methods to SCM in practice, the SCM courses are frequently enhanced by decision-support software. ALX is one of them. ALX can be widely used at universities to support SCM, operation, and logistics courses. Using ALX, it becomes possible to develop real life examples in regard to the most important SCM domains such as:

- Facility Location Planning
  - Center-of-Gravity Method for Single and Multiple Locations
  - Network Optimization using Mixed-Linear Programming
- Capacity Planning of Distribution Centers
- Inventory Control Policies and Ordering Rules
- Sourcing Policies (Single and Multiple Sourcing)
- Transportation Policies (LTL, FTL)
- Batching in Transportation, Production, and Sales
- Bullwhip Effect and Ripple Effect Analysis in the SC

The quality of decisions in these domains can be analysed by using KPI (key performance indicators) for analysis of financial, operational, and customer performance in the SC. The mutual impacts and interfaces of decisions and KPI in all these domains can be perceived in ALX in regard to the following questions:

- What are the best locations for warehouses, distribution centers, and production sites?
- What are the best policies for replenishment, sourcing, and transportation
- How robust is the SC?
- What happens if we change inventory policy?
- What happens if we increase the capacity of a distribution center (DC)?
- What happens if the demand changes?
- What happens if we introduce a new product?
- What is the costs of an out-of-stock event?

There are two ways to model the SC (Fig. I-1):

- Analytical modeling where the SC is investigated by using optimization models
- Simulation modeling where the SC is represented as a set of objects and the rules that describe the dynamic behavior of the objects and their interactions

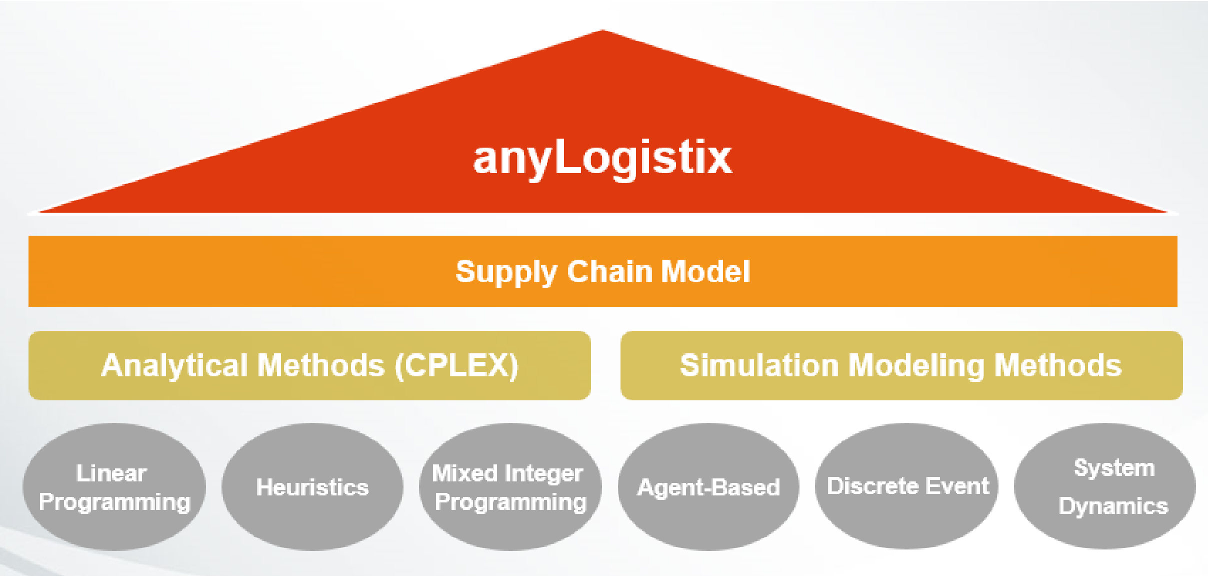


Fig. I-1. Analytical and simulation methods in ALX

Both methods have certain application areas, advantages and disadvantages. ALX uses both of them and helps to understand both differences and application issues. For example, facility location structure of the SC can be first optimized and then simulated in regard to inventory control policies, transportation and sourcing rules. The principle of how ALX works in regard to simulation and optimization is shown in Fig. I-2.

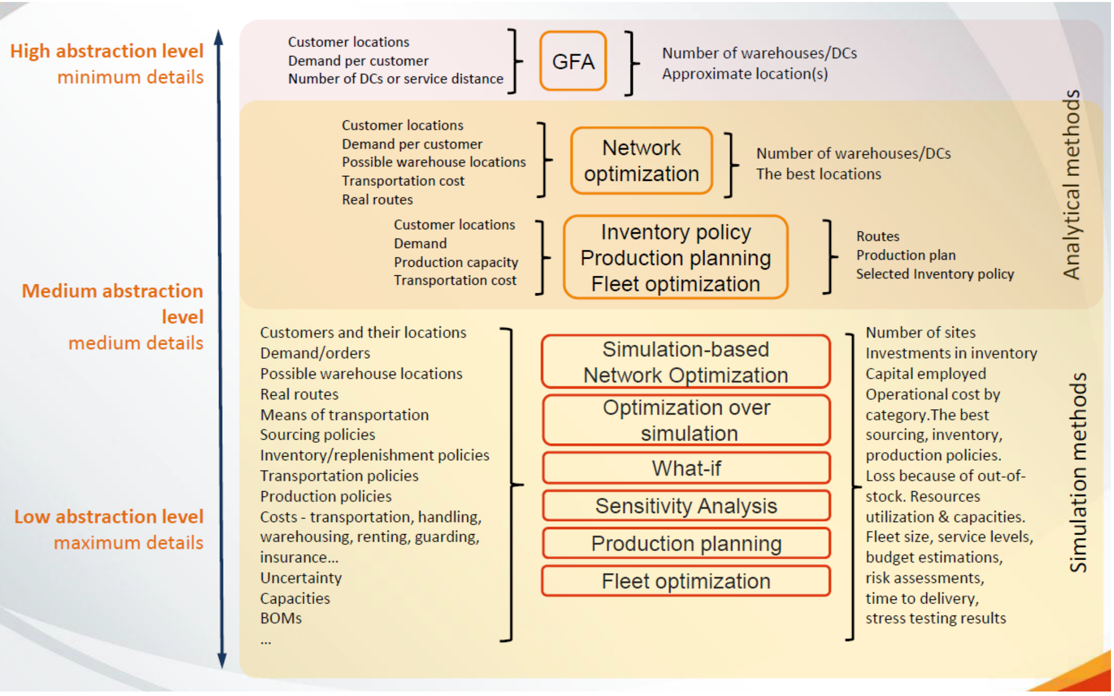


Fig. I-2. ALX modelling principle

The main idea is to start at the strategic level with a few parameters to define the SC design using center-of-gravity (GFA: green field analysis) method. At the second stage, additional parameters such as transportation costs, real routes, and feasible facility locations are included and network optimization is performed. In the next steps, the problem statements become more and more detailed and can be simulated in regard to different constellations of inventory control, sourcing, transportation, and production policies (Fig. I-3).

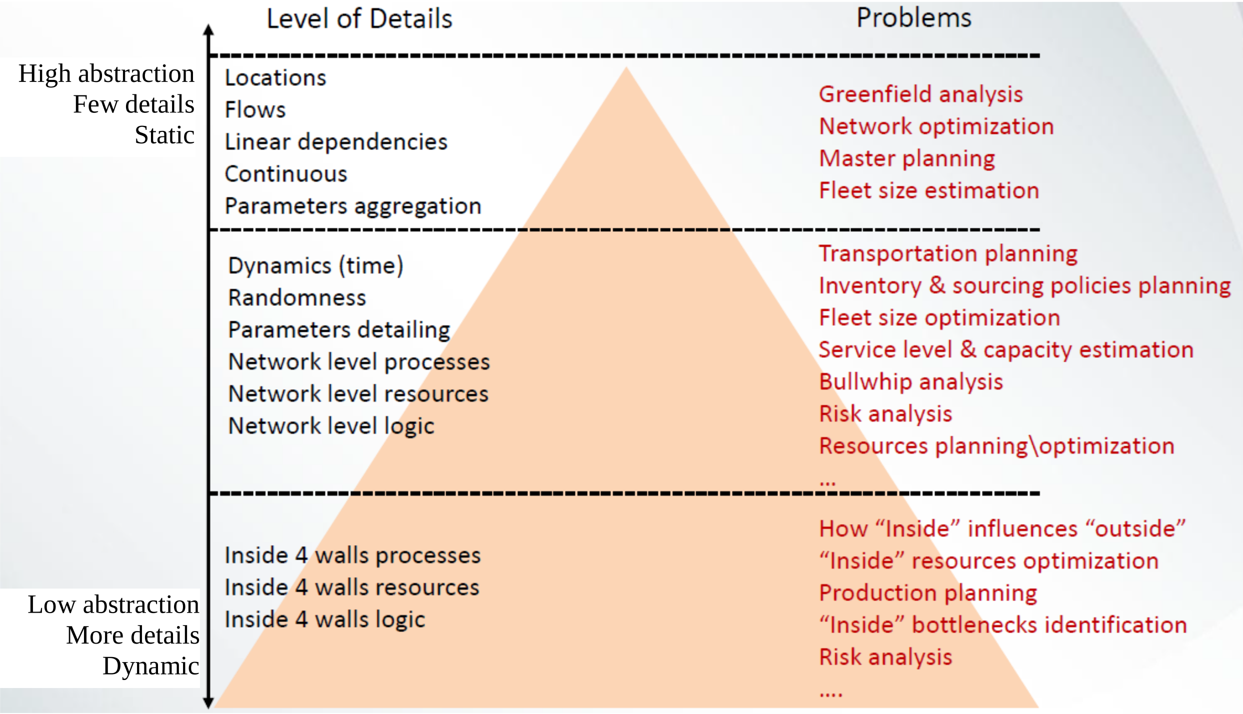


Fig. I-3. From network optimization to supply chain simulation

Along with using the standard ALX functionality, each policy or structural object in ALX can be extended in AnyLogic (Fig. I-4).

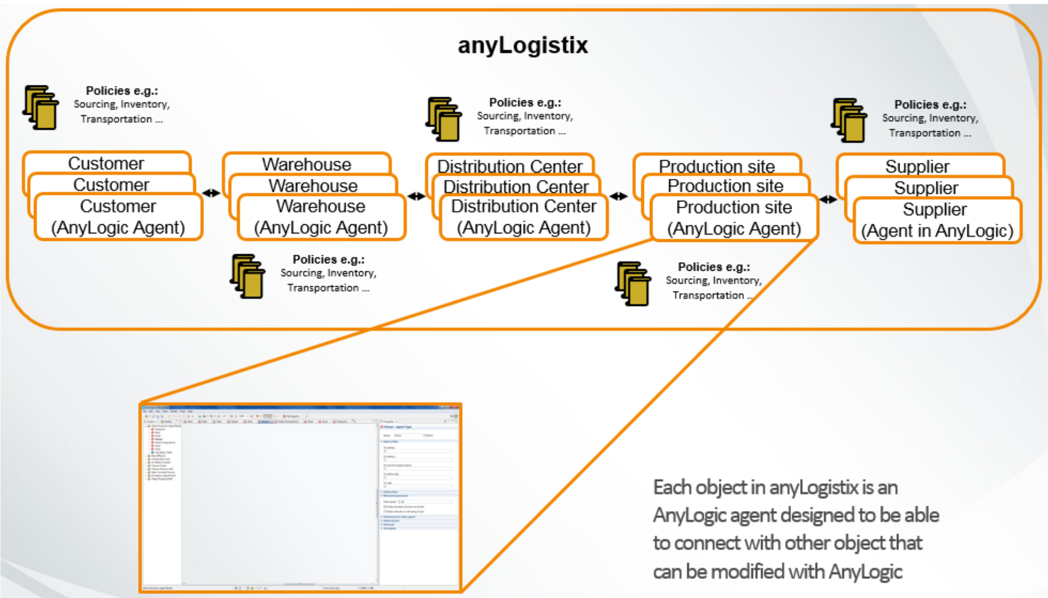


Fig. 4. SC modelling in ALX with AnyLogic extension

Agent-based, discrete-event, and system dynamics simulation models can be used in AnyLogic to customize inventory control, sourcing, transportation, and production policies as well as distribution centers, customers, or suppliers in ALX. For example, instead of defining processing time at a distribution center as a fixed time in ALX, it is possible to embed a simulation model of this distribution centers from AnyLogic where forklift capacities, real layouts, loading and unloading times are modelled. It is also possible to integrate anyLogistix with ERP or SCM systems (Fig. I-5).

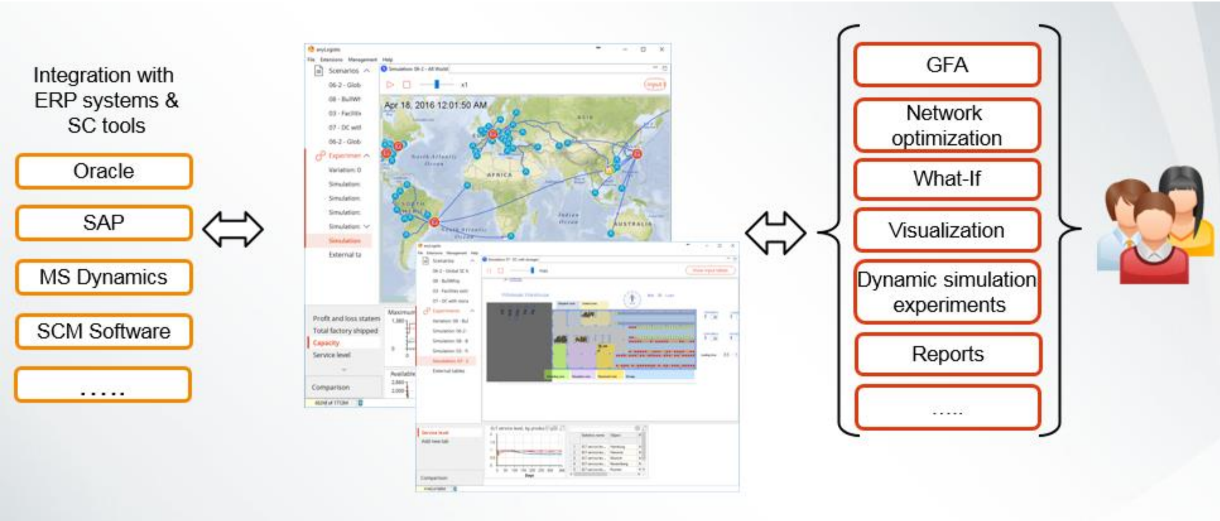


Fig. 5. Integration with ERP and SCM systems

ALX Development Environment

In anyLogistix data and experiments are organized by projects. Each project can include any number of scenarios and experiments. When you create a project ALX will automatically create a dedicated database which includes all project related information. Only one project can be worked with at a time.

ALX-based simulation and optimization starts with a scenario creation. A scenario comprises:

- SC design structure
- Sourcing, transportation, inventory control and production policies
- Parameters of SC structural elements and policies

Scenarios can be created in ALX or imported from MS Excel files. For the scenarios, the following experiments can be performed (Fig. I-6):

- SC Optimization: Green Field Analysis (GFA) and Network Optimization
- SC Analysis: optimization-based simulation, simulation, variation, comparison

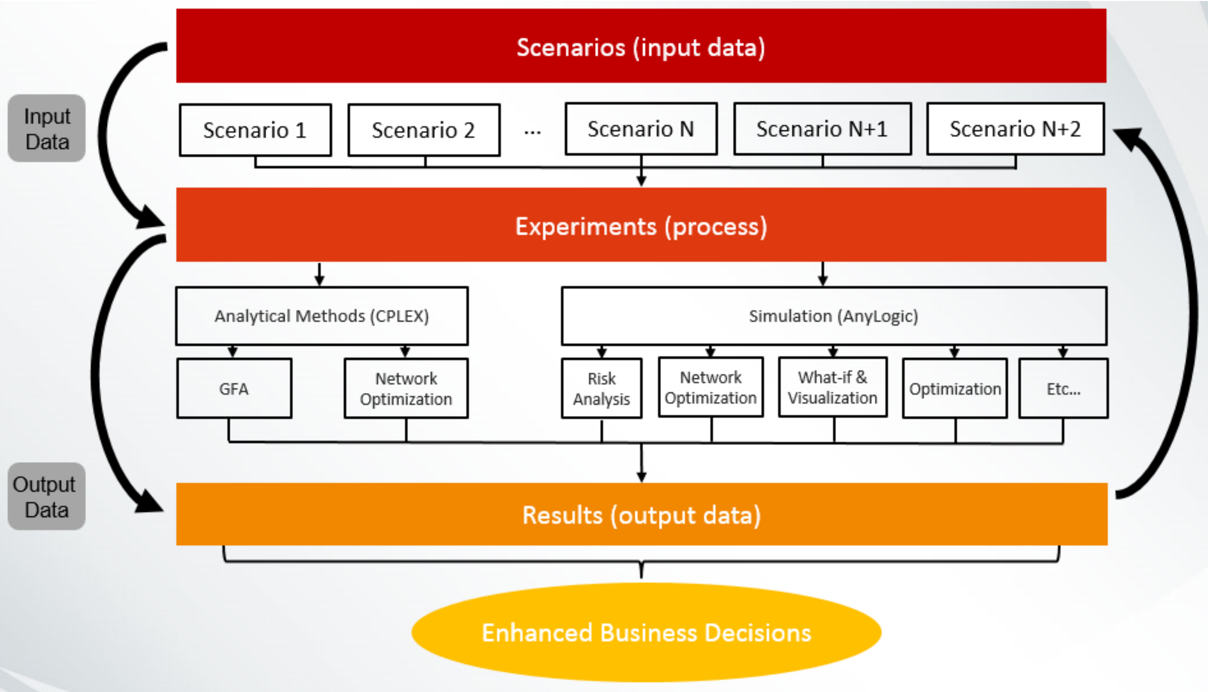


Fig.I- 6. ALX: How it works

The following illustrations (Figs I-7 – I-22) show the basics of ALX user interface. Fig. I-7 illustrate projects menu of ALX. Fig. I-8 depicts basic steps to create new project. Fig. I-9 describes how to log in ALX (if no user with this username exists, ALX will ask if you want to create this user). Fig. I-10 depicts basic steps to create new scenario. In Fig. I-11 the control of geographic user interface is shown. In Fig. I-12, the navigation in ALX menu is explained. Fig. I-13 explains how to create new customers. In analogy, new suppliers, factories, and warehouses can be created. Figs I-14 andI-15 explain how to set parameters for demand, sites, and products. Figs I-15 – I-19 depict how to setup and modify KPI dashboard and collect statistics on SC performance. Figs I-20 and I-21 explain how to prepare new GFA (green field analysis) and network optimization experiments. In Fig. I-22 extensions of ALX objects in AnyLogic are presented. All these steps will be explained throughout the book on numerous examples. The Figs I-7 – I-22 can be used as general technical support. For more detailed technical insights of how to use ALX, we recommend using HELP option in ALX software.

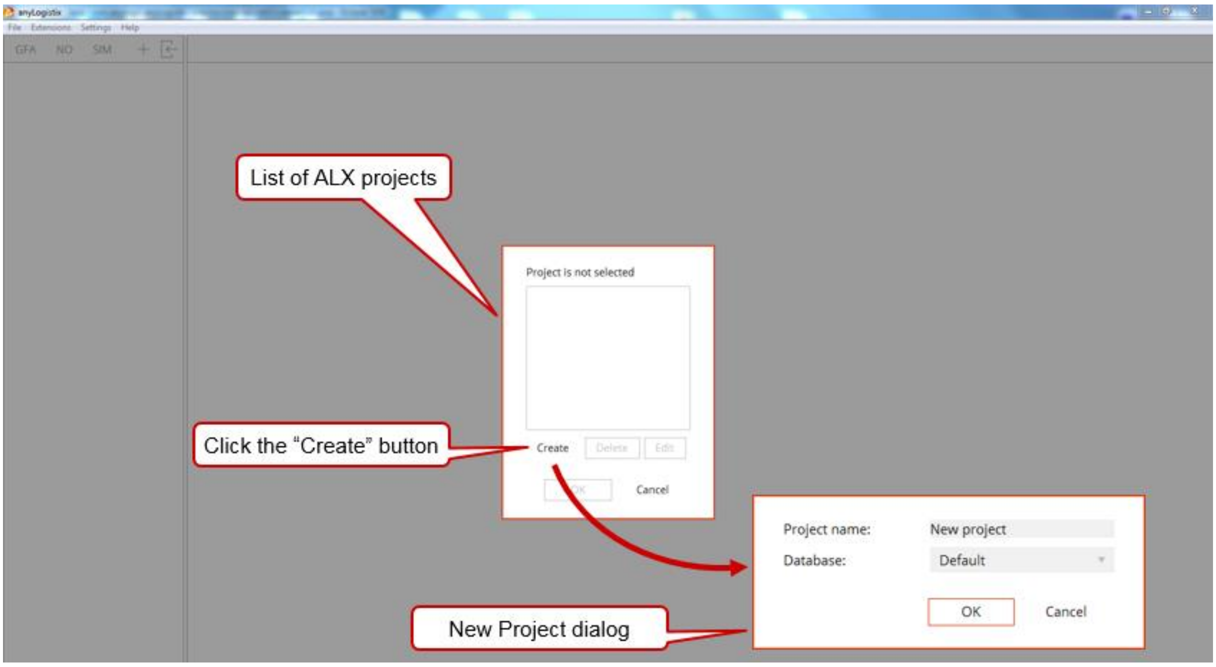


Fig. I-7. ALX Projects Menu

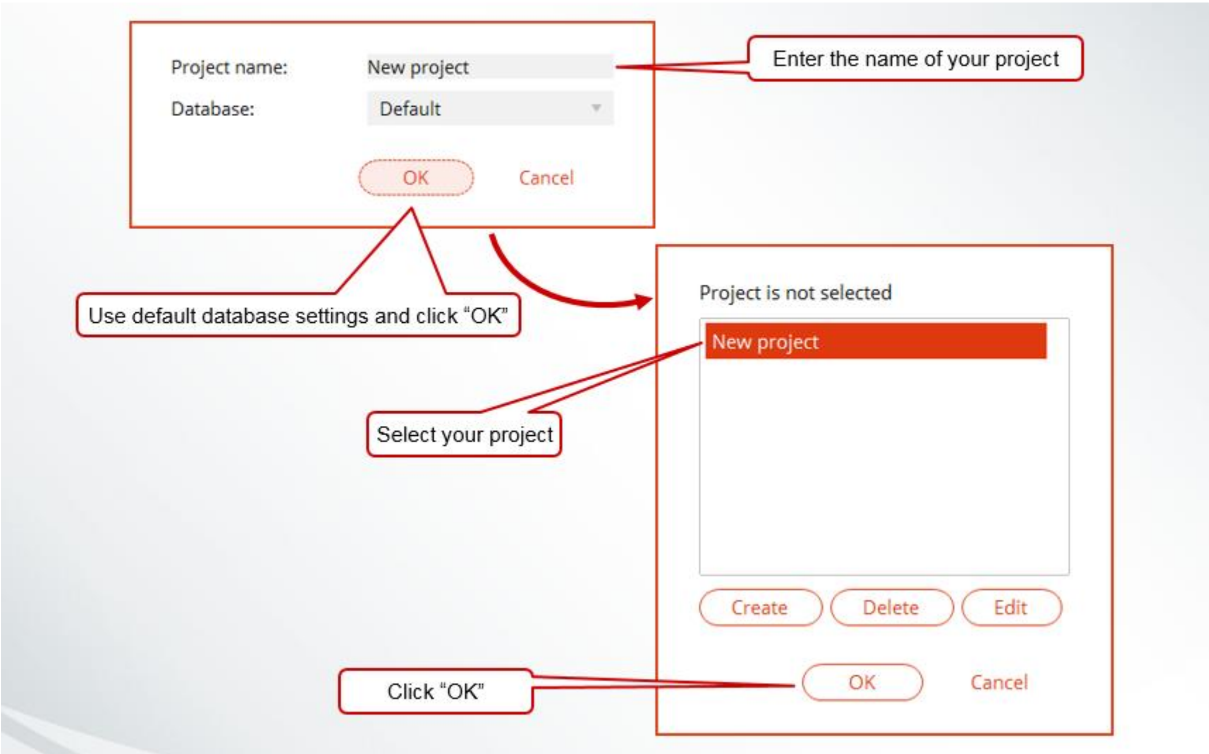


Fig. I-8. ALX Project Creation

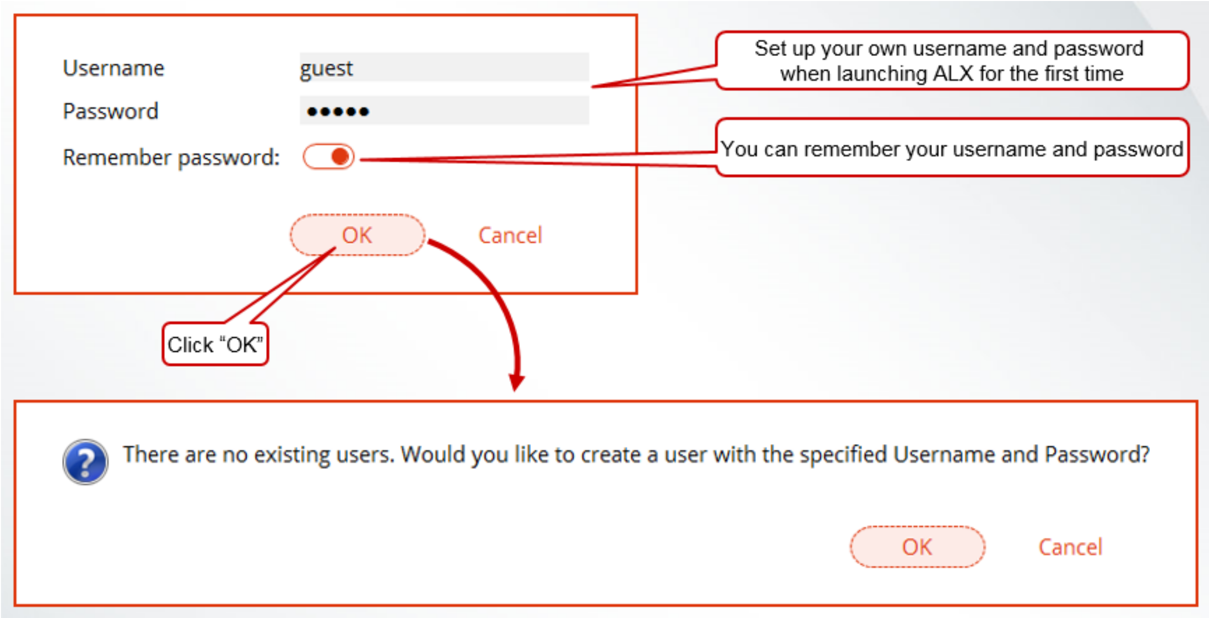


Fig. I-9. Login to ALX Project

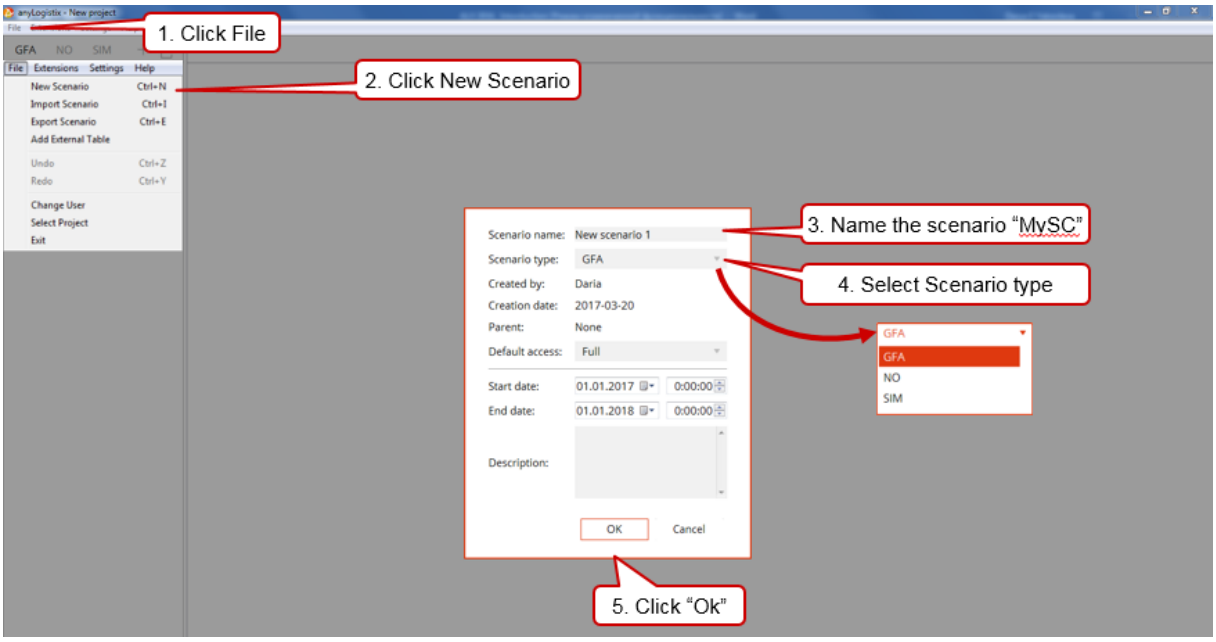


Fig. I-10. Create new scenario

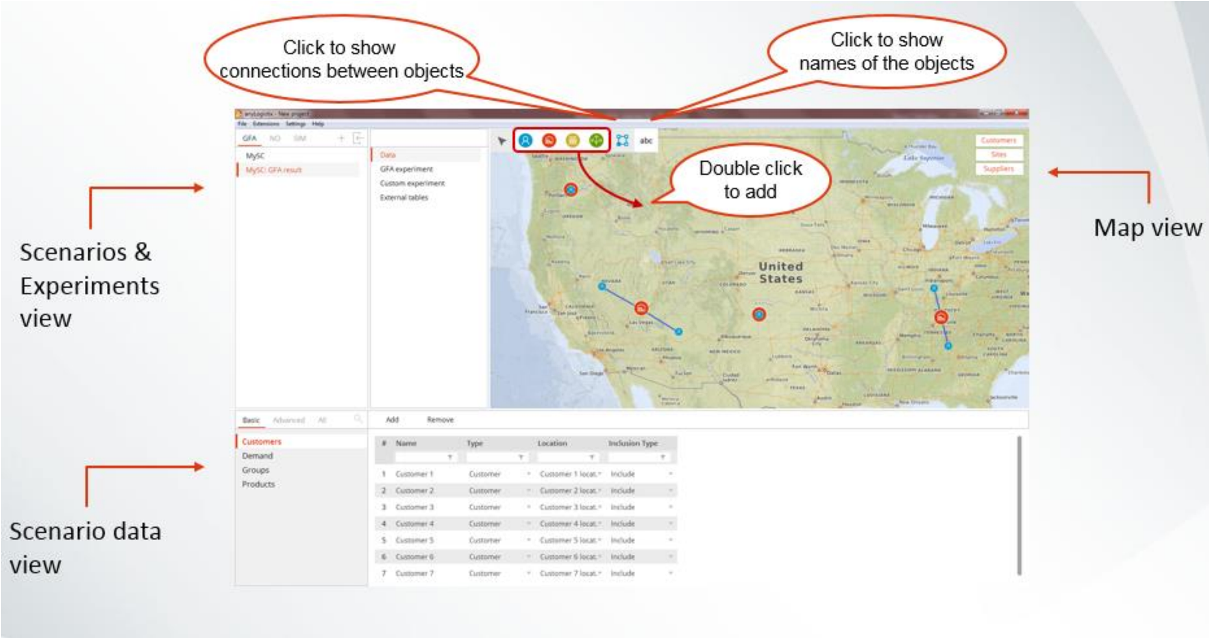


Fig. I-11. ALX GUI

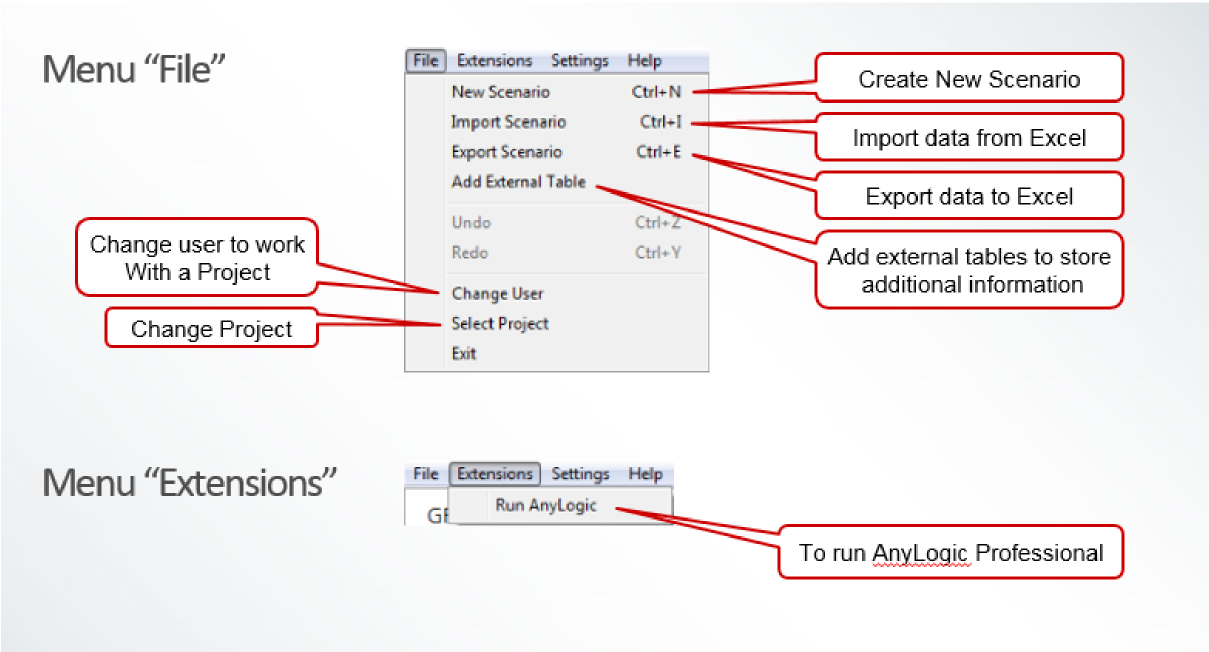


Fig. I-12. ALX menu

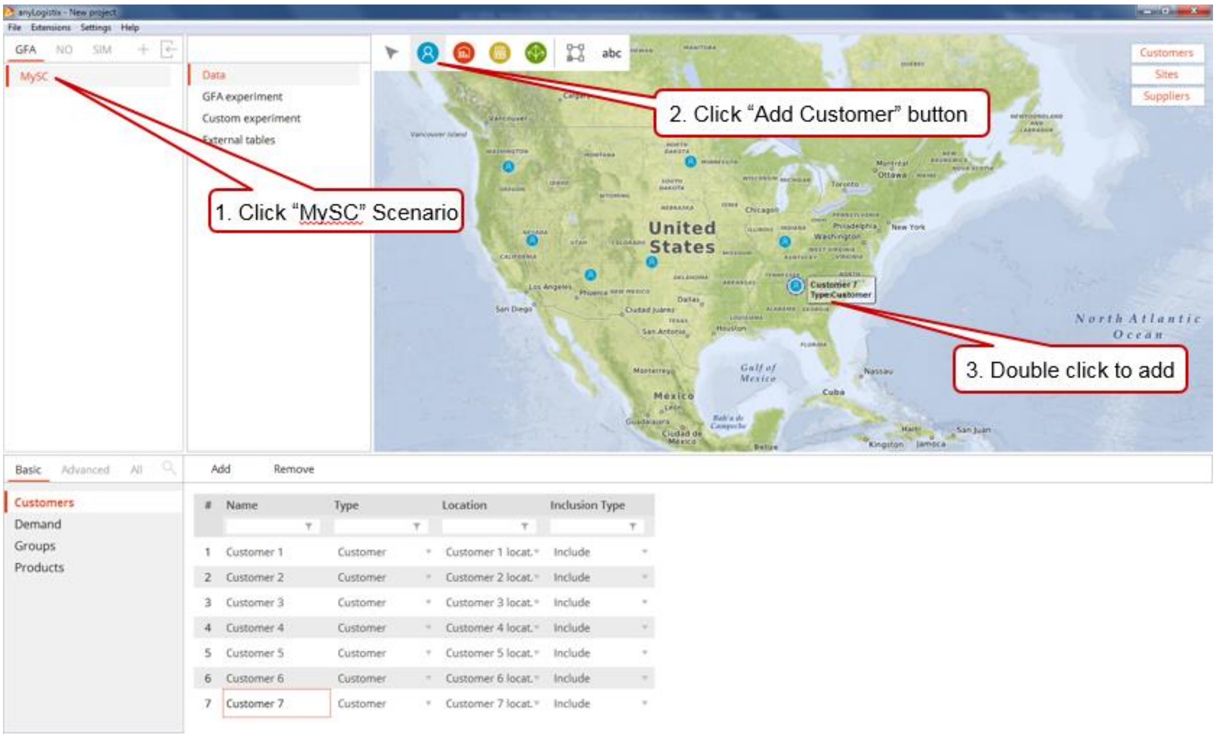


Fig. I-13. Create customers

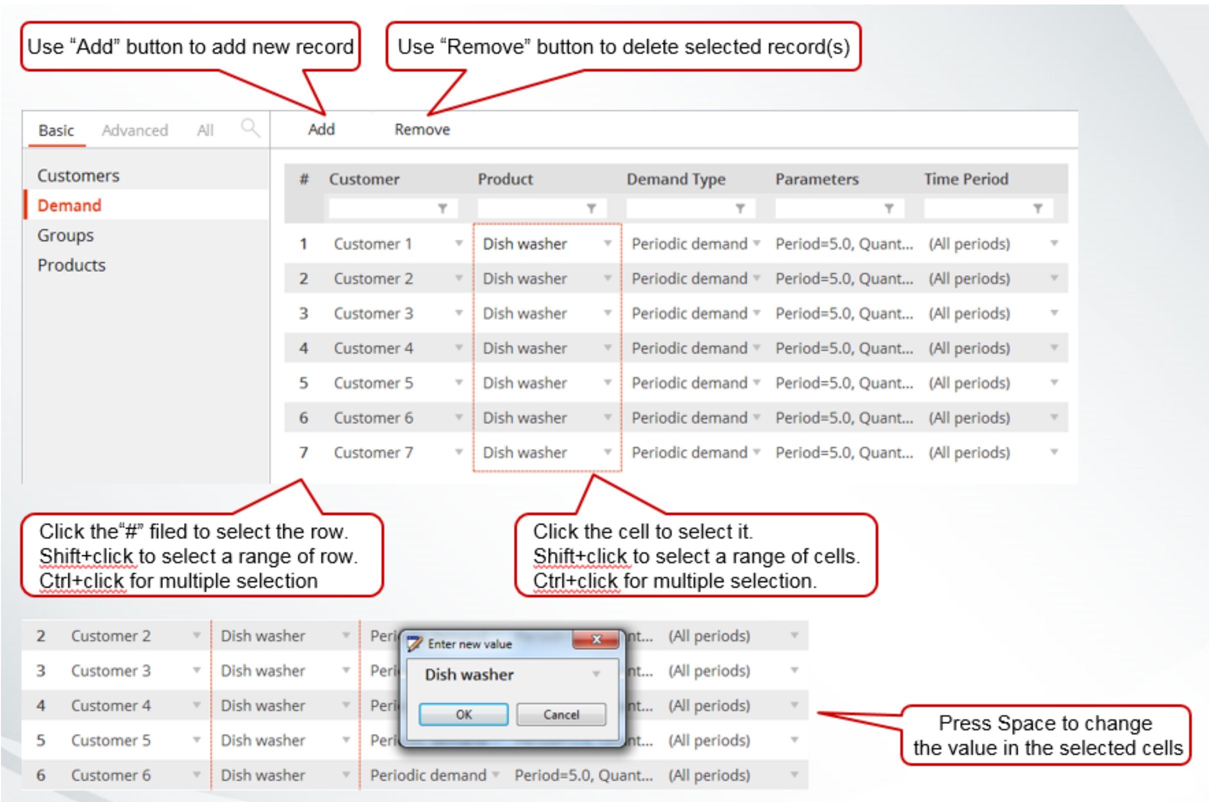


Fig. I-14. Parameter setting

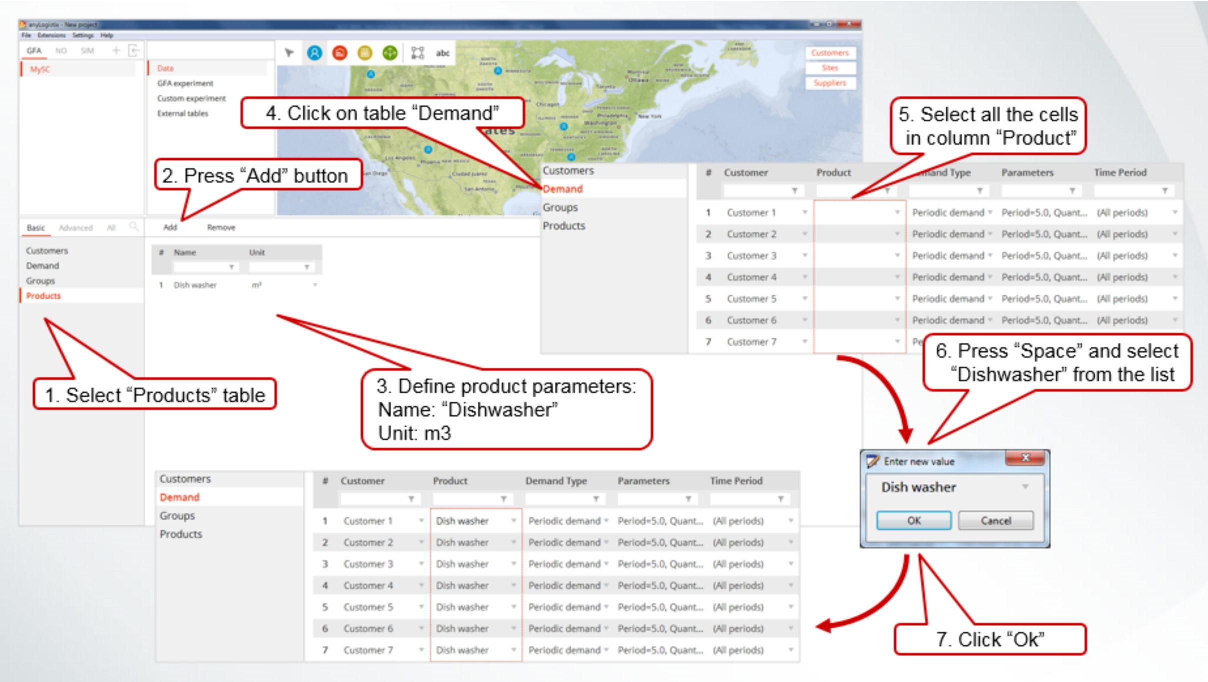


Fig. I-15. Products and demand setting

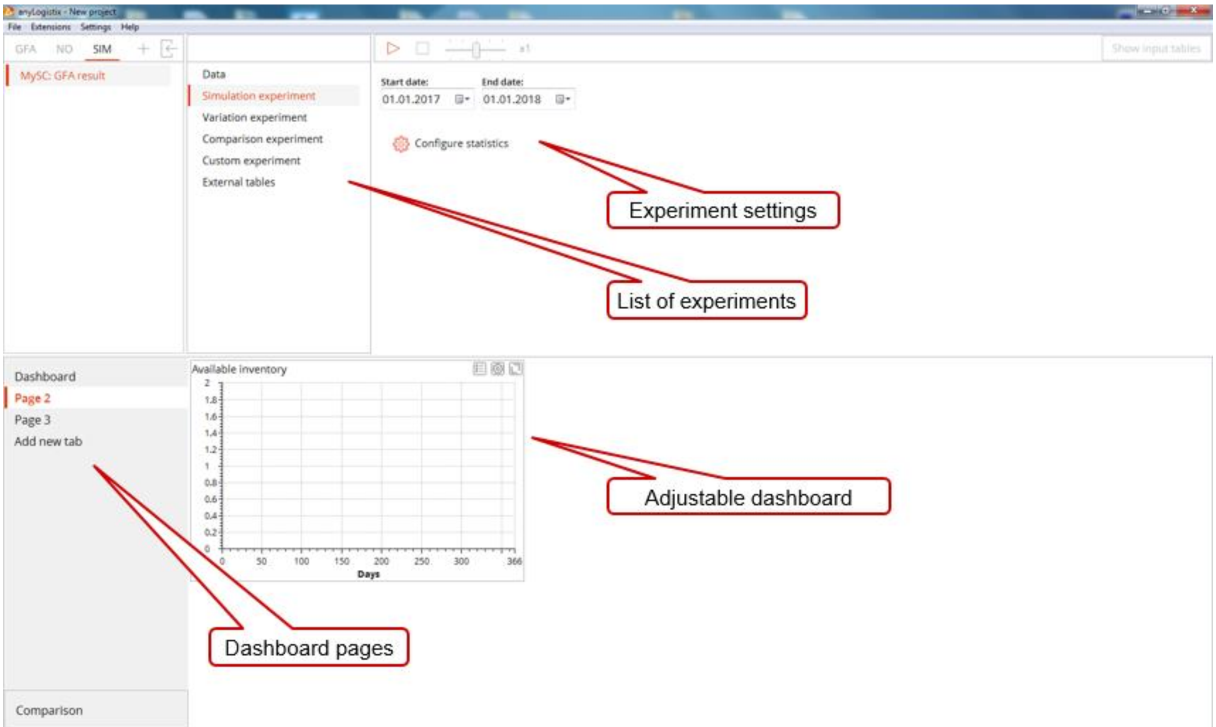


Fig. I-16. Experiments and KPI dashboard setting

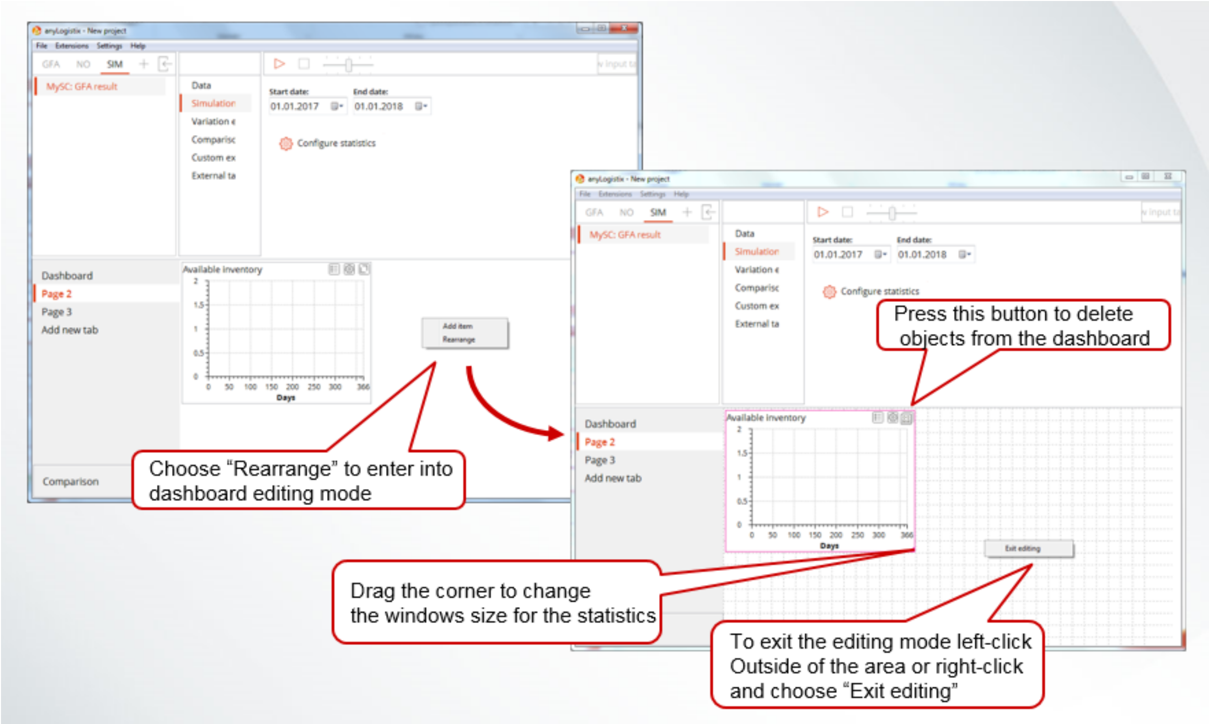


Fig. I-17. Adding new KPI to dashboard

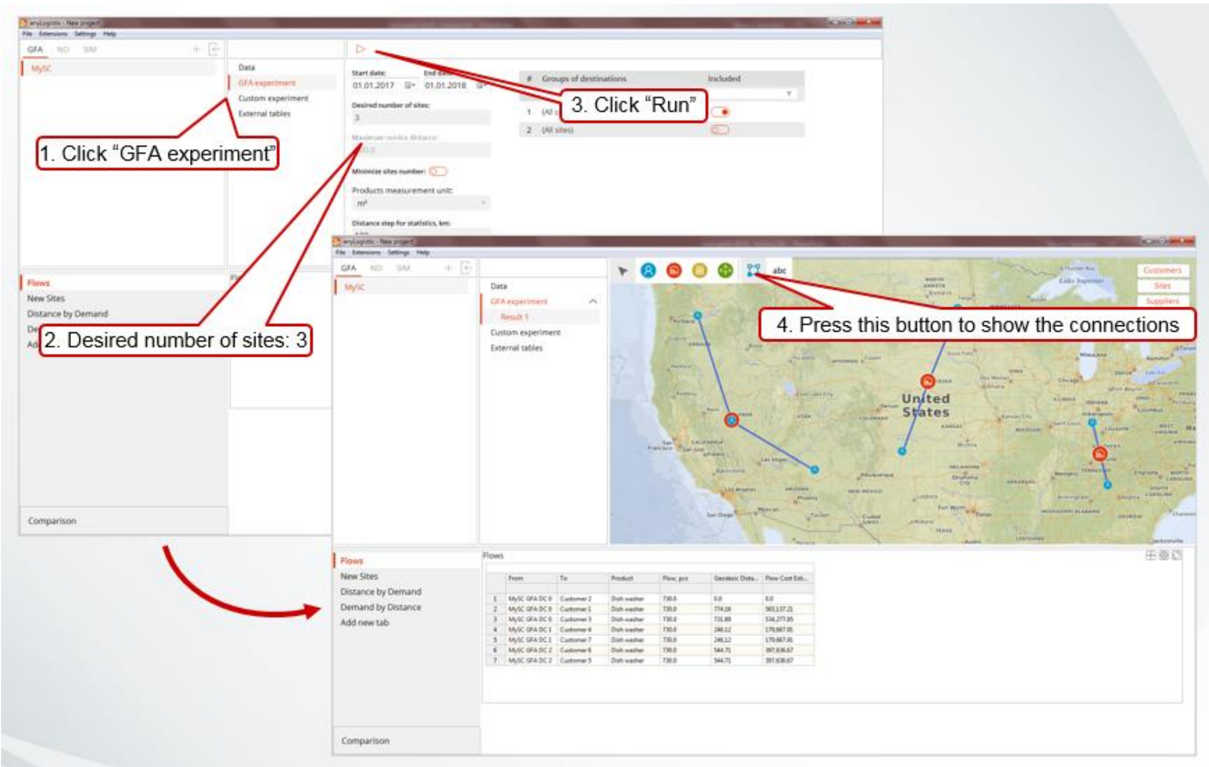


Fig. I-18. New experiment and statistics setting

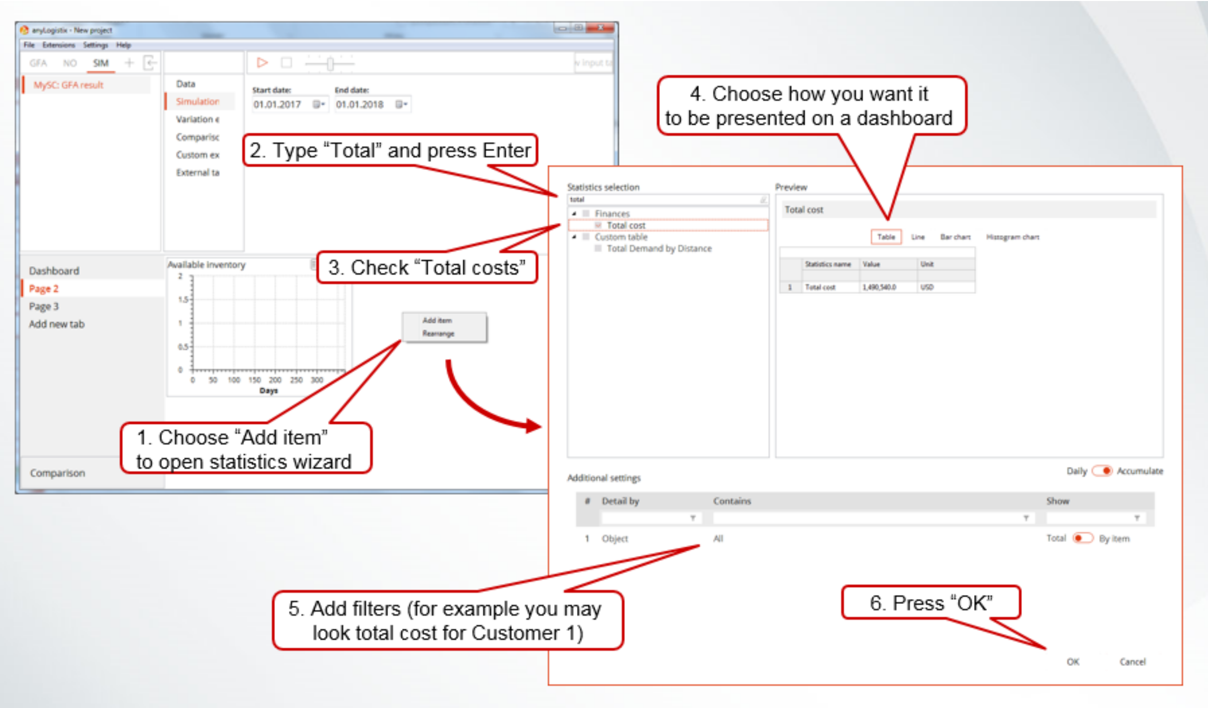


Fig. I-19. KPI configuration

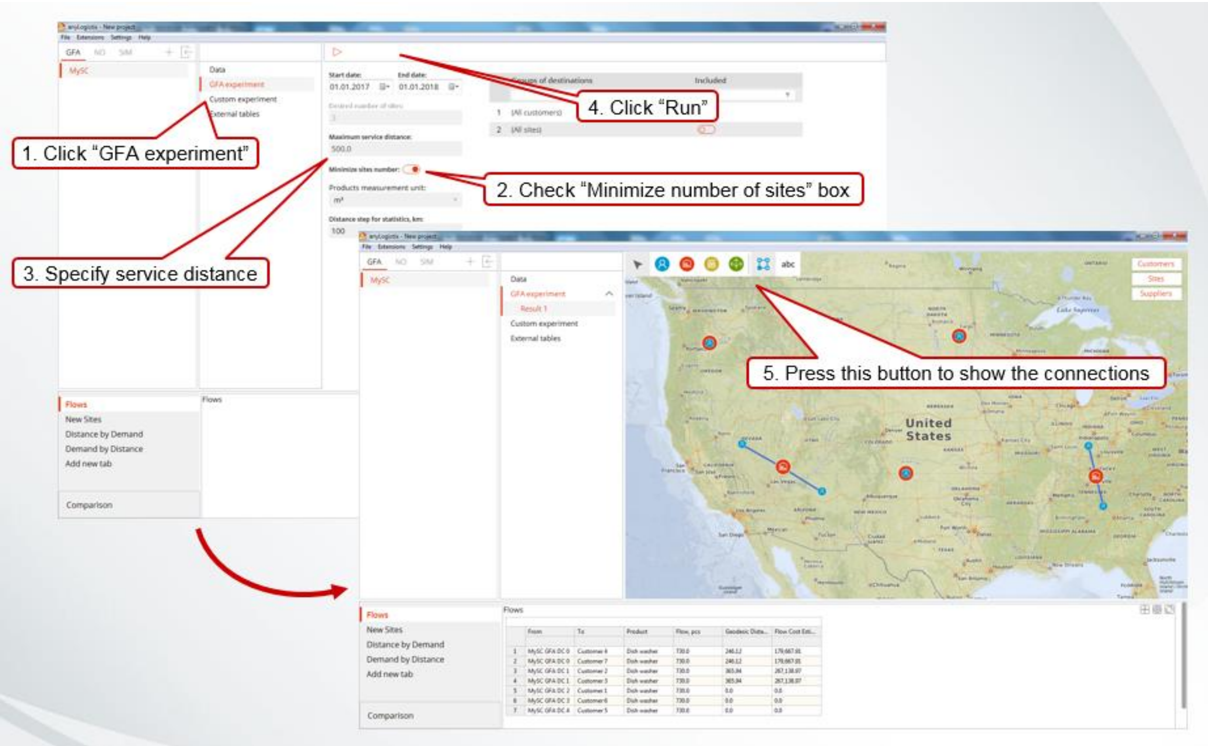


Fig. I-20. GFA experiment setting

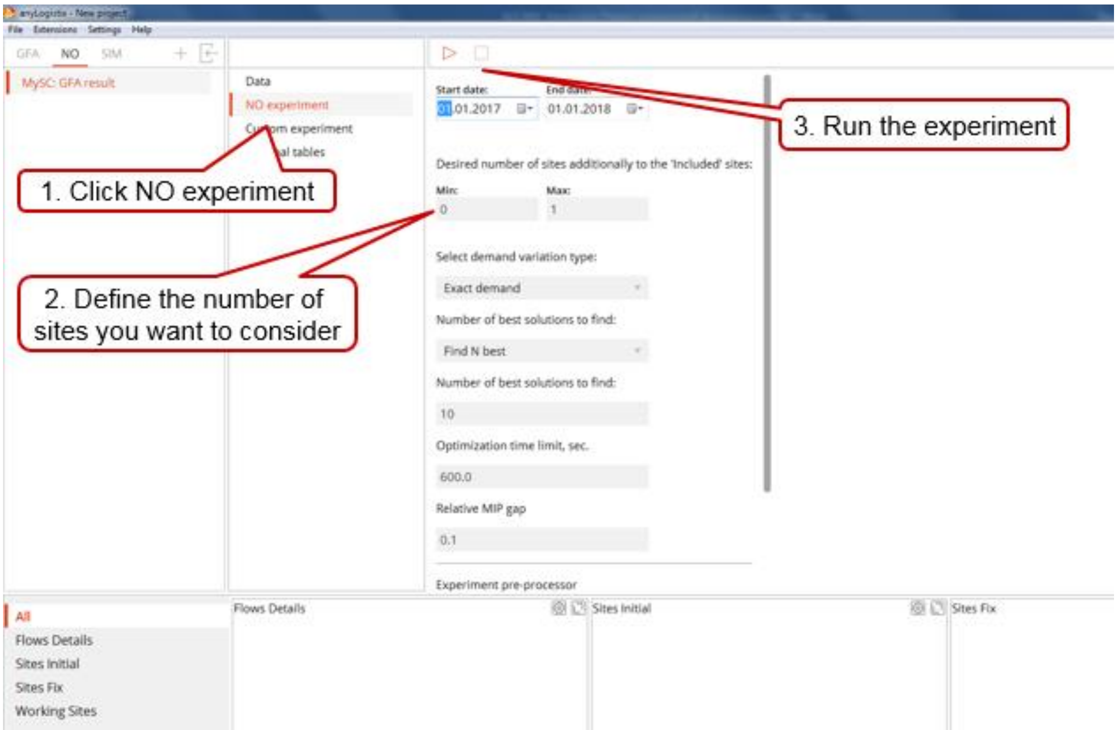


Fig. I-21. Network optimization experiment setting

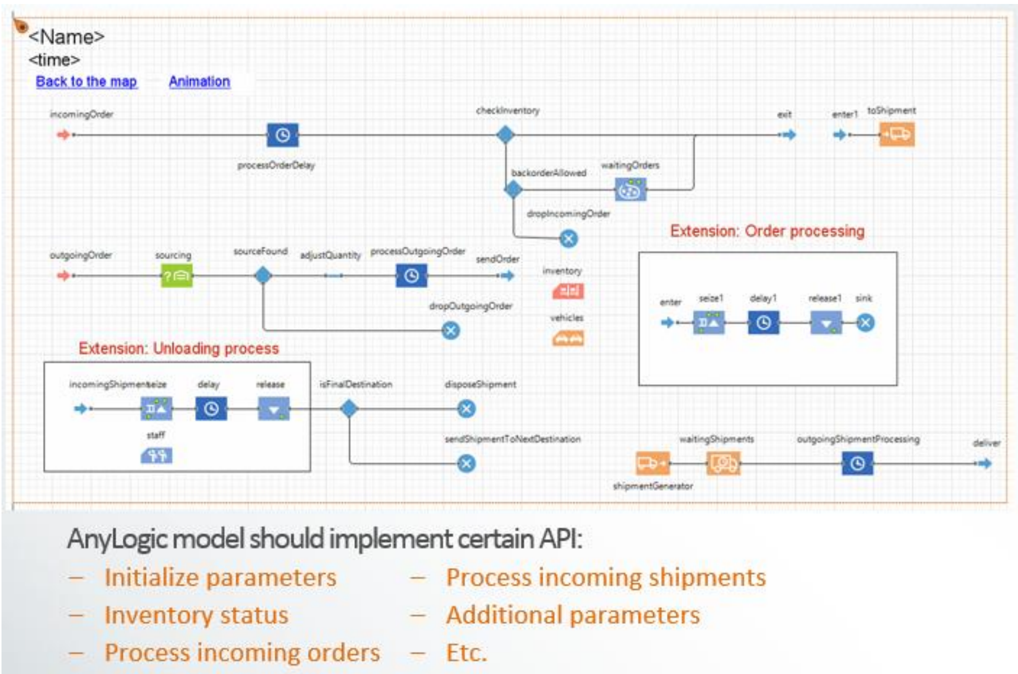


Fig. I-22. ALX extension by AnyLogic

Working with ALX is very intuitively. We will describe major and specific ALX features throughout this book.

Enjoy the SC simulation and optimization with anyLogistix!

Chapter 1. Two-stage supply chain: Facility Location Planning and Distribution Network Design

Learning objectives

1) To develop analytical and management skills on facility location planning using center-of-gravity method and network optimization (uncapacitated facility location planning)
2) To develop technical skills on creating two-stage supply chain models, performing experiments and measuring performance in anyLogistix (ALX) multimethod simulation software
3) To understand major trade-offs in facility location planning in regard to the number of sites, lead-time, demand uncertainty
4) To understand the application areas of simulation and optimization

1. Green-field analysis (GFA) for a new facility

1.1. Case-study „Facility Location Planning“: Greenfield analysis

Suresh, a SC manager at a discount network in retail business in Germany needs to decide where to locate new distribution centers (DC) and how many of them needs to be opened so that total SC costs are minimized. Suresh developed a list of input data needed for such an analysis as follows:

- List of customers and their geographical locations
- List of products and measurement units
- Customer demand
- Transportation costs for each kilometer
- Distances in the supply network

At the first step, Suresh asked the sales and marketing managers to estimate annual demand of customers in different regions and grouped them into ten major markets. Second, Suresh asked the transportation manager to estimate the shipment costs.

In the following, we show how to use ALX for helping Suresh to improve the DC network. The following steps will contain:

1. How to create new experiment in ALX and define the SC design structure
2. How to define customer demand, transportation, and sourcing policy in the SC
3. How to parametrize the sites and policies
4. How to perform the GFA experiment in order to determine optimal locations for the cases with single and multiple warehouses
5. How to create KPI dashboard and collect statistics on SC performance
6. How to simulate the SC design with GFA locations and analyse the SC performance impact

1.2. New experiment

The first step to build a decision-support model for facility location planning is to create new scenario (Fig. 1).

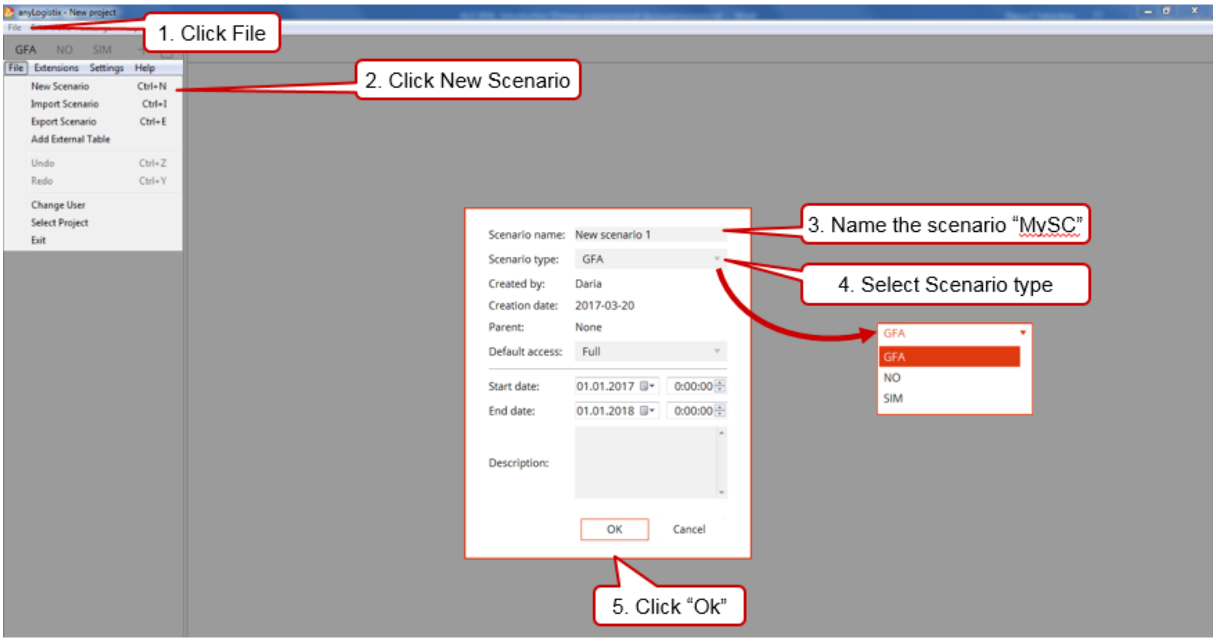


Fig. 1. Creating new scenario in ALX

Fig. 1 depicts basic steps to create new scenario (cf. Fig 10 in Introduction). The new scenario will be instantly opened in the central panel. You can always modify the scenario properties later by right-clicking the scenario in the Project tree and selecting Properties in the context menu. In addition, it is possible to import scenarios from Excel files and perform experiments with scenarios. Each scenario contains a SC structure and parameters that will be used for simulation and optimization experiments (Fig. 2).

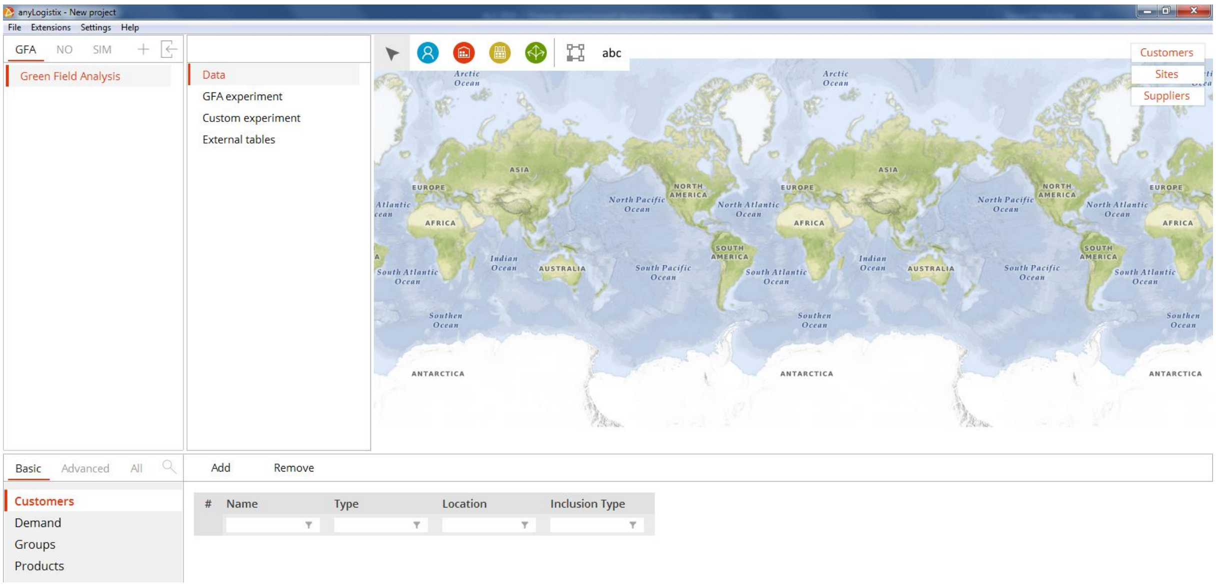


Fig. 2. Start window to prepare new scenario

We named new scenario “Green Field Analysis” (GFA) and this scenario can now be seen in the list of scenarios. Now let us define the SC structure and parameters.

1.3. Supply chain structure and parameter definition

1.3.1. Customer locations

With a right click on the map, locations of customers (or markets) can be created (Fig. 3; cf. Fig. 13 in Introduction). Having defined the customer position on the map, this location is automatically added to the lists of locations and customers with the respective latitude and longitude coordinates of this location (Fig. 4).

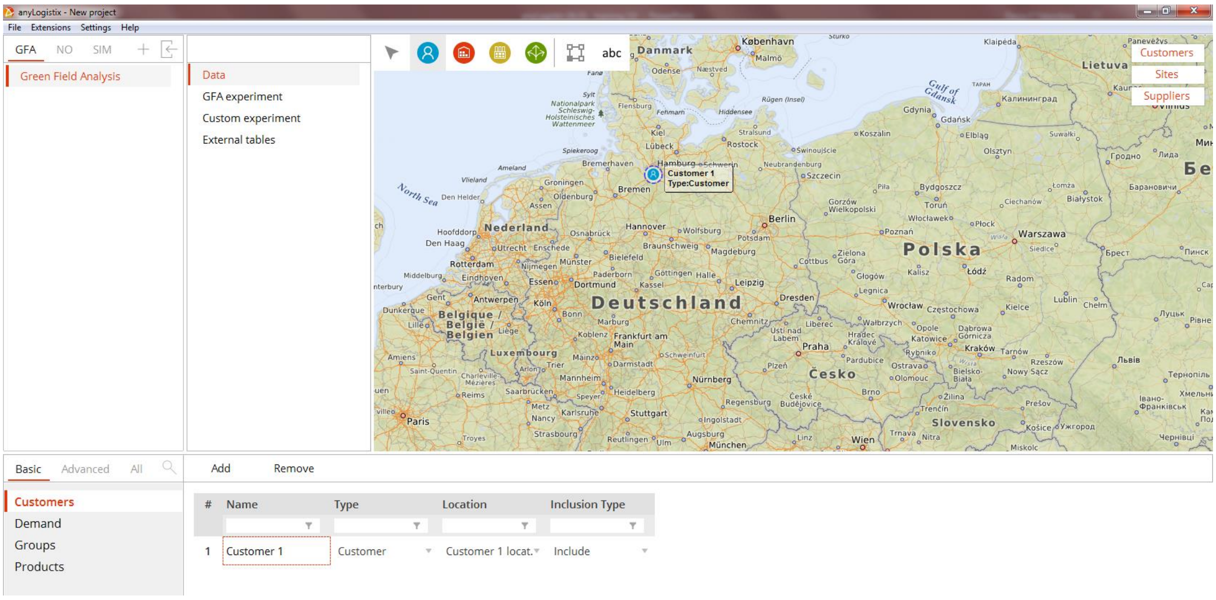


Fig. 3. New customer definition

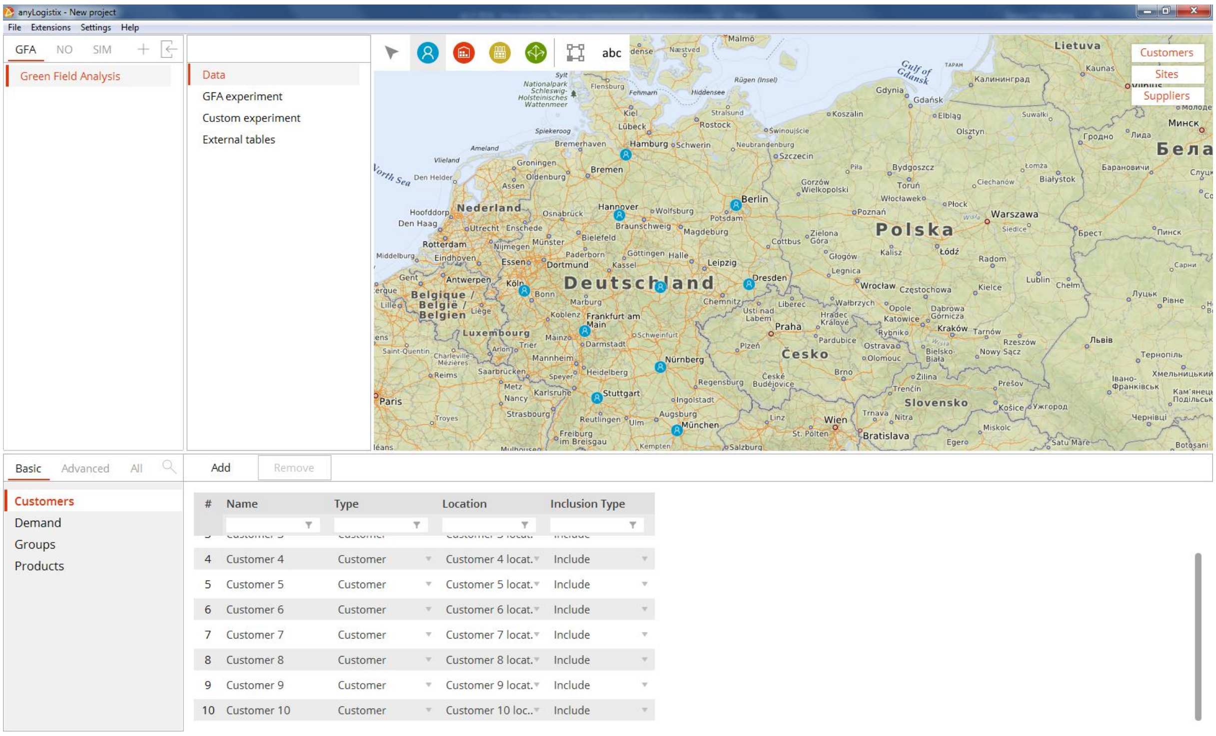


Fig. 4. Customer locations

1.3.2. Customer demand and products

Next step is to define customer demand. Before demand definition, we need to define the products to be shipped to the customers. Please consult Fig. 15 in the Introduction for technical issues of demand and product definition. Let us define a new product "Water" clicking at the button "Add" (Fig. 5).

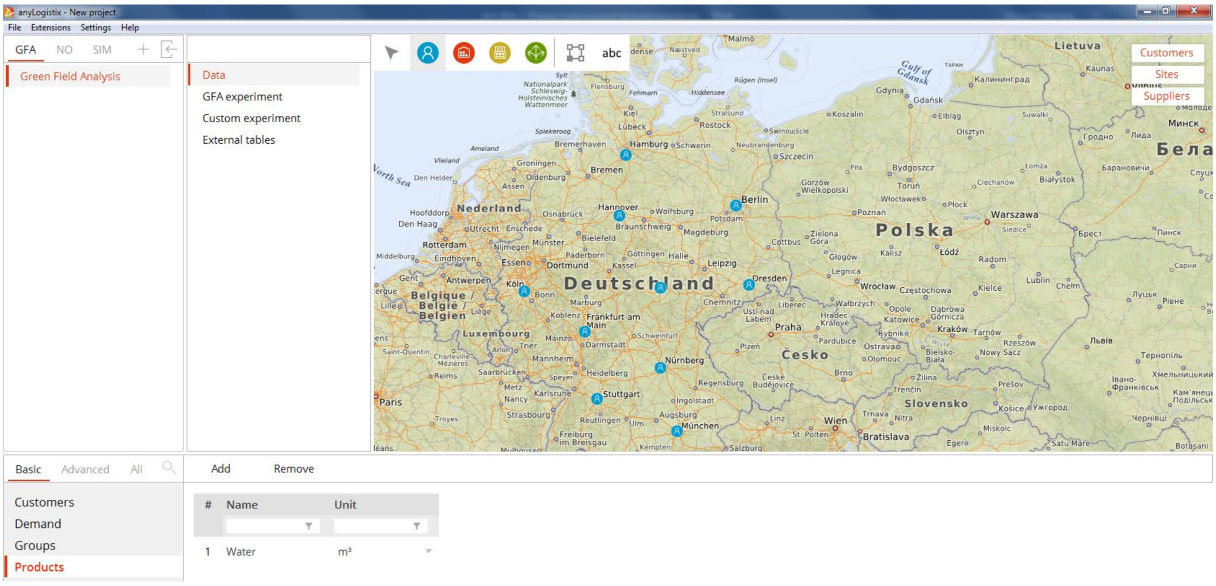


Fig. 5. Product definition

The list of the products can be very large. The products can be aggregated into “Product groups”. Without loss of generality, we consider one product in this example. Having defined the product “Water”, we can start defining the customer demands. Customer demand can be setup either *deterministic* or *stochastic* as periodic demand and historical demand (Fig. 6).

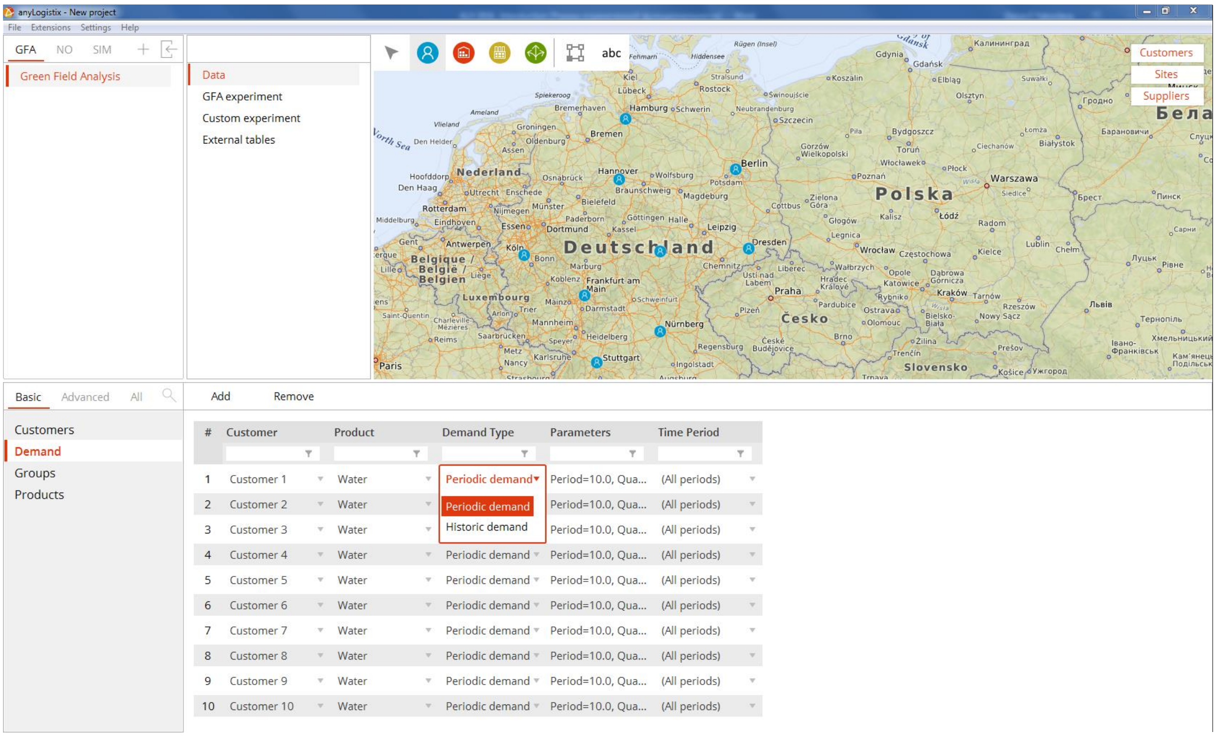


Fig. 6. Selection of demand data

In order to parametrize the demand, we open table „Demand“ on the left-hand side of the screen. Here we can select by double click in the respective cell the demand type, demand parameters for each customer will be used for service level computation (see further in this book). For example, we defined in Fig. 6 for each customer periodic demand with parameters Period = 10 days and Quantity = 5. This means that every ten days, the customers or markets will send new order of five units to the distribution center.

Periodic demand can be used if the sales quantity can be determined for a time period, e.g., we can expect to sell X water pallets within Y days. Historical demand assumes the usage of past data about sales, e.g., in previous year. In order to define historical data, we select the option “Historic demand” and define demand for previous periods by clicking “Add” (Fig. 7).

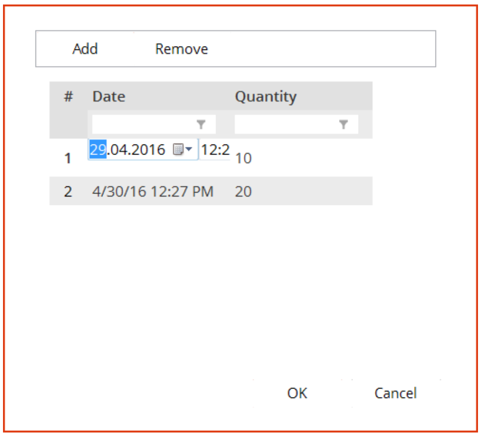


Fig. 7. Historical demand setup

In order to define periodic demand data, we select the option “Periodic demand” and define demand for a certain period of time. For example, demand of five water pallets for the period of ten days at customer #1 can be defined as shown in Fig. 8.

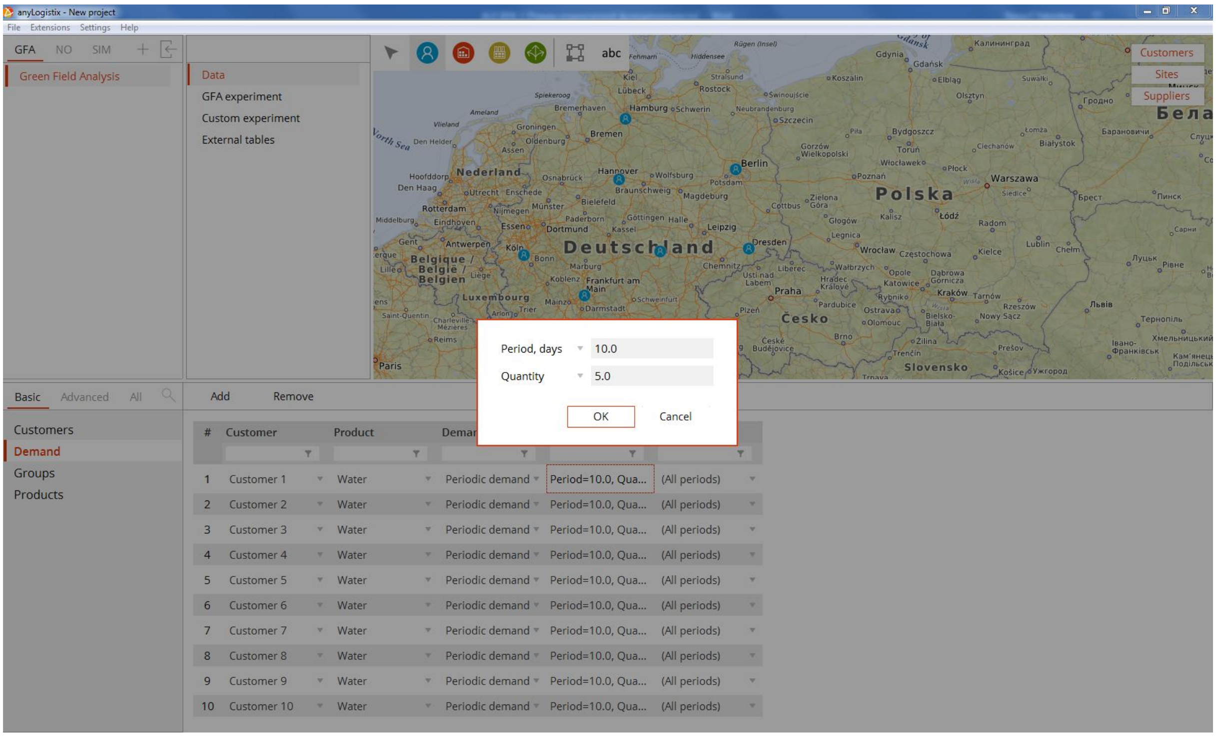


Fig. 8. Periodic demand setup

To make further analysis more depictive, we rename the anonymous “Customers” into concrete demand regions under “Customers” (Fig. 9).

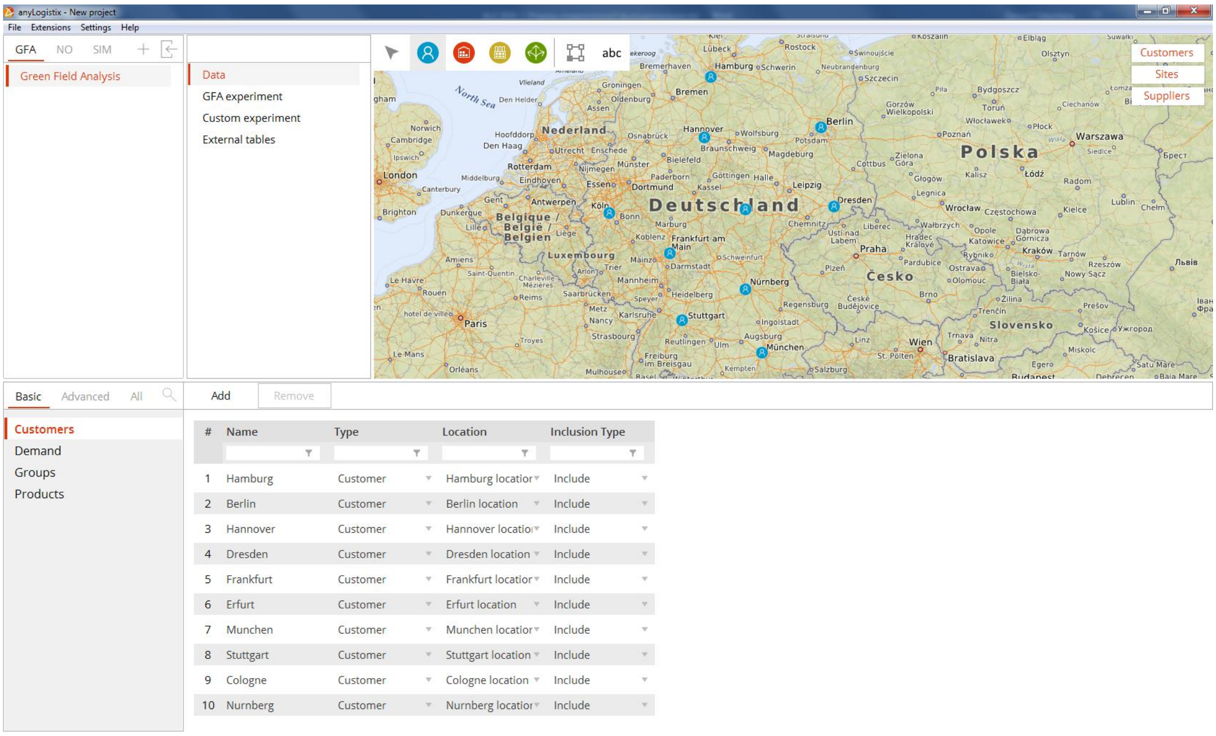


Fig. 9. Re-naming of the customers

Subsequently, we define periodic demand for each customer (Fig. 10).

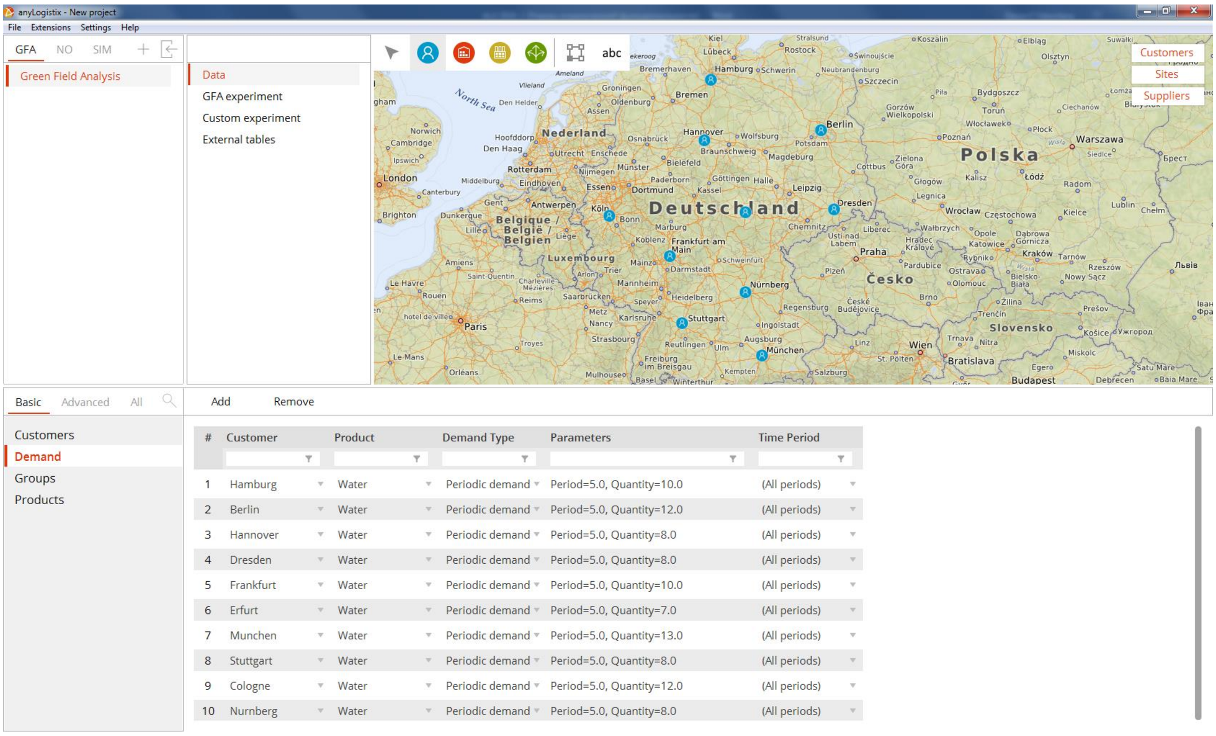
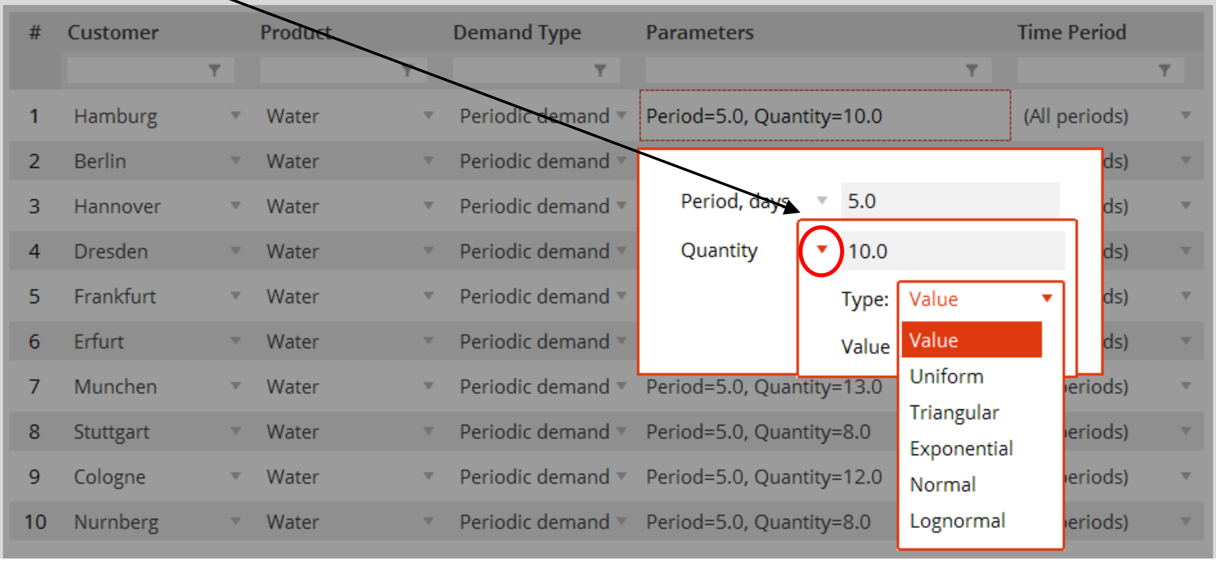


Fig. 10. Demand data setting for experiment

→ **Note**: demand data can be defined more flexible if you define different periods (e.g., summer, winter, spring and fall) in “Periods” and then define demand coefficients in “Demand Forecast” (Fig. 11).

→ In order to define stochastic demand, we can select different types of distributions clicking on the arrow in the respective parameter (i.e., period or quantity):



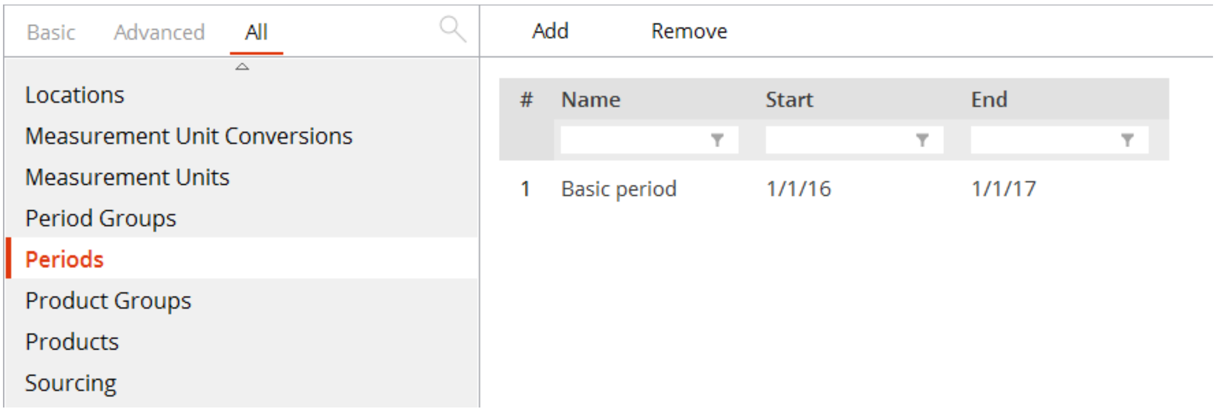


Fig. 11. Period definition

1.3.3. Data import from MS Excel files

For real cases, the list of customers and products may be quite long. In addition it is quite time consuming to enter historical or periodic demand data manually. That is why it can be recommend importing this data that is frequently available in MS Excel format. For doing that we need to select “Import” in the menu “File”. You can import sample ALS scenarios and your own previously created scenarios with experiments. It is also possible to create new scenario as an Excel file and import it in ALX in order to accelerate the scenario creation.

1.3.4. Creating groups

The problem in this example is not large and it is good observable. In reality (see example models in anyLogistix, e.g., Retail example), those problems can be complex. In order to simplify simulation modelling and experiments, it might be useful to group similar objects, such as DCs, customers, suppliers, etc. This happens in "Groups" (Fig. 12).

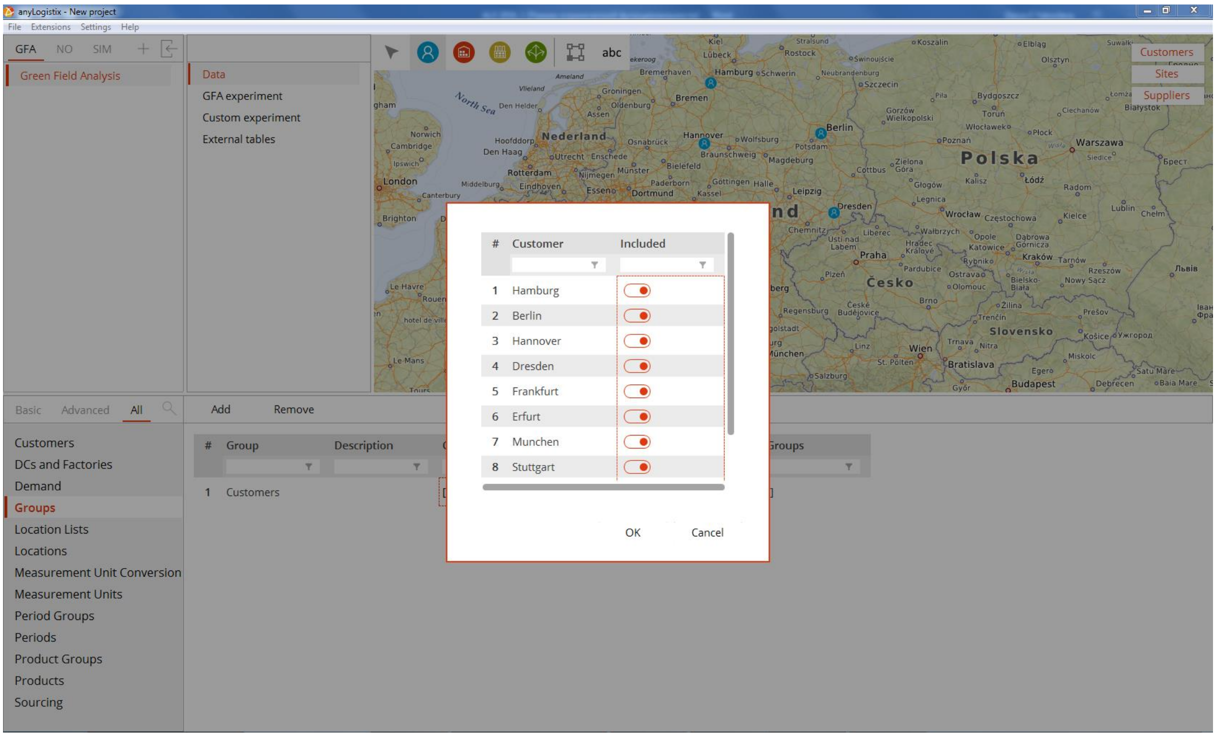


Fig. 12. New group creation

First, we need to click on "Add" and name a new group, e.g., "Customers". Second, we open the list of all customers in the table "Customers" and activate those of them which need to be included in the group. For DCs and factories, we activate objects in the column "Sites". Supplier groups are created in the column "Suppliers". Having created the groups, we can widely use them in sourcing, transportation, inventory, and production policy definitions instead of working with individual objects. In "Product groups", individual products can be grouped in the similar way. This helps to *reduce modeling complexity*.

Now all the data is setup and we are ready to perform the first experiment.

1.4. Experiments with green field analysis

The objective of our first experiment is to define the optimal location for the distribution center so that all the customer demands are fulfilled at minimal total transportation costs.

1.4.1. New experiment

In “Experiments”, we select “Greenfield Analysis”. We further refer to Fig. 20 in Introduction for further details on GFA experiment.

1.4.2. Greenfield analysis

We select scenario “Green Field Analysis” that we just created (Fig. 13).

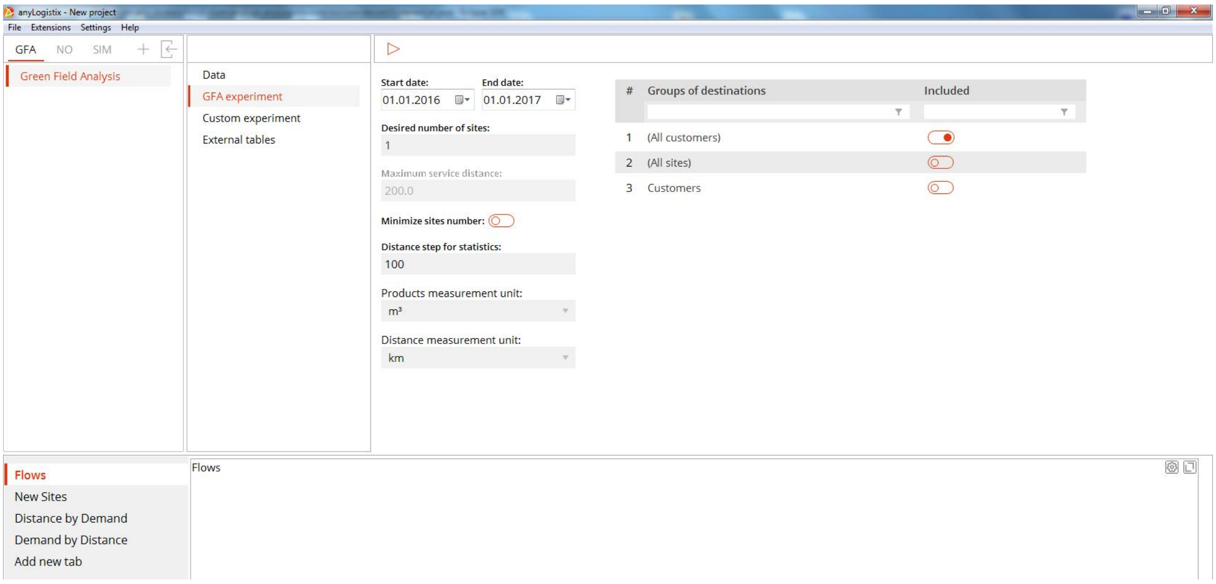


Fig. 13. Data setting for experiment

GFA, also known as center-of-gravity analysis, is a common method to find optimal facilitz locations (Ivanov et al. 2017). All relevant issues in this decision problem are customer locations, distances from warehouse to customers, and customer demands. Each customer location is represented by the ordered pair of (x;y)-coordinates. These data cannot be modified; they are input data or problem *parameters*. In contrast, the (x;y)-coordinates (p_x;p_y) of the new warehouse are variable and have to be determined. Consequently, p_x as well as p_y are the *decision variables* in the investigated decision scenario. Further, it is assumed that the transportation cost is linearly proportional to the distance and the transportation volume (i.e., the demand). We can observe that the total transportation costs depend on the coordinates p_x and p_y of the prospective warehouses and distances. We assume that the transportation costs from the prospective warehouse location (p_x;p_y) to a customer location (x_i;y_i) is more or less equal to the distance and demand. Therefore, the distances d((p_x;p_y); (x_i;y_i)) between the *i*-customer location and the warehouse should be determined in order to calculate transportation costs. In order to minimize the payments to the forwarding company it is necessary to vary p_x as well as p_y as long as Z(p_x;p_y) becomes minimal.

First, we can select locations and customers to be included in the analysis. In this example, we include all the customers. Second, the computation can be performed in two modes:

- Define optimal location for a single warehouse
- Define minimal number of warehouses and their locations subject to maximum service distance.

1.4.2.1. Optimal location for single warehouse

By default, the parameter “Desired number of sites” in the GFA experiment is setup as “1”. That is why we just start the experiment. In the case you are looking for more than one facility location, this number can be easily changed. Here we perform computation for the case when we need to define optimal location for a single warehouse (Fig. 14).

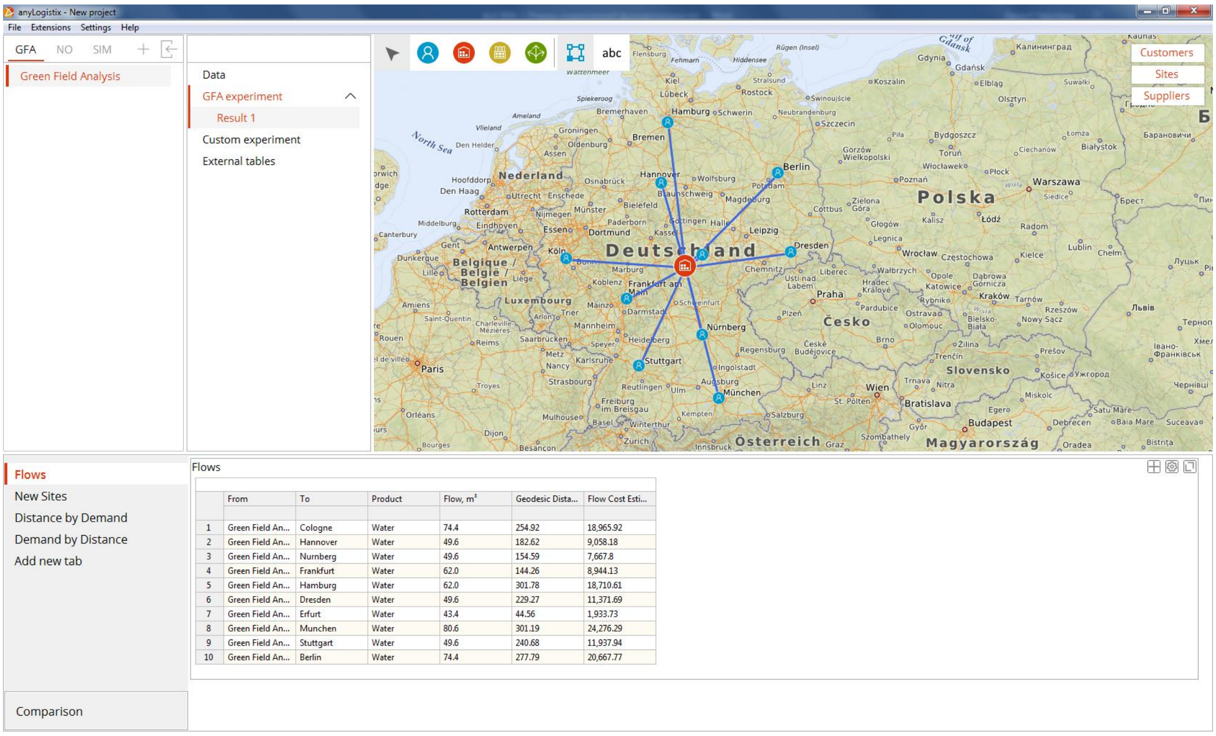


Fig. 14. Computed optimal location for single warehouse

1.4.2.2. Minimal number of warehouses and their locations subject to maximum service distance

In the settings of the experiment, we now activate the option “Minimize site number” and setup maximum service distance, e.g., 300 km (Fig. 15).

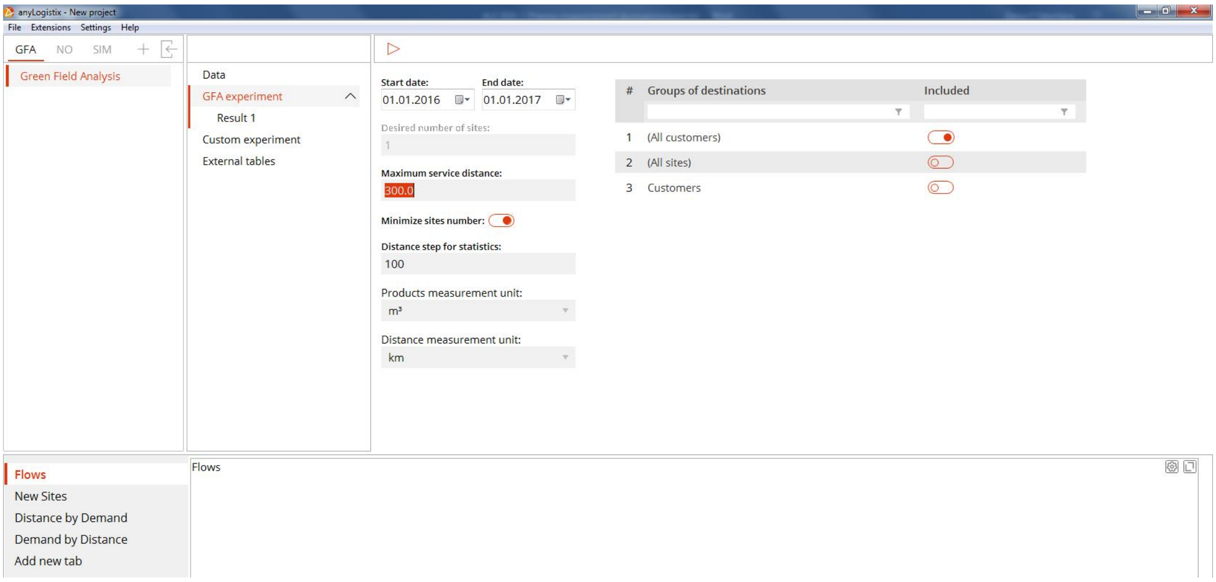
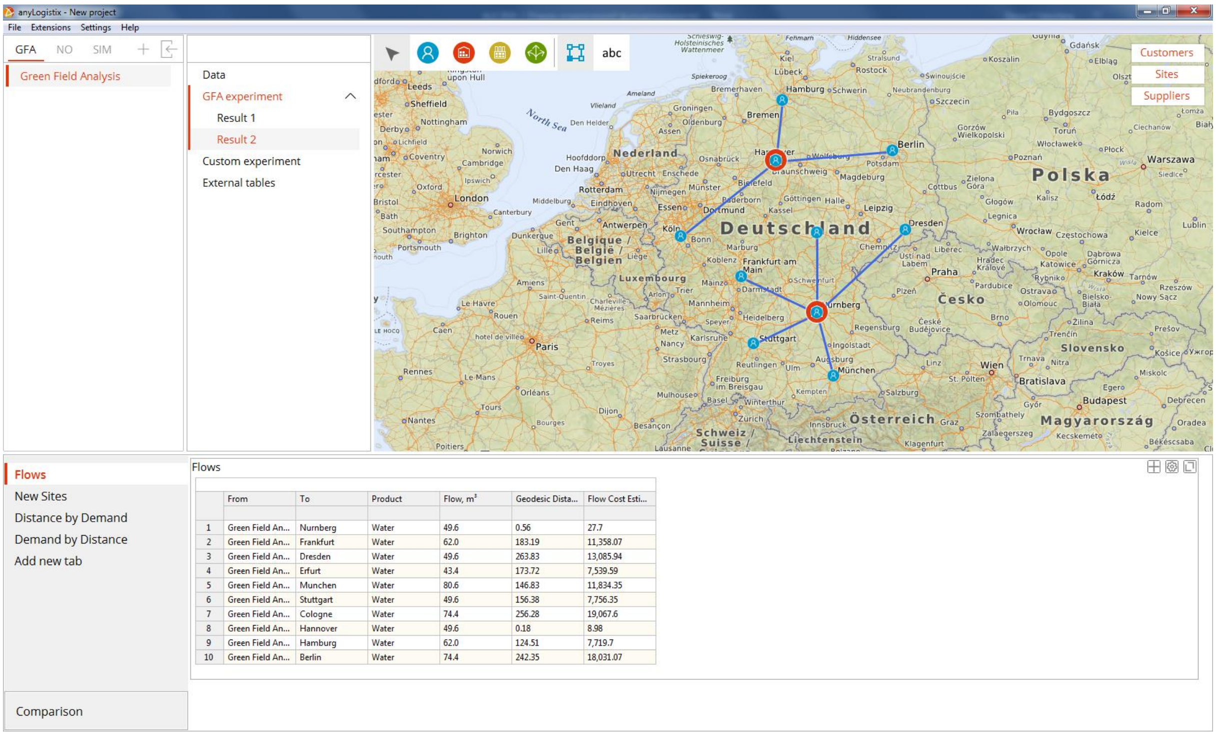


Fig. 15. Experiment settings to determine minimal number of warehouses and their locations subject to maximum service distance.



	From	To	Product	Flow, m³	Geodesic Dista...	Flow Cost Esti...
1	Green Field An...	Nurnberg	Water	49.6	0.56	27.7
2	Green Field An...	Frankfurt	Water	62.0	183.19	11,358.07
3	Green Field An...	Dresden	Water	49.6	263.83	13,085.94
4	Green Field An...	Erfurt	Water	43.4	173.72	7,539.59
5	Green Field An...	Munchen	Water	80.6	146.83	11,834.35
6	Green Field An...	Stuttgart	Water	49.6	156.38	7,756.35
7	Green Field An...	Cologne	Water	74.4	256.28	19,067.6
8	Green Field An...	Hannover	Water	49.6	0.18	8.98
9	Green Field An...	Hamburg	Water	62.0	124.51	7,719.7
10	Green Field An...	Berlin	Water	74.4	242.35	18,031.07

Fig. 16. Computation result for minimal number of warehouses and their locations subject to maximum service distance

It can be observed from Fig. 16 that two DCs or warehouses need to be opened subject to maximum service distance of 300 km.
In order to decide on exact location of new facilities, additional factor-rating-based analysis is needed.

➔ Questions for a discussion:

1) If we would decrease the maximum service distance, what would happen with the number of distribution centers or warehouses? Try to compute the case with maximum service distance of 150 km!
2) What other costs and factors need to be included in the final decision on facility location planning?

→ **Note:** GFA results can be exported to new scenario. This is helpful to perform simulation experiments.

1.5. New simulation experiment

The objective of the simulation experiment is to observe SC behavior in dynamics. *Static* view on SC structure will be now transformed into a *dynamic* form. In this example, we will simulate the SC with two DCs determined in the green field analysis for the case of maximum service distance of 300 km. First, we convert GFA result into a SIM scenario by right clicking on "Results 2" in GFA 1 (Fig. 17).

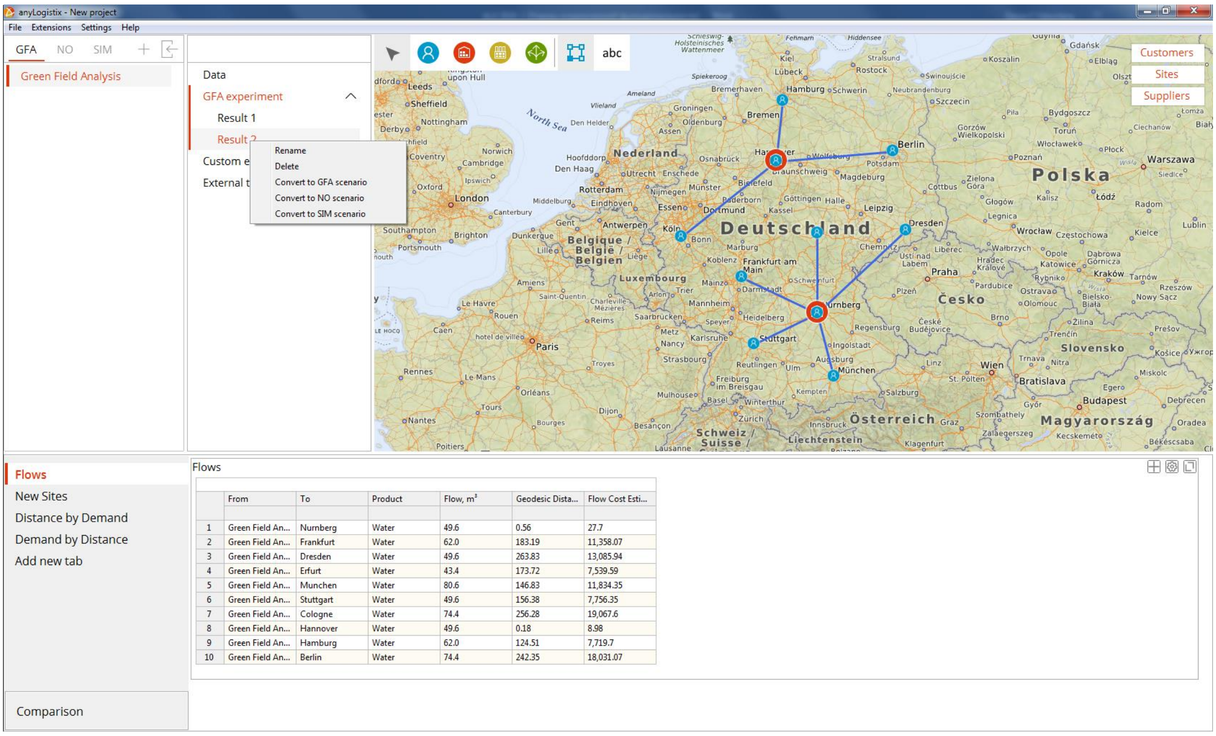


Fig. 17. Transformation of the GFA result to SIM scenario

"GFA 1: Results 2" appears now in the list of scenarios.

1.6. KPI dashboard

We select "GFA1: Results 2" as scenario for simulation experiment and click on "Configure statistics" in order to create a KPI (key performance indicators) dashboard (Fig. 18). We refer to Figs 16-19 in the Introduction for further insights on KPI setting and statistics collection.

→ Note: ALX uses a general term „statistics" instead of KPI. Throughout this book we use the term KPI since it is more common term for managers.

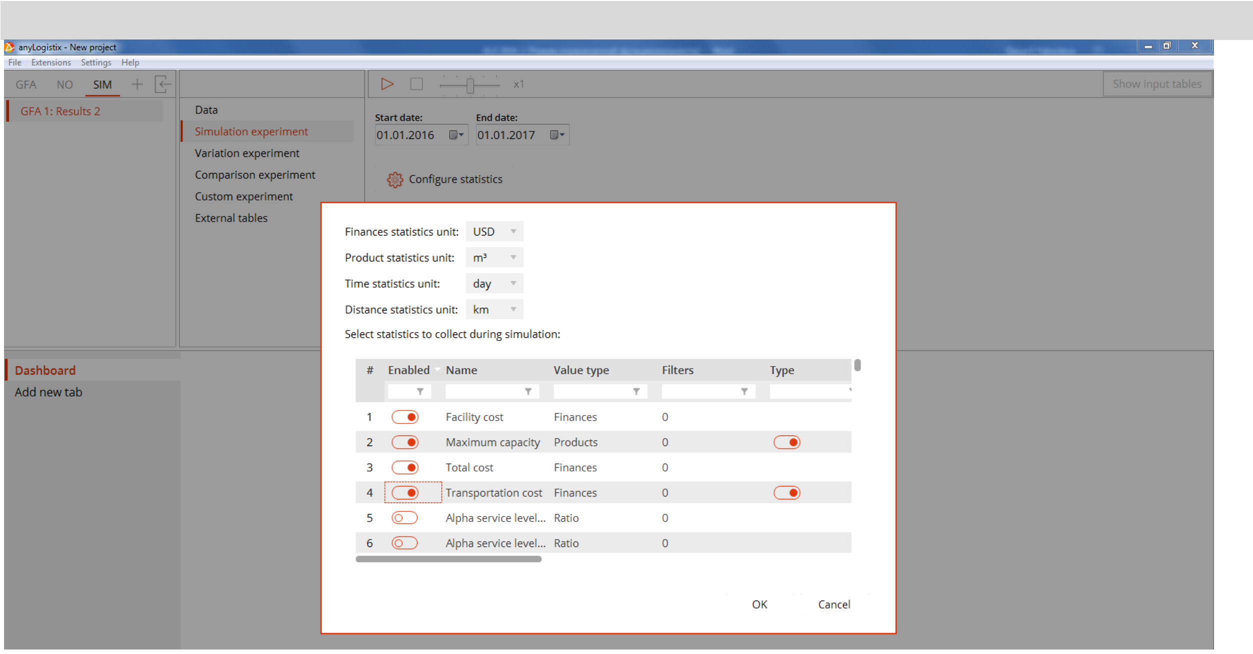


Fig. 18. KPI list by default

→ Note: Statistics configuration interface in ALX can be changed with new updates of software. That is why some KPI can be structured differently as shown in this example, and some new KPI can be added. However, the basic principles of statistics dashboard creation remain unchanged.

In order to add new KPI to the dashboard, we right click on the dashboard area, select “Add item”, and then get the following screen to select the KPI and their form (Fig. 19).

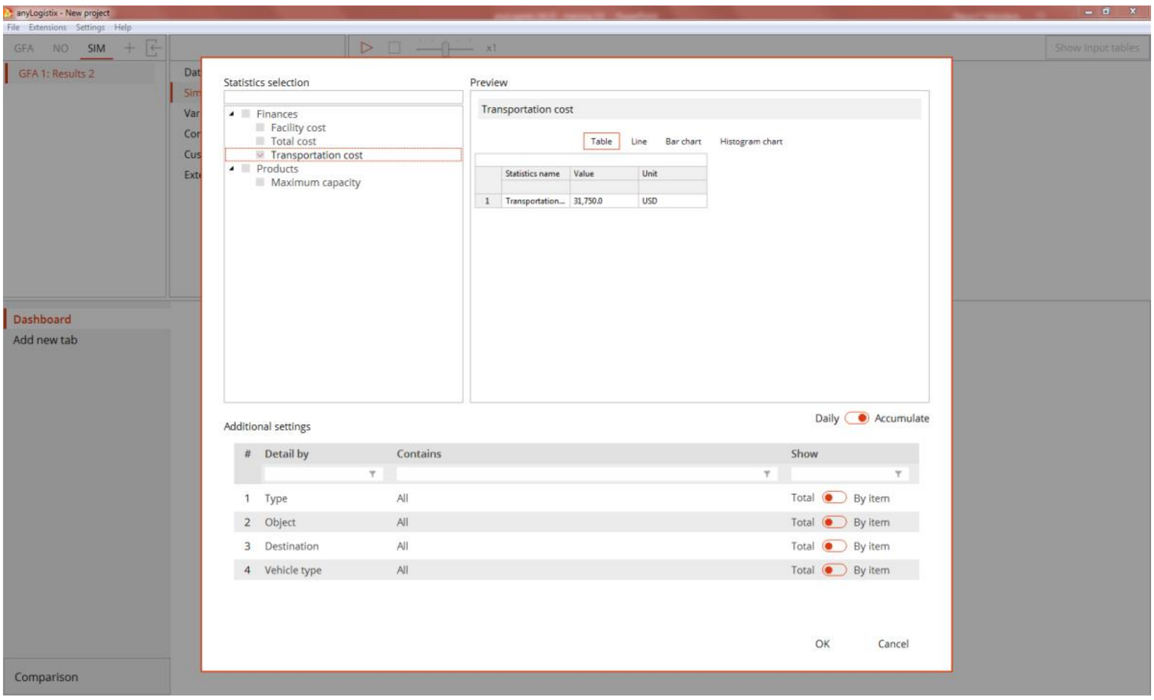


Fig. 19. Start of KPI dashboard creation

1.6.1. KPI system

By default, more than 200 KPI are classified into six groups:

- KPI for DC
- KPI for factories
- KPI for DC with storage
- KPI for DC with staff
- KPI for customers and
- KPI for suppliers

With the help of pre-defined KPI, it becomes possible to analyze financial, operational, and customer performance.

KPI in “Statistics collection” are organized in the following groups:

- Finances - detailed information on generated revenue and incurred expenses.
- Distance - detailed information on the distance covered by the vehicles.
- Volume - detailed information on the volume of products in stock.
- Quantity - detailed information on the quantity of processed (as well as dropped/lost) orders/products.
- Ratio - detailed information on the quality of provided delivery services basing on the analysis of the received or initially dropped orders/ordered products.
- Time - detailed information on time spent processing tasks or being idle.
- Custom table - tables created by the user within the Anylogic environment.
- Preset - grouped sets of regular statistics, which allow to view and analyze data in a more convenient way.

In each group, we just need to select KPI and chart type (i.e., table, line, barchart or histogram chart). In the case of a large model, KPI can be detailed or filtered by products, types, and objects:

- Types: DC, Factory, Supplier, Customer,
- Objects: individual DCs, factories, suppliers, customers
- Products: individual products

1.6.2. Revenue, costs, service level, lead time, on-time delivery

Let us create a KPI dashboard for our example. Since we consider a two-stage SC in this example, we will take a closer look at KPI for DCs and customers. The following KPI will be included in the dashboard:

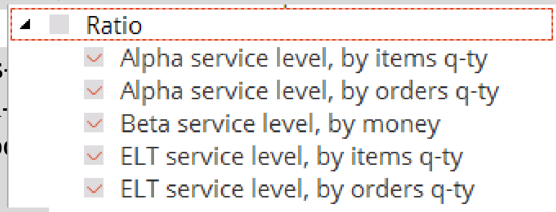
Financial performance:

- transportation costs, fixed warehousing costs, total costs, total profit, total revenue

Customer performance:

- ELT service level*, customer revenue, OTD (on-time-delivered) orders, delayed orders, lead-time (i.e. the time within which the product is expected to be received by the customer)

* → **Note:** three types of service level are used in ALX:



- alpha – measures the probability that all customer orders arriving within a given time interval will be completely delivered from sto on hand, i.e. without delay
- beta – quantity-oriented service level with backordering consideration
- ELT – ratio of orders delivered within "Expected lead time" (table demand) to total number of orders

→ In Alpha Service Level, there is no backlog. If an SC can't fulfil the order, the order is rejected. ELT Service Level takes into account backlog and transportation time to the customer.

Service Levels can be calculated for both products and orders.

Since we DCs have been created during the GFA analysis, no parameters at DCs have been defined so far. We need to define variable processing and fixed warehousing costs ("Other costs" in table "Facility expenses" and "Outbound processing costs" in table "Processing costs") (Fig. 20).

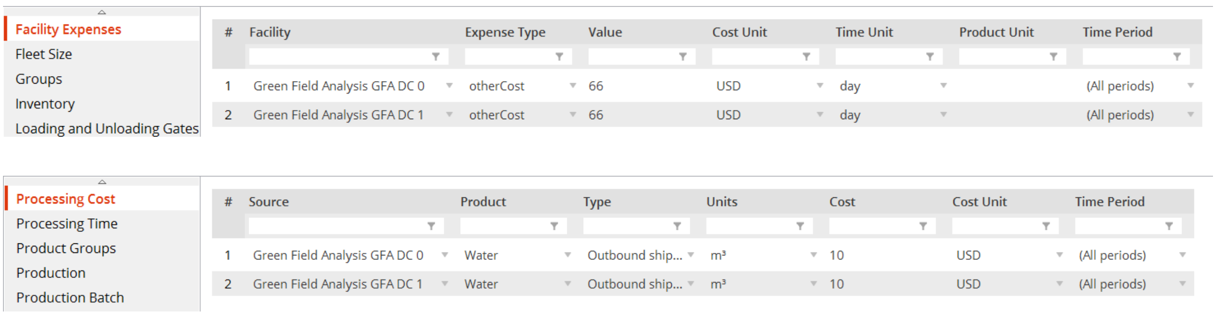


Fig. 20. DC cost parameters

For both DCs we define fixed warehousing costs per day at \$66. Outbound processing costs is setup at \$10 per m^3. Fixed warehousing costs is defined as "Other Cost". Inventory holding costs can be defined either via "interest ratio" or by setting "carrying costs" for each unit per year. In addition, if we have inventory, "facility costs" needs to be defined per month per m^3. Inventory management problems in the SC and their implementation in ALX will be discussed in detail in Chapter 2.

Also, we need to define cost and selling price for our product:

#	Name	Unit	Selling Price	Cost	Cost Unit
1	Water	m³	100	50	USD

Fig. 21. Product cost parameters

1.6.3. Transportation distance and costs

The last step in input data setting is the definition of the transportation distance and costs. At the beginning, vehicle type, its capacity and speed need to be defined in "Vehicle Types" (Fig. 22).

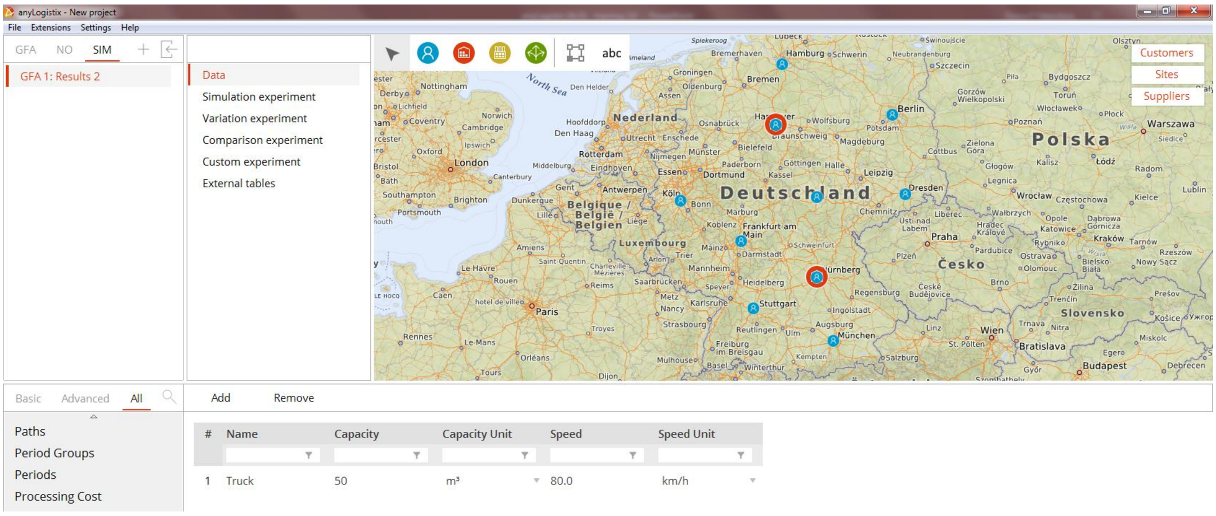


Fig. 22. Vehicle type definition

Next, in the "Paths", routes and shipment parameters need to be defined (Fig. 23).

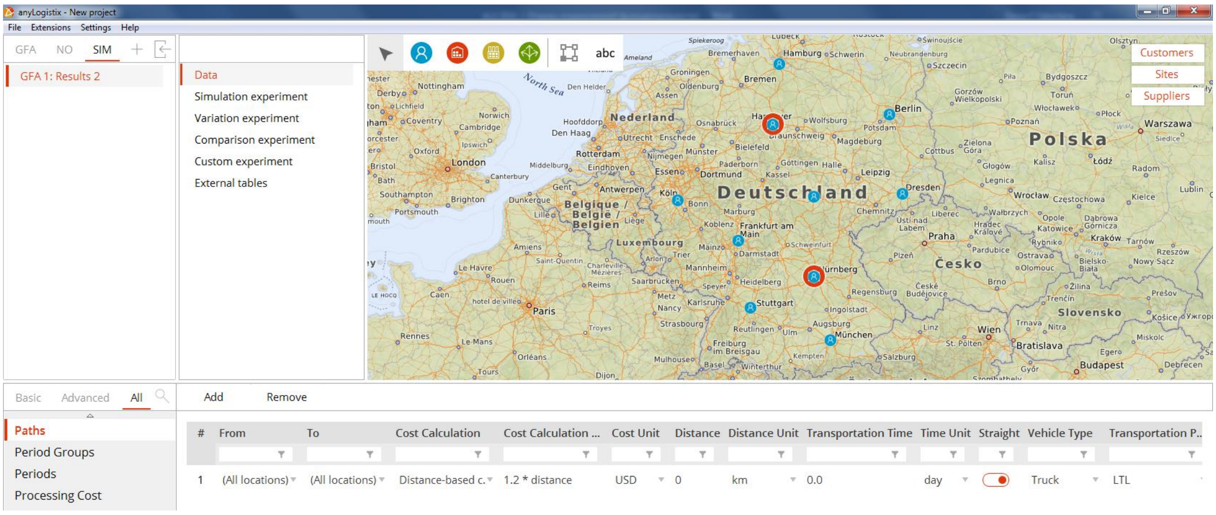
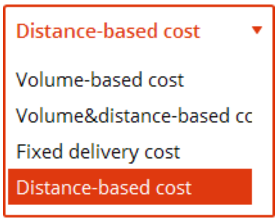


Fig. 23. Routes and shipment parameter definition

In the “Paths”, the first step is to define the routes “From”-“To”. In our example (Fig. 23), we identify only one group of routes “From All locations To All locations”. In the presence of different SC layers such as distribution centers, production factories, and suppliers, different paths can be added in order to differentiate shipment parameters at different SC echelons.

Second, we need to define a rule for shipment cost calculation. Shipment cost computation can be based on different rules:



For our example, we select distance-based costs and setup coefficient 1.2 for one kilometer which means that we pay $1.20 for one kilometer.

Third, distance and transportation time can be either defined explicitly or they can be computed automatically on the basis of truck speed and customer locations. We allow an automatic computation in this example.

Fourth, we can decide on which distance metrics to use: straight distances or real routes. For simplification, in this example we will use straight lines.

Fifth, LTL or FTL transportation options can be selected. It is possible to define minimal load for LTL as well as the rules for order aggregation.

→ **Note**: in order to define the rules for transportation batching, we can use MinLoad and Aggregation Period columns:

Vehicle Type	Transportation Policy	Min Lo...	Aggregate ...	Aggregation Period
Truck	FTL	0.6		10

In this example, we allow for a shipment by minimum load of 60%, but we wait not longer than 10 days. In ten days, the truck will be dispatched for shipment even if the load is below 60%.

1.6.4. Sourcing policy definition

In “Sourcing”, we need to define sourcing rules. The most general rule could be that all the customers can be supplied from all the sites (DCs).

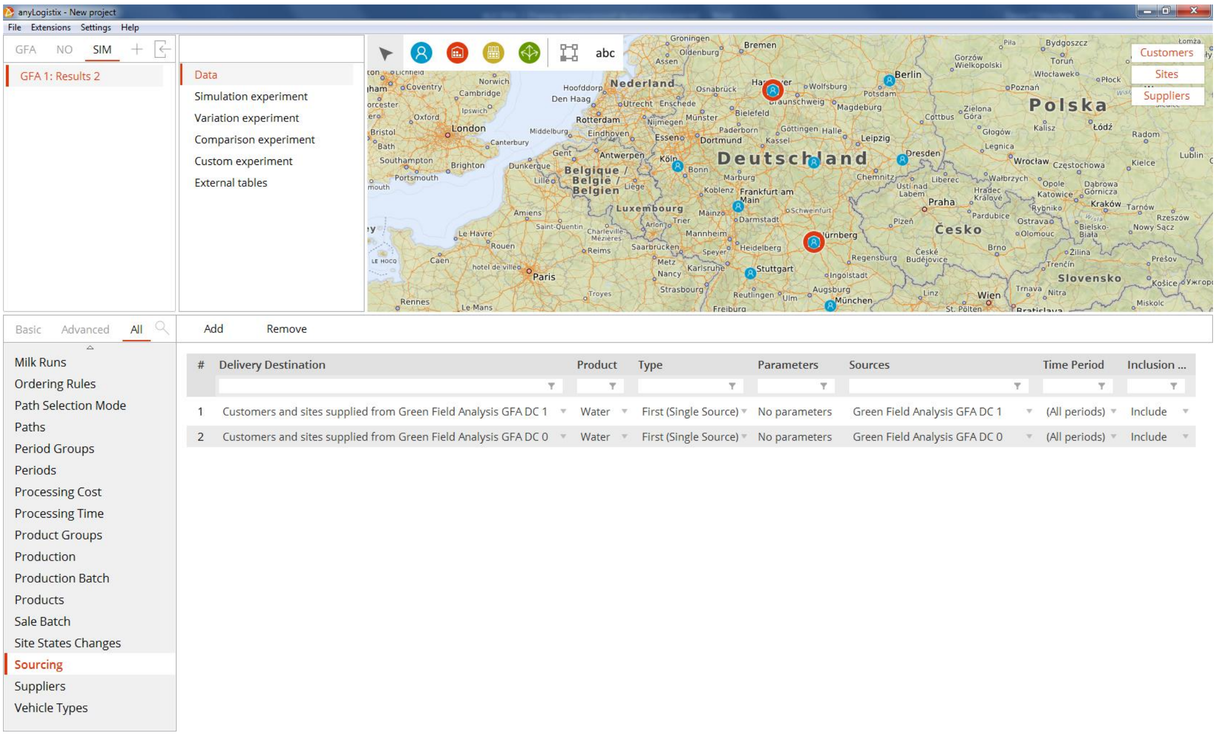
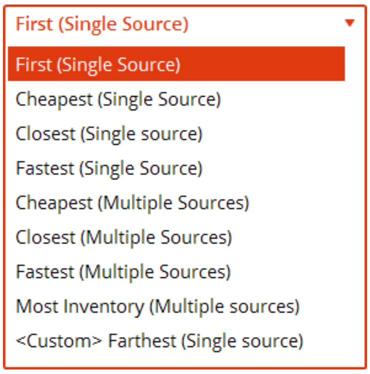


Fig. 24. Sourcing rules

In addition, we can select among different sourcing rules as follows:



→ **Note**: for multi-stage SCs, sourcing policies can be setup separately for each SC echelon that makes the simulation modelling very flexible and convenient. Even in the two stage SC, it might be necessary to differentiate different sourcing policies for different DCs, products and customers.

The created KPI dashboard is depicted in Fig. 25.

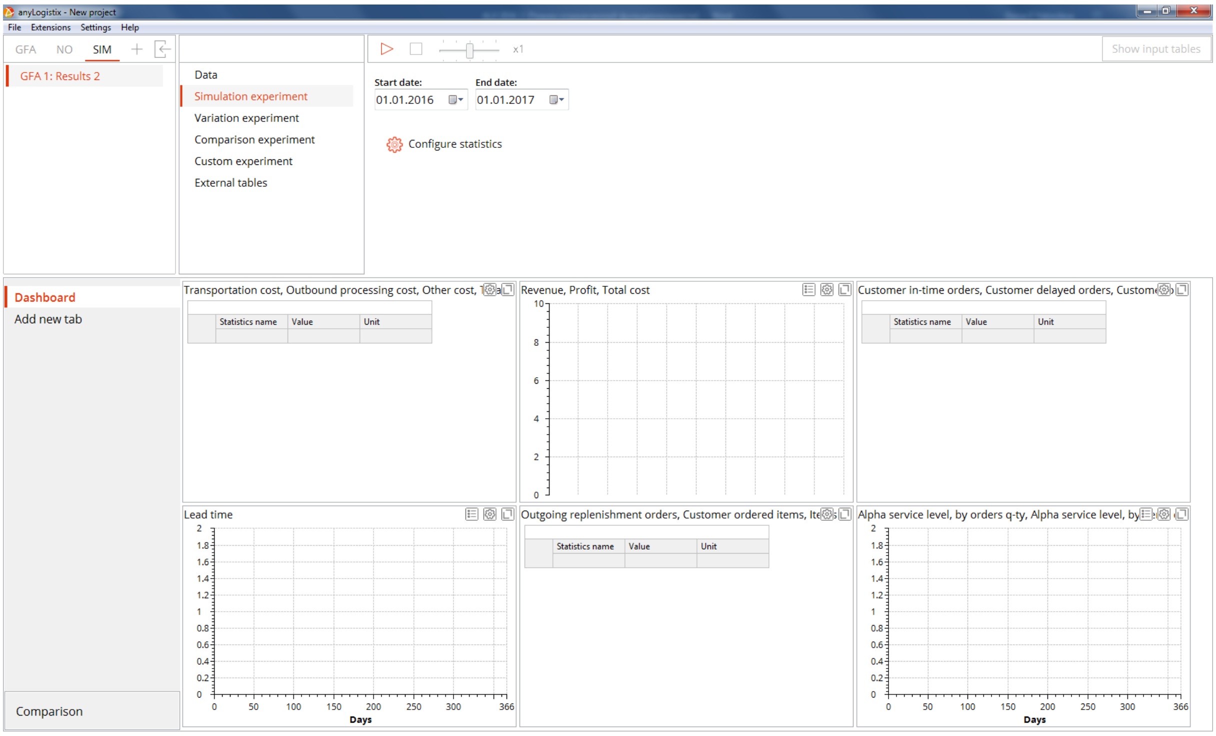
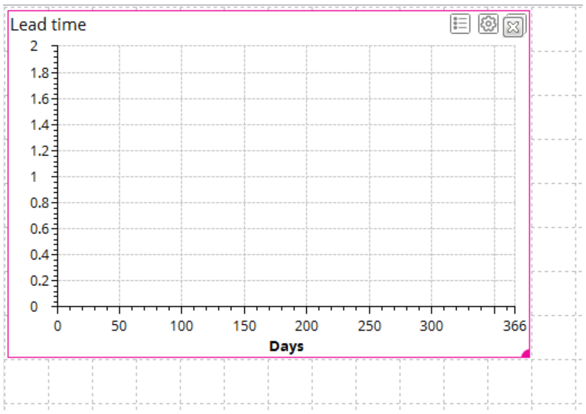


Fig. 25. KPI dashboard

Presentation of each KPI can be customized by enlarging the KPI window and using a toolbar (Fig. 26).

Fig. 26. KPI presentation customization in the toolbar

→ In order to change the size of a diagram in the dashboard, right click in the dashboard area and select “rearrange”. Then draw the bottom right corner of the diagram. In order to delete a diagram, just close this diagram.



1.7. Experiment and analysis

1.7.1. Simulation experiments for multiple warehouses with real routes

Now we can run a simulation experiment and analyze KPI (Fig. 27).

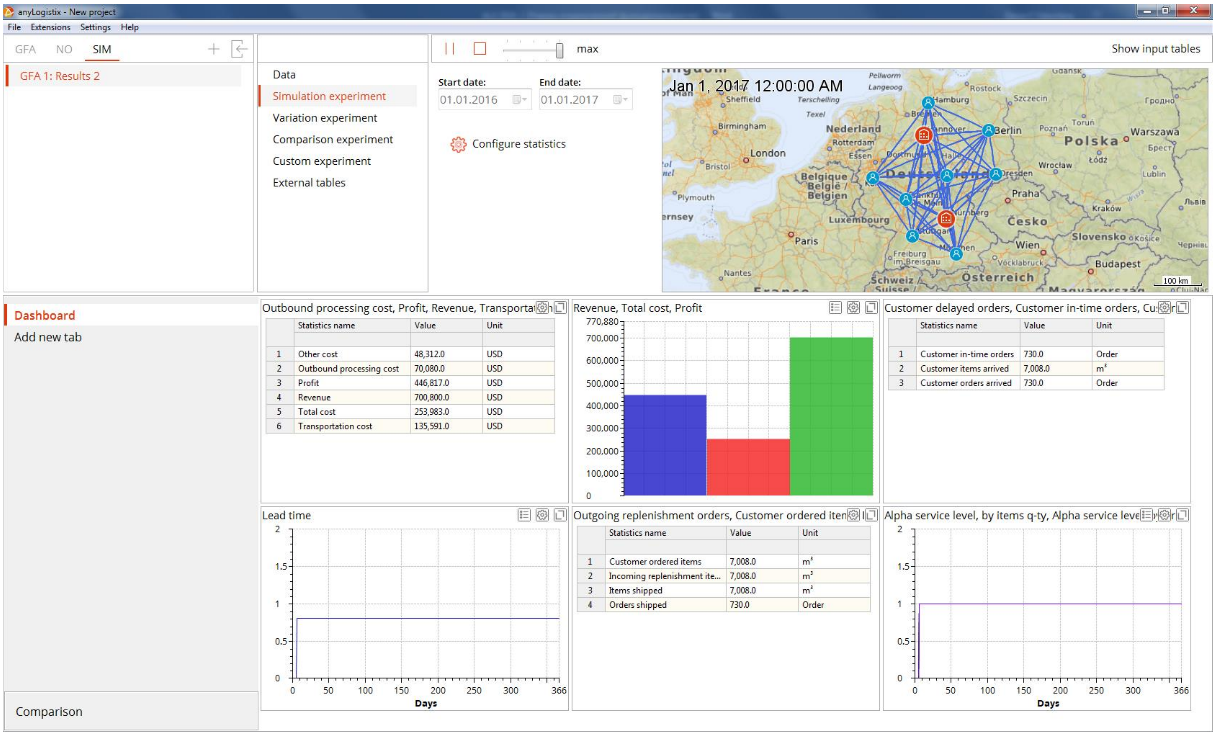


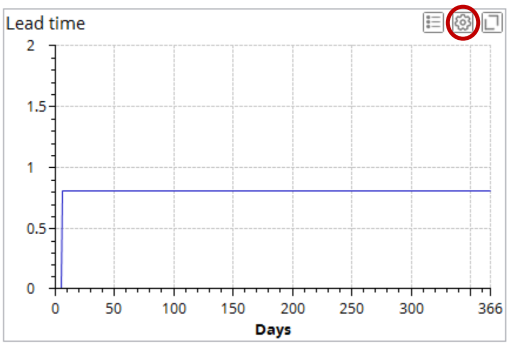
Fig. 27. Experimental results

It can be observed from the experiment that our SC would perform with the following KPI (Table 1).

Table 1 KPI for GFA analysis with two DCs

KPI	Value
Financial DC performance:	
Other cost, $	48 312.0
Outbound processing cost, $	70 080.0
Profit, $	446 817.0
Revenue, $	700 800.0
Total cost, $	253 983.0
Transportation cost, $	135 591.0
Customer performance:	
Lead time, days	0.81*
Service level, %	100*
Customer delayed orders	0
Customer in-time orders	730.0
Customer items arrived	7 008.0
Customer orders arrived	730.0
Current backlog orders	0
Customer ordered items	7008.0
Incoming replenishment items	7008.0
Items shipped	7008.0
Orders shipped	730.0
Outgoing replenishment orders	0

**Please note that these KPI present total lead time and total service level in regard to ten customers. The presentation can be changed by detailizing for objects as follows:*



(Additional setting → Detailization by → Add → Objects) in the lead time and service level diagrams. Then individual service levels (the ration would be 1) and lead times would be presented.

→ Note: KPI can be exported to an Excel file in "File → Export" in order to facilitate their further assessment and comparisons.

To check the quality of the computed solution to the DC location planning, create a copy of current scenario and arbitrary move the DCs to other points (click on a site icon on the map area, then drag-and-drop object to another point) and simulate the SC with these new locations. The results are presented in Figs 28 and 29 as well as in Table 2.

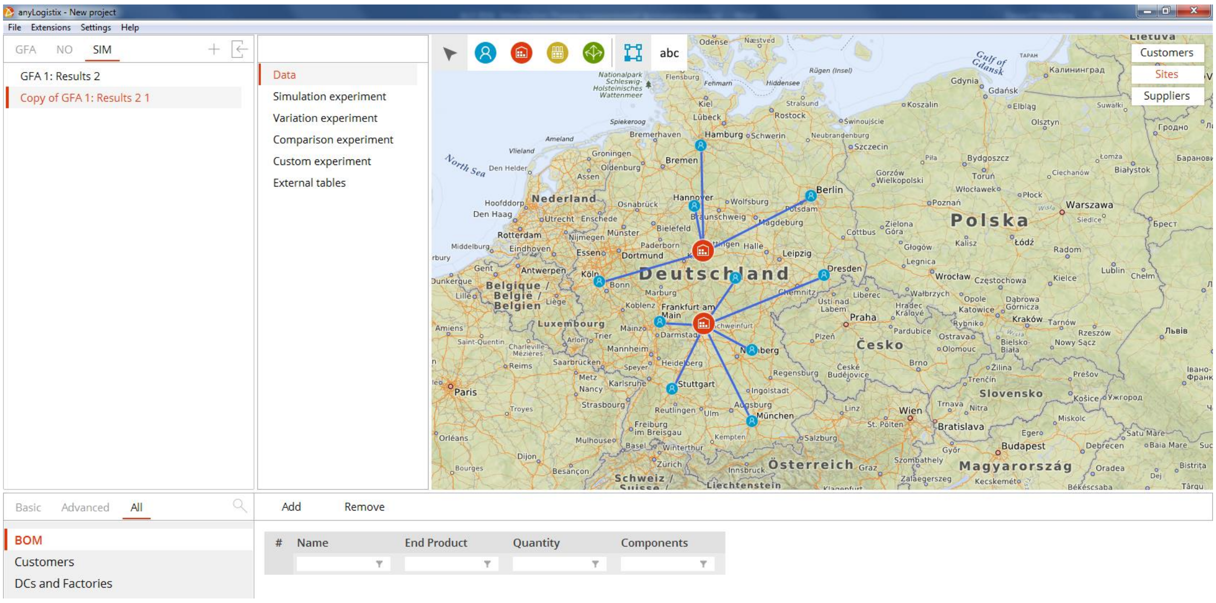


Fig. 28. Changed DC locations

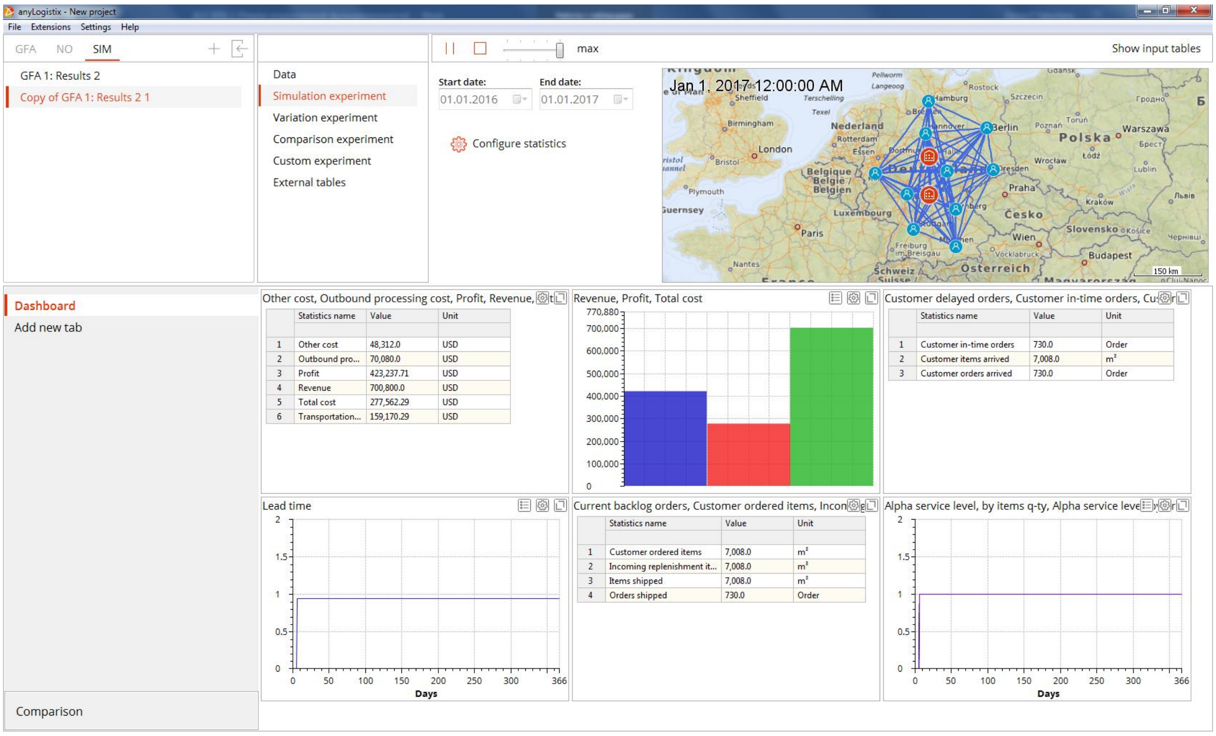


Fig. 29. Experimental results with changed DC locations

Table 2 KPI comparison for GFA and changed DC locations

KPI	**GFA locations**	**Changed locations**
Financial DC performance:		
Other cost, $	48 312.0	48 312.0
Outbound processing cost, $	70 080.0	70 080.0
Profit, $	446 817.0	**423 238.71**
Revenue, $	700 800.0	700 800.0
Total cost, $	253 983.0	**277 562.29**
Transportation cost, $	135 591.0	**159 170.29**
Customer performance:		
Lead time, days	0.81	**0.95**
Service level, %	100	100
Customer delayed orders	0	0
Customer in-time orders	730.0	730.0
Customer items arrived	7 008.0	7 008.0
Customer orders arrived	730.0	730.0
Current backlog orders	0	0
Customer ordered items	7008.0	7008.0
Incoming replenishment items	7008.0	7008.0
Items shipped	7008.0	7008.0
Orders shipped	730.0	730.0
Outgoing replenishment orders	0	0

It can be observed from Table 2 that total costs have been increased ($277 562.29 as compared to $253 983.0) due to increase in transportation costs and profit has been reduced ($423 238.71 as compared to $446 817.0) as the consequence of the location changes.

1.7.2. Simulation experiments for single warehouse with real routes

Since the SC with two DCs is more flexible and responsive but at the same time more expensive, we now run the simulation with one DC using the location from our first GFA experiment. We convert experimental result GFA1: Result 1 into a new scenario. The results are depicted in Fig. 30 and Table 3.

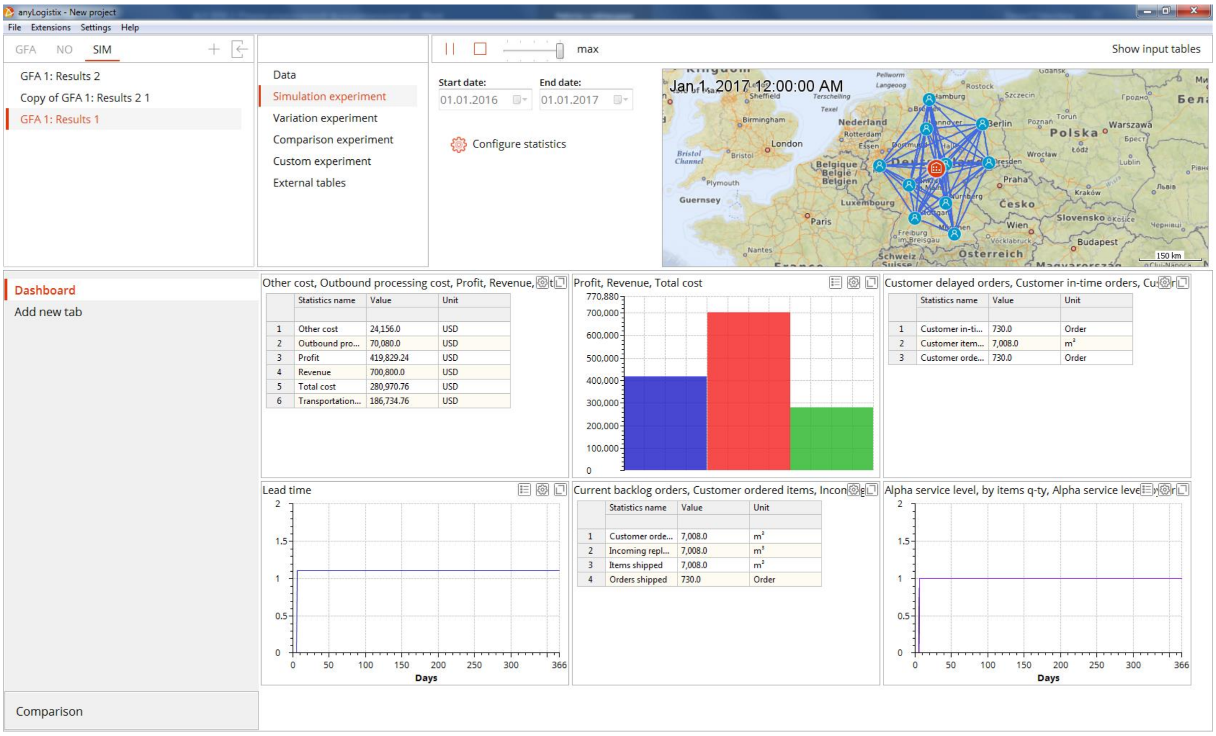


Fig. 30 Simulation results for the SC with single DC

Table 3 KPI comparison for two DCs (GFA and changed DC locations) and single DC

KPI	**2 DCs: GFA locations**	**2 DCs: Changed locations**	**Single DC**
Financial DC performance:			
Other cost, $	48 312.0	48 312.0	**24 156.0**
Outbound processing cost, $	70 080.0	70 080.0	70 080.0
Profit, $	446 817.0	**423 238.71**	**419 829.24**
Revenue, $	700 800.0	700 800.0	700 800.0
Total cost, $	253 983.0	**277 562.29**	**280 970.76**
Transportation cost, $	135 591.0	**159 170.29**	**186 734.760**
Customer performance:			
Lead time, days	0.81	**0.95**	1.11
Service level, %	100	100	100
Customer delayed orders	0	0	0
Customer in-time orders	730.0	730.0	730.0
Customer items arrived	7 008.0	7 008.0	7 008.0
Customer orders arrived	730.0	730.0	730.0
Current backlog orders	0	0	0
Customer ordered items	7008.0	7008.0	7008.0
Incoming replenishment items	7008.0	7008.0	7008.0
Items shipped	7008.0	7008.0	7008.0
Orders shipped	730.0	730.0	730.0
Outgoing replenishment orders	0	0	0

It can be observed from Table 3 that in the case of a single DC, DC-related costs has been decreased. On the contrary, transportation costs increased significantly resulting in higher total costs. In this example we can nicely observe consolidation and centralization effects in the SC design (see Fig. 31, adopted from Chopra and Meindl, 2015).

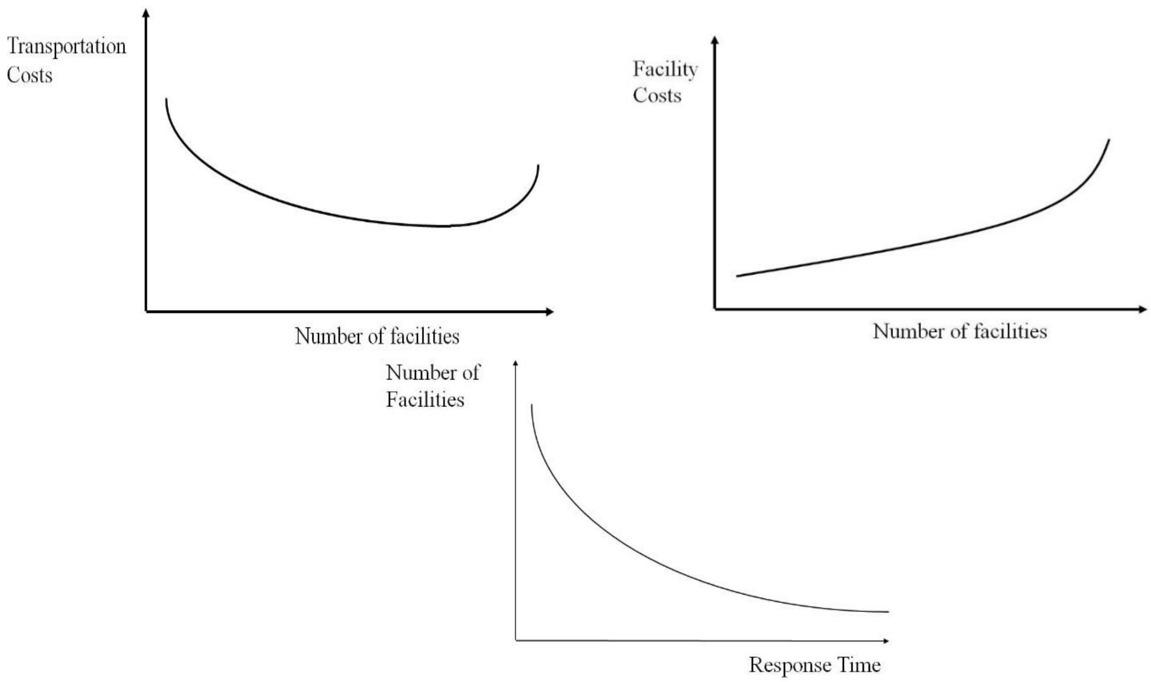


Fig. 31. General relations in the SC design

We summarize e major aspects of this chapter as follows.

- Greenfield analysis is used to find the areas to locate the facilities
- Input data: to conduct a GFA experiment you need to define:
  - ✓ Locations – table “Locations”
  - ✓ Customers – table “Customers”
  - ✓ Products – table “Products”
  - ✓ Demand – table “Demand”
- The following GFA algorithms are used for computation:
  - ✓ K-means algorithm for clustering
  - ✓ Aykin and Babu algorithm for a facility location problem
  - ✓ Criteria: estimation of transportation cost based on volume
- GFA Results are presented in the following tables:
  - ✓ Locations
  - ✓ DC/Factories – suggested facilities linked to “Locations” table
  - ✓ Sourcing – defines where and which product to buy
  - ✓ Locations for the facilities
  - ✓ Inventory – GFA creates simple inventory policies for simulation experiment

Note that GFA does not count roads, cities, means of transportation etc. thus it may suggest to put DCs in unrealistic locations, i.e. on the top of the mountain or in the middle of the sea. GFA considers all customers with coefficients equal to sum on all products of total demand multiplied by product volume.

2. Supply Chain Re-Design

2.1. Case-study „Facility Location Planning“: Multi-Product Supply Chain Re-Design

Alexander, a SC manager at a FMCG company in U.S. needs to reduce total SC costs in a distribution network (DN). The SC comprises customers with the following periodic demands and lead-time requirements (Table 4).

Table 4 Customer demand

Customer	Product	Parameters	Expected lead time
New York City 1	Lighting	Quantity=8.0;Period, days=5.0	5
Philadelphia 2	Gardening equipment	Quantity=20.0;Period, days=5.0	5
New York City 8	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Fort Worth	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Boston	Gardening equipment	Quantity=20.0;Period, days=5.0	5
New York City 2	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Portland	Furniture	Quantity=16.0;Period, days=5.0	5
Phoenix 3	Lighting	Quantity=8.0;Period, days=5.0	5
San Jose 2	Gardening equipment	Quantity=20.0;Period, days=5.0	5
San Francisco	Small appliances	Quantity=4.0;Period, days=5.0	5
Memphis	Large home appliances	Quantity=12.0;Period, days=5.0	5
New York City 14	Small appliances	Quantity=4.0;Period, days=5.0	5
Charlotte	Large home appliances	Quantity=12.0;Period, days=5.0	5
Oklahoma City	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Nashville	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Columbus	Furniture	Quantity=16.0;Period, days=5.0	5
Chicago 3	Lighting	Quantity=8.0;Period, days=5.0	5
Philadelphia 3	Furniture	Quantity=16.0;Period, days=5.0	5
New York City 12	Large home appliances	Quantity=12.0;Period, days=5.0	5
Los Angeles 3	Furniture	Quantity=16.0;Period, days=5.0	5
New York City 6	Lighting	Quantity=8.0;Period, days=5.0	5
San Jose 1	Small appliances	Quantity=4.0;Period, days=5.0	5
Tucson	Small appliances	Quantity=4.0;Period, days=5.0	5
Columbus	Large home appliances	Quantity=12.0;Period, days=5.0	5
San Antonio 1	Large home appliances	Quantity=12.0;Period, days=5.0	5
Chicago 2	Gardening equipment	Quantity=20.0;Period, days=5.0	5
New York City 15	Lighting	Quantity=8.0;Period, days=5.0	5
Nashville	Large home appliances	Quantity=12.0;Period, days=5.0	5
Washington D.C.	Lighting	Quantity=8.0;Period, days=5.0	5
Houston 4	Furniture	Quantity=16.0;Period, days=5.0	5
Dallas 1	Large home appliances	Quantity=12.0;Period, days=5.0	5
Baltimore	Small appliances	Quantity=4.0;Period, days=5.0	5
Denver	Lighting	Quantity=8.0;Period, days=5.0	5
Austin	Small appliances	Quantity=4.0;Period, days=5.0	5

Houston 3	Small appliances	Quantity=4.0;Period, days=5.0	5
Indianapolis	Small appliances	Quantity=4.0;Period, days=5.0	5
New York City 11	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Louisville	Furniture	Quantity=16.0;Period, days=5.0	5
Memphis	Furniture	Quantity=16.0;Period, days=5.0	5
New York City 7	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Chicago 4	Large home appliances	Quantity=12.0;Period, days=5.0	5
Dallas 2	Small appliances	Quantity=4.0;Period, days=5.0	5
Phoenix 2	Small appliances	Quantity=4.0;Period, days=5.0	5
San Diego 1	Furniture	Quantity=16.0;Period, days=5.0	5
Los Angeles 2	Lighting	Quantity=8.0;Period, days=5.0	5
Boston	Large home appliances	Quantity=12.0;Period, days=5.0	5
Jacksonville	Furniture	Quantity=16.0;Period, days=5.0	5
Chicago 5	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Los Angeles 1	Large home appliances	Quantity=12.0;Period, days=5.0	5
Albuquerque	Furniture	Quantity=16.0;Period, days=5.0	5
Fresno	Furniture	Quantity=16.0;Period, days=5.0	5
Jacksonville	Lighting	Quantity=8.0;Period, days=5.0	5
New York City 16	Small appliances	Quantity=4.0;Period, days=5.0	5
Houston 1	Furniture	Quantity=16.0;Period, days=5.0	5
El Paso	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Chicago 1	Lighting	Quantity=8.0;Period, days=5.0	5
Portland	Lighting	Quantity=8.0;Period, days=5.0	5
Los Angeles 7	Small appliances	Quantity=4.0;Period, days=5.0	5
Baltimore	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Albuquerque	Large home appliances	Quantity=12.0;Period, days=5.0	5
Milwaukee	Small appliances	Quantity=4.0;Period, days=5.0	5
Austin	Gardening equipment	Quantity=20.0;Period, days=5.0	5
New York City 5	Large home appliances	Quantity=12.0;Period, days=5.0	5
San Diego 2	Small appliances	Quantity=4.0;Period, days=5.0	5
Los Angeles 4	Small appliances	Quantity=4.0;Period, days=5.0	5
Houston 2	Furniture	Quantity=16.0;Period, days=5.0	5
Seattle	Furniture	Quantity=16.0;Period, days=5.0	5
El Paso	Large home appliances	Quantity=12.0;Period, days=5.0	5
New York City 10	Large home appliances	Quantity=12.0;Period, days=5.0	5
San Antonio 2	Lighting	Quantity=8.0;Period, days=5.0	5
Detroit	Large home appliances	Quantity=12.0;Period, days=5.0	5
Detroit	Furniture	Quantity=16.0;Period, days=5.0	5
San Francisco	Lighting	Quantity=8.0;Period, days=5.0	5
New York City 9	Small appliances	Quantity=4.0;Period, days=5.0	5
New York City 13	Furniture	Quantity=16.0;Period, days=5.0	5
Phoenix 1	Large home appliances	Quantity=12.0;Period, days=5.0	5
Los Angeles 6	Large home appliances	Quantity=12.0;Period, days=5.0	5
Milwaukee	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Fort Worth	Small appliances	Quantity=4.0;Period, days=5.0	5

Philadelphia 1	Gardening equipment	Quantity=20.0;Period, days=5.0	5
Los Angeles 5	Small appliances	Quantity=4.0;Period, days=5.0	5
New York City 4	Lighting	Quantity=8.0;Period, days=5.0	5
New York City 3	Lighting	Quantity=8.0;Period, days=5.0	5
Las Vegas	Large home appliances	Quantity=12.0;Period, days=5.0	5

→ **Note:** this data is pre-defined in the sample Excel file “01 – Greenfield Analysis” located in “Help→ Examples”

The SC handles five products:

#	Name	Unit
1	Small appliances	pcs
2	Large home appliances	pcs
3	Lighting	pcs
4	Gardening equipment	pcs
5	Furniture	pcs

Fig. 31. Products

Presently, the SC comprises three DCs. Fig. 32 shows these DCs and parameters of their operation.

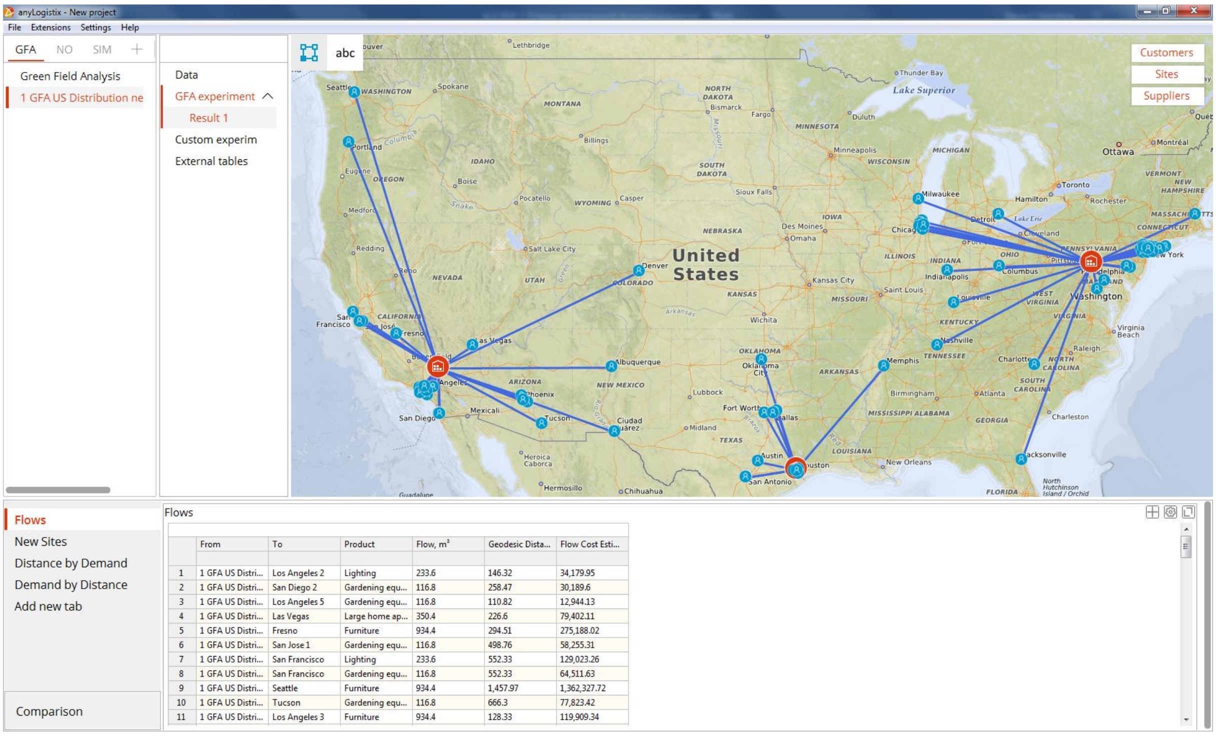


Fig. 32. Existing DCs in the supply chain

2.2. Scenario settings

During the executive meeting, Alexander suggests to increase the SC responsiveness by locating DCs at maximum distance of 1,000 km from the customers. Using GFA analysis, he gets the following result (Fig. 33).

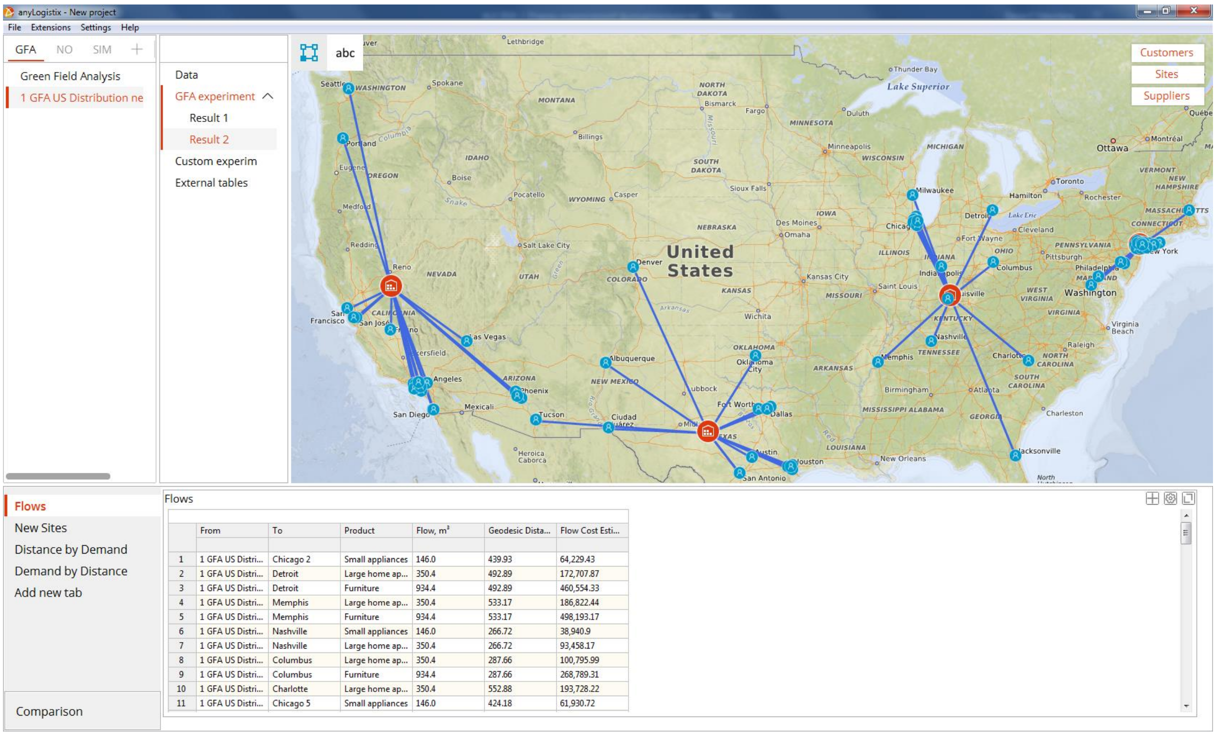


Fig. 33. SC design for maximum service distance of 1,000 km

According to GFA analysis, the number of DCs needs to be increased from three to four. In addition, location coordinates need to be changed. In the next step we build KPI dashboard similar to the example in Sect. 1.

2.3. Simulation experiments

Before we start to compare simulation experiment results of our AS-IS and re-designed SC scenarios, we convert both GFA results to SIM scenarios. Then put the following data to related tables in both scenarios:

- New group named "DCs" (activate all objects in the column "Sites");
- Vehicle type "Truck" with capacity of 20 m3 and an average speed of 50 km/hour (to be defined in "Vehicle Types");
- Transportation costs computation is based on the rule "volume x distance x $15". LTL shipments are allowed;
- Unlimited inventory policy type for all products (this policy assumes that the specified products are always on stock at the given facility at any required quantity);
- Products cost parameters:

#	Name	Unit	Selling Price	Cost	Cost Unit
1	Small appliances	pcs	2,000	700	USD
2	Large home appliances	pcs	6,000	2,500	USD
3	Lighting	pcs	5,000	2,000	USD
4	Gardening equipment	pcs	5,500	2,500	USD
5	Furniture	pcs	8,000	300	USD

2.3.1. AS-IS supply chain simulation

To analyze the existing SC, Alexander needs to define variable processing and fixed warehousing costs (Fig. 34).

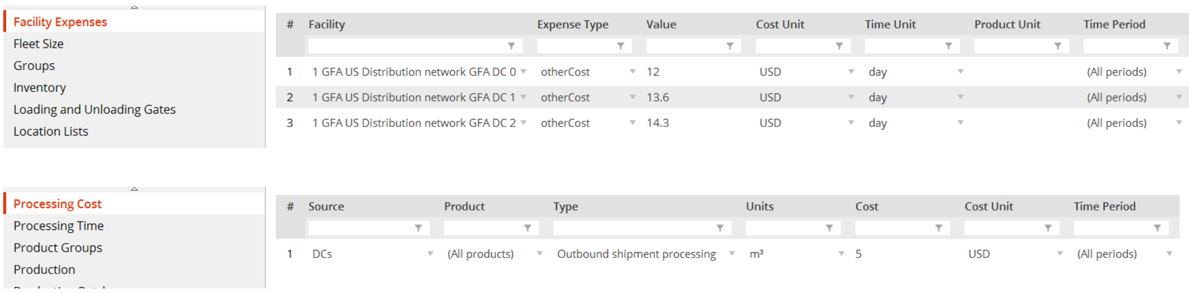


Fig. 34. DC-related costs for existing supply chain

In the first experiment, AS-IS SC is simulated. The results are depicted in Fig. 35.

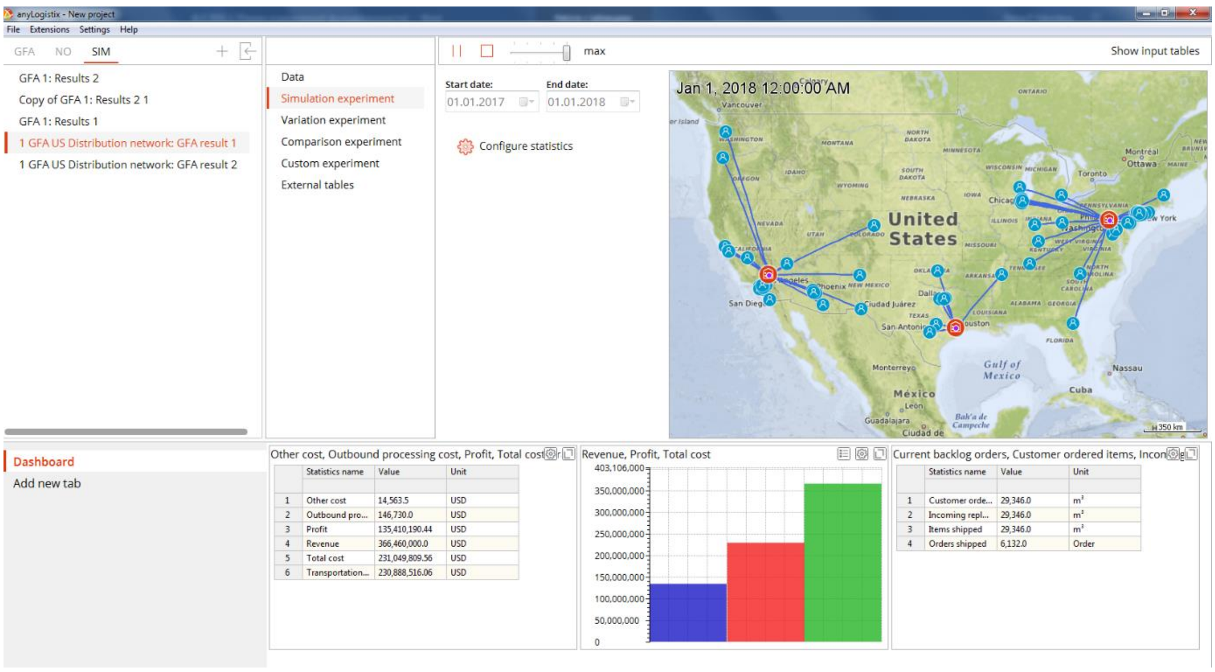


Fig. 35. Experimental result for AS-IS supply chain

2.3.2. Supply chain re-design

Alexander is now going to analyze SC efficiency by changing the locations of DCs according to the GFA result. First he estimates DC-related operational costs as shown in Fig. 36.

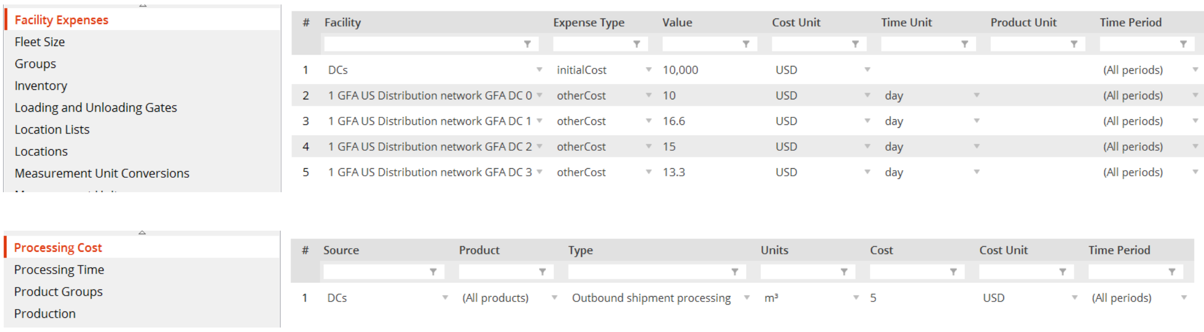


Fig. 36. DC-related costs for new supply chain design

Now Alexander simulates this new SC design. The simulation results are depicted in Fig. 37 and Table 5.

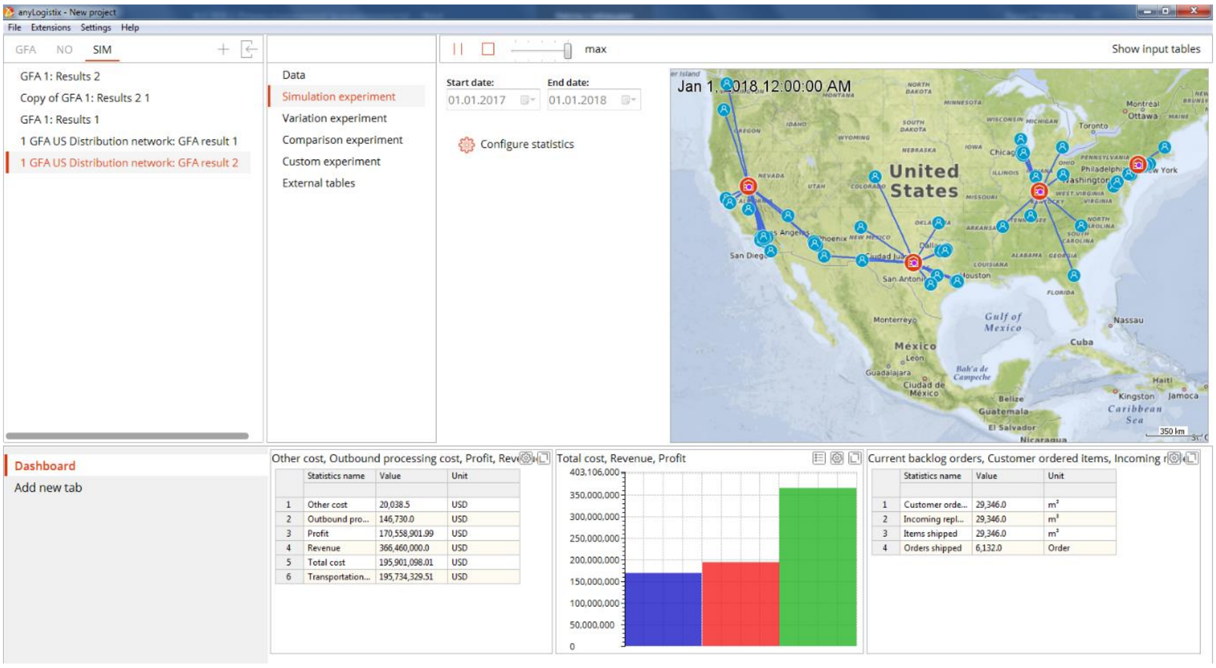


Fig. 37. Experiment results for GFA analysis

Table 5. KPI comparison

KPI	AS-IS	Re-designed SC
Financial DC performance:		
Other cost, $	**14 563.49**	**20 038.5**
Outbound processing cost, $	146 730.0	146 730.0
Profit, $	**135 410 190.44**	**170 558 901.99**
Revenue, $	366 460 000.0	366 460 000.0
Total cost, $	**231 049 809.56**	**195 901 098.01**
Transportation cost, $	**230 888 516.06**	**195 734 329.5**
Customer performance:		
Current backlog orders	0	0
Customer ordered items	29 346.0	29 346.0
Incoming replenishment items	29 346.0	29 346.0
Items shipped	29 346.0	29 346.0
Orders shipped	6 132.0	6 132.0
Outgoing replenishment orders	0	0

It can be observed from Table 5 that SC design with four DCs is more efficient and profitable. Total SC costs could be reduced from $231 049 809.56 to $195 901 098.01 and total profit could be increased by almost 35 million U.S. dollars from $135 410 190.44 to $170 558 901.99 without any decrease in customer performance.

Alexander understands that it will be too expensive to build four new warehouses. He observes that new suggested locations at the East and West coast are close to the existing locations. The south location in Texas is also not far away from the existing location in Houston. So he decides to analyze SC efficiency for three existing locations + opening new DC in Louisville (1 GFA US Distribution network GFA DC 0).

Create copy of AS-IS SC scenario, then add new site and activate it in our group DCs.

As we now have new site, our inventory policies and sourcing paths may be changed, so first remove all records in table “Inventory” except for the last one, then remove all records in table “Sourcing” and add the new row as shown in Fig. 38.

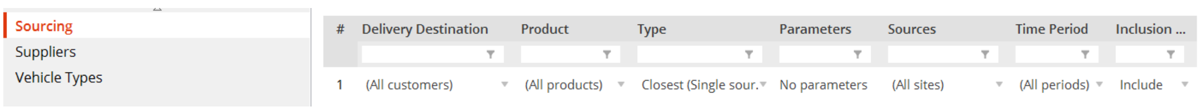


Fig. 38. Inclusion type

Every site has its own facility expenses. Find all records about Louisville DC-related costs in re-designed SC scenario and add them to the related tables.

The simulation results are depicted in Fig. 39 and Table 6.

➔ Note: for correct comparison of different runs, it is to ensure the same data in all the compared scenarios, especially while converting the GFA or optimization results into a scenario. It is advisable to check groups, paths and sourcing policies in the scenario being converted from an experimental result.

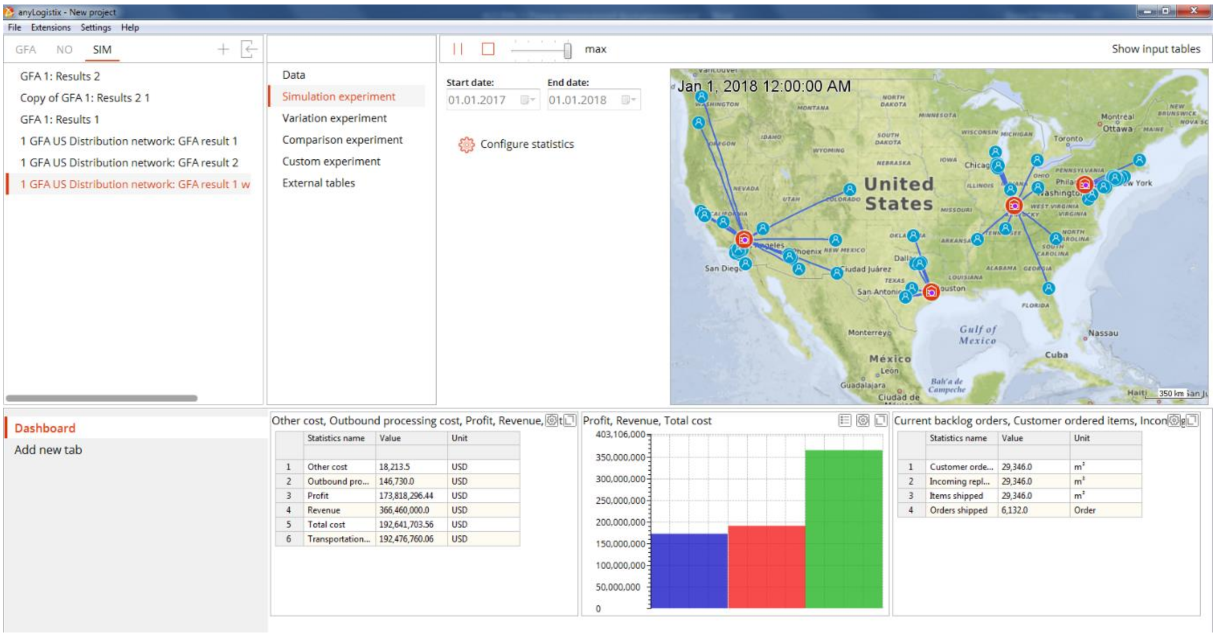


Fig. 39. Re-Designed supply chain with adapted GFA result

Table 6 KPI comparison

KPI	AS-IS	Re-designed SC	Adapted GFA result
Financial DC performance:			
Other cost, $	**14 563.49**	**20 038.5**	**18 213.5**
Outbound processing cost, $	146 730.0	146 730.0	146 730.0
Profit, $	**135 410 190.44**	**170 558 901.99**	**173 818 296.44**
Revenue, $	366 460 000.0	366 460 000.0	366 460 000.0
Total cost, $	**231 049 809.56**	**195 901 098.01**	**192 641 703.56**
Transportation cost, $	**230 888 516.06**	**195 734 329.5**	**192 476 760.06**
Customer performance:			
Current backlog orders	0	0	0
Customer ordered items	29 346.0	29 346.0	29 346.0
Incoming replenishment items	29 346.0	29 346.0	29 346.0
Items shipped	29 346.0	29 346.0	29 346.0
Orders shipped	6 132.0	6 132.0	6 132.0
Outgoing replenishment orders	0	0	0

It can be observed in Fig. 39 and Table 6 that the SC design with three old and one new DC is even more efficient and profitable as the GFA result. The explanation for this effect can be seen in the impact of transportation policy (LTL) and expected lead time on the number of deliveries, and therefore on transportation costs.

Are other improvements possible? If yes, where? If no, why? The fundamental problem with the GFA method has been the consideration of transportation costs in the facility location optimization only. The corresponding DC-related costs could be included in the simulation phase only. As such, the GFA results hold only for the case of similar DC-related costs at different DCs. In the case the DC-related costs at different DCs are not equal, GFA results became sub-optimal and the search for SC design improvement is possible on "*what happens if* …" rule only. In the case we need to optimize SC design by consideration of both transportation and DC-related costs, network optimization needs to be used. We exemplify the network optimization and optimization-based simulation on an example of a smaller dimensionality to make the analysis more detailed.

3. Network optimization approach and optimization-based simulation

3.1. Case study

We consider a distributor of drinks in U.S. with five DCs and six demand regions. Create a simulation experiment, add six customers and five sites, and name them as shown in Fig. 40.

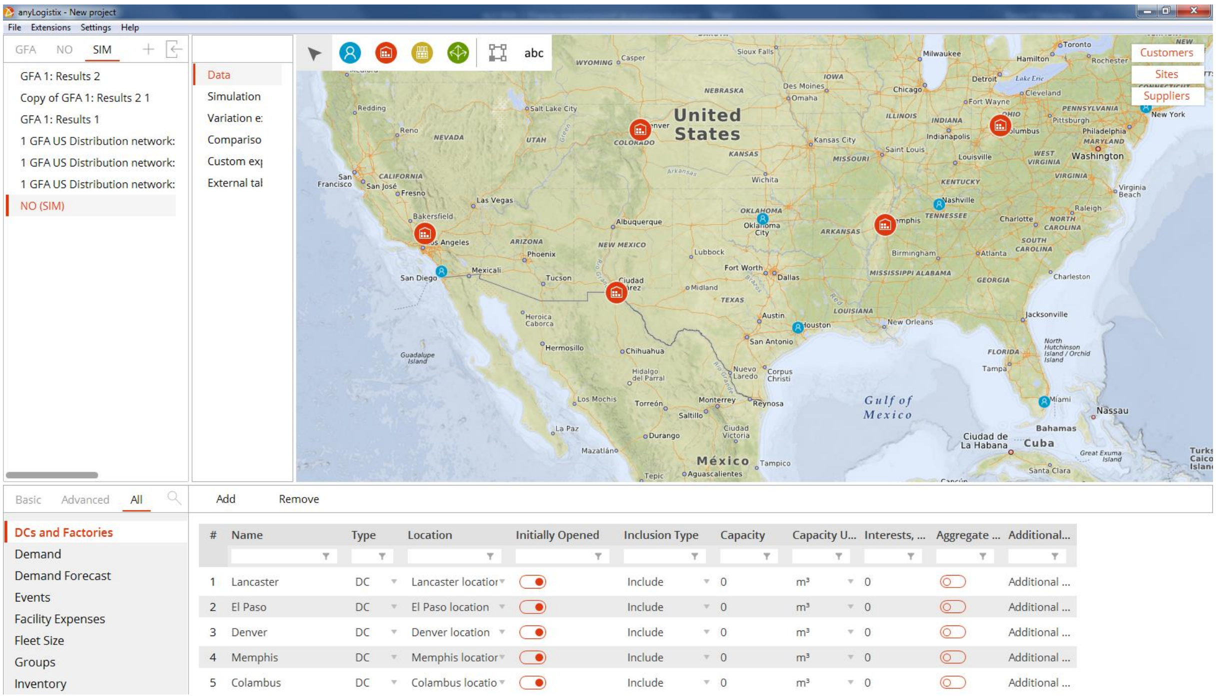


Fig. 40. Distribution centers

Then create a new product “Juice” and define periodic demand for each customer (Fig. 41).

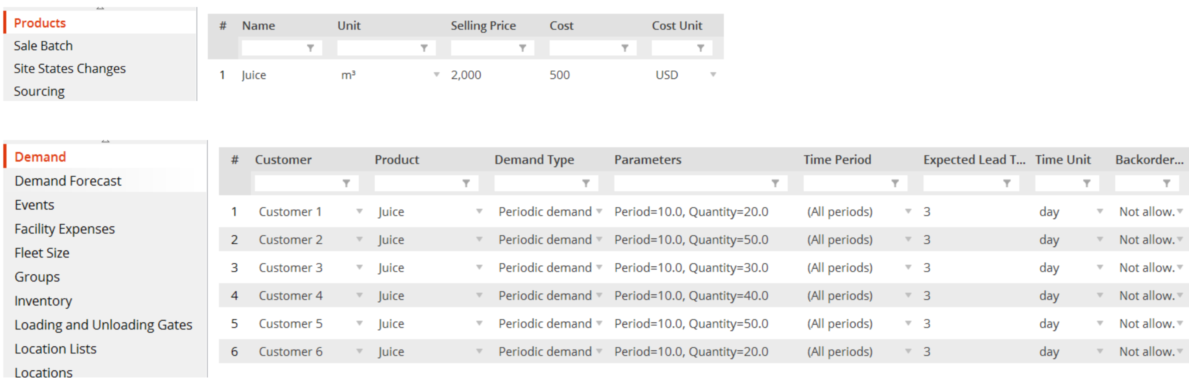
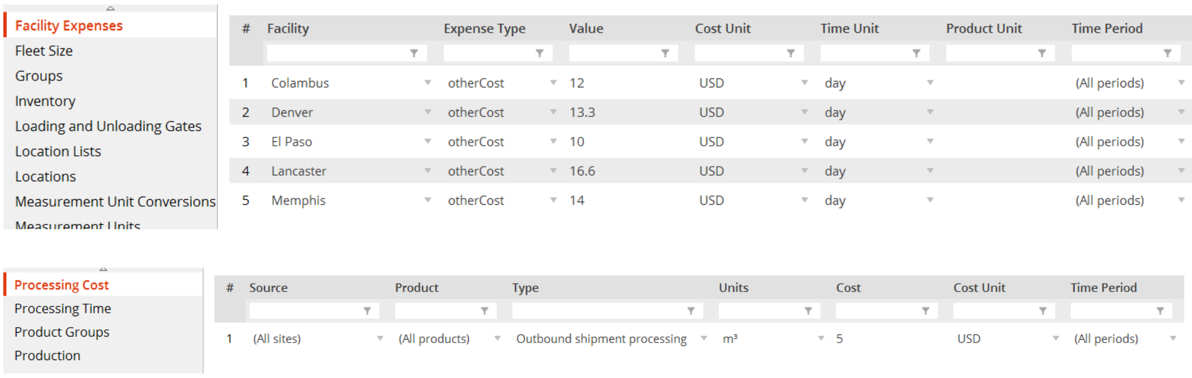


Fig. 41. Customer demand and product data

Define variable processing and fixed warehousing costs (Fig. 42).



#	Facility	Expense Type	Value	Cost Unit	Time Unit	Product Unit	Time Period
1	Colambus	otherCost	12	USD	day		(All periods)
2	Denver	otherCost	13.3	USD	day		(All periods)
3	El Paso	otherCost	10	USD	day		(All periods)
4	Lancaster	otherCost	16.6	USD	day		(All periods)
5	Memphis	otherCost	14	USD	day		(All periods)

#	Source	Product	Type	Units	Cost	Cost Unit	Time Period
1	(All sites)	(All products)	Outbound shipment processing	m³	5	USD	(All periods)

Fig. 42. DC-related costs for the existing supply chain

Further inputs are as follows:

- Sourcing policy: single sourcing (closest)
- Vehicle type: capacity 30 m^3, speed 50 km/h
- Transportation costs: \$1.0 x volume x distance
- Inventory policy: unlimited

3.2. Simulation experiment

The simulation result is presented in Fig. 43.

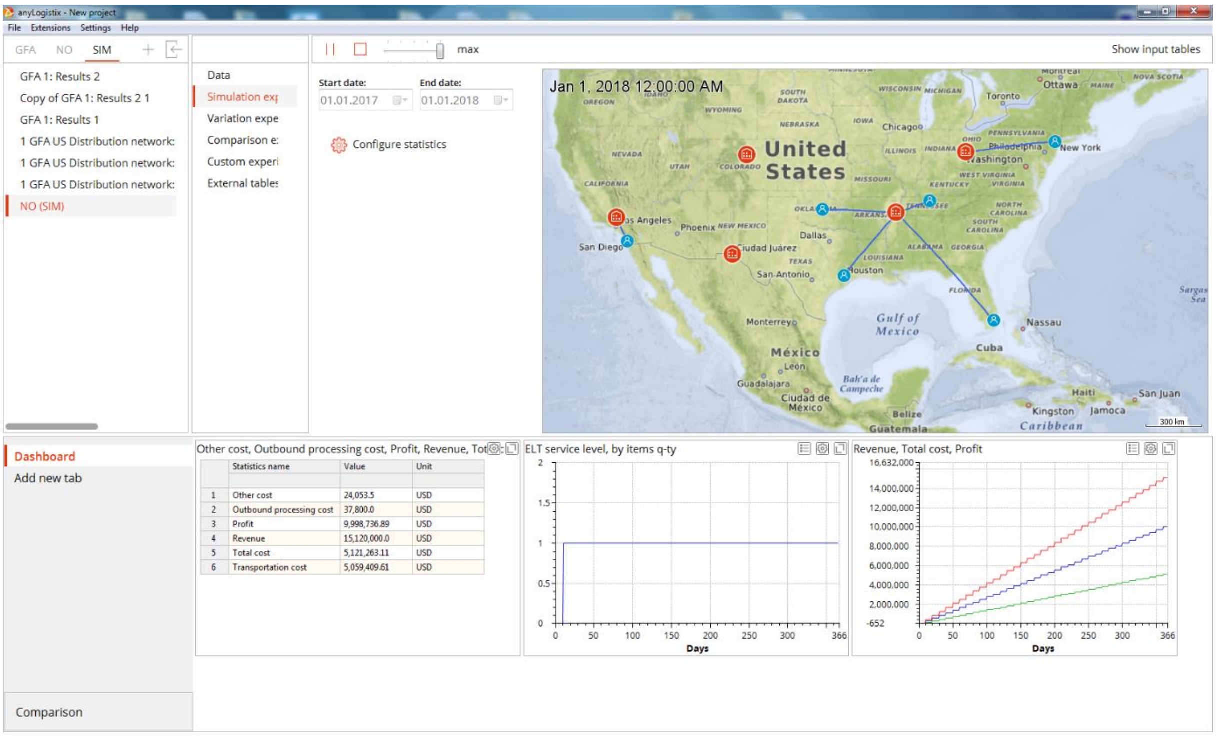


Fig. 43. Simulation result for five DCs

CEO of the company observes from the simulation that only three DCs of five are used. But is it the optimal SC design with minimal total costs? CEO would like to have the SC design with minimal total costs (i.e., a sum of fixed and variable costs). In order to determine the costs of different alternative SC designs with different number of DCs, he runs an optimization experiment.

3.3. Optimization experiment

In order to answer the question of what is the optimal SC design, we convert current simulation scenario to an NO scenario.

Change Inclusion type of all sites in table "DC's and Factories" to "Consider".

As our DCs don't produce any products, we need to add a Supplier that will provide our sites with a regular scale of Juice: it doesn't matter where our Supplier is located on the map because we will not compute any costs related with the DC's sided purchases, so put the following data to related tables:

- New group named "DCs" (activate all objects in the column "Sites");
- Change Linear Flow Constraints table:

#	Source	Expand Sources	Destination	Expand Destinati...	Product	Expand Products	Min throughput
1	(All sites)		(All customers)		(All products)		0
2	Supplier 1		(All sites)		(All products)		0

Fig. 44. Linear flow constraint table

- Change Paths table:

#	From	To	Cost Calculation	Cost Calculation ...	Cost Unit	Distance	Distance Unit	Straight	Vehicle ...	Time ...	Inclusion Ty...
1	DCs	(All locations)	Volume&distance-based c.	1.0 * amount (m^3) ...	USD	0	km		Truck	(All p.	Include
2	Supplier 1	DCs	Fixed delivery cost	0.0	USD	0	km		Truck	(All p.	Include

Fig. 45. Path table

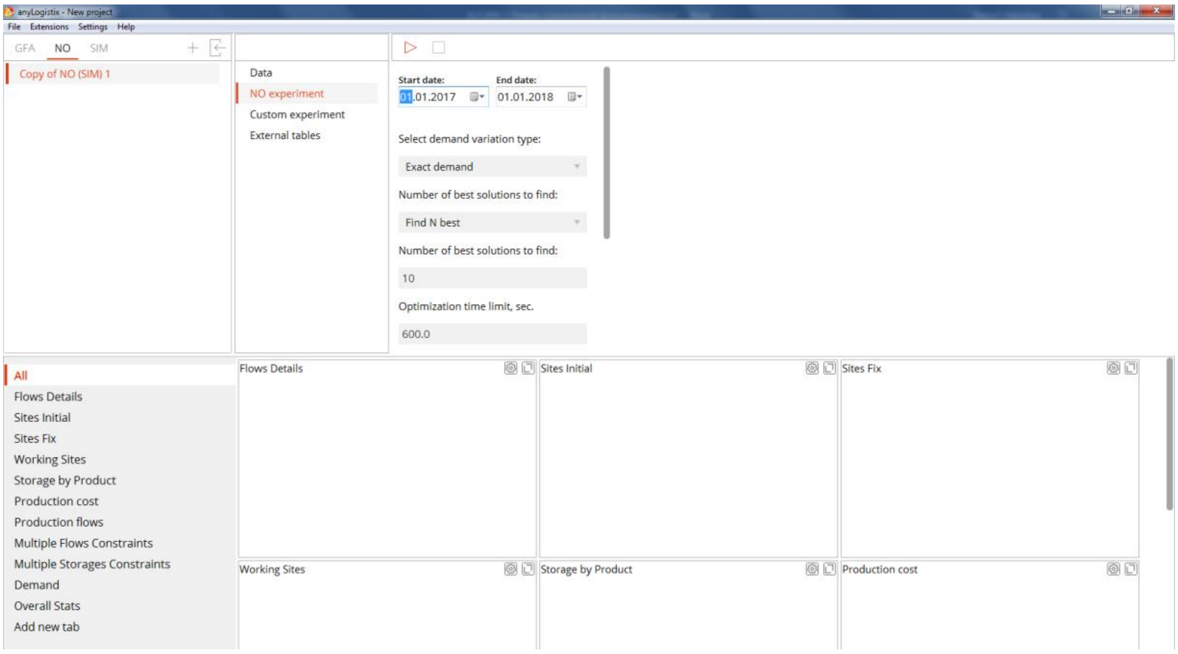


Fig. 46. Start dialog for optimization experiment

We run the optimization experiment (Fig. 47).

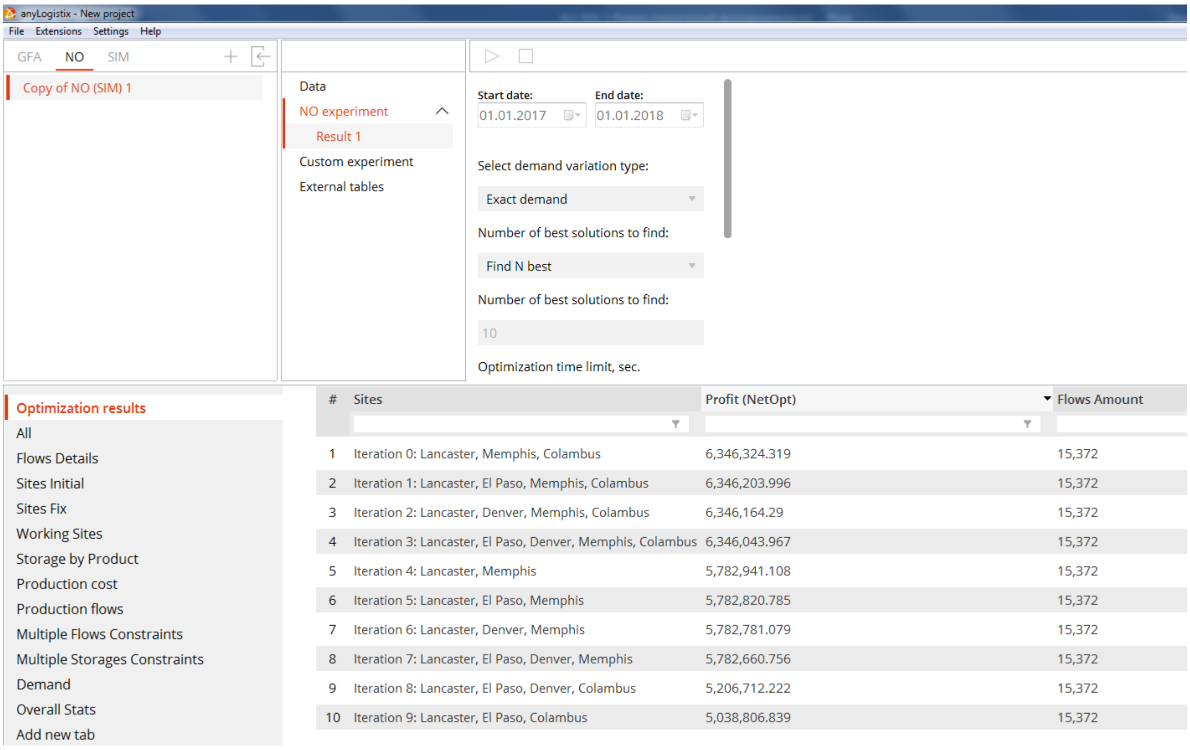


Fig. 47. Solution to the network optimization problem in Network Optimization (CPLEX)

We can observe that the optimization result suggests that having three DCs in Memphis, Columbus and Lancaster would imply an increase in SC efficiency. Alexandre is now going to prove this result using simulation with three DCs.

3.4. Optimization-based simulation experiment

Now we use the result from optimization experiment and perform new simulation experiment with three DCs in Memphis, Columbus and Lancaster. Convert the best NO experiment result to SIM scenario. In the scenario data under “DCs/Factories” we need to change the “Inclusion Type” for Denver and El Paso from “consider” to “exclude”. Delete all rows in the table “Inventory” and add one recordfor All sites with Unlimited Inventory Policy. The simulation result is shown in Fig. 48 and Table 7.

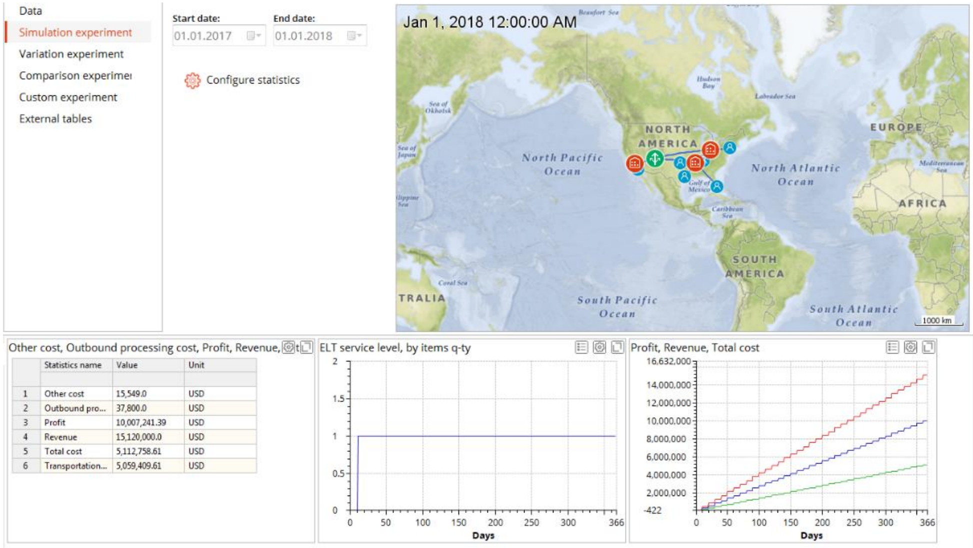


Fig. 48. Simulation result for three DCs

→ **Note:** in the optimization experiment, we compute optimal SC structure and minimum costs for a given set of parameters. In the simulation experiment, we can observe dynamic SC behavior and dynamics of different KPI in this structure in time.

It can be observed from Fig. 45 that EBIDTA increases from $7,017,493.13 to $7,558,944.8 (as compared to Fig. 42) due to reduction of fixed warehousing costs (i.e., “other costs” in the dashboard).

Table 7 KPI comparison

KPI	**AS-IS (five DCs)**	**Three DCs**
Financial DC performance:		
Other cost, $	24 053.5	15 549.0
Outbound processing cost, $	37 800.0	37 800.0
Profit, $	9 998 736.88	10 007 241.39
Revenue, $	15 120 000.0	15 120 000.0
Total cost, $	5 121 263.11	5 112 758.61
Transportation cost, $	5 059 409.61	5 059 409.61
Customer performance:		
Service level, %	100	100

It can be observed from Table 7 that SC design with three DCs is more efficient and profitable. Due to lower fixed warehousing costs, total SC efficiency has been increased. This has proved that two DCs in El Paso and Denver have been an excessive capacity in the SC.

→ **Note:** In ALX, we can also use “Comparison” experiment in order to compare KPI of different SC designs with different policies and parameters. It is a convenient and fast way for KPI comparison. However, since “Comparison” experiment compares different scenarios, we would need to describe each SC design alternative as individual scenario. We will learn how to use this option in Chapter 4 “Risk Management”

This example of network optimization nicely illustrates advantages and limitations of simulation and optimization. It is also helpful to understand better the application areas of both methods. *Optimization* is an analysis method that determines the best possible option of solving a particular operations or SC problem. The main advantage of optimization is the finding the best decision to a problem. Optimization works through representing problem choice as decision variables and seeking values that extremized objective functions of the decision variables subject to constraints on variable values expressing the limits on possible decision choice. The drawback of using optimization is difficulty in developing a model that is sufficient detailed and accurate in representing complexity and uncertainty, while keeping the model simple enough to be solved. Furthermore, most of the optimization models are deterministic and static. Unless mitigating circumstances exist, optimization is the preferred approach. However, in reality most of the SC and operations problems are of dynamic nature. Those problems contain a lot of mutually dependent parameters and variables that are difficult to restrict to an optimization model.

Simulation is imitating the dynamic behavior of one system with another. By making changes to the simulated SC, one expects to gain understanding of the dynamics of the physical SC. Rather than deriving a mathematical analytical solution to the problem, experimentation with the model is done by changing the parameters of the system to study the differences in the outcome of the experiments. Another advantage of simulation is to visualize the processes and structures. However, since simulation works on the “what happens if..?” principle, the questions of result extremity, completeness and consistency remain open. That is why simulation can be considered as an ideal tool for further analyzing the performance of a proposed SC design derived from an optimization model. Therefore optimization-based simulation is a promising area to support SC and operations managers in making better decisions.

Chapter 2. Three-stage supply chain: Inventory Control and Transportation Policies

So far we did not include different inventory control policies (e.g., fixed period or re-order point policies) and transportation policies (such as FTL – full truck load and LTL – low truck load) into consideration. In practice, inventory control and transportation policies may significantly impact decisions on SC design and operations. The learning objectives of this chapter are as follows:

1) To develop analytical and management skills on impact of inventory control and transportation policies on supply chain and logistics performance
2) To develop technical skills on creating three-stage supply chain models, performing experiments and measuring performance in anyLogistix multimethod simulation software
3) To understand major trade-offs
4) To develop skills on coordinated decision-making

4. Inventory control policies

4.1 Case-study "Distribution centers with storage"

We consider a SC that comprises six customers, two distributions centers (DC), and a supplier. The SC offers three products (PC, monitor and MFP) whereas there are two customers for each product respectively. The customer demand is steady and fixed at 50 units a day. The SC runs 90% CSL (customer service level) policy. Min-max (i.e., s,S) inventory control policy is used at the DCs for each product. Minimum level is 57 units subject to the CSL of 90%. Maximum level is 113 units subject to maximum storage area capacity for each product at each DC. The customer requires 2 days of lead time at maximum whereas the lead time from the supplier to DCs is fixed at 0.7 days and lead time from DCs to customers varies from 1.7 to 1.95 days depending on the internal loading/unloading processes at the DCs. Transportation between the supplier and DCs is organized by trucks each of which with the capacity of 60 m^3 and between DCs and customer by lorries each of which with the capacity of 20 m^3. LTL shipments are used without minimum load restriction and order aggregation. Direct shipment distribution network is used.

In an executive meeting, Davis (CEO), Marina (inventory manager), and Cheng (transportation manager) will first analyse the performance of the existing SC subject to financial, customer, and operational KPI. In the next step, they will analyse different options for changing inventory control and transportation policies in order to improve the SC performance.

4.1.1. Supply chain structure

We use the Excel template "8 SIM Distribution Network inside 4 Walls Models" supplied with ALX, import this scenario and consider an SC that comprises six customers, two DCs, and a supplier (Fig. 49).

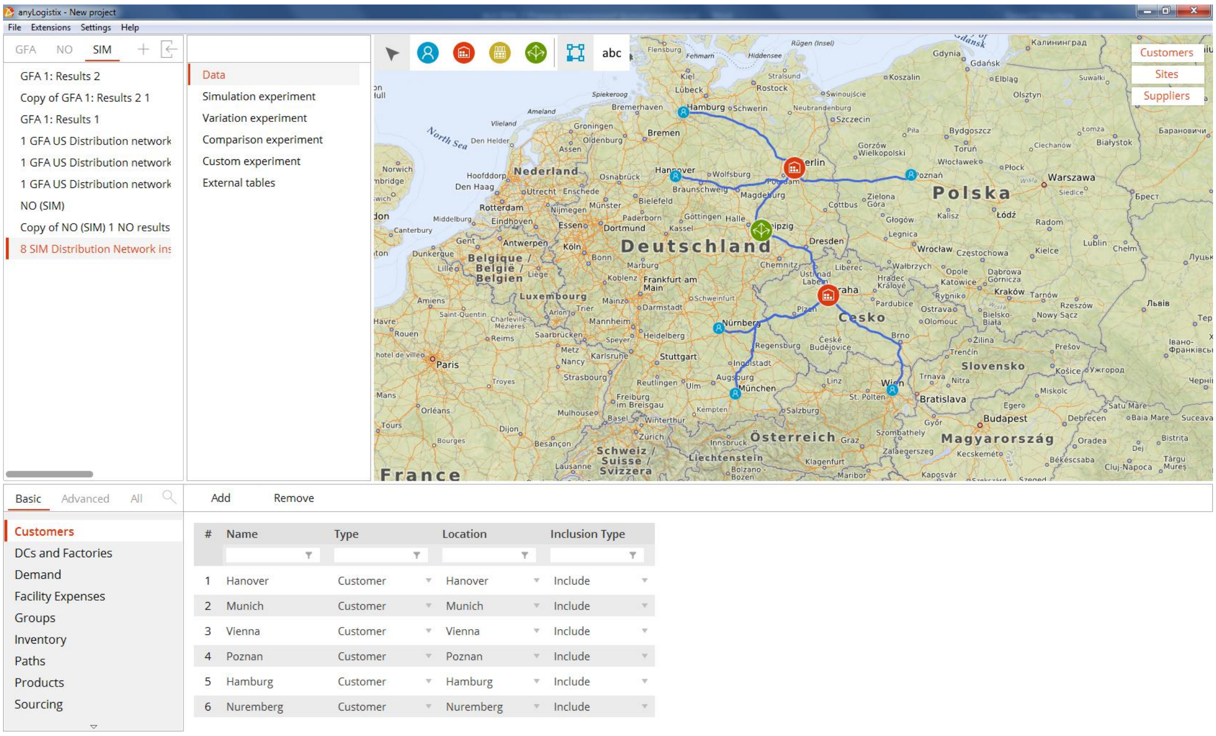


Fig. 49. Three-Stage SC

Locations of the customers are depicted in Fig. 46, DCs are located in Berlin and Prague, and the supplier is in Leipzig.

Three products are involved in this example: PC, Monitor and MFP. Their prices and costs are shown in Fig. 50.

#	Name	Unit	Selling Price	Cost	Cost Unit
1	PC	pcs	1,150	350	USD
2	Monitor	pcs	850	250	USD
3	MFP	pcs	700	200	USD

Fig. 50. Products in the supply chain

We need to know the products volume to fill the vehicles. You can use the Measurement Unit Conversions table to create conversions for the user-defined weight and volume units (previously created in the Measurement units table) that will be used exclusively within the current scenario.

#	Product	Amount from	Unit from		Amount to	Unit to
1	MFP	1	pcs	=	0.1	m³
2	Monitor	1	pcs	=	0.1	m³
3	PC	1	pcs	=	0.1	m³

Fig. 51. Measurement unit conversions

4.1.2. Demand and expected lead time

Demand and expected lead time are as follows (Fig. 52).

#	Customer	Product	Demand Type	Parameters	Time Period	Expected Lead Ti...	Time Unit	Backorder Policy
1	Hanover	MFP	Periodic demand	Period=1.0, Quant...	(All periods)	2	day	Not allowed
2	Nuremberg	Monitor	Periodic demand	Period=1.0, Quant...	(All periods)	2	day	Not allowed
3	Munich	MFP	Periodic demand	Period=1.0, Quant...	(All periods)	2	day	Not allowed
4	Poznan	PC	Periodic demand	Period=1.0, Quant...	(All periods)	2	day	Not allowed
5	Hamburg	Monitor	Periodic demand	Period=1.0, Quant...	(All periods)	2	day	Not allowed
6	Vienna	PC	Periodic demand	Period=1.0, Quant...	(All periods)	2	day	Not allowed

Fig. 52. Customer demand and expected lead time

4.1.3. Transportation policy and costs

Further, we can use two types of vehicles (Fig. 53).

#	Name	Capacity	Capacity Unit	Speed	Speed Unit
1	Lorry	20	m^3	50.0	km/h
2	Truck	60	m^3	50.0	km/h

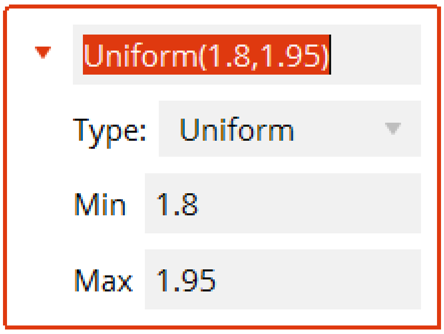
Fig. 53. Vehicle types

Transportation costs and time computation is based on the following rules (to be defined in the "Paths" (Fig. 54).

#	From	To	Cost Calculation	Cost Calculation ...	Cost Unit	Distance	Distance Unit	Transportation Ti...	Time Unit	Straight	Vehicle Type	Transportat
1	Leipzig	DCs	Volume&distanc...	1.0 * amount (m^3) ...	USD	0	km	0.7	day		Truck	LTL
2	DCs	All customers	Volume&distanc...	1.0 * amount (m^3) ...	USD	0	km	Uniform(1.8,1.95)	day		Lorry	LTL

Fig. 54. Transportation policy

→ **Note**: Some numerical values can be either fixed or stochastic (defined by probability distribution). The corresponding table cells provide the drop-down menu that allows you to set the desired value. You can also type the value manually.



To modify a numerical value, do the following:

1. Click the table cell to activate the edit box.
2. Click the arrow next to the cell value to open the drop-down menu.

- To set a fixed value, choose Value from the Type drop-down list and type the desired value in the Value field below.

- To set a stochastic value, choose the desired probability distribution from the Type drop-down list (ALX currently supports Uniform, Triangular, Exponential, Normal and Lognormal probability distributions). Set the distribution parameters in the fields below the list (the set of parameters differs for every probability distribution type).

3. To save the changes, press Enter or click outside of the cell. To discard changes, press Escape.

To type the desired value manually:

1. Click the table cell to activate the edit box.
2. Type the desired value:
   - To set a fixed value, type in the desired numerical value.
   - To set a stochastic value, type the value in the following format: Distribution Type(Parameter 1, Parameter 2, ...), for example Uniform(5.0, 6.0).

In the table "Paths", the following parameters are setup:

- "From" – defines the origin location of the path. This is the reference to the table "Locations"
- "To" – defines the target location of the path. This is the reference to the table "Locations"
- "Cost Calculation" – defines the basis for transportation cost calculation. i.e.:
  - ✓ *0.0 * weight + 0.0 - for Weight-based cost. The formula parameters are weight and Add cost.*
  - ✓ *0.0 * volume + 0.0 - for Volume-based cost. The formula parameters are volume and Add cost.*
  - ✓ *0.0 * weight * distance - for Weight&distance-based cost. The formula parameters are Cost per kg-km, weight and distance.*
  - ✓ *0.0 * volume * distance - for Volume&distance-based cost. The formula parameters are Cost per m3-km, volume and distance.*
  - ✓ *0.0 - for Fixed delivery cost. The parameter is Cost.*
  - ✓ *0.0 * distance - for Distance-based cost. The formula parameters are Cost per km and distance.*
- "Cost Calculation Parameters"- the parameters for cost calculation formulas
- "Distance"- defines the path length in km/miles. If set to zero, the path length is calculated based on GIS information
- "Transportation Time" – defines transportation time for the path in days. If set to zero time is calculated based in GIS information
- "Straight" – defines if ALX should use straight paths between sites or real roads
- "Vehicle Type" – defines the vehicle type (previously defined vehicles in the Vehicle Types table) used for shipping products along the path
- "Transportation Policy" – regulates the handling of the orders for the amount smaller than the selected vehicle capacity
- "Min Load, ratio" – In case of FTL transportation policy, it defines the minimum load ratio
- "Aggregate Orders"– The option defines whether the orders are accumulated during the time period defined in "Aggregation Period, days"
- "Aggregation period" – The time period during which the orders are aggregated
- "Inclusion Type" – The status of the path:
  - ✓ *Include - the path is included, so vehicles can use it to get to the destination.*
  - ✓ *Exclude - the path is not used in the scenario.*

It can be observed from Fig. 54 that transportation costs is computed as $1.0 x volume x distance. Further we setup the transportation time that is fixed at 0.7 days from the supplier in Leipzig to both DCs and not uniformly distributed in the range [1.8; 1.95] days between the DCs and the customers.

4.1.4. Groups of supply chain elements

In the next step, we create four groups (i.e., All Customers, DCs, Customers Prague and Customers Berlin) in the model in order to simplify further model development and result analysis (Fig. 55). In particular, instead of creating, e.g., paths between DC in Prague and its customers, we will be able just to create a path from DC Prague to the group “Customers Prague” instead of creating multiple individual paths top each of the customers.

#	Group	Description	Customers	Sites	Suppliers	Groups
1	DCs		[]	[DC Prague, DC Berlin]	[]	[]
2	Customers Prague		[Munich, Vienna, Nuremberg]	[]	[]	[]
3	All customers		[Hanover, Munich, Vienna, Poznan, Hamburg, Nuremberg]	[]	[]	[]
4	Customers Berlin		[Hanover, Hamburg, Poznan]	[]	[]	[]

Fig. 55. Groups

4.1.5. Inventory control policy

Inventory control policy in this example is (*s*,*S*) according to the following parameters (Fig. 56).

#	Facility	Product	Policy Type	Policy Parameters	Initial Stock, units	Periodic Check	Period	Policy Basis	Stock Calculation...	Time Unit
1	DCs	(All products)	Min-max policy	s=57, S=113	57		0	Quantity	0	day

Fig. 56. Inventory control policy

→ Note: ALX uses table “Inventory” to define parameters of inventory policies. Throughout this book, we use the term “Inventory control policy” for parameters defined in table “Inventory”.

In the table “Inventory”, the following parameters are setup:

- “Facility” – Defines the facility/group of facilities for which an inventory policy is specified
- “Product” – Defines the product/group of products to which the policy is applied to
- “Policy Type” – Defines the type of inventory control policy
- “Policy Parameters” – Parameters for selected inventory control policy
- “Initial Stock” – defines the initial quantity of products at the site(s)
- “Periodic Check”- Defines if inventory is checked periodically or after each change.
- “Period” – Period in days between inventory level check
- “Policy Basis” – Defines if quantity or days of demand is used as policy basis
- “Stock Calculation Window” – defines the number of days to calculate the mean daily demand
- “Time Period” – the time period during which the inventory policy will be considered
- “Inclusion Type” – Defines the status of given inventory policy

4.1.6. Sourcing policy

Sourcing policy is shown in Fig. 57.

#	Delivery Destinat...	Product	Type	Parameters	Sources	Time Period	Inclusion Type
1	DCs	(All products)	Closest (Single s...	No parameters	Leipzig	(All periods)	Include
2	Customers Berlin	(All products)	Closest (Single s...	No parameters	DC Berlin	(All periods)	Include
3	Customers Pragu	(All products)	Closest (Single s...	No parameters	DC Prague	(All periods)	Include

Fig. 57. Sourcing policy

4.1.7. Operational costs at DCs

Finally, we define operational costs for the DCs in “DCs/Factories” subject to interest rate of 10% (0.1) and inventory carrying costs per day per m^3 as \$0.01 in “Facility Expenses” (Fig. 58).

#	Name	Type	Location	Initially Opened	Inclusion Type	Capacity	Capacity Unit	Interests, ratio per year	Aggregate Orde
1	DC Prague	ExtendedDC	Prague	on	Include	34	m³	0.1	off
2	DC Berlin	ExtendedDC	Berlin	on	Include	34	m³	0.1	off

#	Facility	Expense Type	Value	Cost Unit	Time Unit	Product Unit	Time Period
1	DCs	carryingCost	0.01	USD	day	m³	(All periods)

Fig. 58. Inventory holding costs at DCs

4.2. Creation of new KPI Dashboard

For the experiments with the three-stage model, we will define an extended KPI dashboard, i.e., we will create four new tabs as follows:

- Financial and customer performance KPI
- Operational performance KPI
- Inventory and capacity dynamics

4.2.1. Financial and customer performance KPI

In order to assess financial and customer performance, six blocks are included into the dashboard (Fig. 59).

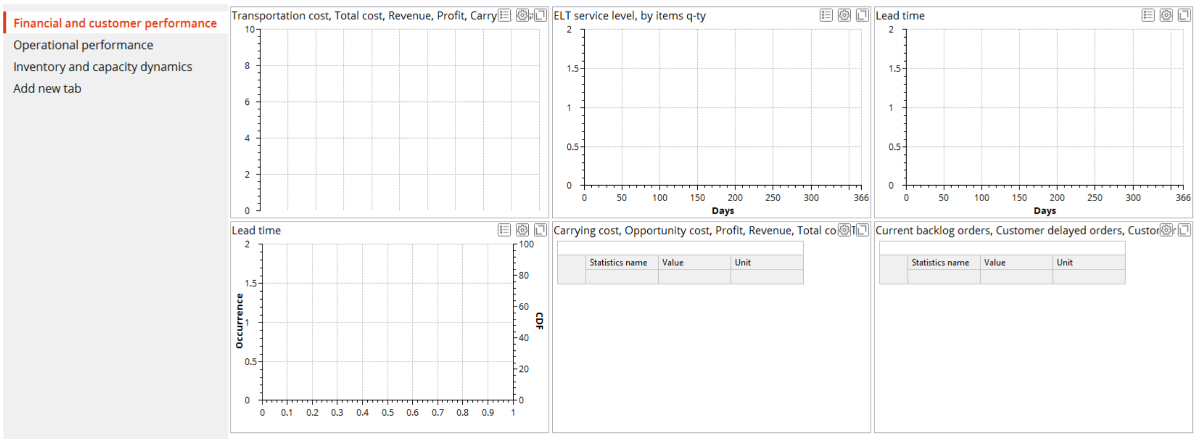


Fig. 59. Financial and customer performance KPI

For technical issues of KPI dashboard design, please consult Chapter 1.

First, we include a block to collect statistics about revenue, total costs, profit, carrying costs, opportunity costs, and transportation costs (Fig. 60).

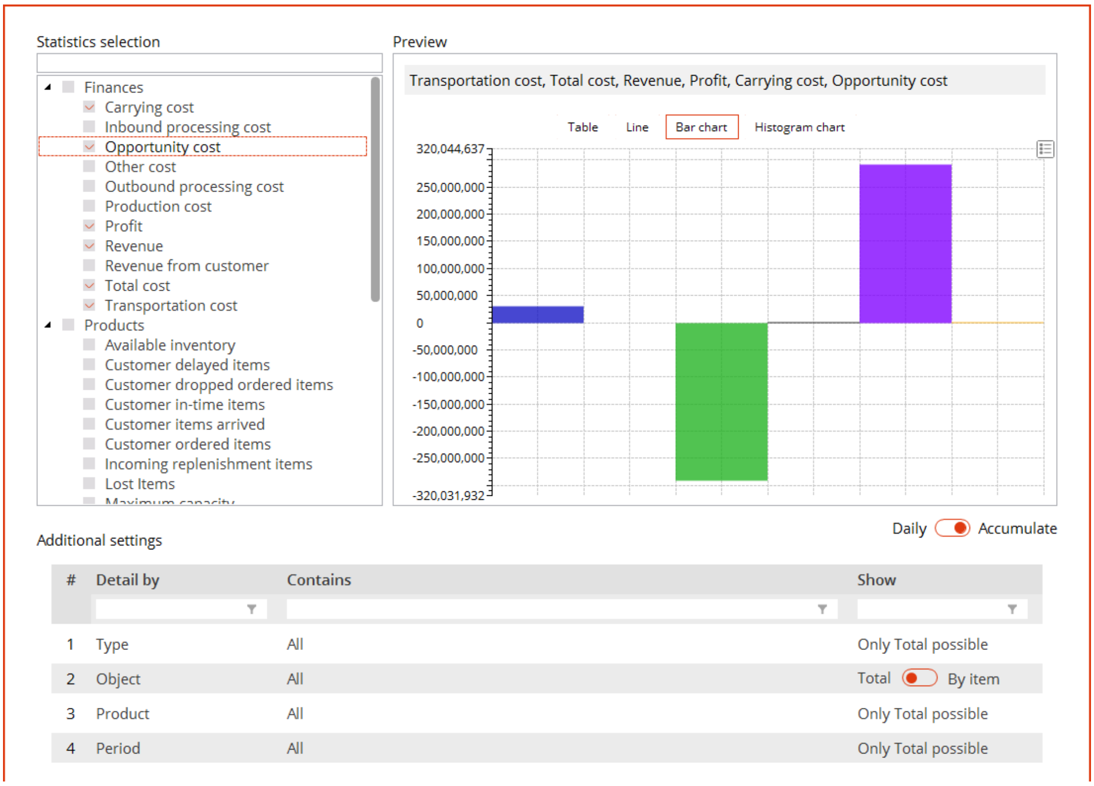


Fig. 60. Financial performance statistics

Second, service level will be measured (Fig. 61).

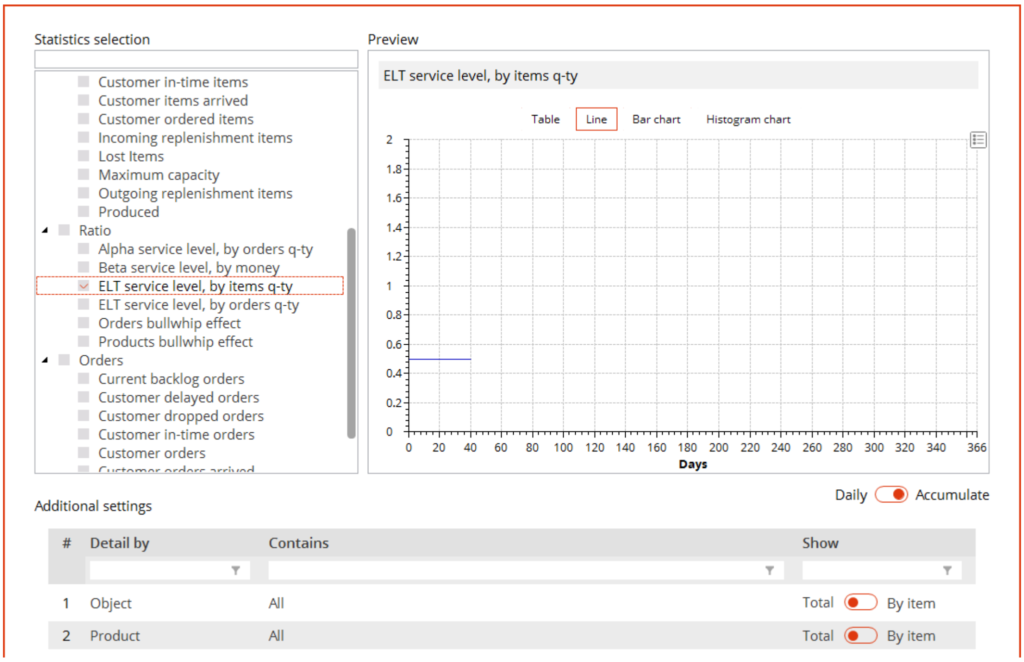


Fig. 61. General orders service level statistics

For a more detailed analysis, we can also analyse service level at each DC and/or for each product (showed by item).

Third, we include lead time analysis for each DC and customer as a line and as a histogram chart (Figs. 62-63).

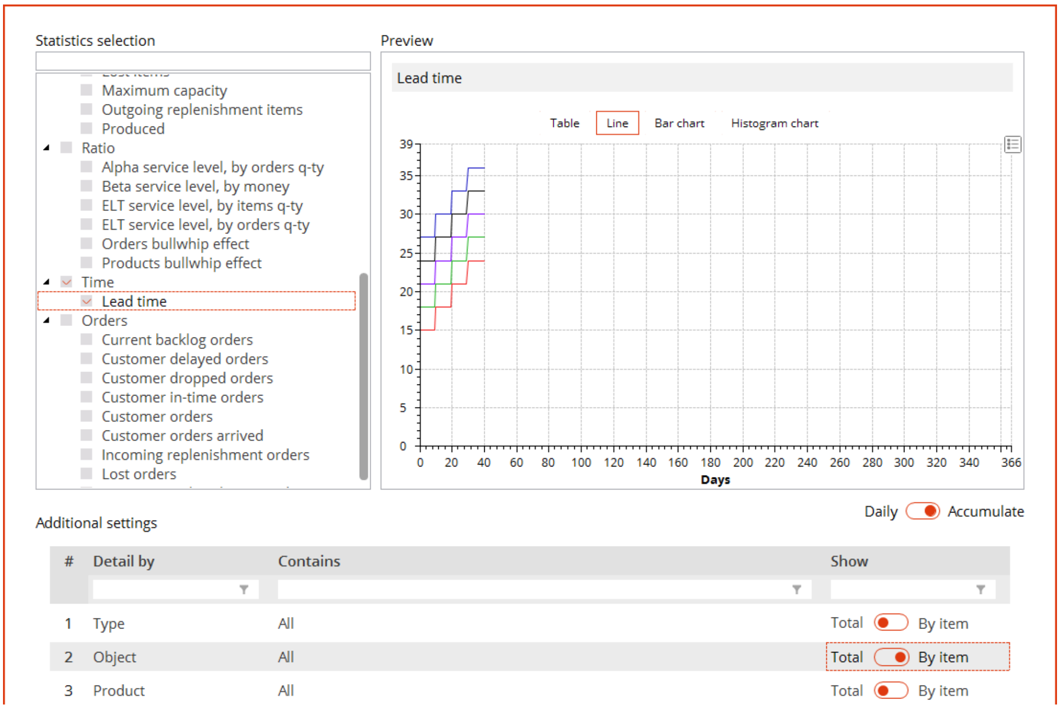


Fig. 62 Lead time statistics as a line

Fig. 63 Lead time statistics as a histogram chart

Finally, we introduce two tables for representing the financial performance subject to Fig. 60 and customer performance subject to order fulfilment and backlog (Figs 64 and 65).

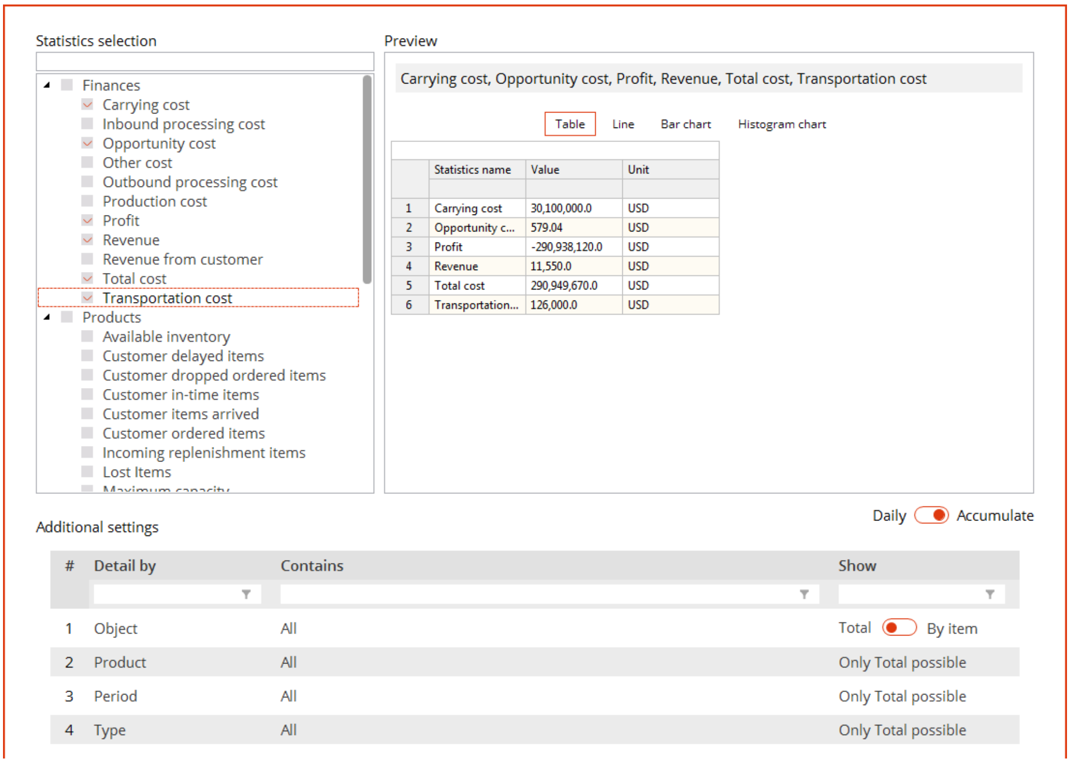


Fig. 64 Financial performance statistics

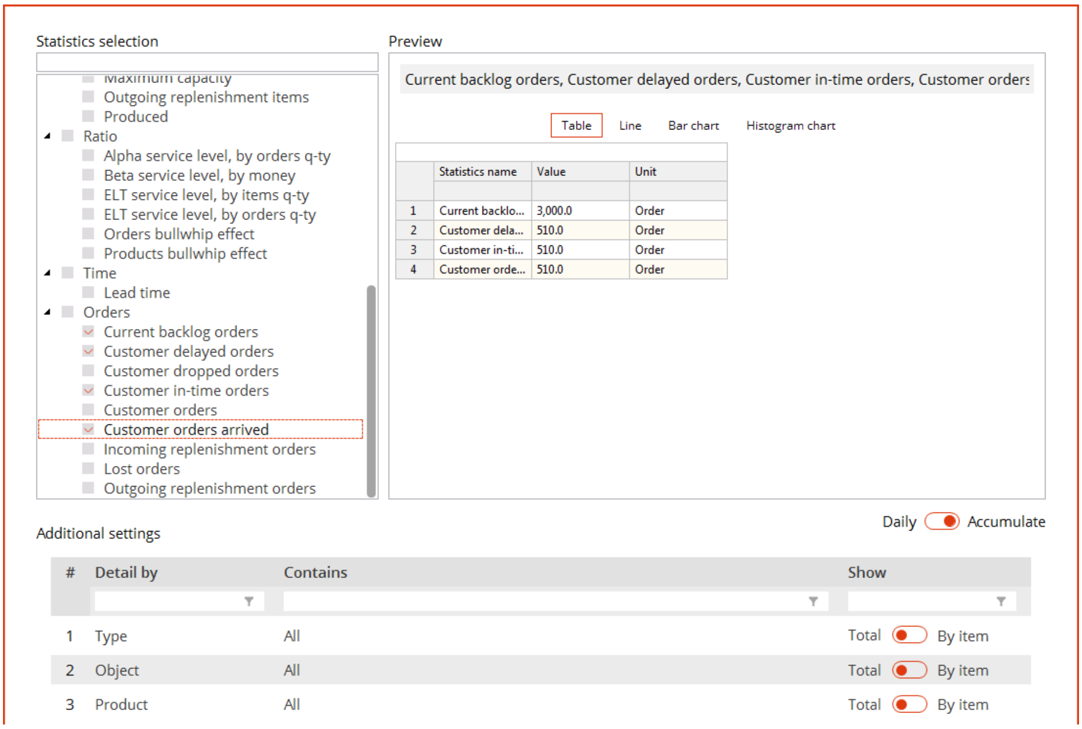


Fig. 65 Order fulfilment performance statistics

4.2.2. Operational performance KPI

Operational performance dashboard will include capacity and inventory analysis for the overall SC (Fig. 66).

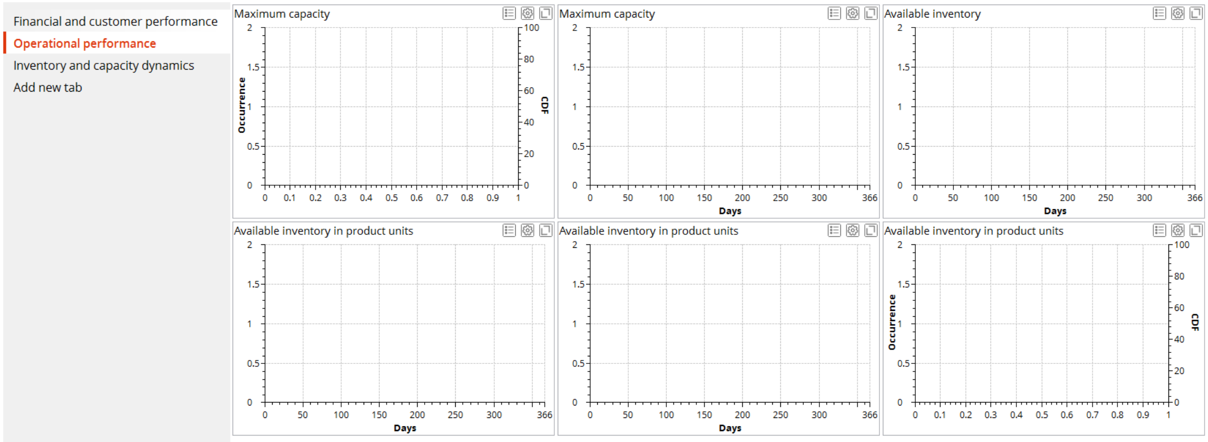


Fig. 66. Capacity and inventory analysis for the overall SC

First, analysis of maximum DC capacity consumption will be used as a histogram chart and as a line (Figs 67 and 68).

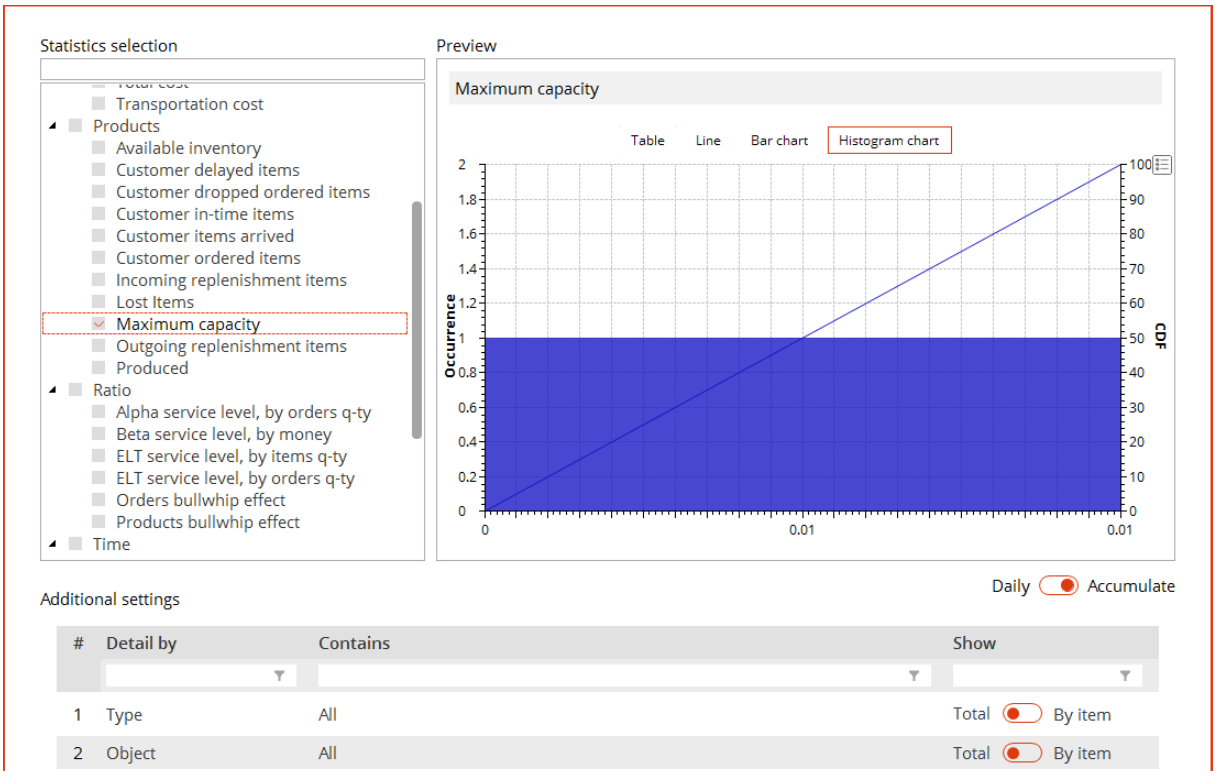


Fig. 67. Analysis of maximum DC capacity consumption as a histogram chart

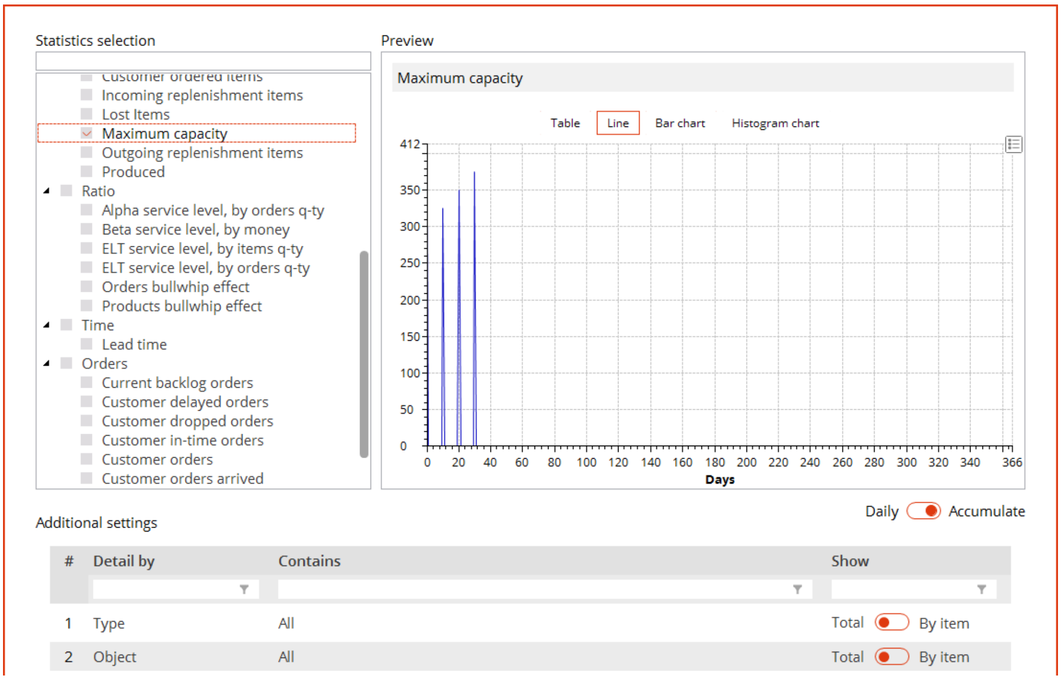


Fig. 68. Analysis of maximum DC capacity consumption as a line

This analysis will be helpful to observe real capacity usage (in m^3) in dynamics in order to make decisions on DC capacities.

Second, dynamics of available inventory volume in the SC will be presented as a line (Fig. 69).

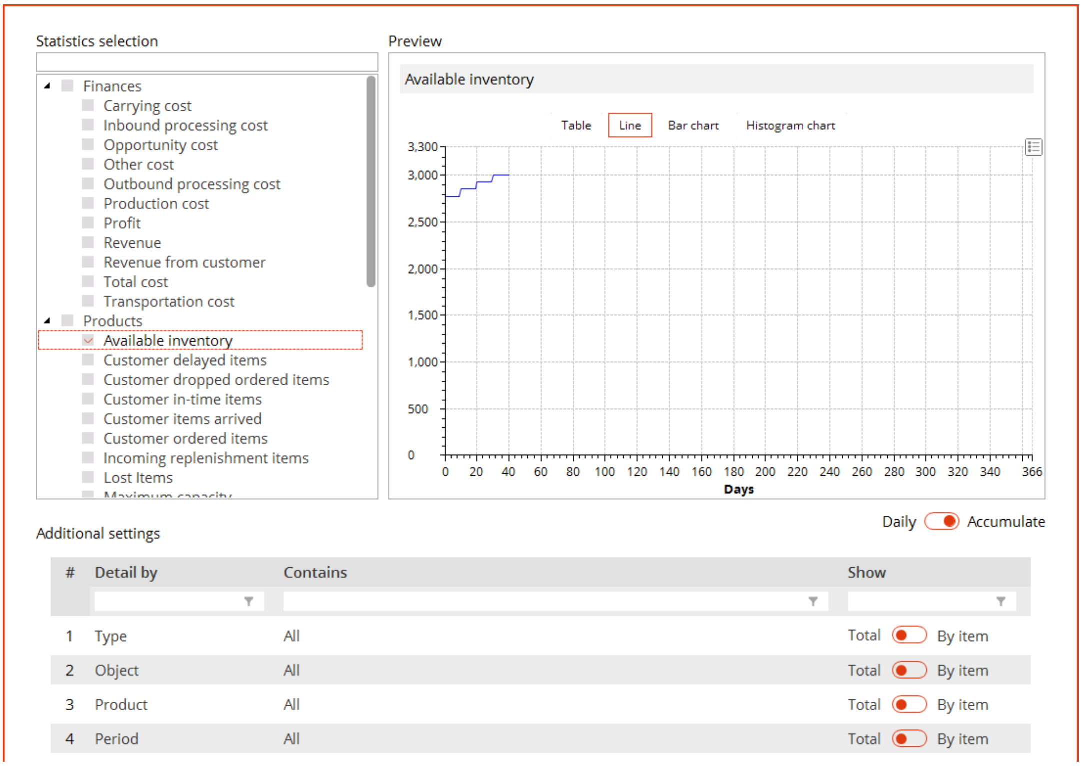


Fig. 69. Dynamics of available inventory volume in the SC as a line

Third, dynamics of available inventory quantity will be presented as a line and as a histogram chart for the overall SC and for different objects and products as a line (Figs 70-71).

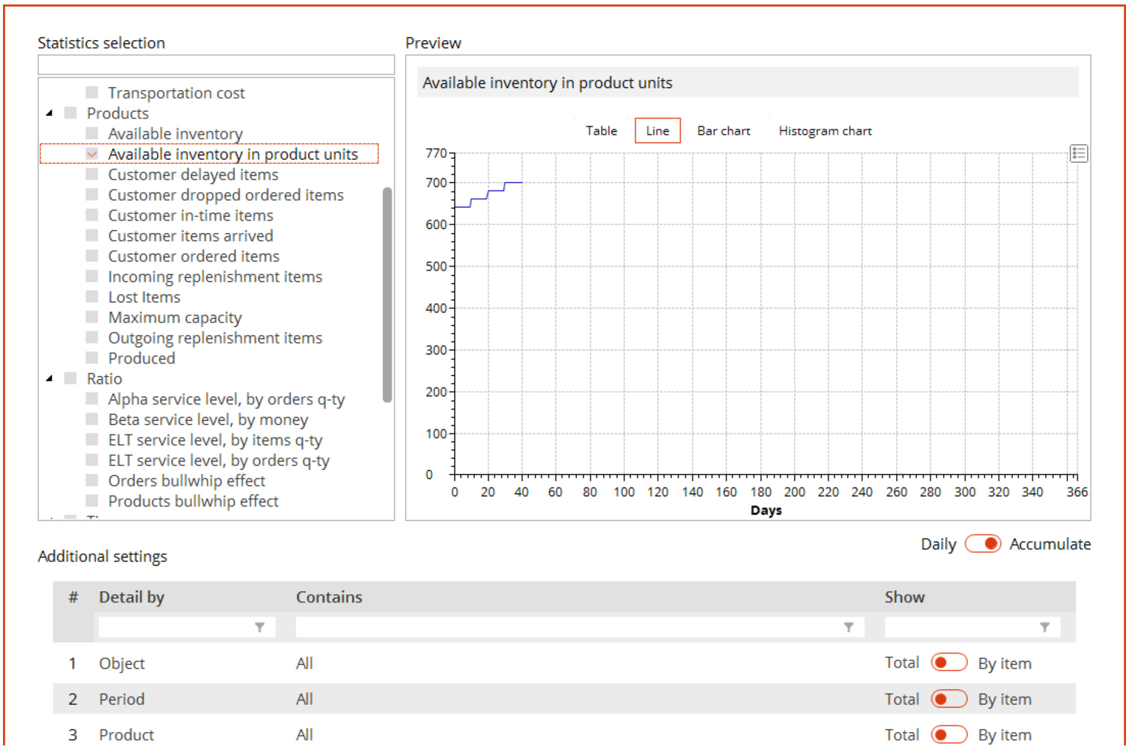


Fig. 70. Dynamics of available inventory quantity in the SC as a line

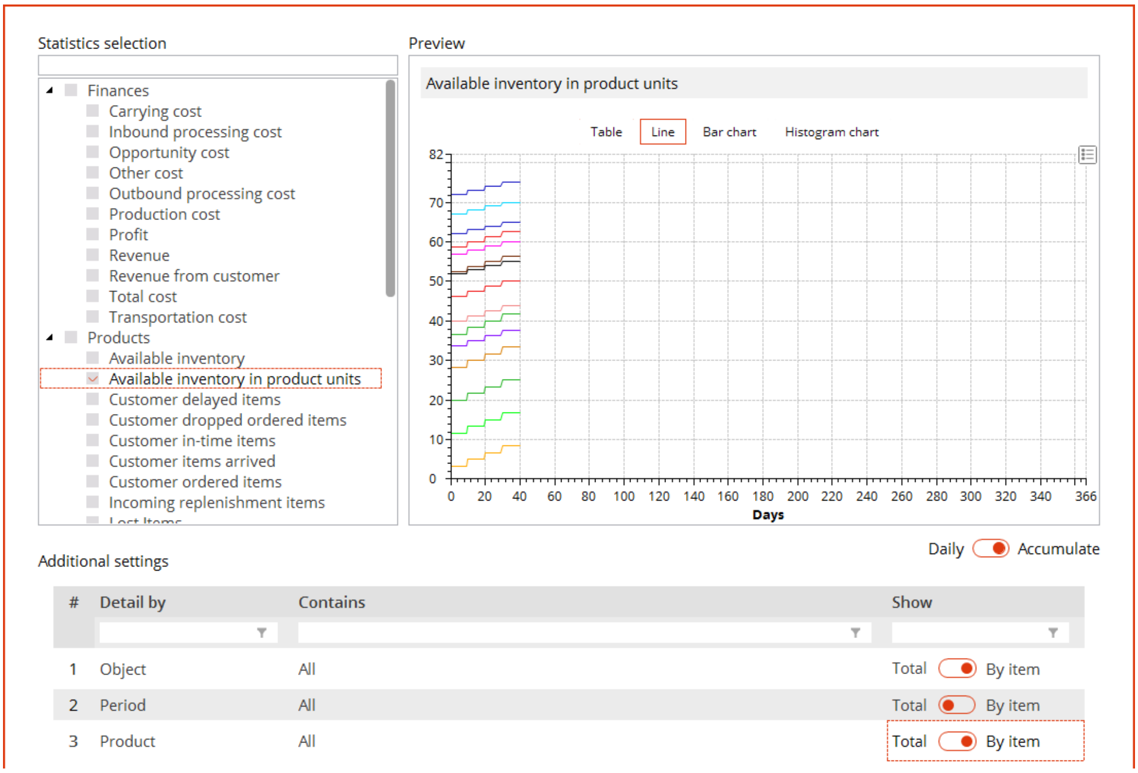


Fig. 71. Dynamics of available inventory quantity at objects and for different products as a line

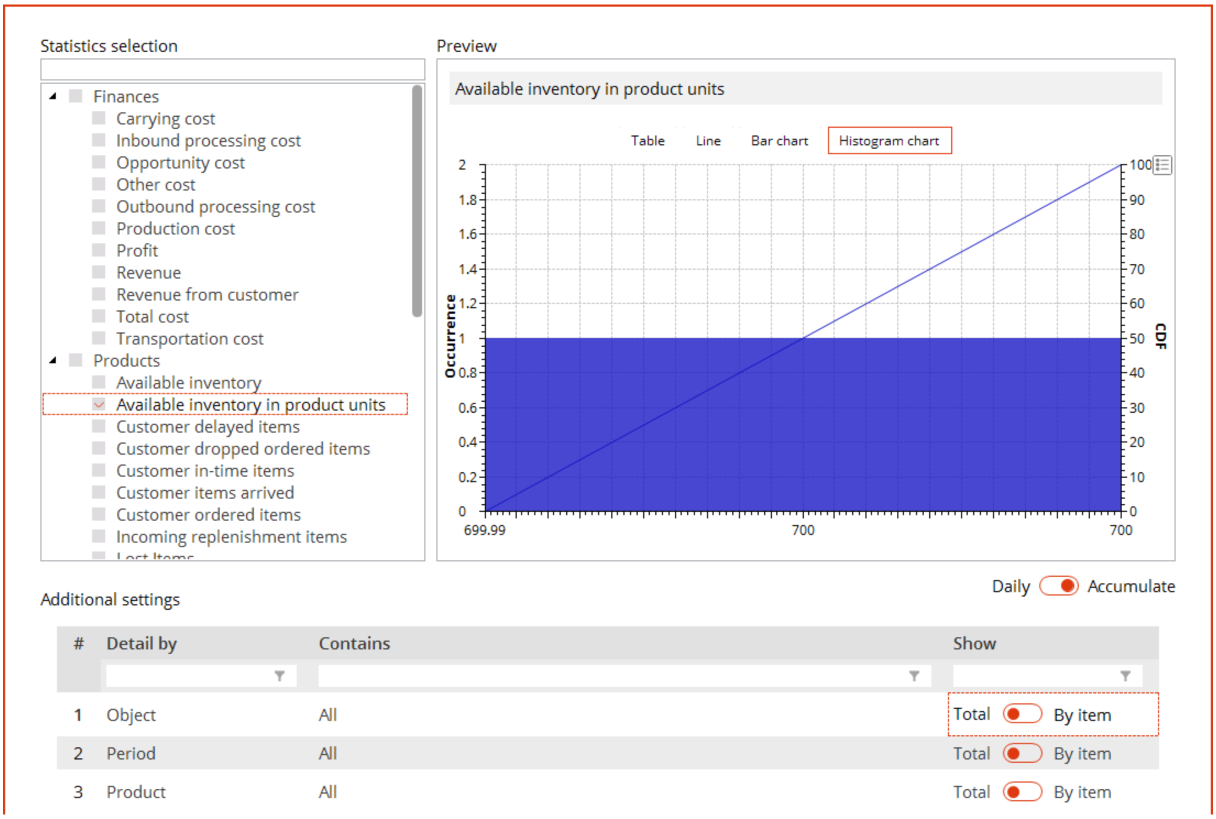


Fig. 72. Dynamics of available inventory quantity in the SC as a histogram chart

4.2.3. Inventory and capacity dynamics

In this dashboard, we present inventory and capacity usage dynamics at the object and product levels (Fig. 73).

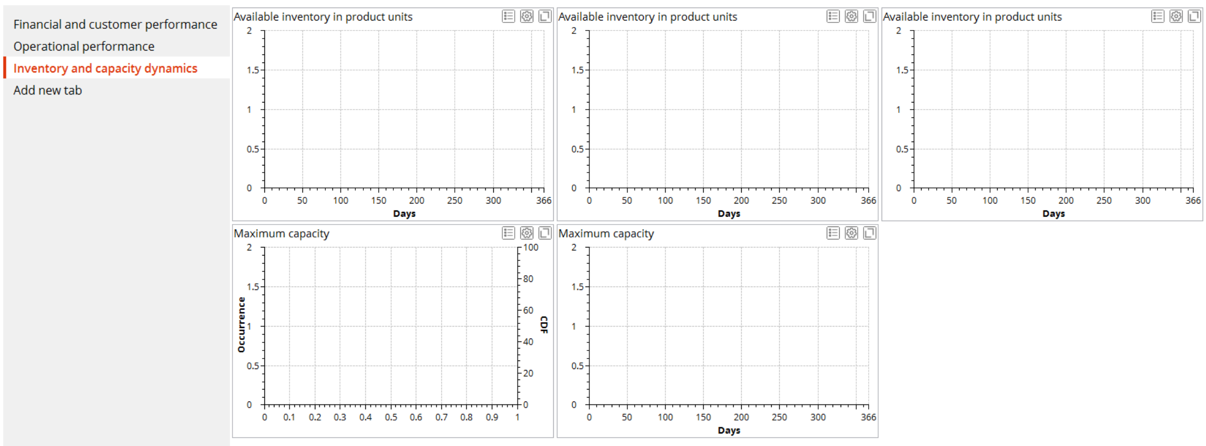


Fig. 73. Dashboard for dynamics of inventory and capacity at the object and product levels

The upper three blocks present inventory dynamics at each DC for monitors, PC, and MFP individually. An example for product “monitor” is shown in Fig. 74.

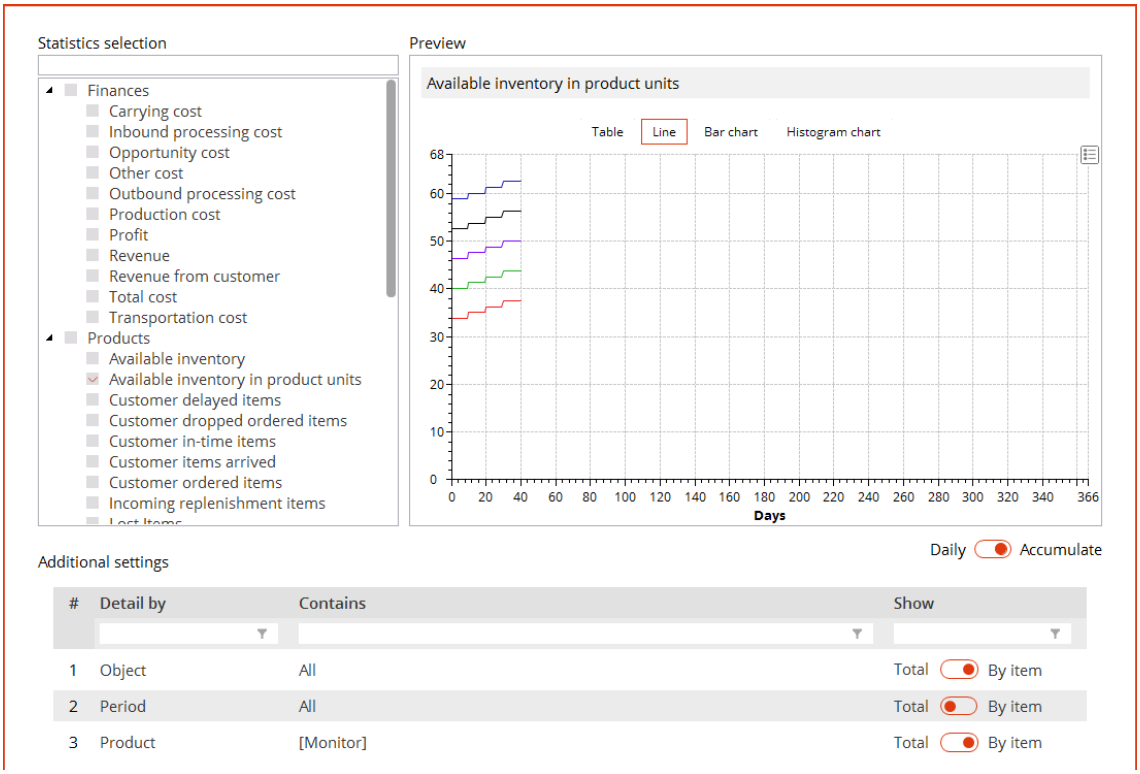


Fig. 74. Inventory dynamics for product "Monitor" at each DC

Other blocks in this dashboard (on the bottom) present capacity usage dynamics for each DC as a line and as a histogram chart (Figs 75-76).

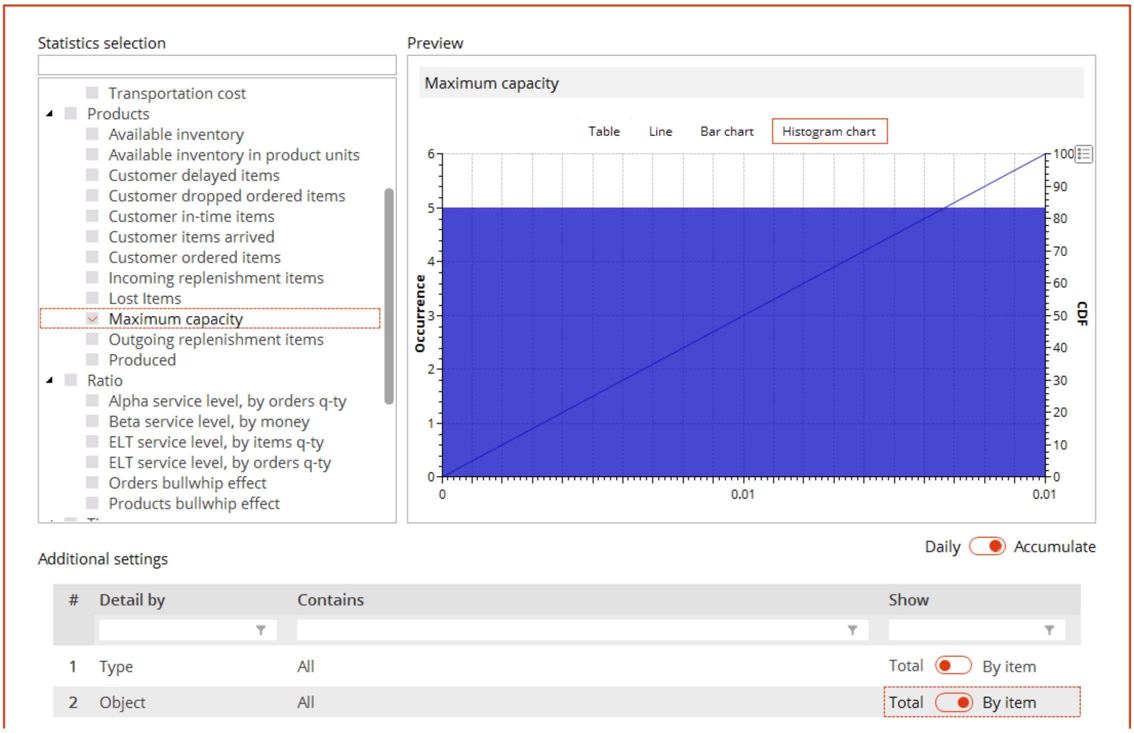


Fig. 75. Capacity usage dynamics for each DC as a histogram chart

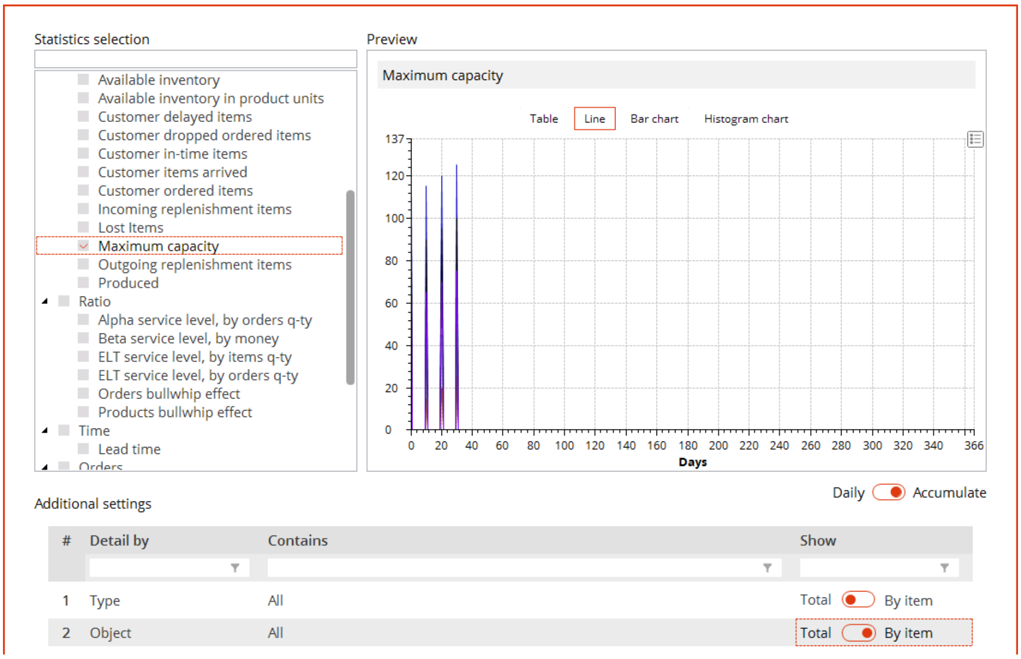


Fig. 76. Capacity usage dynamics for each DC as a line

4.3. *Experiment and result analysis*

4.3.1. Experimental results

In their first executive meeting, Davis (CEO), Marina (inventory manager), and Cheng (transportation manager) analyse the performance of the existing SC subject to financial, customer, and operational KPI. They start new simulation experiment for scenario “8 SIM Distribution Network inside 4 Walls Models”. The simulation results are shown in Figs 77-81.

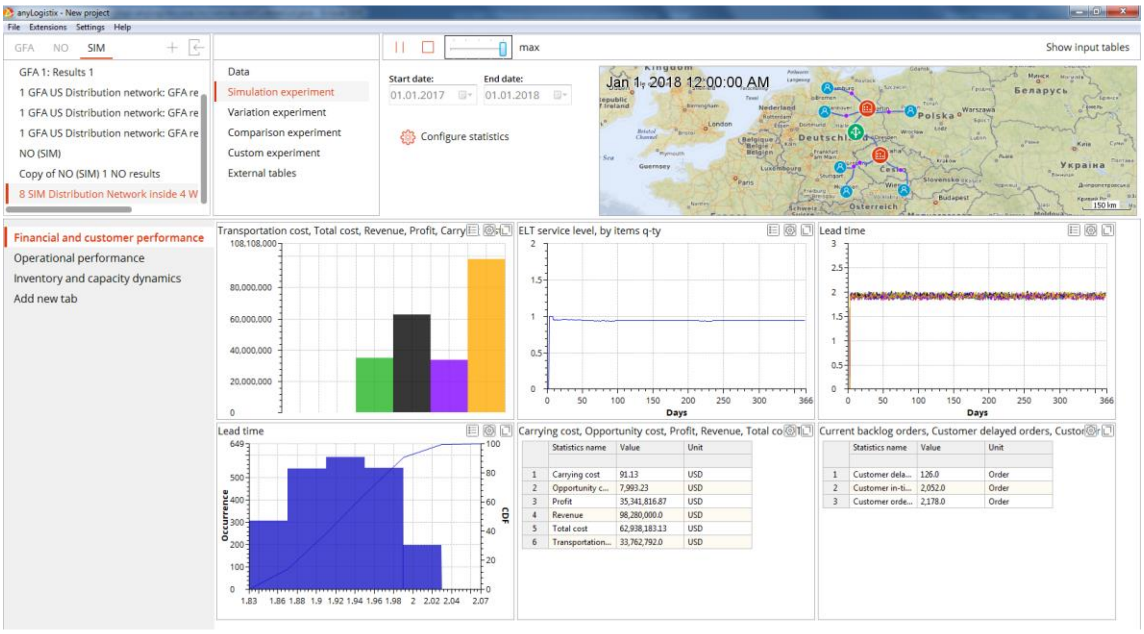


Fig. 77. Financial and customer KPI

It can be observed from Fig. 76 that the SC generates a revenue of $98,280,000.0 and profit of $35,341,816.87. Lead time from DCs to customers is between 1.9 and 1.99 days. There are no backlog orders. Lead time < 2 days and no backlog result jointly into the nearly 100% service level. In total, 2,178 orders have been generated by customers of which 2,052 orders have been fulfilled in time and 126 orders have been delayed. We can also observe from the lead time histogram chart that lead times to all the customers are levelled and uniformly distributed.

→ Note: Detailed costs and profit analysis can be seen while selecting "by item" and additional settings "object" both in the bar chart diagram and in the table of financial performance. Next, detailed view of each diagram can be seen (Fig. 77).

Carrying cost, Opportunity cost, Profit, Revenue, Total co

	Statistics name	Value	Unit
1	Carrying cost	91.13	USD
2	Opportunity c...	7,993.23	USD
3	Profit	35,341,816.87	USD
4	Revenue	98,280,000.0	USD
5	Total cost	62,938,183.13	USD
6	Transportation...	33,762,792.0	USD

Carrying cost, Opportunity cost, Profit, Revenue, Total co

	Statistics name	Object	Value	Unit
1	Carrying cost	DC Berlin	45.51	USD
2	Carrying cost	DC Prague	45.63	USD
3	Opportunity c...	DC Berlin	3,996.62	USD
4	Opportunity c...	DC Prague	3,996.62	USD
5	Profit	DC Berlin	22,267,304.49	USD
6	Profit	DC Prague	22,267,304.37	USD
7	Profit	Leipzig	-9,192,792.0	USD
8	Revenue	DC Berlin	49,140,000.0	USD
9	Revenue	DC Prague	49,140,000.0	USD
10	Total cost	DC Berlin	26,872,695.51	USD

	Statistics name	Object	Value	Unit
1	Carrying cost	DC Berlin	45.51	USD
2	Carrying cost	DC Prague	45.63	USD
3	Opportunity c...	DC Berlin	3,996.62	USD
4	Opportunity c...	DC Prague	3,996.62	USD
5	Profit	DC Berlin	22,267,304.49	USD
6	Profit	DC Prague	22,267,304.37	USD
7	Profit	Leipzig	-9,192,792.0	USD
8	Revenue	DC Berlin	49,140,000.0	USD
9	Revenue	DC Prague	49,140,000.0	USD
10	Total cost	DC Berlin	26,872,695.51	USD
11	Total cost	DC Prague	26,872,695.63	USD
12	Total cost	Leipzig	9,192,792.0	USD
13	Transportation...	DC Berlin	12,285,000.0	USD
14	Transportation...	DC Prague	12,285,000.0	USD
15	Transportation...	Leipzig	9,192,792.0	USD

Fig. 78. Costs and profit detailization

It can be observed from Fig. 78 that revenue at DC Prague is $49,140,000.00 and revenue at DC Berlin is $49,140,000.00. Total costs at DC Prague is $26,872,695.51 and total costs at DC Berlin is $26,872,695.51. Transportation costs from the supplier in Leipzig to both DCs is $9,192,972.0. Transportation costs from the DC Prague to its customer is $12,285,000.0. Transportation costs from the DC Berlin to its customer is $12,285,000.0.

→ Note: please be careful with *total* costs, profit and revenue evaluation! In this case, total transportation costs is calculated for the overall SC (i.e., costs of transportation across all the stages, from the suppliers to the customers), whereas the total costs, profit and revenue is computed for the DCs. This is because we selected the respective costs in “Configure statistics“ for all the objects. That is why, in this particular case, total transportation costs can be higher as total costs of DCs. In addition, in this example, we have an extended DC where staff costs (about $1,000) for each DC are included in total costs computation.

In order to analyse individual performance of different DCs and customers, the same diagrams can be used (Fig. 79).

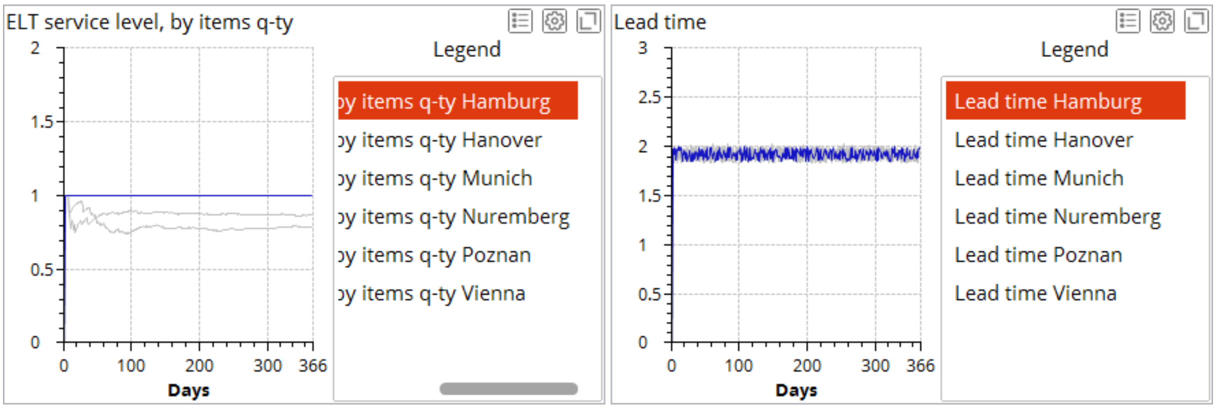


Fig. 79. Detailed service level and lead time analysis for customer in Hamburg

Next, let us consider operational performance for the overall SC (Fig. 80).

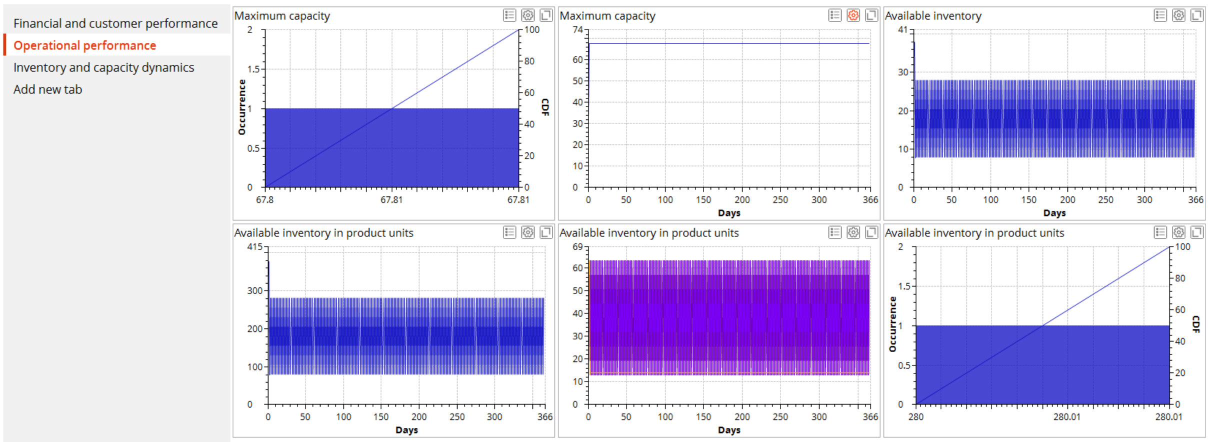


Fig. 80. Operational performance for overall SC

It can be observed from the diagrams in Fig. 80 that maximum capacity usage at DCs in Prague and Berlin has been 67.8 m^3 in total or 33.9m^3 for each DC. Available inventory amount for each individual product at each DC changed between 13 and 63 units (as setup in Min-Max policy) while total inventory amount in the SC changed between 80 and 380 units.

➔ Note: in the diagrams, inventory level does not drop to exactly 57 units (for all products in total) since we always replenish in advance

These results are detailed in the third and fourth dashboards “Inventory and Capacity Dynamics” (Fig. 81).

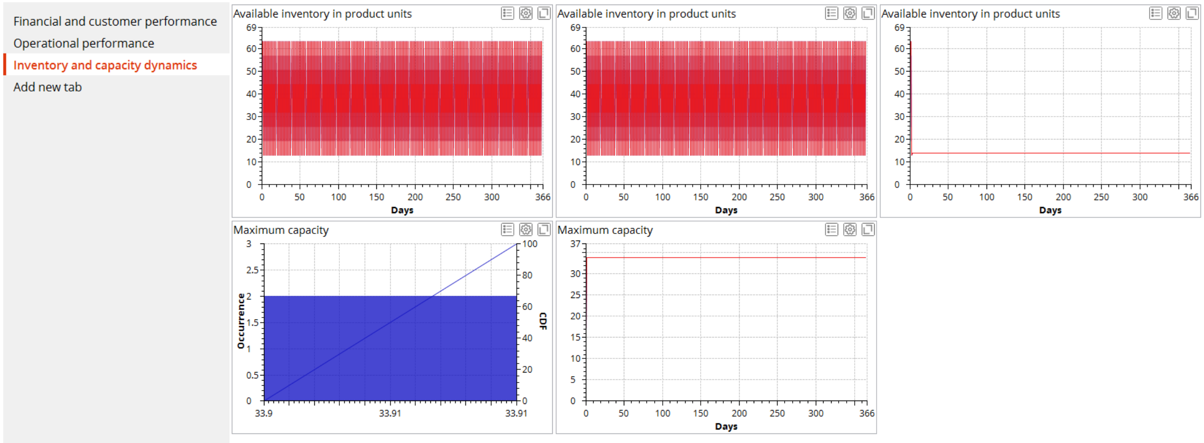


Fig. 81. Inventory and Capacity Dynamics Analysis

4.3.2. Result analysis

Davis, Marina, and Cheng (transportation manager) analyze the gained results. For example, they observe that the DC achieved total revenue of $98,280,000.0. They have in the SC demand for three products of 50 units respectively each of which is handled via two DCs. Assuming 365 working days, annual demand of each product is 3,630 units (36,300 m^3). In other words, they are able to fulfil the demand to 100% and achieved maximum possible revenue.

In the min-max inventory control policy, they set min = 57 and max = 113. Having these parameters, total inventory costs (i.e., opportunity costs) is $8,084.36. Further, both DCs need to run at capacity of 40 m^3. 2,178 customer orders have been generated for three products supplied from two DCs. In other words, every day a new customer order has been generated for each product. Finally, we can observe that using LTL transportation policy, trucks with capacity of 60 m^3 used for deliveries from the supplier in Leipzig to DCs are utilized at 87.5% considering total volume of each delivery as 0.1 + 0.1 + 0.15 (total volume of three products) x 150 units = 52.5 m^3. Two trucks are needed since two DCs need to be served. For lorries, we have six direct shipments each of which of 50 units. This results into average capacity utilization of 25% only since merely 5% of 20 m^3 is used.

The gained results are of high practical importance to support decision-making in different areas of SCM such as

- Capacity design
- Lead time agreements
- Inventory control policy and its parameters
- Transportation policy (FTL/LTL)
- Replenishment planning
- Sales planning
- Budget planning

For example, the real DC productivity can be analyzed using capacity usage dynamics diagrams. This extends classical methods based on throughput capacity analysis or setting maximum capacity for some material flows. The understanding of real lead times, order fulfilment dynamics and service levels allows to create a solid decision-support basis for negotiations and contract design with suppliers and customers. Inventory dynamics analysis makes it possible to estimate different inventory control policies and their parameters.

4.4. Impact of inventory control policy

In the standard ALX settings, ten inventory control policies can be used (Fig. 82).

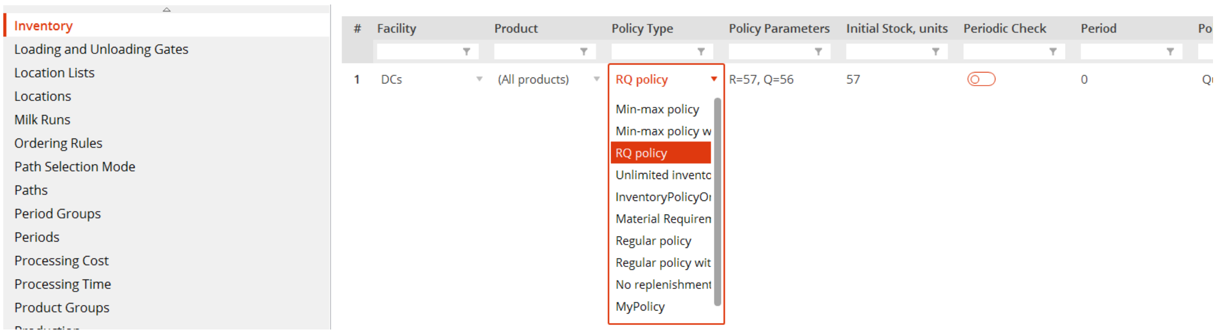


Fig. 82. Inventory control policy selection

- Min-max policy - also named (s, S) inventory policy. Products are ordered when the inventory level falls below a fixed replenishment point (s). The ordered quantity is set to such a value that the resulting inventory quantity equals S.
- Min-max policy with safety stock - the (s, S) inventory policy with safety stock. Products are ordered when the inventory level falls below a fixed replenishment point (s + safety stock). The ordered quantity is set to such a value that the resulting inventory quantity equals S + safety stock.
- RQ policy - (R, Q) inventory policy. Fixed replenishment point / fixed replenishment quantity policy. When the inventory level falls below a fixed replenishment point (R), the fixed replenishment quantity (Q) of products is ordered.
- Unlimited inventory - selected by default. Selecting Unlimited inventory policy, we assume that the products are always in stock in any required quantity.
- Inventory policy on demand - DC does not keep products in stock. The required number of products is ordered only on receiving an order from a customer/factory or other DC.
- Material Requirements Planning -

- Regular policy - [Periodic check option must be enabled] Products are ordered every specified Period (in the specified).
- No replenishment - DC will not be replenishing its inventory. If certain initial stock is available, DC will be shipping products until it runs out of stock.
- My policy - The user defined policy. Use this option for policies designed with the help of AnyLogic.
- XDock policy - DC operated like a cross-docking facility. It does not have inventory, it only transfers products from one type of transport to another.

Additional parameters of the inventory control policies that can be setup are as follows:

- Policy type: RQ Policy
- Policy type: R=57, Q=56

It is also possible to define the policies based on the days of supply.

4.4.1. Experiment

In the next executive meeting, Davis, Marina, and Cheng analyse different options for changing inventory control and transportation policies in order to improve the SC performance. Marina noticed that Min-level for inventory has been computed based on steady demand for all the products fixed at 50 units a day and the lead time variation between 1.7 and 1.95 days (i.e., standard deviation of lead time is 0.125 days). Since the SC is running 90% CSL policy, safety stock was computed as

ss = z x σ_{LT} x d_{daily} = 1.28 x 0.125 x 50 = 8 units *

** see the theory on safety stock and reorder point computation in:*

Ivanov D., Tsipoulanidis A., Schönberger J. (2017). Global Suppy Chain and Operations Management, Springer, 1st Edition.

Therefore, Min inventory level (i.e., the re-order point) was setup at 57 units (Marina reduced the safety stock from statistically computed 8 units to 7 units by her expert decision).

Marina suggests now to reduce safety stock. First, she observed that demand is always very close to the average and therefore 90% CSL is very high. She decides to reduce the re-order point to 53 units. Subsequently, in collaboration with the procurement manager, Alice, they found out that if they change the contract with the supplier in Leipzig from the Min-Max contract to the fixed-order quantity contract, the supplier can reduce the unit costs by 10 % for each of three products. With respect to the customer lead time requirements of two days and fixed demand of 50 units a day, Marina and Alice decide to set the target level (MAX) at 105 units.

They run simulation experiment created in the first executive meeting. The results are shown in Figs. 83-86 and Table 8.

Fig. 83. Financial and customer performance dashboard

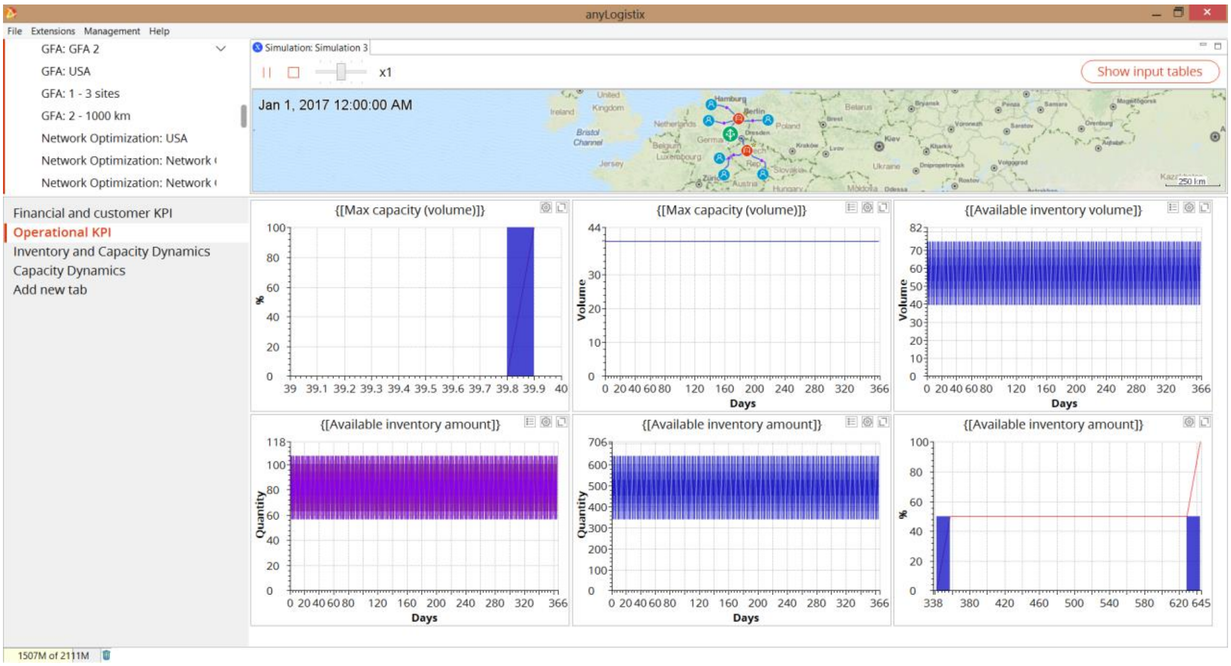


Fig. 84. Operational performance dashboard

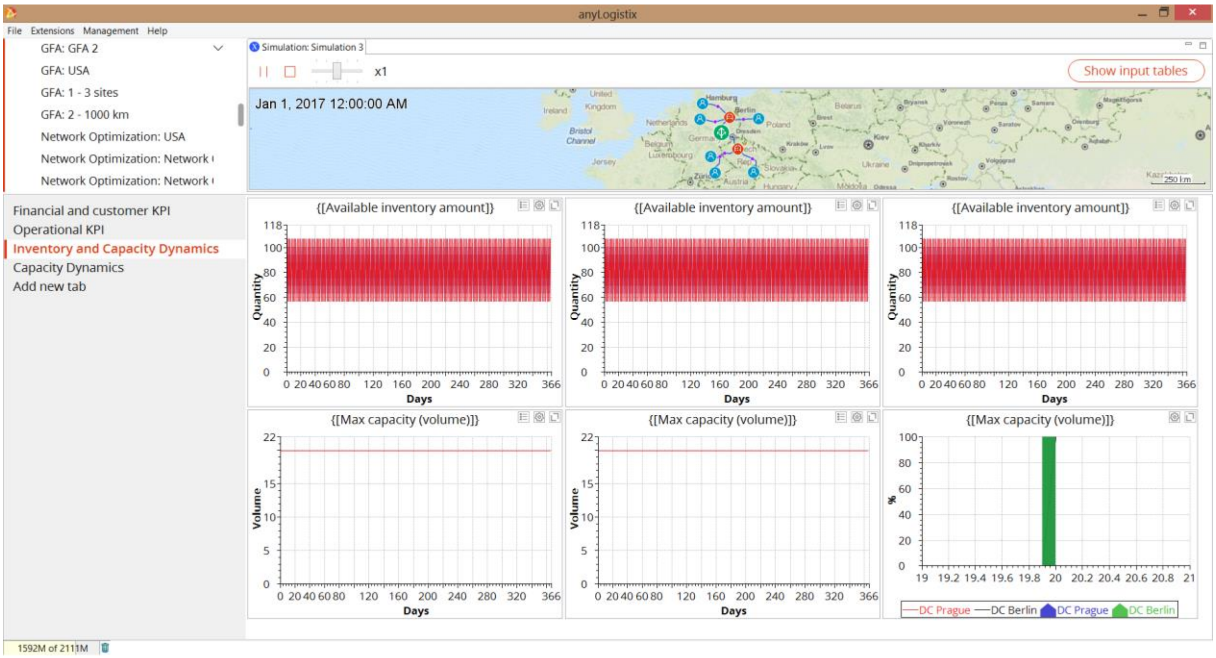


Fig. 85. Inventory and capacity dashboard

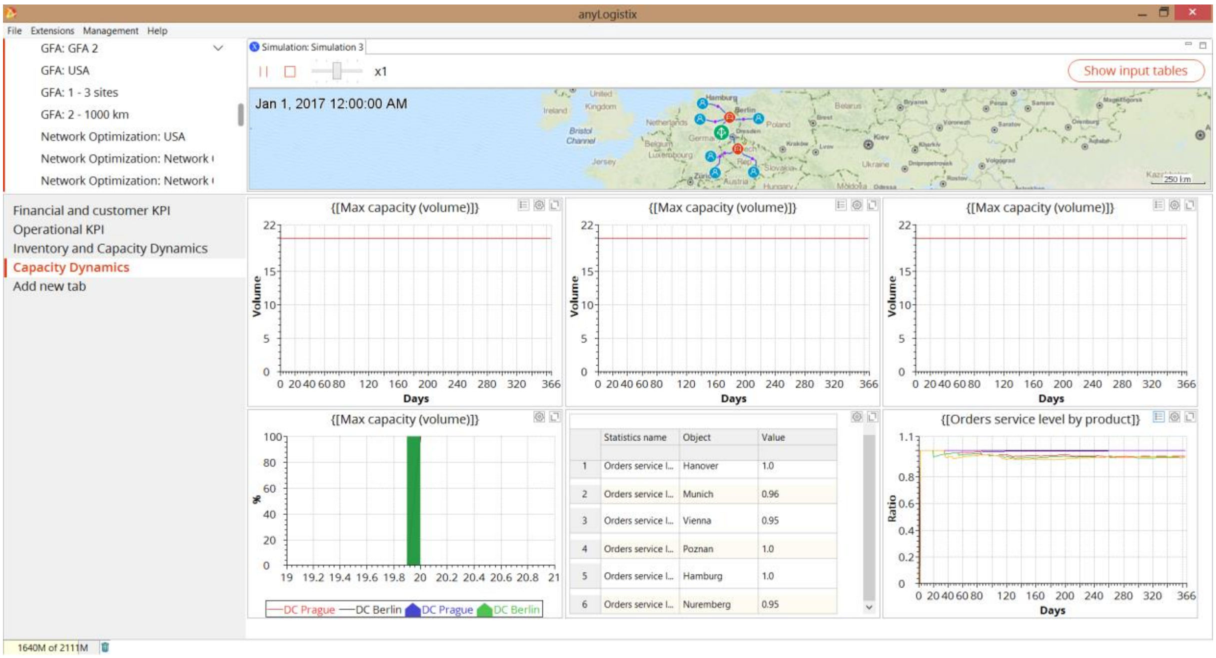


Fig. 86. Capacity usage and service level dashboard

Table 8 KPI comparison

KPI	**Initial SC**	**New inventory control policy**
Financial DC performance:		
Carrying cost	91.13	174.35
Opportunity cost	7 993.23	7 988.03
Profit	35 341 816.87	35 368 125.65
Revenue	98 280 000.0	98 280 000.0
Total cost	62 938 183.13	62 911 874.35
Transportation cost	33 762 792.0	33 755 400.0
Customer performance:		
Maximum lead time, days	11.81	11.78
Min-Max Service level, %	10-100	11-100
Current backlog orders	0	0
Customer delayed orders	706.0	690.0
Customer in-time orders	1472.0	1488.0
Customer orders arrived	2175.0	2175.0
Operational performance:		
Maximum capacity usage in the SC, m^3	67.8	104.6
Maximum inventory in the SC, units	580	936

4.4.2. Results analysis

It can be observed from the results that new inventory policy allows to increase the SC profit and improve inventory management performance. An additional benefit is that service level has been improved.

What can be improved next? Cheng suggests thinking about new order quantities and lead time requirements of the customer. An increase in order quantity and transition from daily deliveries to deliveries twice a week would improve transportation capacity utilization. However, Marina points out that an increase in order quantity is impossible now because of limited maximum warehouse capacity. Marina and Cheng use now anyLogistix with an embedded AnyLogic functionality in order to observe warehouse processes in dynamics.

4.5. Extensions to ALX using AnyLogic

An advantage of anyLogistix is the possibility to extend any object using AnyLogic. For example, the DC operations can be extended in AnyLogic to simulate internal processes at the DC in regard to forklift capacity utilization, loading times, etc. (Fig. 87).

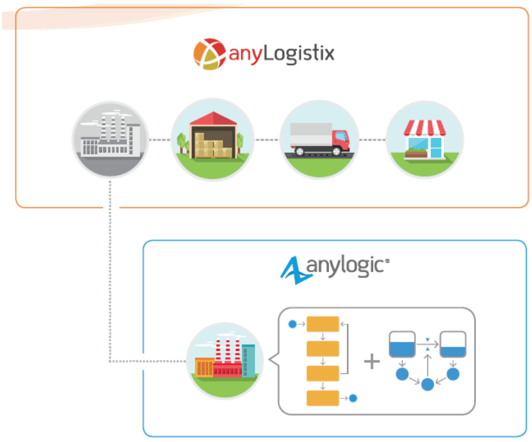


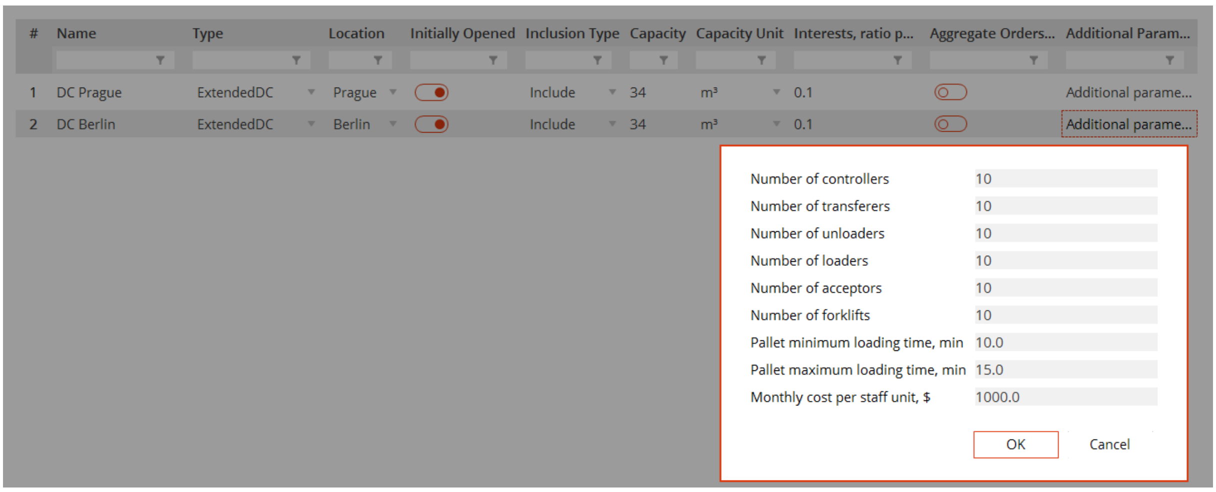
Fig. 87. Extensions to ALX in AnyLogic

In the main menu, we need to select “Extensions → Run AnyLogic”. For creating inventory control policies or DC operational models in AnyLogic, we refer to:

- The book “AnyLogic in Three Days”
- The book “Operations and Supply Chain Simulation with AnyLogic”
- Sample models in AnyLogic such as “Distribution Center”, “Adaptive Supply Chain”, “Supply Chain”, “Wholesale Warehouse”.

In AnyLogic, we need to extend a template describing behavior of network object. Export is implemented as a library (C:\Users\User\.anyLogistix\Extensions\extension.jar). Then we need to restart anyLogistix.

For example, in the sample Excel file “8 SIM Distribution Network inside 4 Walls Models”, additional parameters are embedded into the DCs activities:



The dynamics of the DC operation can be observed in the simulation run by clicking on the DC icon (Figs 88-89).

Fig. 88. Embedded AnyLogic model in the ALX: 2D view

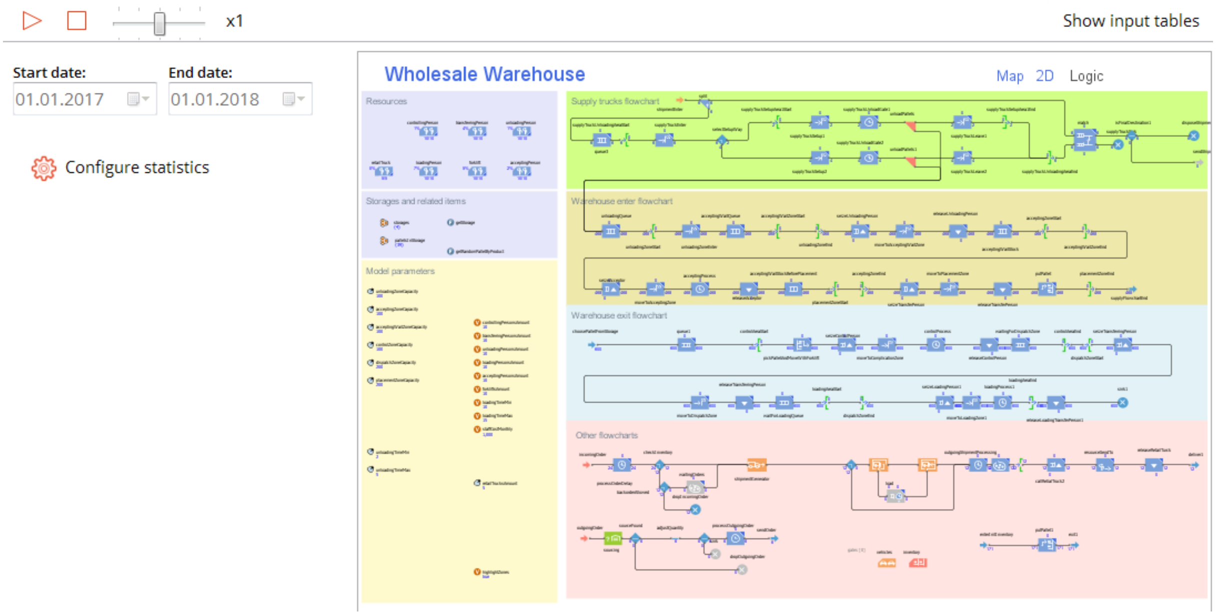


Fig. 89. Embedded AnyLogic model in the ALX: process logic view

Mutual extensions of ALX and anyLogistix are multi-facet and include the following issues but not limited to:

- Customized SC model based on ALX scenario data
- Additional data sources (external DB, files, internet)
- Data pre/post processing
- External solvers
- Your own optimization algorithms
- Heuristics
- Custom statistics
- Results: New ALX scenarios (like GFA and NetOpt)

The extensions are possible in regard to numerous ALX elements such as DC, Factory or-Customer. It is also possible to customize sourcing, inventory, transportation policies as well the logic of making decisions subject to shipment times, grouping of shipments, source selection logic or route selection logic. Custom experiments can also be created.

4.6. Impact of transportation policy

Transportation policy is managed in “Vehicle” and “Paths”. In “Vehicle”, transportation means, their capacity and speed can be setup. In “Paths”, FTL or LTL policy, transportation costs and time computation scheme, minimum load and order aggregation parameters can be setup.

Transportation costs computation can be based on four rules:

- Weight x volume x distance
- Distance-based
- Fixed delivery costs
- Weight-based costs

Transportation time can be either fixed or determined automatically based on real routes and transportation speed.

4.6.1. Experiment

In the next executive meeting, Davis, Marina, and Cheng analyse different options for changing transportation policy in order to improve the SC performance. Cheng noticed that capacity utilization of lorries is very low (25%). There are many options to improve it. First, deliveries may happen not daily but every four days based on the FTL policy. However, this would imply order quantity of at least 200 units which exceeds maximum storage capacity of 113 units. Davis holds a short-term capacity extension for impossible. Cheng would like to try another option, namely replacing the lorries with capacity of 20 m^3 by lorries with capacity of 7 m^3. This would result in reduction of transportation costs from \$0.01 for km and m^3 to \$0.005 for km and m^3. The simulation result is shown in Fig. 90 and Table 9.

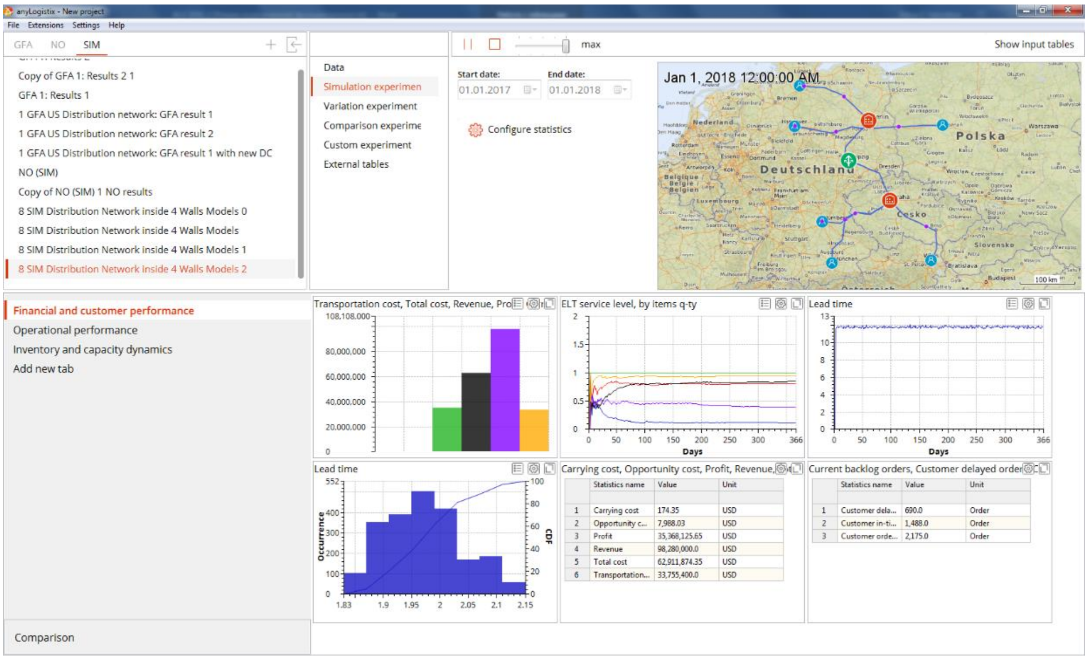


Fig. 90. Financial and customer performance for changed transportation capacity

Table 9 KPI comparison

KPI	**Initial SC**	**New inventory control policy**	**New inventory control policy + new transportation policy**
Financial DC performance:			
Carrying cost	91.13	174.35	174.35
Opportunity cost	7 993.23	7 988.03	7 988.03
Profit	35 341 816.87	35 368 125.65	35 368 125.65
Revenue	98 280 000.0	98 280 000.0	98 280 000.0
Total cost	62 938 183.13	62 911 874.35	62 911 874.35
Transportation cost	33 762 792.0	33 755 400.0	33 755 400.0
Customer performance:			
Maximum lead time, days	11.81	11.78	11.78
Min-Max Service level, %	10-100	11-100	11-100
Current backlog orders	0	0	0
Customer delayed orders	706.0	690.0	690.0
Customer in-time orders	1472.0	1488.0	1488.0
Customer orders arrived	2175.0	2175.0	2175.0
Operational performance:			
Maximum capacity usage in the SC, m^3	67.8	104.6	104.6
Maximum inventory in the SC, units	580	936	936

4.6.2. Results analysis

It can be observed from Table 9 that new transportation policy does not impact the SC performance. Explain! Finally, Davis would like to estimate the impact of the lead time reduction on SC performance since this would increase SC competitiveness and might result in sales increase in future. Reduction of the lead time from two days to one day would imply lower inventory (good for Marina!) but higher transportation costs (problematically for Cheng!). They change “Expected lead time” in the “Demand” to “1” day, lead time from DCs to the customers to [0.7; 0.9], and transportation costs to $0.02 from DCs to the customers. The simulation result is shown in Fig. 91 and Table 10.

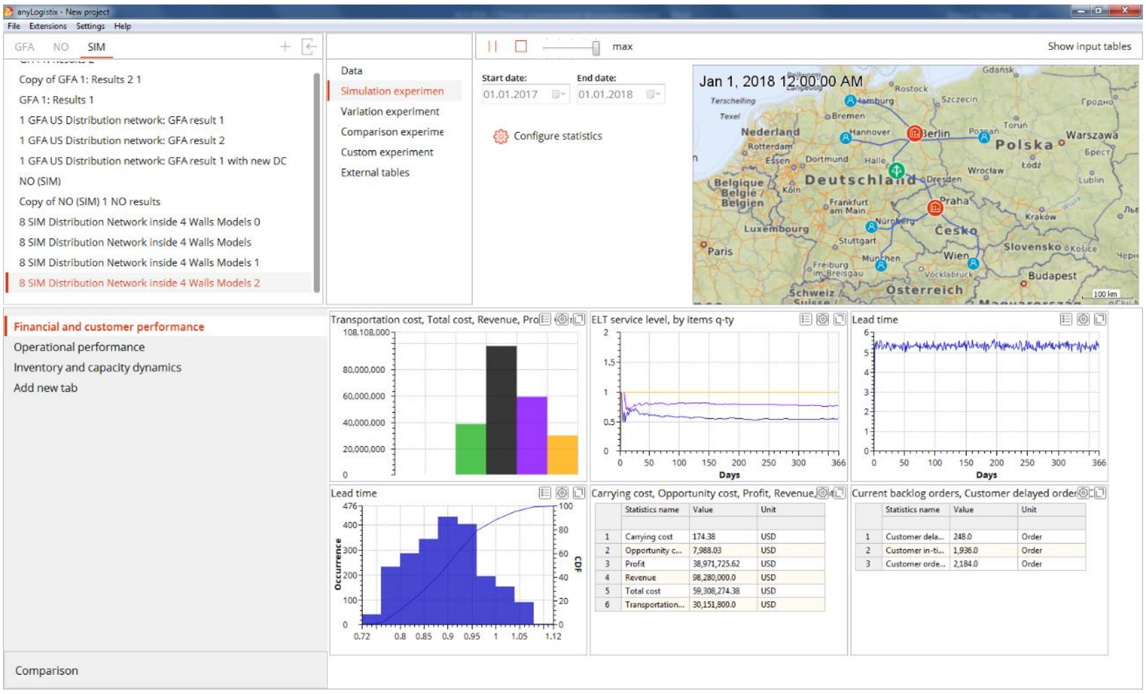


Fig. 91. Financial and customer performance

Table 10 KPI comparison

KPI	Initial SC	New inventory control policy	Lead time = 1 day
Financial DC performance:			
Carrying cost	91.13	174.35	174.38
Opportunity cost	7 993.23	7 988.03	7988.03
Profit	35 341 816.87	35 368 125.65	38 971 725.62
Revenue	98 280 000.0	98 280 000.0	98 280 000.0
Total cost	62 938 183.13	62 911 874.35	59 308 274.38
Transportation cost	33 762 792.0	33 755 400.0	30 151 800.0
Customer performance:			
Maximum lead time, days	11.81	11.78	5.26
Min-Max Service level, %	10-100	11-100	55-100
Current backlog orders	0	0	0
Customer delayed orders	706.0	690.0	248.0
Customer in-time orders	1472.0	1488.0	1936.0
Customer orders arrived	2175.0	2175.0	2184.0
Operational performance:			
Maximum capacity usage in the SC, m^3	67.8	104.6	104.6
Maximum inventory in the SC, units	580	936	936

In comparing the results in Table 10, we can observe an increase in SC profit as a result of lead time reduction. Reduction of lead time to 1 day also allows to improve inventory efficiency, order fulfilment rates, and service level. Moreover, shorter lead time implies the chance to strengthen the competitive position in the market.

Chapter 3. Four-stage supply chain: Production factories and sourcing policies

Learning objectives for this chapter are as follows:

1) To develop analytical and management skills on impact of production and sourcing policies on supply chain and logistics performance
2) To develop technical skills on creating four-stage supply chain models, performing experiments and measuring performance in AnyLogistix multimethod simulation software
3) To understand major trade-offs

5. Production factories

5.1. Case-study "Smartphone supply chain"

WHC is a supply chain for smartphone production and distribution (Fig. 93).

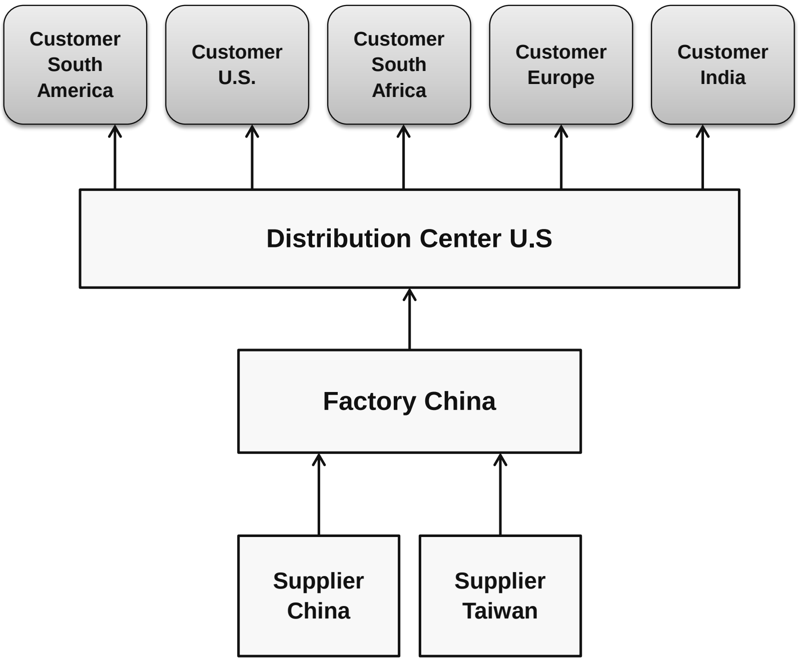


Fig. 93. WHC supply chain

Smartphone assembly is performed in the factory in China. For assembly, one display and two chips are needed. The Chinese supplier delivers displays by trucks and the supplier from Taiwan delivers two chips by ferry to the assembly plant respectively. From the factory, goods are delivered by air to the DC in U.S. From there, the goods are shipped by air to the customers. DC and factory are running Min-Max inventory control policy at 1% of interest rate. Two demand scenarios need to be analyzed, i.e., a positive and a negative market development for smartphones.

Understanding questions:

- What production strategy is used in this case study?
- What distribution strategy is used in this case study?
- What sourcing strategy is used in this case study?
- What transportation strategy is used in this case study?
- What other inventory control policies do you know?

5.2. Supply chain design

5.2.1. Multi-stage supply chain design

In Fig. 94, we start new scenario and setup the SC design in accordance to Fig. 93.

Fig. 94. Supply chain design

Rename Suppliers and Customers according to their locations (Supplier China, Supplier Taiwan, US, Brazil, South Africa, Italy, India), Site 1 as DC and Site 2 as Factory.

5.2.2. Transportation, sourcing and inventory policy

Subsequently, we define the following model elements (Figs 95-100):

- products
- demand and lead time
- vehicle types
- sourcing policy
- the paths
- inventory control policy

#	Name	Unit	Selling Price	Cost	Cost Unit
1	Smartphone	pcs	600	200	USD
2	Display	pcs	30	10	USD
3	Chip	pcs	20	5	USD

Fig. 95. Products

#	Product	Amount from	Unit from		Amount to	Unit to
1	Smartphone	1	pcs	=	0.001	m³
2	Display	1	pcs	=	0.0005	m³
3	Chip	1	pcs	=	0.000001	m³

Fig. 96. Measurement unit conversions

#	Name	Capacity	Capacity Unit	Speed	Speed Unit
1	Airplane	40	m³	800.0	km/h
2	Truck	20	m³	50.0	km/h
3	Ship	2,000	m³	50.0	km/h
4	Ferry	2,000	m³	50.0	km/h

Fig. 97. Vehicle types

#	Delivery Destinat...	Product	Type	Parameters	Sources	Time Period	Inclusion Type
1	Factory	Display	Closest (Single s...	No parameters	Supplier China	(All periods)	Include
2	Factory	Chip	Closest (Single s...	No parameters	Supplier Taiwan	(All periods)	Include
3	DC	Smartphone	Closest (Single s...	No parameters	Factory	(All periods)	Include
4	(All customers)	Smartphone	Closest (Single s...	No parameters	DC	(All periods)	Include

Fig. 98. Sourcing policy

#	From	To	Cost Calculation	Cost Calculation ...	Cost Unit	Distance	Distance Unit	Transport...	Time Unit	Straight	Vehicle Type	Transpo
1	Supplier China	Factory	Distance-based c.	0.5 * distance	USD	0	km	0.0	day		Truck	LTL
2	Supplier Taiwan	Factory	Distance-based c.	0.8 * distance	USD	0	km	0.0	day		Ferry	LTL
3	Factory	DC	Volume&distanc..	0.01 * amount (m...	USD	0	km	2.0	day		Airplane	LTL
4	DC	(All locations)	Volume&distanc..	0.01 * amount (m...	USD	0	km	2.0	day		Airplane	LTL

Fig. 99. Paths

#	Facility	Product	Policy Type	Policy Parameters	Initial Stock, units	Periodic Check	Period
1	DC	Smartphone	Min-max policy	s=20, S=50	40		0
2	Factory	Smartphone	Min-max policy	s=30, S=60	40		0
3	Factory	Chip	Unlimited invent.	Unlimited	∞		0
4	Factory	Display	Unlimited invent.	Unlimited	∞		0

Fig. 100. Inventory control policy

As our objective is to compare two scenarios with different customer demands, we rename the current scenario as “Four-Stage SC (Optimistic scenario)”, create its copy and name it “Four-Stage SC (Pessimistic scenario)”. Define the demand for both scenarios as follows (Fig. 101-102):

#	Customer	Product	Demand Type	Parameters	Time Period	Expected Lead Ti...	Time Unit	Backorder Policy
1	US	Smartphone	Periodic demand	Period=10.0, Quantity=35.0	(All periods)	30	day	Not allowed
2	Brazil	Smartphone	Periodic demand	Period=10.0, Quantity=15.0	(All periods)	30	day	Not allowed
3	South Africa	Smartphone	Periodic demand	Period=10.0, Quantity=10.0	(All periods)	30	day	Not allowed
4	Italy	Smartphone	Periodic demand	Period=10.0, Quantity=10.0	(All periods)	30	day	Not allowed
5	India	Smartphone	Periodic demand	Period=10.0, Quantity=30.0	(All periods)	30	day	Not allowed

Fig. 101. Optimistic scenario for positive market development

#	Customer	Product	Demand Type	Parameters	Time Period	Expected Lead Ti...	Time Unit	Backorder Policy
1	US	Smartphone	Periodic demand	Period=10.0, Quantity=7.0	(All periods)	30	day	Not allowed
2	Brazil	Smartphone	Periodic demand	Period=10.0, Quantity=3.0	(All periods)	30	day	Not allowed
3	South Africa	Smartphone	Periodic demand	Period=10.0, Quantity=2.0	(All periods)	30	day	Not allowed
4	Italy	Smartphone	Periodic demand	Period=10.0, Quantity=2.0	(All periods)	30	day	Not allowed
5	India	Smartphone	Periodic demand	Period=10.0, Quantity=6.0	(All periods)	30	day	Not allowed

Fig. 102. Pessimistic scenario for negative market development

5.2.3. Production policy and BOM (bill-of-materials)

Since we have in this example a factory and two suppliers, we need to define the following parameters (Figs 103-104):

- BOM (bill-of-material)
- production policy

#	Name	End Product	Quantity	Components
1	BOM 1	Smartphone	1	[Display:1.0, Chip:2.0]

Fig. 103. BOM (bill-of-materials)

#	Site	Product	Type	Parameters	BOM	Production Cost	Cost Unit	Time Period	Inclusion Type
1	Factory	Smartphone	Simple make pol.	Time = 0.01 (day)	BOM 1	50	USD	(All periods)	Include

Fig. 104. Production policy

5.2.4. Production and sales batches

As additional parameters, production and sales batches can be setup using main menu "Production Batch" and "Sales Batch". For simplification, we do not consider these options here (for these options, see Chapter 4, Sect. 6 "Bullwhip Effect").

5.3. AS-IS simulation

5.3.1. Experiment preparation and KPI dashboard

→ Note: a good modeler tends to modify the existing models for similar problem statements instead of creating models from scratch each time.

As we chose "pcs" as our product unit, we need to change Product statistic unit: click "Configure statistics" and select "pcs" as shown in Fig. 105.

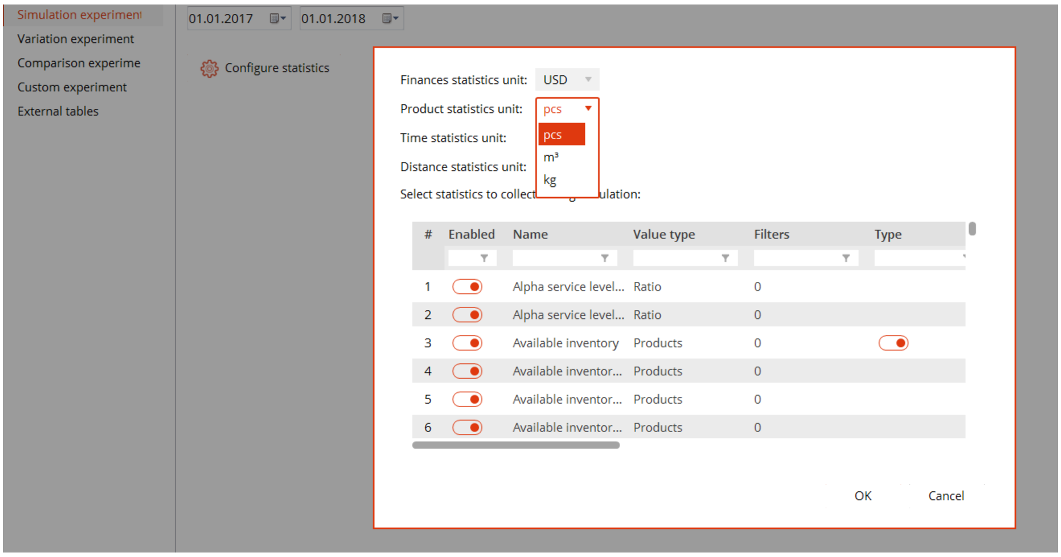


Fig. 105. Product statistic unit

Let us create a KPI dashboard for our example:

Financial and customer performance:

- Opportunity cost, Production cost, Profit, Revenue, Total cost, Transportation cost (table)
- ELT service level by orders (line)
- Lead-time (line)

Operational performance:

- Maximum capacity (line)
- Available inventory (line)

Production and Sourcing:

- Production cost, Transportation cost (table, “Object” show → by item)
- Current backlog orders, Customer delayed orders, Customer dropped orders, Customer in-time orders, Customer orders, Customer orders arrived, Produced (table)

5.3.2. Experimental result for pessimistic scenario

The simulation provides the following results for the pessimistic scenario with low demand (Figs 106-108).

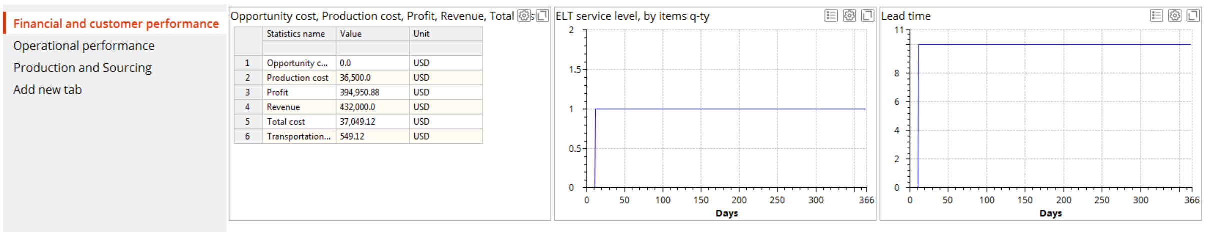


Fig. 106. Financial and customer performance

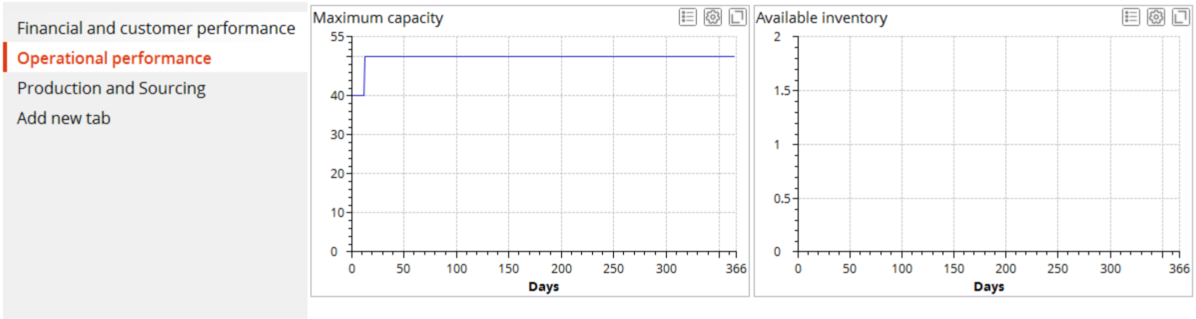
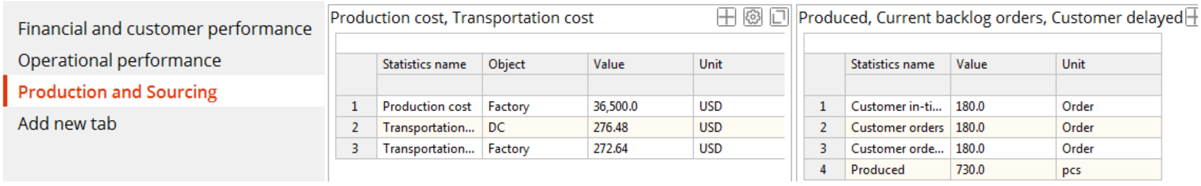


Fig. 107. Operational performance



	Statistics name	Object	Value	Unit
1	Production cost	Factory	36,500.0	USD
2	Transportation...	DC	276.48	USD
3	Transportation...	Factory	272.64	USD

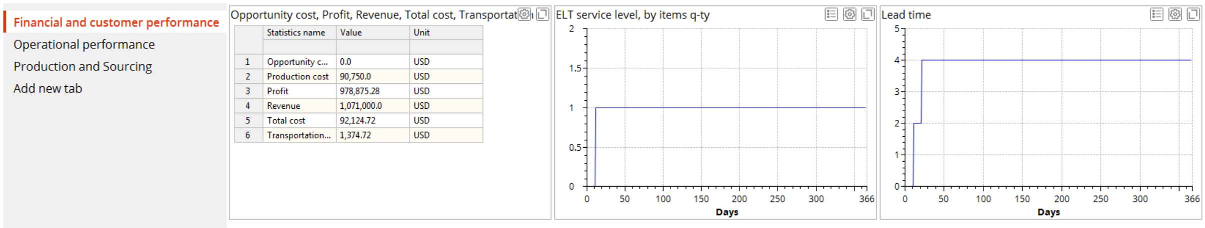
	Statistics name	Value	Unit
1	Customer in-ti...	180.0	Order
2	Customer orders	180.0	Order
3	Customer orde...	180.0	Order
4	Produced	730.0	pcs

Fig. 108. Production and sourcing performance

We can observe that there is no result on “Available inventory” statistic. Why is it so? Look at “Inventory” table and choose correct additional settings.

5.3.3. Experimental result for optimistic scenario

The simulation provides the following results for the optimistic scenario with high demand (Figs 109-111).



	Statistics name	Value	Unit
1	Opportunity c...	0.0	USD
2	Production cost	90,750.0	USD
3	Profit	978,875.28	USD
4	Revenue	1,071,000.0	USD
5	Total cost	92,124.72	USD
6	Transportation...	1,374.72	USD

Fig. 109. Financial and customer performance

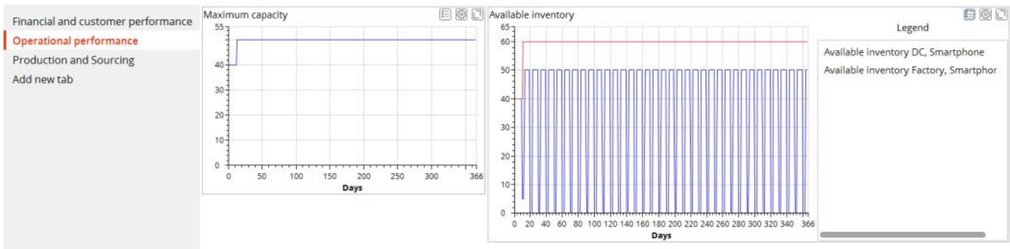


Fig. 110. Operational performance

Take a note of result on “Available inventory” statistic.

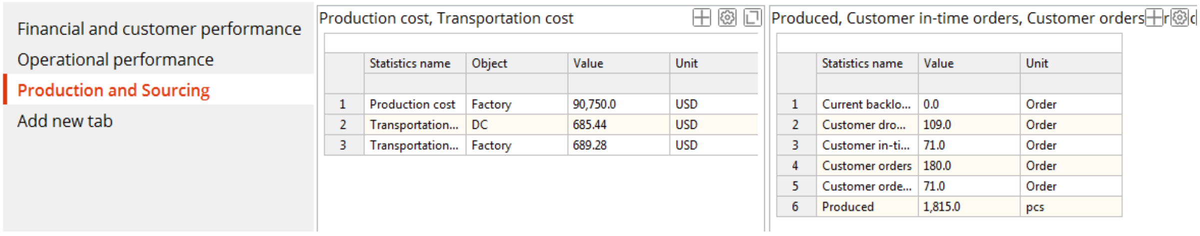


Fig. 111. Production and sourcing performance

5.3.4. Result analysis

The KPI from both pessimistic and optimistic scenario are compared in Table 11.

Table 11 KPI comparison

KPI	**Pessimistic scenario**	**Optimistic scenario**
Financial and customer performance:		
Opportunity cost, $	0.0	0.0
Production cost, $	36 500.0	**90 750.0**
Profit, $	394 950.88	**978 875.28**
Revenue, $	432 000.0	**1 071 000.0**
Total cost, $	37 049.12	**92 124.72**
Transportation cost (DC), $	276.48	**685.44**
Transportation cost (Factory), $	272.64	**689.28**
Service level, %	100%	100%
Lead time, days	10	**4**
Operational performance:		
Maximum capacity usage in the SC, pcs	50	50
Maximum inventory in the SC (DC), pcs	50	50
Maximum inventory in the SC (Factory), pcs	60	60
Production and sourcing performance:		
Current backlog orders	0	0
Customer delayed orders	0	0
Customer dropped orders	0	**109.0**
Customer in-time orders	180.0	**71.0**
Customer orders	180.0	**180.0**
Customer orders arrived	180.0	**71.0**
Produced, pcs	730.0	**1815.0**

According to the results in Table 11, we can observe an increase in SC profit as a result of higher demand. At the same time, order fulfilment rates have been significantly shrunk. This analysis shows the limits of the existing SC design and provides evidence that the SC re-design is needed if considering the optimistic scenario for realistic market development.

6. Sourcing policies

6.1. Case study "Extended Supply Chain for Smartphones"

The SC manager at WHC suggests to analyze two possible ways to improve the SC performance (cf. Table 11) in the case of positive market development:

- To increase DC capacity and imply new Min-Max values 100-200 at DC and 120-240 at factory in the inventory control policy
- To build second DC in China and imply Dual Sourcing

The fixed costs of the first option is $10,000 for capacity extension. The fixed costs of the second option is $50,000 for building new DC.

6.2. Improvement action "*single DC - increased capacity*"

6.2.1. Experimental result

The simulation provides the following results for the optimistic scenario with high demand and SC re-design in the option "single DC-increased capacity" (Figs 112-114).

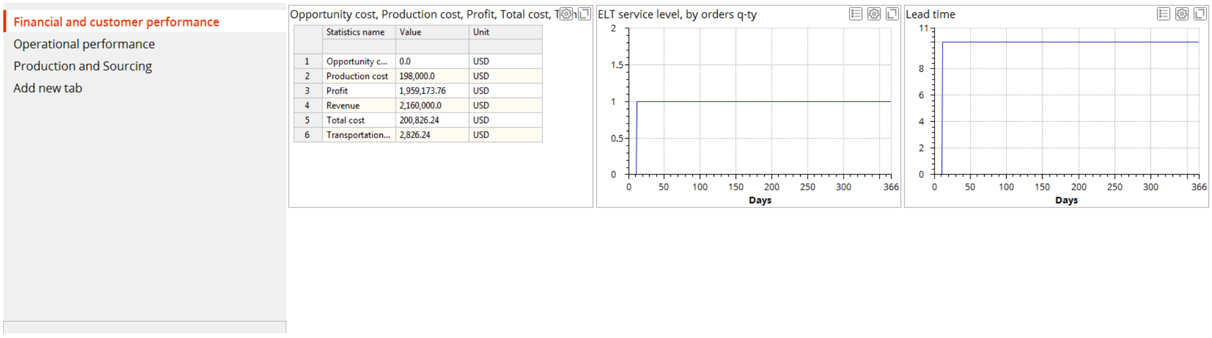


Fig. 112. Financial and customer performance

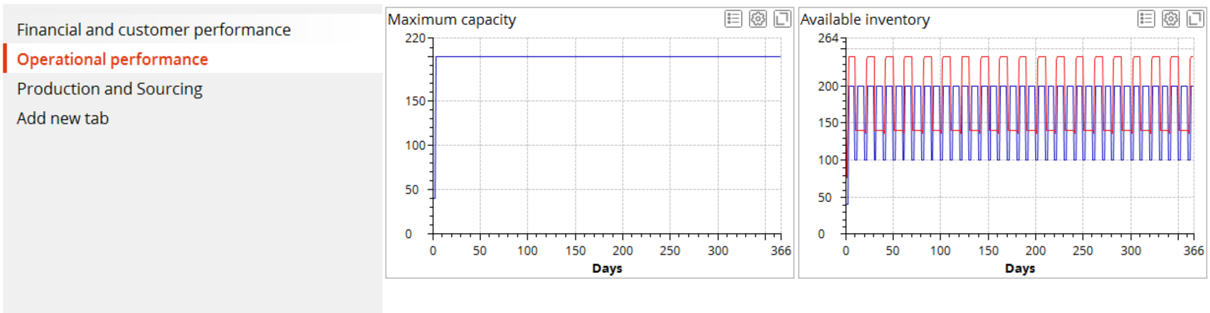


Fig. 113. Operational performance

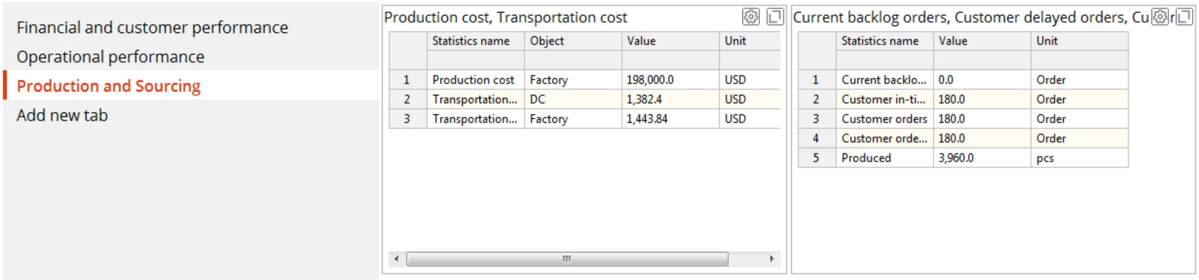


Fig. 114. Production and sourcing performance

6.2.2. Result analysis

In Table 12, the impact of the re-designed SC on the KPI is presented.

Table 12 KPI comparison

KPI	**Optimistic** **scenario** **AS-IS SC Design**	**Optimistic scenario SC Re-Design** **“single DC - increased capacity”**
Financial and customer performance:		
Opportunity cost, $	0.0	0.0
Production cost, $	90 750.0	**198 000.0**
Profit, $	978 875.28	**1 959 173.76**
Revenue, $	1 071 000.0	**2 160 000.0**
Total cost, $	92 124.72	**200 826.24**
Transportation cost (DC), $	685.44	**1 382.4**
Transportation cost (Factory), $	689.28	**1 443.84**
Service level, %	100%	100%
Lead time, days	4	**10**
Operational performance:		
Maximum capacity usage in the SC, pcs	50	**200**
Maximum inventory in the SC (DC), pcs	50	**200**
Maximum inventory in the SC (Factory), pcs	60	**240**
Production and sourcing performance:		
Current backlog orders	0	0
Customer delayed orders	0	0
Customer dropped orders	109.0	**0**
Customer in-time orders	71.0	**180.0**
Customer orders	180.0	180.0
Customer orders arrived	71.0	**180.0**
Produced, pcs	1815.0	**3 960.0**

It can be observed from Table 12 that the re-designed SC performs much better as compared to the AS-IS SC design. Both financial, customer, and operational performance has been improved. The WHC can almost double its total profit in this case. The results also provide the evidence of the maximum DC capacity needed for the extended DC (200 pcs) as well as the required production capacity (3,960 units).

6.3. Improvement action "*New DC - Dual Sourcing*"

6.3.1. Dual sourcing policy setting

In order to perform an experiment with dual sourcing, some scenario modifications are needed. First, we need to change the single sourcing policy to multiple source policy in "Sourcing" for deliveries from DCs to the customers. Do not forget to create new DC in China! (Fig. 115).

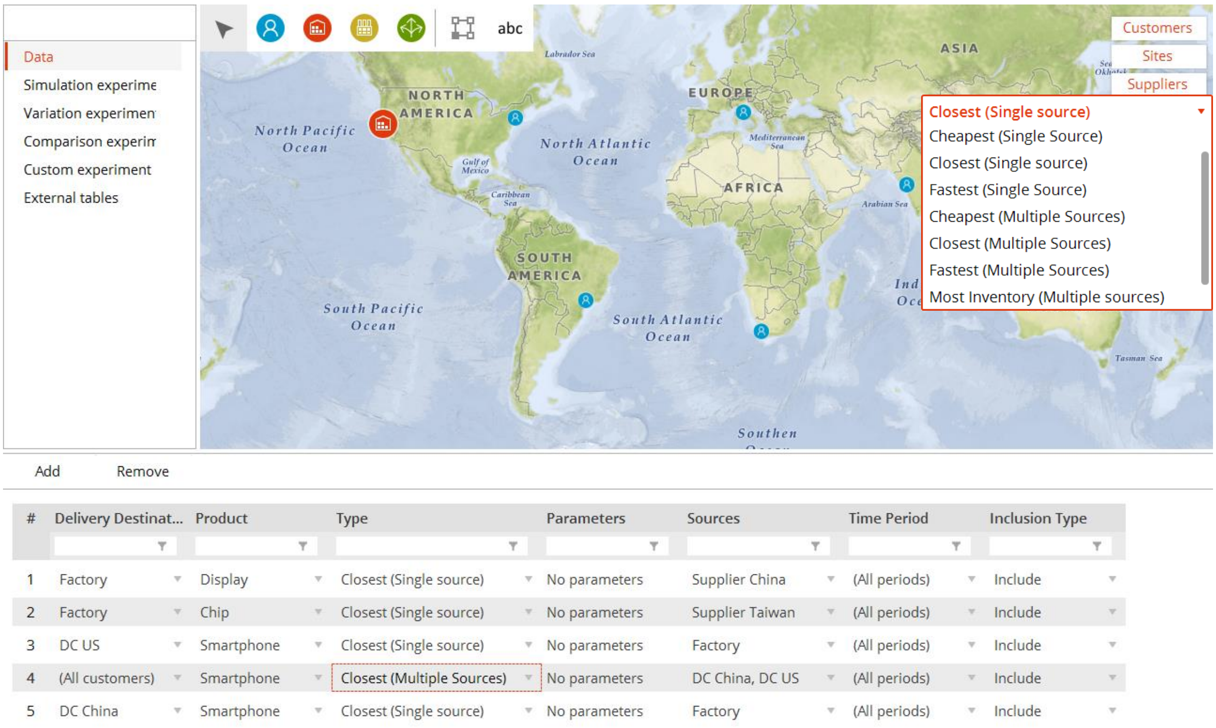


Fig. 115. Sourcing policy selection

Second, we setup inventory control parameters (Fig.116).

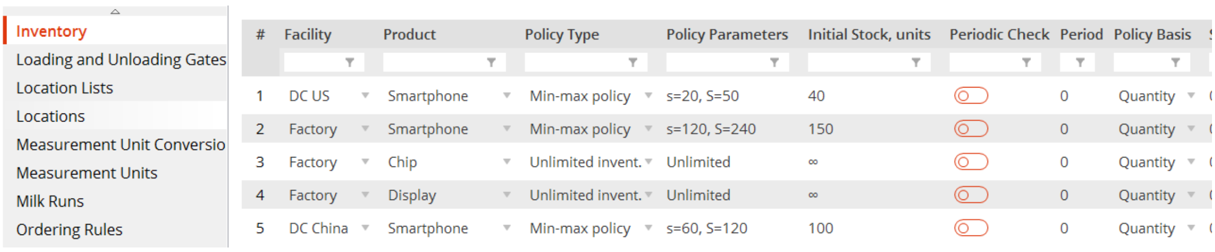
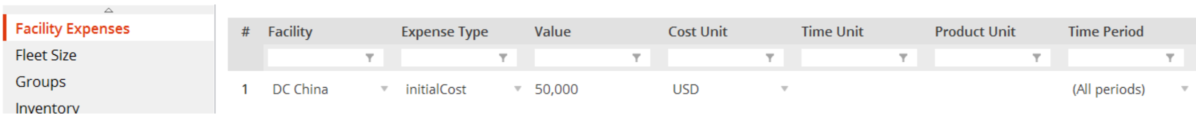


Fig. 116. Inventory control policy

Third, we consider the amount of $50,000 as fixed costs for opening new DC in China (Fig. 117).

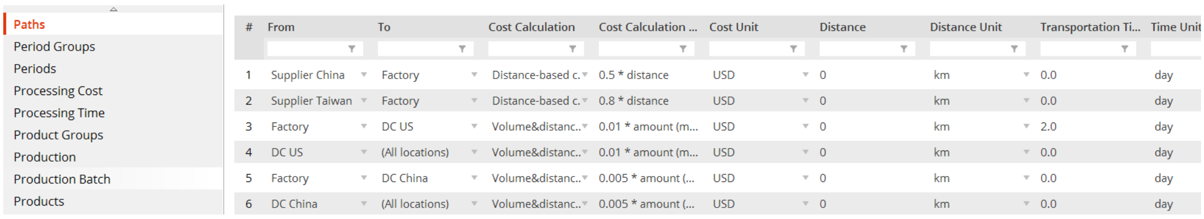


Facility Expenses
Fleet Size
Groups
Inventory

#	Facility	Expense Type	Value	Cost Unit	Time Unit	Product Unit	Time Period
1	DC China	initialCost	50,000	USD			(All periods)

Fig. 117. DC/factory settings

Finally, we add paths from and to new DC in China (Fig. 118).



Paths
Period Groups
Periods
Processing Cost
Processing Time
Product Groups
Production
Production Batch
Products

#	From	To	Cost Calculation	Cost Calculation ...	Cost Unit	Distance	Distance Unit	Transportation Ti...	Time Unit
1	Supplier China	Factory	Distance-based c.	0.5 * distance	USD	0	km	0.0	day
2	Supplier Taiwan	Factory	Distance-based c.	0.8 * distance	USD	0	km	0.0	day
3	Factory	DC US	Volume&distanc..	0.01 * amount (m...	USD	0	km	2.0	day
4	DC US	(All locations)	Volume&distanc..	0.01 * amount (m...	USD	0	km	0.0	day
5	Factory	DC China	Volume&distanc..	0.005 * amount (...	USD	0	km	0.0	day
6	DC China	(All locations)	Volume&distanc..	0.005 * amount (...	USD	0	km	0.0	day

Fig. 118. Transportation policy

→ Note: inventory control policies immediately interact with production policy. Production is controlled by parameters of inventory policies.

6.3.2. Experimental result

The simulation provides the following results for the optimistic scenario with high demand and SC re-design in the option "new DC – dual sourcing" (Figs 119-122).

Fig. 119. Dual sourcing experiment

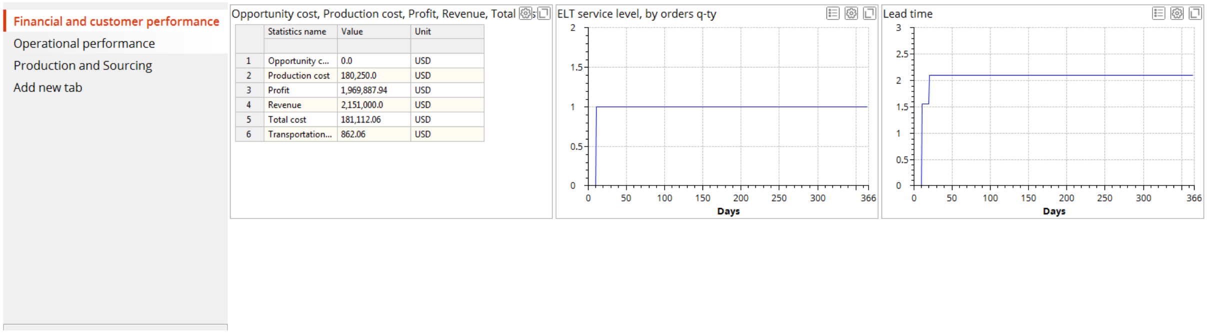


Fig. 120. Financial and customer performance

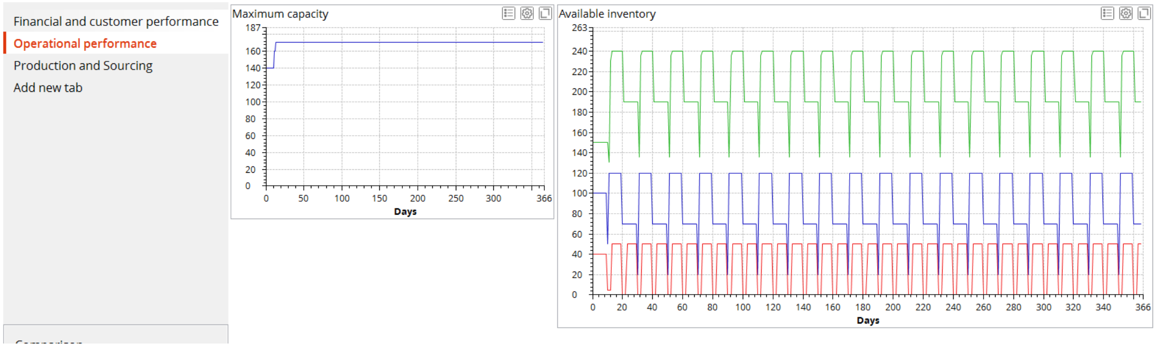


Fig. 121. Operational performance

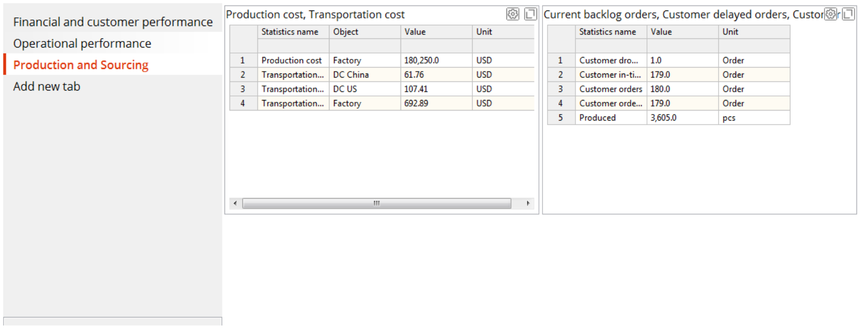


Fig. 122. Production and sourcing performance

6.3.3. Result analysis

In Table 13, the impact of the re-designed SC on the KPI is presented.

Table 13 KPI comparison

KPI	Optimistic scenario AS-IS SC Design	Optimistic scenario SC Re-Design “single DC - increased capacity”	Optimistic scenario SC Re-Design “new DC – dual sourcing”
Financial and customer performance:			
Opportunity cost, $	0.0	0.0	0.0
Production cost, $	90 750.0	**198 000.0**	180 250.0
Profit, $	978 875.28	**1 959 173.76**	1 969 887.94
Revenue, $	1 071 000.0	**2 160 000.0**	2 151 000.0
Total cost, $	92 124.72	**200 826.24**	181 112.06
Transportation cost (DC US), $	685.44	**1 382.4**	**107.41**
Transportation cost (DC China), $	-	**-**	**61.75**
Transportation cost (Factory), $	689.28	**1 443.84**	**692.89**
Service level, %	100%	100%	100%
Lead time, days	4	**10**	2.09
Operational performance:			
Maximum capacity usage in the SC, pcs	50	**200**	**170**
Maximum inventory in the SC (DC US), pcs	50	**200**	**50**
Maximum inventory in the SC (DC China), pcs	-	**-**	**70**
Maximum inventory in the SC (Factory), pcs	60	**240**	**190**
Production and sourcing performance:			
Current backlog orders	0	0	0
Customer delayed orders	0	0	0
Customer dropped orders	109.0	**0**	1.0
Customer in-time orders	71.0	**180.0**	**179.0**
Customer orders	180.0	180.0	180.0
Customer orders arrived	71.0	**180.0**	**179.0**
Produced, pcs	1815.0	**3 960.0**	**3 605.0**

It can be observed from Table 13 that re-designed SC performs much better as compared to the AS-IS SC design and even to the first option of the SC re-design. Both financial, customer and operational performance has been improved. The WHC can double its total profit in this case as compared to the first SC re-design option. The results also provide the evidence of the maximum DC capacity needed for new DC in China (170 m^3) as well as the production capacity (3,605 units). For more detailed analysis, warehousing costs in regard to the second DC in China need to be included in the analysis.

6.3.4. Comparison to “new DC – single sourcing”

In order to estimate whether the dual sourcing policy performs better then single sourcing policy, we simulate the same example but with single sourcing policy. DC in U.S. ships to the customers in U.S. and Brazil, and DC in China ships to all other customers (Fig. 123).

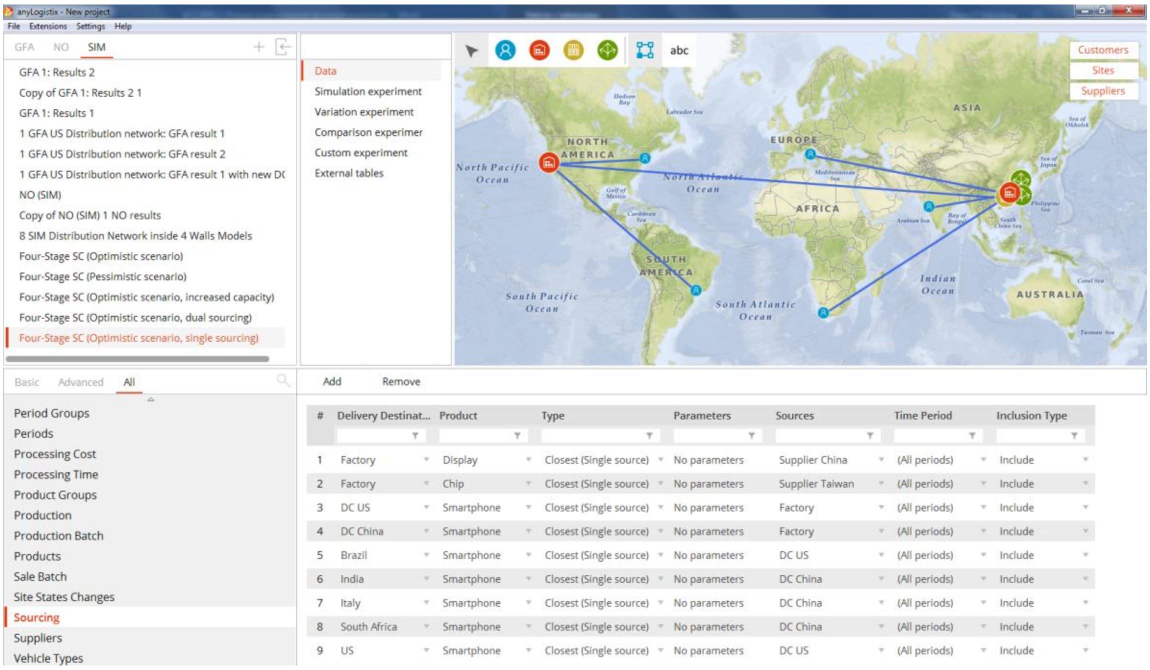


Fig. 123. Single sourcing policy for the SC design with second DC

The simulation provides the following results for the optimistic scenario with high demand and SC re-design in the option “new DC – single sourcing” (Figs 124-126).

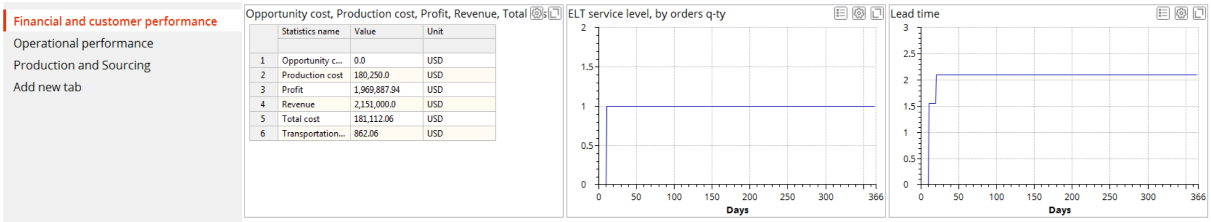


Fig. 124. Financial and customer performance

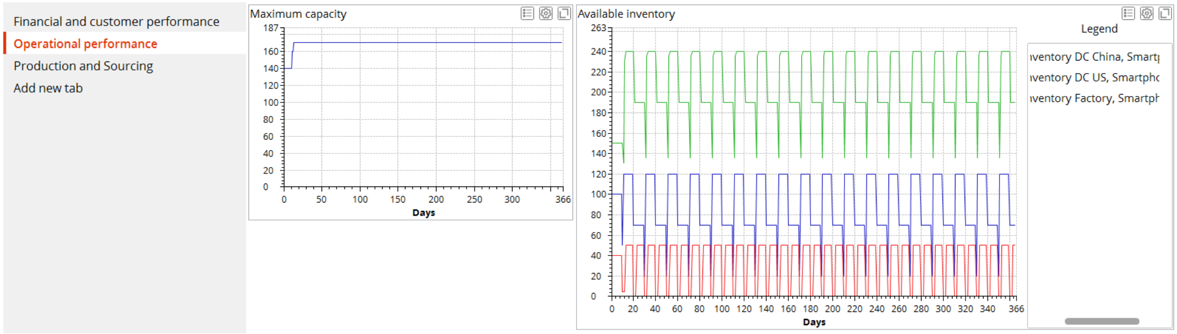


Fig. 125. Operational performance

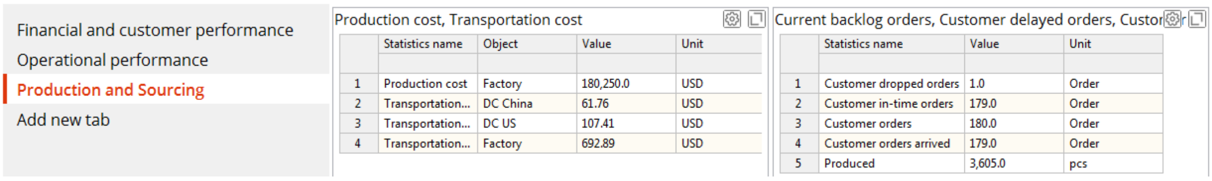


Fig. 126. Production and sourcing performance

In Table 14, the results are presented and compared.

Table 14 KPI comparison

KPI	Optimistic scenario SC Re-Design “single DC - increased capacity”	Optimistic scenario SC Re-Design “new DC – dual sourcing”	Optimistic scenario SC Re-Design “new DC – single sourcing”
Financial and customer performance:			
Opportunity cost, $	0.0	0.0	0.0
Production cost, $	**198 000.0**	180 250.0	180 250.0
Profit, $	**1 959 173.76**	1 969 887.94	1 969 887.94
Revenue, $	**2 160 000.0**	2 151 000.0	2 151 000.0
Total cost, $	**200 826.24**	181 112.06	181 112.06
Transportation cost (DC US), $	**1 382.4**	**107.41**	**107.41**
Transportation cost (DC China), $	**-**	**61.75**	**61.76**
Transportation cost (Factory), $	**1 443.84**	**692.89**	**692.89**
Service level, %	100%	100%	100%
Lead time, days	**10**	2.09	2.09
Operational performance:			
Maximum capacity usage in the SC, pcs	**200**	**170**	**170**
Maximum inventory in the SC (DC US), pcs	**200**	**50**	**50**
Maximum inventory in the SC (DC China), pcs	**-**	**70**	**70**
Maximum inventory in the SC (Factory), pcs	**240**	**190**	**190**
Production and sourcing performance:			
Current backlog orders	0	0	0
Customer delayed orders	0	0	0
Customer dropped orders	**0**	1.0	1.0
Customer in-time orders	**180.0**	**179.0**	**179.0**
Customer orders	180.0	180.0	180.0
Customer orders arrived	**180.0**	**179.0**	**179.0**
Produced, pcs	**3 960.0**	**3 605.0**	**3 605.0**

It can be observed from Table 14 that major impact of building new DC is lower lead time as compared to the option to increase capacity of the existing DC. The SXC design with new DC allows achieving the highest total profit both with single and dual sourcing policy.

6.4. From the simulation result to the decision: single vs dual sourcing; local sourcing vs global sourcing

Before making the final decision on the SC design, some additional factors need to be analysed such as (Ivanov et al. 2017):

- production cost
- use of available resources
- focusing on core competencies
- cost restructuring
- time-to-market
- risk sharing
- know-how sharing
- quality issues
- flexibility
- taxes.

By reducing the supplier base, larger volumes can be ordered from just one supplier (*single sourcing strategy*) with the objective of generating volume bundling (scale) effects. However, there might be a danger that dependence on just one supplier is considered to be a too high risk.

Focusing on single sourcing provides many efficiency advantages. However, a number of recent disruptions force the SC managers to re-think this lean sourcing strategy since the cost savings can be overwhelmed by disruption impacts. Companies which used single sourcing with suppliers in Japan or Thailand, were drastically affected by tsunami and floods in 2011. Many production factories worldwide have been stopped for several months.

Thus, it might also be a reasonable strategy to cooperate with a second or third source for a part or module. This supplier strategy is in contrast to the single sourcing strategy referred to as *dual sourcing* and might even increase to the *multiple sourcing strategy* to better balance the global flows of material and thus to reduce the risks. The discussion above allows us to formulate some critical issues to decide on single vs dual or multiple sourcing. They include:

- volume
- product variety
- demand uncertainty
- lead time importance
- disruption and other risks
- transportation costs
- manufacturing complexity
- coordination complexity
- post-sales issues.

Some of the common *advantages of single sourcing* are as follows:

- long-term agreements
- price stability
- suppliers included in the product development process at a very early stage
- low transactional costs
- scale effects.

As *shortcomings* of the single sourcing strategy the following can be indicated:

- inefficient price policy
- lead time, quality and service issues
  lack of collaboration with many suppliers.

For *global sourcing*, items of high volume, steady demand, and low transportation costs are most preferable. However, different *chances and risks* in regard to costs, service, quality, and sustainability issues should be involved in the analysis.

- Costs: labour, taxes, transportation, insurance, transshipment, duties, and transactions.
- Quality: bill-of-materials, quality control, after-sales service, certifications.
- Service: on-time delivery, responsiveness, flexibility, technical equipment, image, reliability.
- Sustainability: political, economic, social issues.

  Global sourcing offers access to the broadest available range of suppliers (in contrast to local or national sourcing) and it provides many advantages. But at the same time efforts to establish a relationship with the global vendors or partners will increase, as they require certain language skills.

Global sourcing also requires longer time for travelling to suppliers and for the later transportation of goods. Also, aspects such as currency risk or political stability gain very high importance as do different cultures, norms or standards.

Chapter 4. Risk management in supply chains

1) To develop analytical and management skills on analyzing bullwhip effect and ripple effect in the SC
2) To develop technical skills on batching, ordering rules, and events
3) Performing variation and comparison experiments in AnyLogistix multimethod simulation software
4) To understand major trade-offs in SC risk management

In SC design and planning, it is mandatory to take into account uncertainty and risks in order to provide practically relevant problem statements and decision-oriented solutions. Recent literature suggests considering recurrent or *operational* risks and *disruptive* risks. Risks in SCs are characterized by different frequency and performance impact. High-frequency-low-impact disruptions are typically considered in light of bullwhip-effect and refer to demand and lead-time fluctuations. Bullwhip effect considers weekly/daily demand and lead-time fluctuations as primary drivers of the changes in the SC which occur at the parametric level and can be eliminated in a short-term perspective. In light of low-frequency-high-impact disruptions, ripple effect has been considered (Ivanov et al. 2014). In this Chapter we demonstrate how to model both bullwhip and ripple effect in the SC using ALX.

7. Bullwhip effect in the supply chain

7.1. Case study

We consider an SC for beer production and distribution that comprises a supplier, a brewery, a DC, and a customer (Fig. 127).

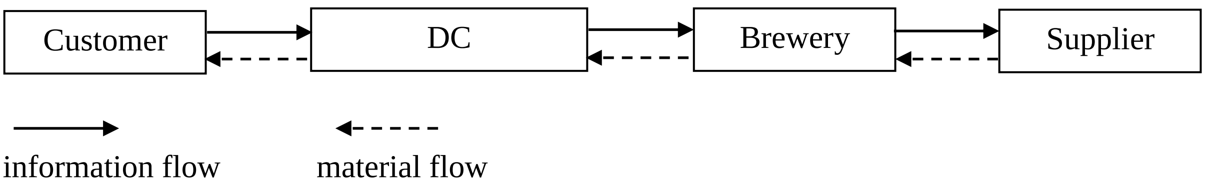


Fig. 127. Supply chain structure

Demand (in units) at the customer fluctuates and is distributed over 36 days (Table 15).

Table 15 Demand distribution

Periods							
1-5	6-10	11-15	16-20	21-25	26-30	31-35	36
4	4	9	7	11	14	8	9
4	4	7	8	9	8	11	
4	10	8	6	4	9	7	
2	11	6	10	11	6	9	
5	7	10	7	9	9	10	

DC and factory use Min-Max [5;20] inventory control policy with initial inventory of 12 units. Production time of one unit is 2 days. Transportation is organized as LTL by trucks with an average speed of 50 km/h. Lead time is three days between the supplier and brewery, two days between the brewery and the DC, and one day between the DC and customer. Lead time requirement at the customer side is two days.

7.2. Experiment and bullwhip effect analysis

7.2.1. Supply chain design and policies

First, we create new scenario "BWE" in ALX and setup the locations (Fig. 128).

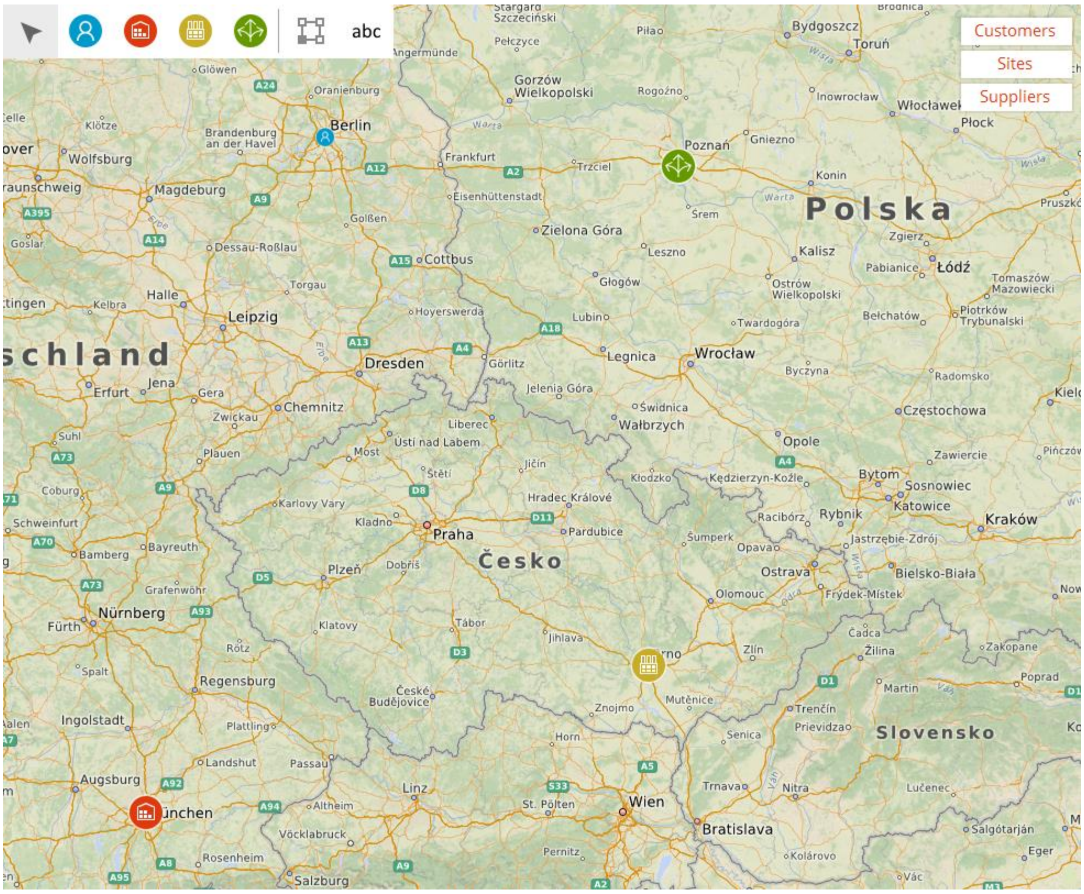


Fig. 128. Supply chain locations

Subsequently, we create a new product "Beer", new vehicle "Truck", setup demand as "historic demand", setup inventory control policy as Min=5;Max=20, setup sourcing policy and production time (Figs 129-136).

#	Name	Unit	Selling Price	Cost	Cost Unit
1	Beer	pcs	2	1	USD

Fig. 129. Product

#	Product	Amount from	Unit from		Amount to	Unit to
1	Beer	1	pcs	=	0.001	m^3

Fig. 130. Unit Conversions

#	Name	Capacity	Capacity Unit	Speed	Speed Unit
1	Truck	6	m^3	50.0	km/h

Fig. 131. Vehicle Type

#	From	To	Cost Calculation	Cost Calculat...	Cost Unit	Distance	Distance Unit	Transportation Ti...	Time Unit	Straight	Vehicle Type	Transportatior
1	Supplier 1	Site 1	Fixed delivery cos	0.0	USD	0	km	3.0	day		Truck	LTL
2	Site 1	Site 2	Fixed delivery cos	0.0	USD	0	km	2.0	day		Truck	LTL
3	Site 2	Customer 1	Fixed delivery cos	0.0	USD	0	km	1.0	day		Truck	LTL

Fig. 132. Transportation policy

#	Delivery Destinat...	Product	Type	Parameters	Sources	Time Period	Inclusion Type
1	Customer 1	Beer	Closest (Single s...	No parameters	Site 2	(All periods)	Include
2	Site 2	Beer	Closest (Single s...	No parameters	Site 1	(All periods)	Include
3	Site 1	Beer	Closest (Single s...	No parameters	Supplier 1	(All periods)	Include

Fig. 133. Sourcing policy

#	Site	Product	Type	Parameters	BOM	Production Cost	Cost Unit	Time Period	Inclusion Type
1	Site 1	Beer	Simple make pol.	Time = 2.0 (day)		0	USD	(All periods)	Include

Fig. 134. Production policy

#	Facility	Product	Policy Type	Policy Parameters	Initial Stock, ...	Periodic Check	Period	Policy Basis	Stock Calculation...	Time Unit	Time Period
1	(All sites)	Beer	Min-max policy	s=5, S=20	12		0	Quantity	0	day	(All periods)

Fig. 135. Inventory control policy

#	Customer	Product	Demand Type	Parameters	Time Period	Expected Lead Ti...	Time Unit	Backorder Policy
1	Customer 1	Beer	Historic demand	total q=277.0	(All periods)	2	day	Allowed total

Add Remove

#	Date	Quantity
1	6/19/17 2:07 PM	4
2	6/20/17 2:07 PM	4
3	6/21/17 2:07 PM	4
4	6/22/17 2:07 PM	2
5	6/23/17 2:07 PM	5
6	6/24/17 2:07 PM	4

OK Cancel

Fig. 136. Demand data

Note that *backordering* is allowed in this case.

7.2.2. KPI dashboard

For bullwhip effect analysis, we design the following KPI dashboard that comprises two parts (Figs 137 and 139).

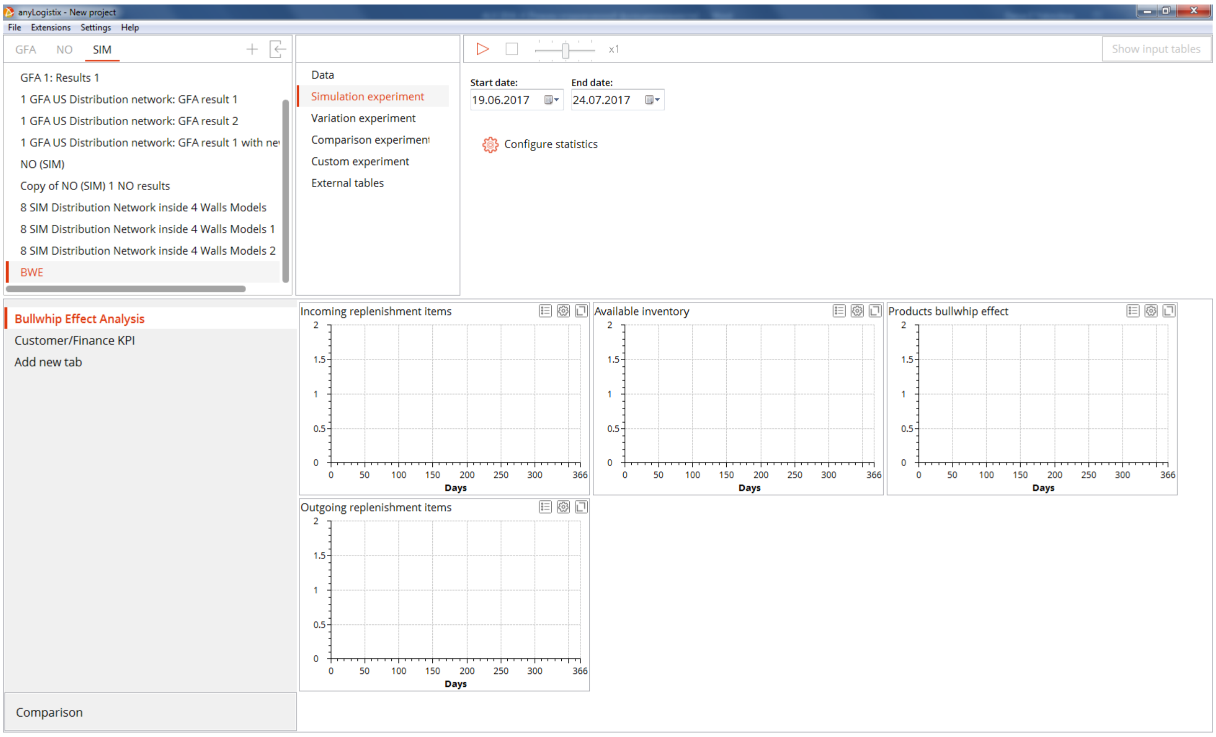


Fig. 137. KPI dashboard for bullwhip-effect analysis

The diagrams “Daily Incoming Products / Daily Outgoing Products” will depict the delivery incoming and outgoing delivery quantities. Computation of incoming and outgoing delivery quantity variation allows us to compute the BWE (bullwhip-effect) index as shown in Fig. 138 (based on Heizer and Render 2014).

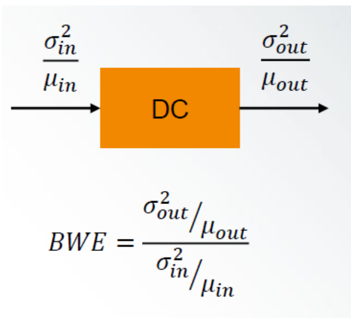


Fig. 138. BWE computation

The BWE index will be used in the diagram “Products bullwhip effect”. If BWE measure is:

> 1 – Variance amplification is present

= 1 – No amplification is present

< 1 – Smoothing or dampening is occurring

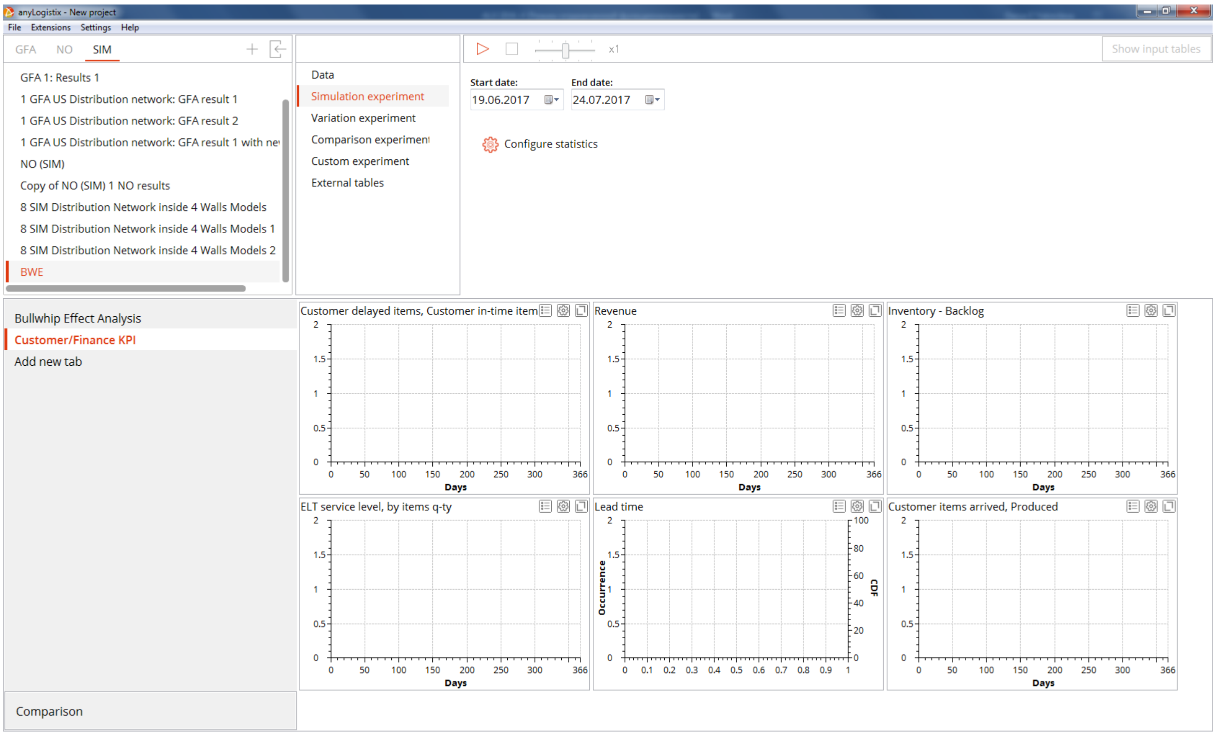


Fig. 139. Dashboard with customer and financial KPI

7.2.3. Experiments and result analysis

We start new simulation experiment for initial data described in the case study. The results are presented in Figs 140-142.

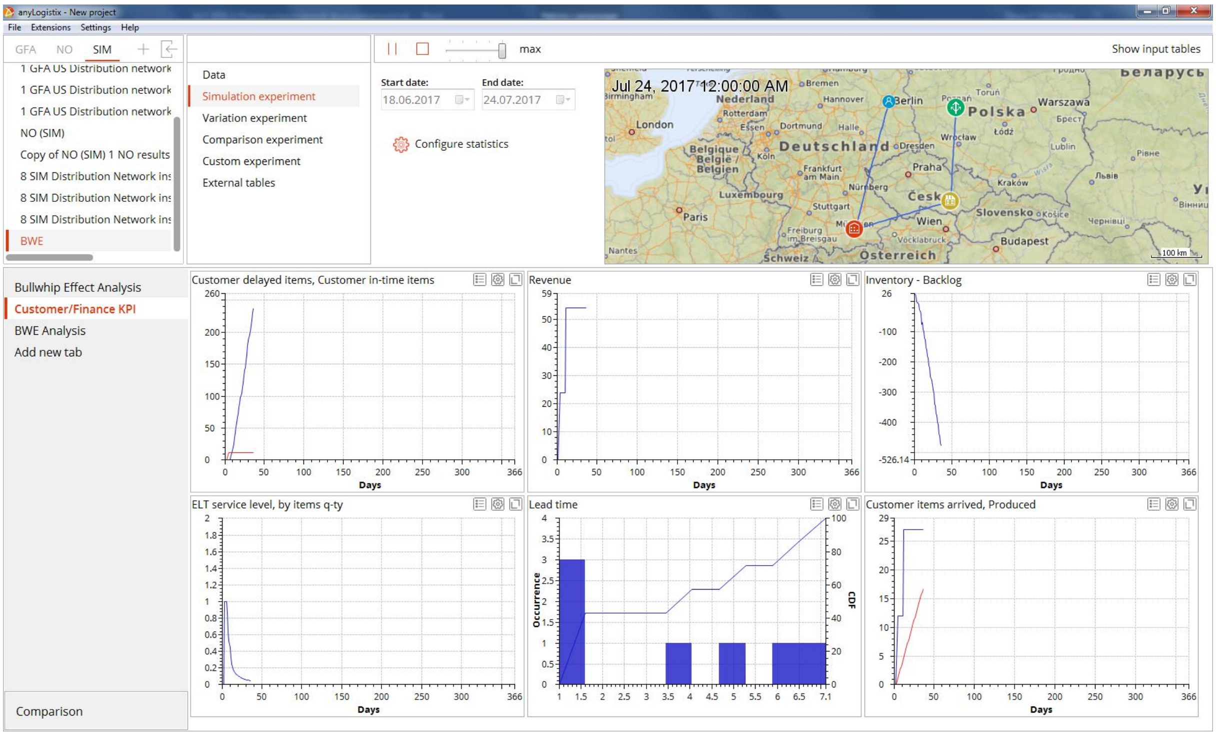


Fig. 140. Customer and financial KPI

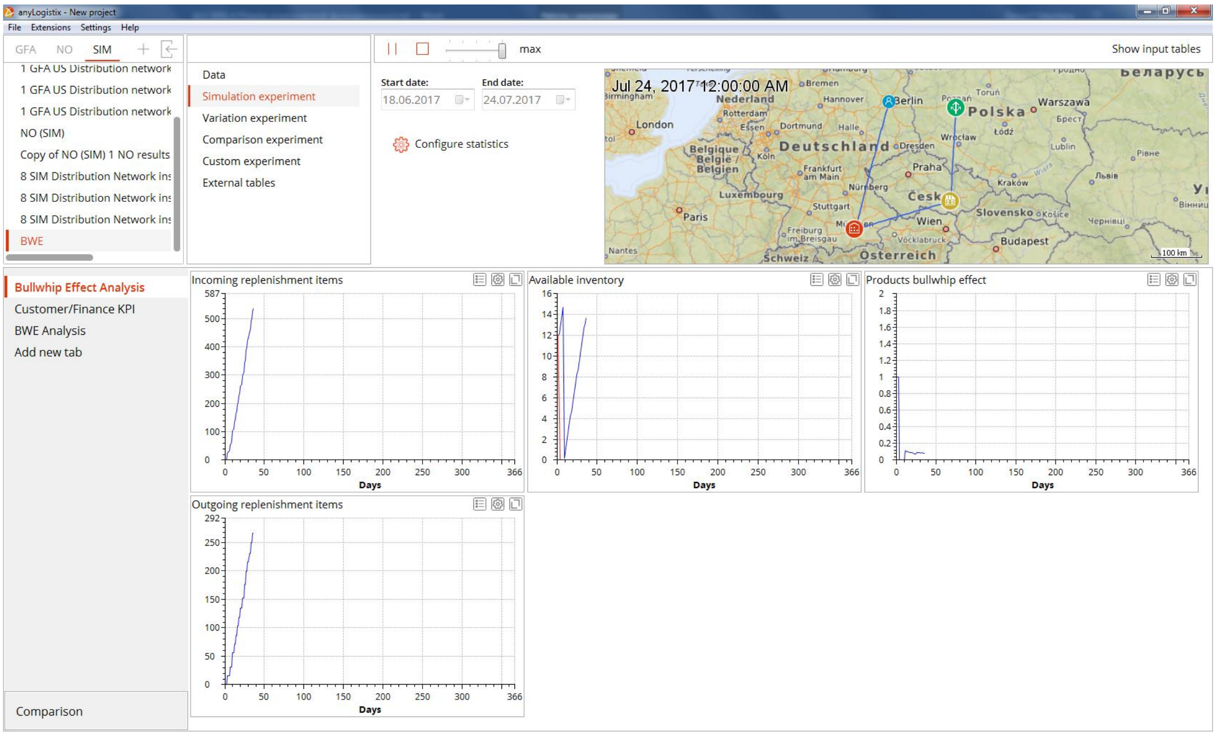


Fig. 141. KPI dashboard for bullwhip-effect analysis

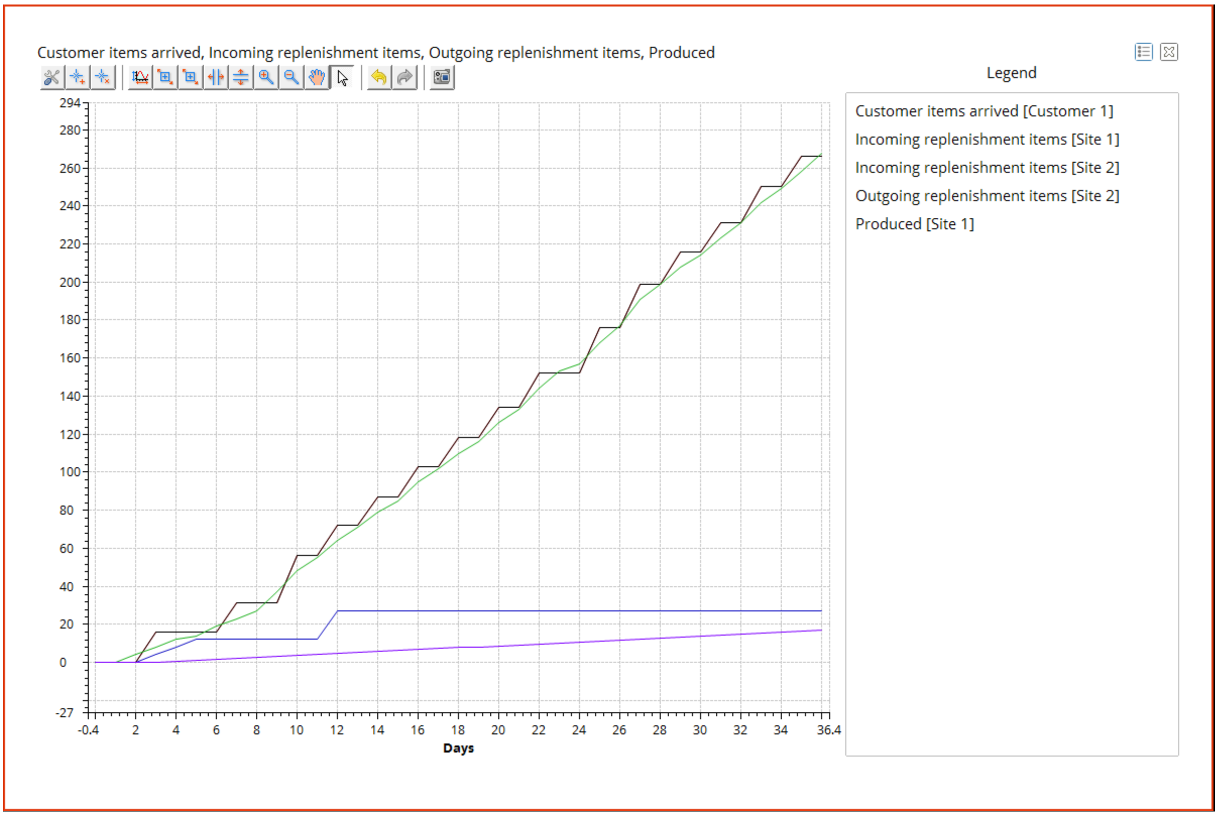


Fig. 142. Detailed view of bullwhip-effect analysis

It can be observed from Fig. 140 that we achieve a revenue of $56 and our service level is very low and it decreases. Lead time for some orders is in the range of 1 to 7 days and it is very long. This results in an increasing number of delayed products and an increasing backlog. It can be observed that the production speed is very low as compared to the incoming customer orders. Moreover, it can be observed from Figs 141 and 142 that no bullwhip effect exists in the SC. The variability of delivered quantities is decreasing.

Note: the diagram “Products bullwhip effect” has a cumulative nature.

The simulation results indicate two major problems in the existing SC, i.e., too low inventory and too long production time. We conduct the next experiment at the following parameters:

- Production time is changed from 2 days to 0.1 day;
- Min-Max levels are changed from 5-20 to 20-40.

The results are presented in Figs 143-144.

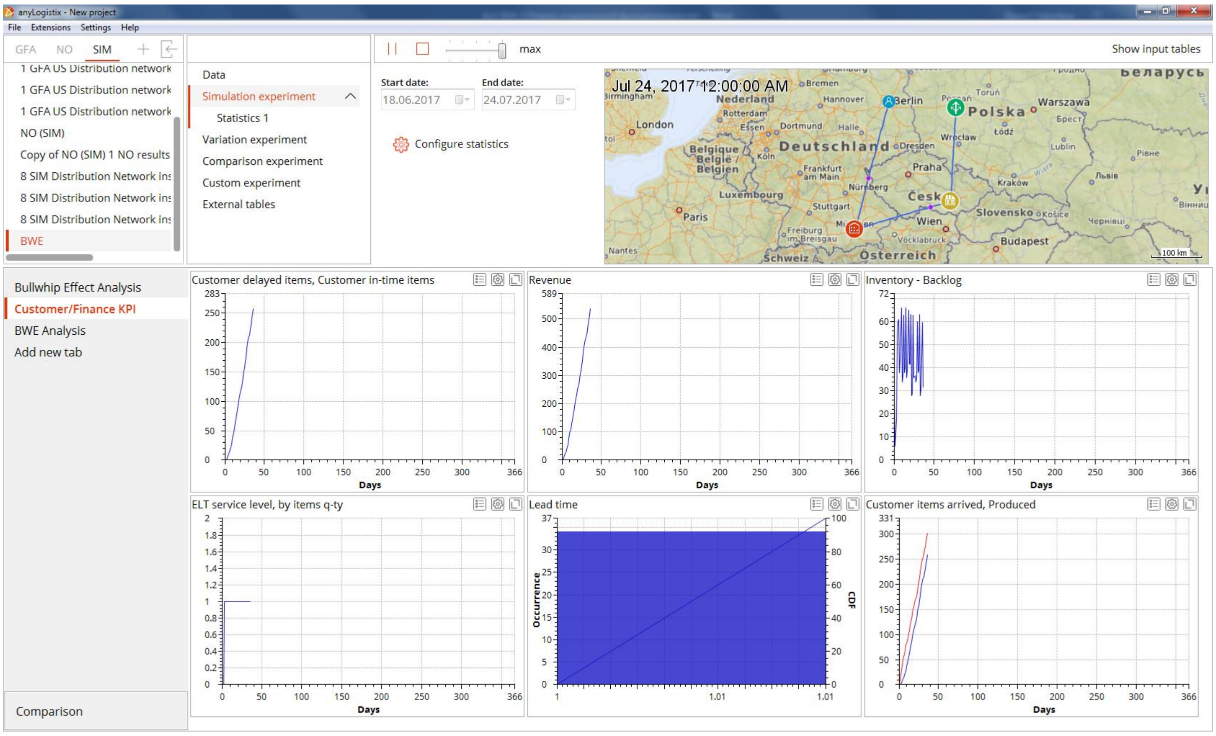


Fig. 143. Customer and financial KPI

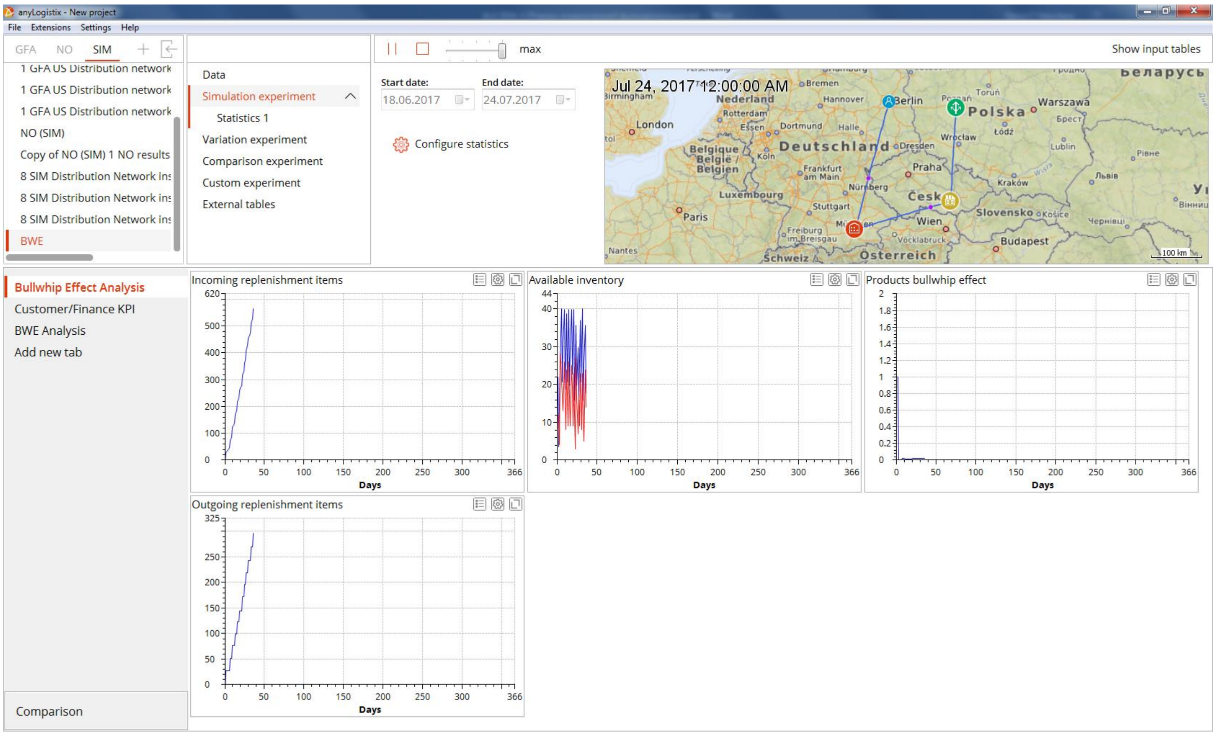


Fig. 144. KPI dashboard for bullwhip-effect analysis

It can be observed from Fig. 143 that we achieve a revenue of more than $500 (compared to $54 in the initial SC) and our service level is 100%. Lead time is 1 days. This results in 100% on-time delivered products and no backlog. It can be observed that production speed is aligned with the incoming customer orders. Moreover, it can be observed from Fig. 144 that no bullwhip effect exists in the SC. The variability of delivered quantities is decreasing. In comparing the results of two experiments, it can be observed that BWE measure has been reduced in the second setting.

7.3. Batching and ordering rules

In practice, the production, sales and transportation quantities can be batched. Let us consider how to setup batching and ordering rules and analyse the impacts of batching on BWE in the SC.

7.3.1. Transportation batches

In order to aggregate transportation orders to a batch, we need to setup the period of time or a minimum load in "Paths" (Fig. 145).

#	From	To	Cost Calcula...	Cost...	Cost Unit	Distance	Dista...	Transpor...	Time Unit	Straight	Vehicle Type	Transpo...	Mi...	Aggregate Ord...	Aggregation Period
1	Supplier 1	Site 1	Fixed delive.	0.0	USD	0	km	3.0	day		Truck	LTL	0		0
2	Site 1	Site 2	Fixed delive.	0.0	USD	0	km	2.0	day		Truck	LTL	0		5
3	Site 2	Customer 1	Fixed delive.	0.0	USD	0	km	1.0	day		Truck	LTL	0		0

Fig. 145. Transportation order aggregation

In Fig. 145, we setup aggregation period at 5 days for shipments from the factory to the DC. This means that the shipments for five days will be batched. Alternatively, minimum load of trucks (e.g., 0.6 that equals 60% of maximum truck capacity) can be setup as a batching rule (cf. Sect. 1.6.3).

7.3.2. Sales and production batches

In order to batch sales and production orders, we need to setup the batch sizes in "Sales Batch" and "Production Batch", respectively (Figs 146-147).

#	Source	Product	Type	Batch Size	Step Size	Price (per unit)	Price (per batch)	Cost Unit
1	Site 2	Beer	Exact	5	5	2	10	USD

Fig. 146. Sales batch setting

#	Source	Product	Type	Batch Size	Step Size	Production Cost (...	Production Cost (...	Cos...	Production Time (...	Production Time (...	Time Unit
1	Site 1	Beer	Exact	10	0	1	10	USI	0.05	0.5	day

Fig. 147. Production batch setting

In Fig. 146, we setup a sales batch with a size of 5 units and a size step (i.e., the amount by which the batch can be increased) of 5 units. In Fig. 147, we setup a production batch with a size of 10 units and a size step 0.

Production batch function works using the following rule:

- Inventory policy for finished goods warehouse tells how much to order (Q)
- If "Production batch" > Q then nothing is produced
- If "Production batch" < Q then the factory produces the closest number of products using policies defined for the batch but not more than Q.

Example 1:

Batch: 100; Q=90 → Nothing produced

Example 2: Batch: 100, Size step: 100, Q: 290 → factory will produce 200 and the rest 90 will be added to the next order

7.3.3. Ordering rules

Table "Ordering rules" is used to specify the rules of how to approach the batch size requirements (Fig. 148).

#	Destination	Product	Rule	Limit, units
1	Customer 1	Beer	Can Increase	5
2	Customer 1	Beer	Can Decrease	5
3	(All sites)	Beer	Can Increase	5
4	(All sites)	Beer	Can Decrease	5

Fig. 148. Ordering rules

- Destination – defines the product destination
- Product – defines the product
- Rule –allows to choose an ordering rule
  Can Increase – allows to increase the order size on up to "Limit" number of units
  Can decrease – allows to decrease the order size by "Limit" number of units
- Limit, units – the number of units within the order size can be adjusted

In our example, we allow increasing or decreasing the batch sizes by five units, respectively.

7.3.4. Impact of batching and ordering rules on bullwhip effect

In this section, we perform a simulation experiment using batching and ordering rules described above. First, we aggregate transportation orders for the period of five days.

→ Note: since we increase the transportation quantity, we also need to increase the MAX-Level in the inventory control policy. Otherwise, the simulation experiment will stop because of insufficient warehouse capacity. It is also advisable to increase the MIN-level since the replenishment interval will be increased.

We change the parameters in inventory control policy from 20-40 to 50-100. The simulation results are presented in Figs 149-150.

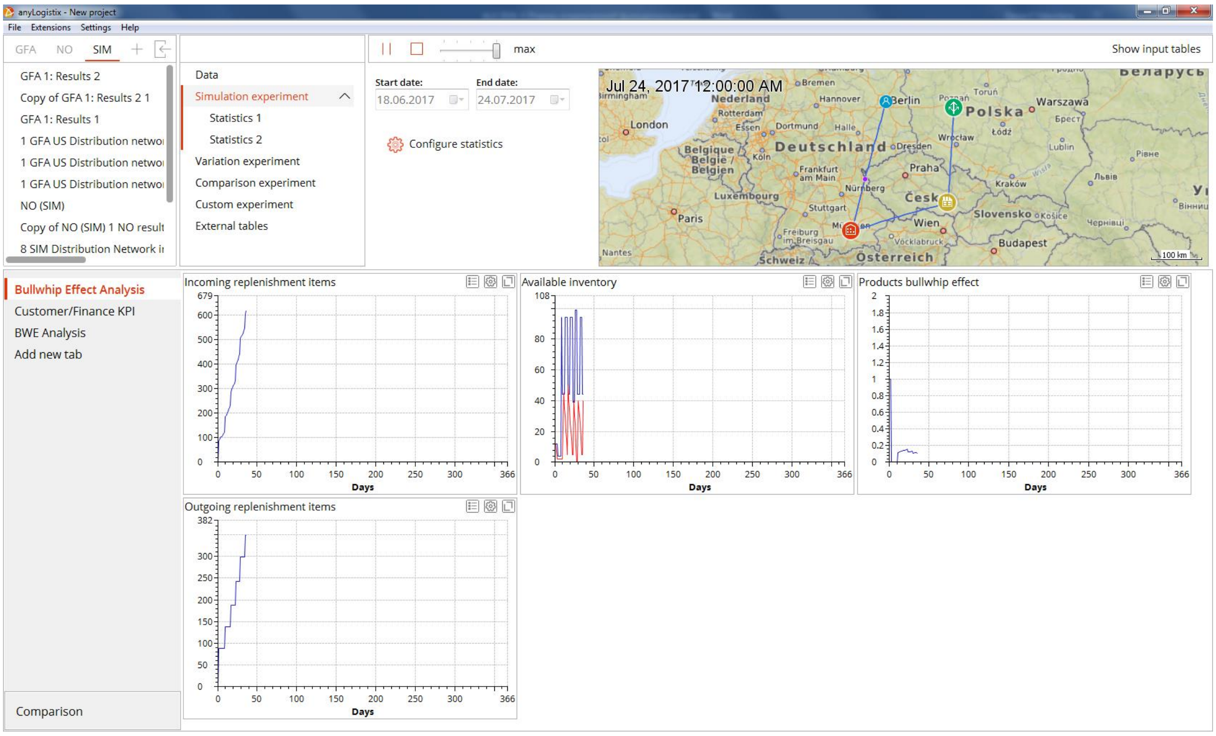


Fig. 149. KPI dashboard for bullwhip-effect analysis

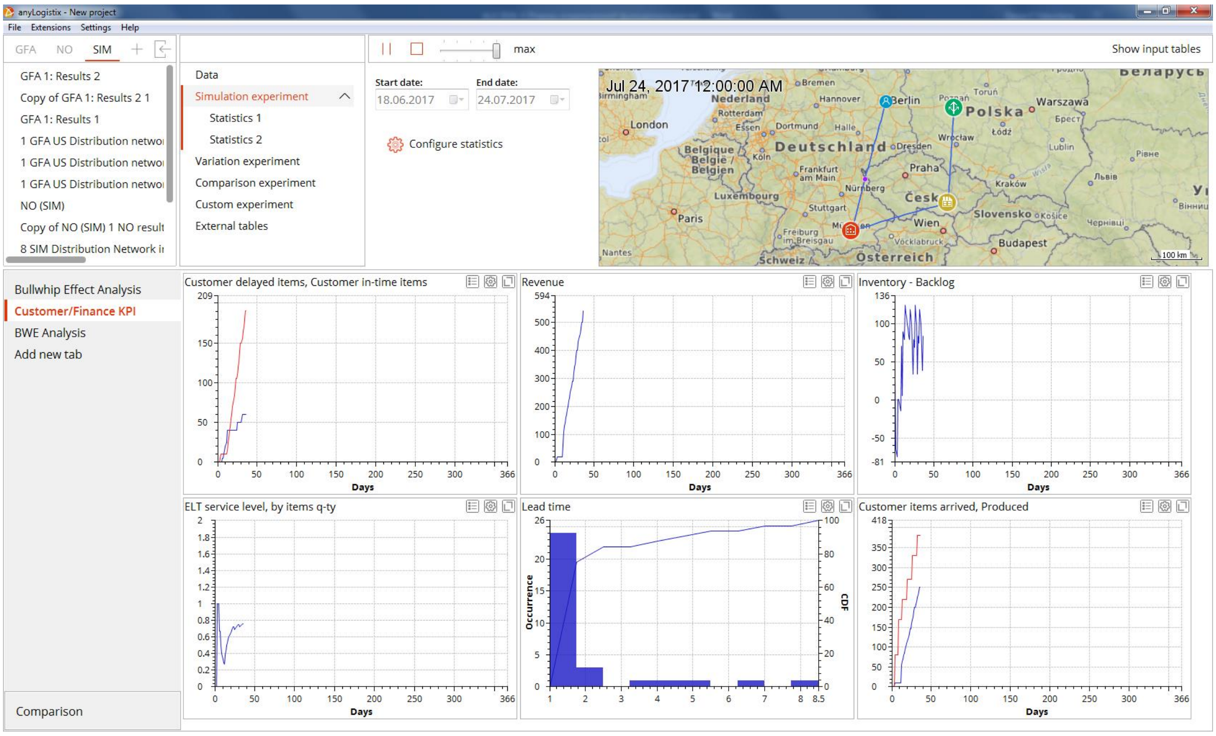


Fig. 150. Customer and financial KPI

It can be observed from Fig. 150 that we achieve a revenue of more than $500 but our service level is quite low. Lead time is unequally distributed between 1 and 9 days. It can be observed that the transportation batch rule is not aligned with the incoming customer orders which results into a backlog and a service level decrease. Moreover, it can be observed from Fig. 149 that bullwhip effect exists in the SC starting from the day 10. The variability of delivered quantities is increasing from day 10 because of high quantities of incoming products to DC as compared to the outgoing deliveries.

We can learn from this experiment that batching can lead to bullwhip effect in the SC.

What happens if we increase our maximum stock level from 100 to 200? The simulation results are shown in Figs 151-152.

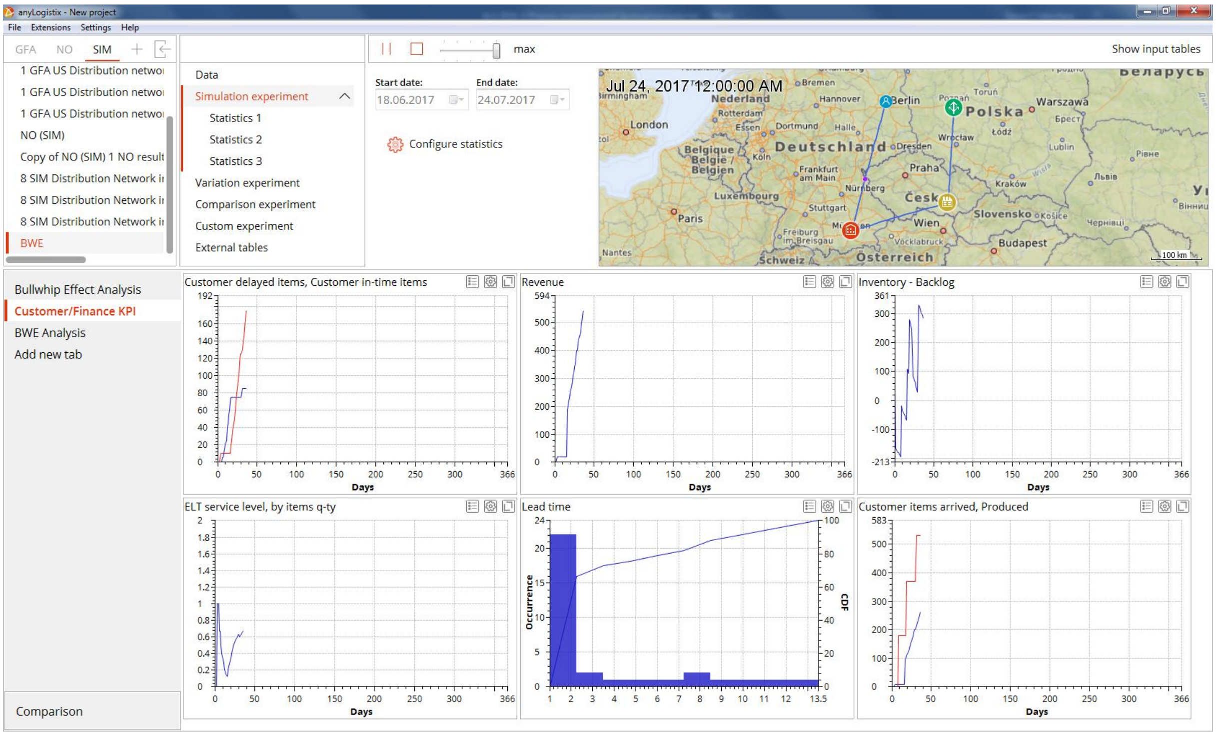


Fig. 151. Customer and financial KPI

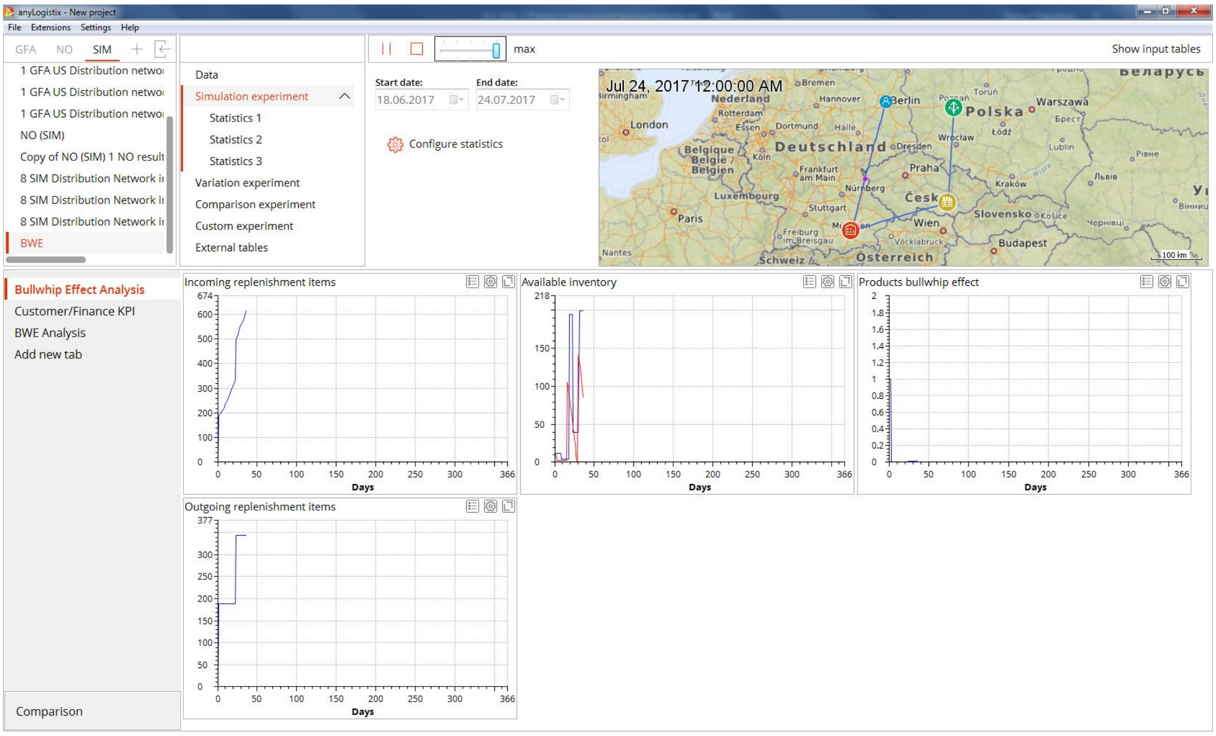


Fig. 152. KPI dashboard for bullwhip-effect analysis

It can be observed from Fig. 151 that we achieve a revenue wasn't changed and our service level is quite low. Lead time is unequally distributed between 1 and 13 days. This results in an increasing number of delayed products and a backlog. It can be observed that the transportation batch and inventory control rules are not aligned with the incoming customer orders which results into a backlog and service level decrease. However, at the same time it can be observed from Fig. 151 that bullwhip effect has been decreased. The variability of incoming products to DC is balanced with the outgoing deliveries.

We can learn from this experiment that inventory increase leads by tendency to bullwhip effect mitigation in the SC.

Finally, we perform simulation experiment using sales and production batching and ordering (cf. Figs 146-148). There are no transportation batches and inventory MIN-MAX levels are 20-40, respectively. We copy the scenario “BWE” and use the new scenario “Copy of BWE” for the simulation. The simulation results are shown in Figs 153-154.

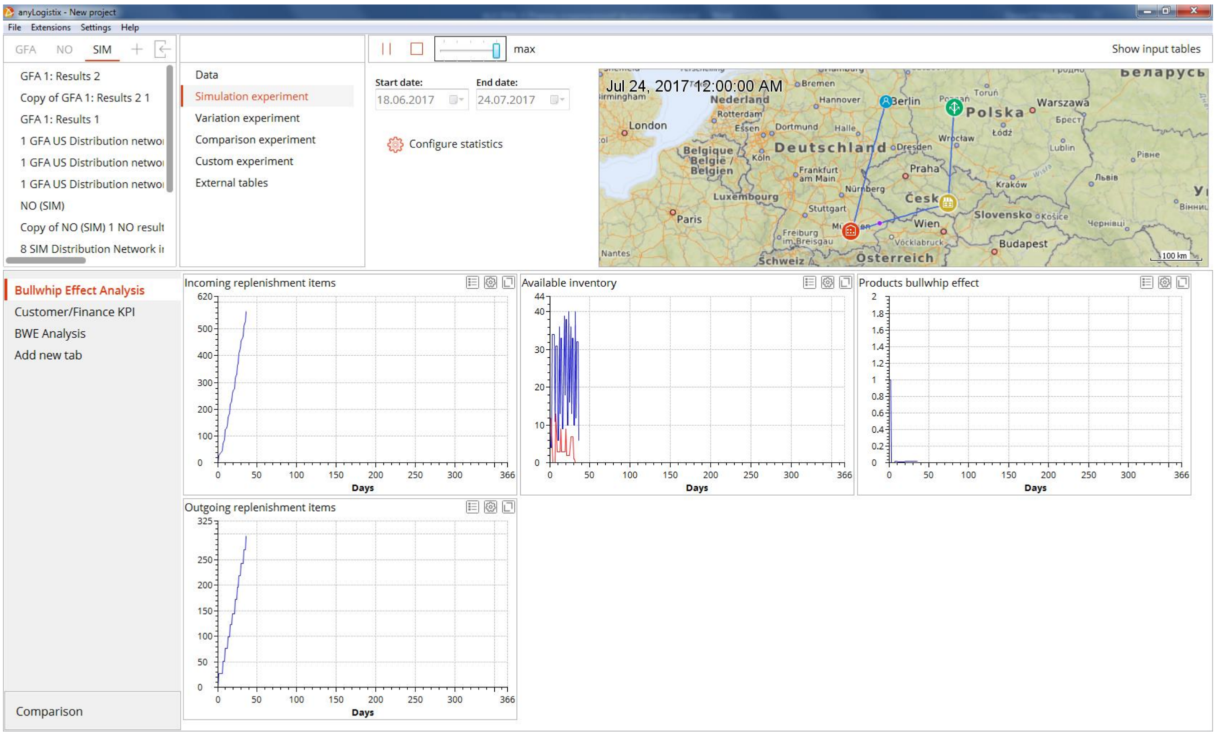


Fig. 153. KPI dashboard for bullwhip-effect analysis

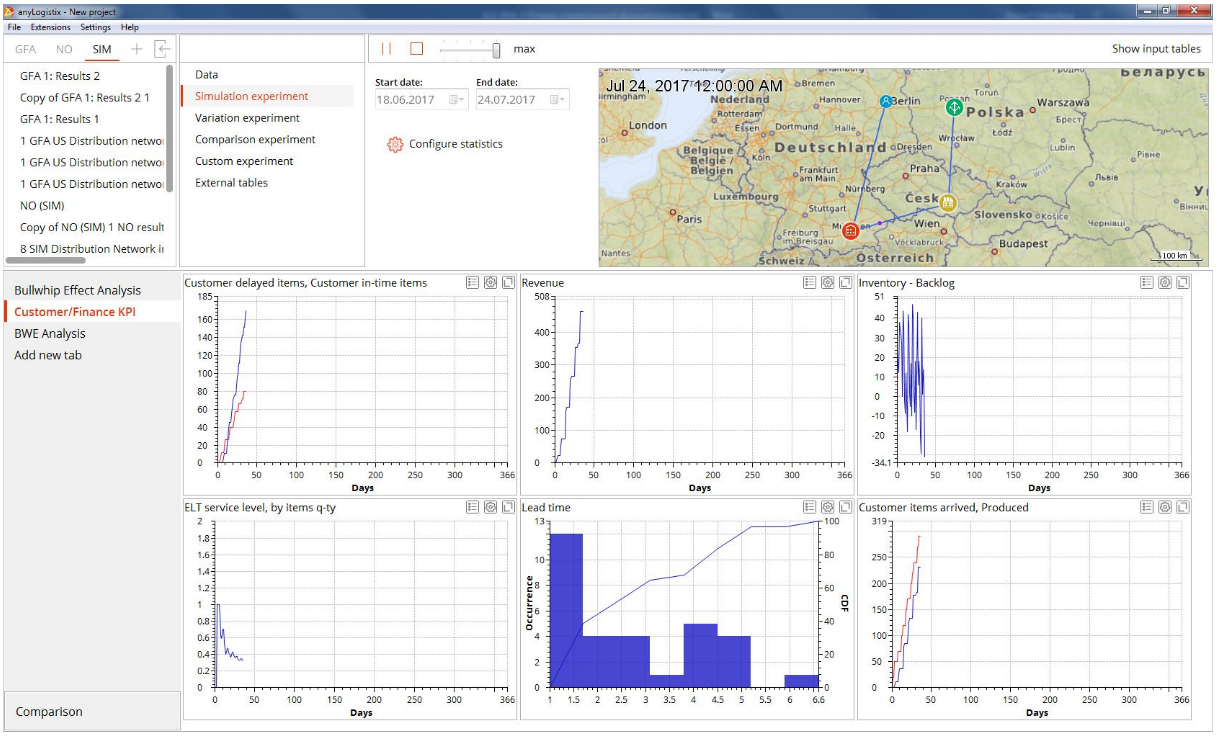


Fig. 154. Customer and financial KPI

It can be observed from Fig. 154 that we achieve a revenue of less than $500 and our service level is quite low. Lead time is between 1 and 6 days. It can be observed that production speed is aligned with the incoming 6 orders. Moreover, it can be observed from Fig. 153 that no bullwhip effect exists in the SC. The variability of delivered quantities is decreasing.

7.4. Comparison experiment

A convenient way to compare KPI and statistics of different experiments is the experiment “Comparison”.

Comparison allows us to compare different SC structures while “Variation” experiment (see further in this book) allows to change parameters only, not the structure of the SC.

In order to perform a comparison, scenarios for the comparison need to be selected. Second, in “Configure statistics”, the respective KPI need to be activated. In comparing the results of two experiments (cf. Figs 143-144 and 152-154), the following results can be observed (Figs 155-156).

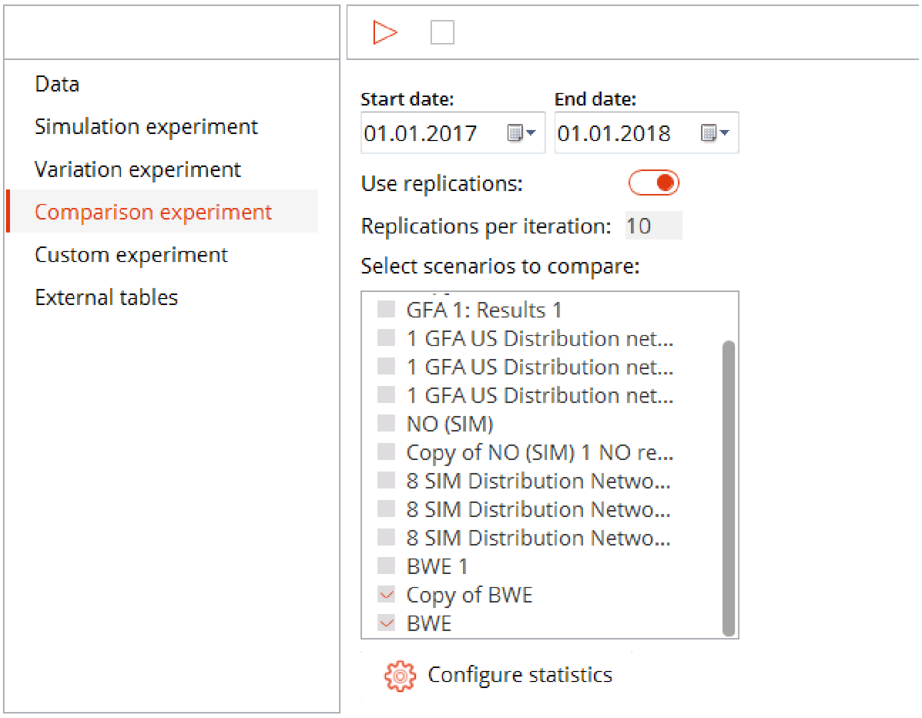


Fig. 155. Selecting scenarios for comparison

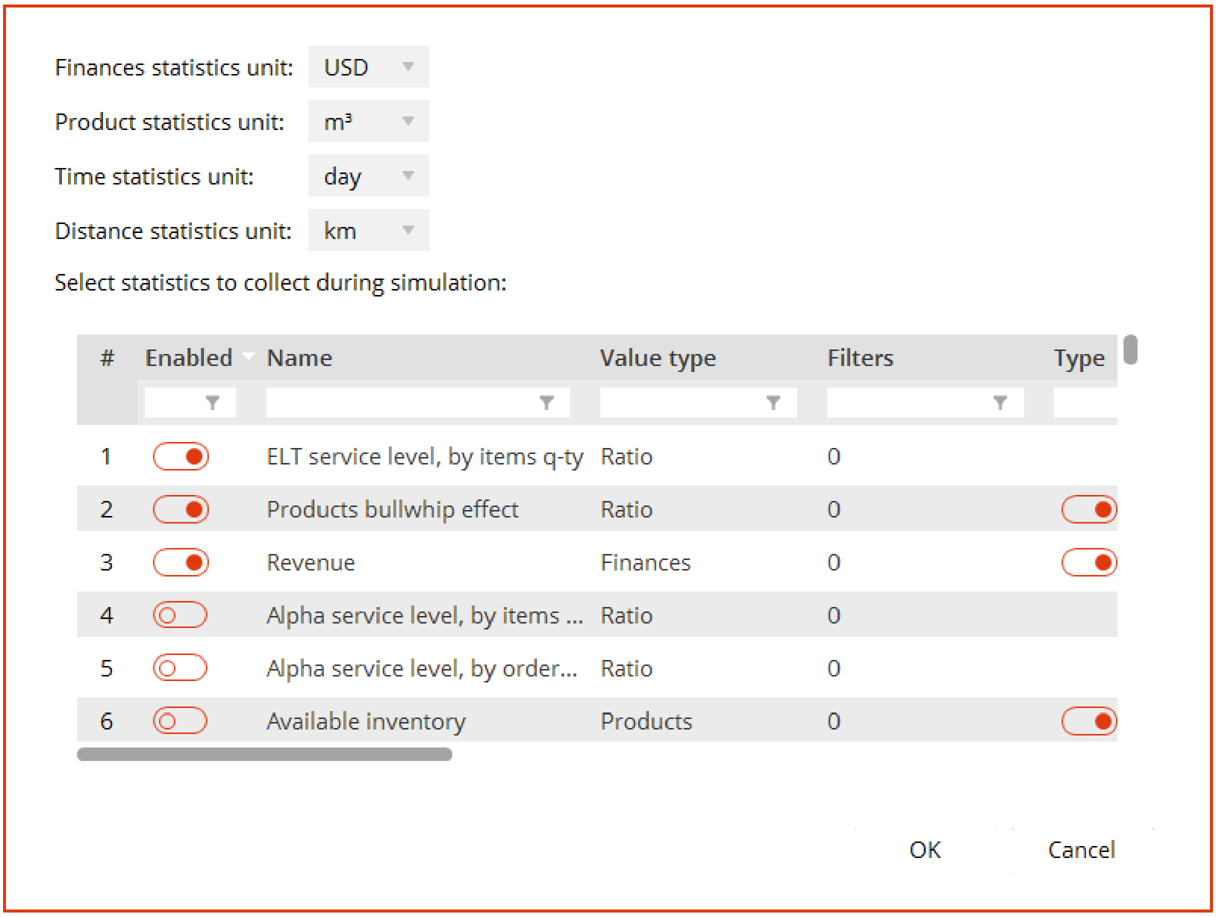


Fig. 156. Statistics selection

	Description	ELT service level, by item... mean	Products bullwhip effect mean	Revenue mean
1	BWE	1	0.02	554
2	Copy of BWE	0.361	0.02	554

Fig. 157. Scenario comparison for three KPI

It can be observed from Fig. 157 that “Comparison” experiment is a useful tool to compare KPI of different scenarios without running full simulation. In Fig. 157 it is depicted that batching (scenario Copy of BWE) leads to a decrease in service level from 100 % to 36.1%.

8. Ripple effect in the supply chain

Severe disruptions may ripple quickly through global SCs and cause significant losses in output performance such as revenues, sales, service level, and total profits. Such risks are new challenge for research and industry who face the *ripple effect* that arises from vulnerability, instability, and disruptions in SCs (Ivanov et al. 2014). We can talk about ripple effect in the SC if a disruption at a supplier or a transportation link cannot be localized and spreads out to other parts of the SC. As opposite to well-known bullwhip effect that considers high-frequency-low-impact *operational risks*, the ripple effect studies low-frequency-high-impact *disruptive risks* (Table 16).

Table 16 Bullwhip effect and ripple effect

Feature	**Ripple Effect**	**Bullwhip Effect**
Risks	Disruptions (e.g. explosion)	Operational (e.g. demand fluctuation)
Affected areas	Structures and critical parameters (such as supplier unavailability or lost sales)	Operational parameters such as lead-time and inventory
Recovery	Middle- and long-term; significant coordination efforts and investments	Short-term coordination to balance demand and supply
Decreased performance	Output performance such as annual sales or profits	Current performance such as stock-out/overage costs

Ripple effect describes the impact of a disruption on SC performance, disruption propagation, and disruption-based scope of changes in the SC structures and parameters (Ivanov 2017). The scope of the rippling and its impact on economic performance depends both on robustness reserves (e.g., redundancies like inventory or capacity buffers), flexibility in products and processes, disruption duration, and speed and scale of recovery measures.

Ripple effect is a phenomenon of disruption propagations in the supply chain and their impact on output supply chain performance (e.g., sales, on-time delivery, and total profit). If a disruption happens in the supply chain, three questions are of high importance:

- What is the impact of the disruption on operational and financial performance?
- What parts of the supply chain are affected by the disruption (i.e., what is the scope of disruption propagation)?
- Is stabilization or recovery needed? If yes, what changes and at which stages in the supply chain are needed?

Two basic approaches to hedging SC against the negative impacts of disruptions – *proactive* and *reactive* have been developed in recent years. Proactive approach creates certain protection and takes into account possible perturbations while designing the SC. Reactive approach aims at adjusting SC processes and structures in the presence of unexpected events.

It is natural to use *simulation* to study the disruption propagations and ripple effect in the SC considering time and length of disruptions and recovery policies.

8.1. Case-study: "What happens if a distribution center stops working for a month?"

The goal of this case-study is to demonstrate how ALX can be used for disruption risk analysis.

Consider the smartphone SC described in Sect. 5.1-5.2 and Fig. 93. A fire disrupts the DC in the US. The expected time-to-recovery is one month. During this time, the DC is not available for incoming and outgoing deliveries. The SC manager needs to estimate the disruption impact on the SC performance for the following KPI:

- Products received (incoming orders)
- Products delivered (outgoing orders)
- Expected magnitude (i.e., lost sales)
- Customer service level

Next, the SC manager needs to select the most efficient proactive and reactive strategies. In particular, two proactive strategies can be applied: inventory increase in the SC and a back-up DC. Two reactive strategies can be applied: fast and expensive DC recovery and slow and efficient DC recovery.

8.2. Events

First we change the inventory policy at DC to s=100, S=200.

In order to "create" a disruption in the SC simulation model, we use the option "Event" (Fig. 158).

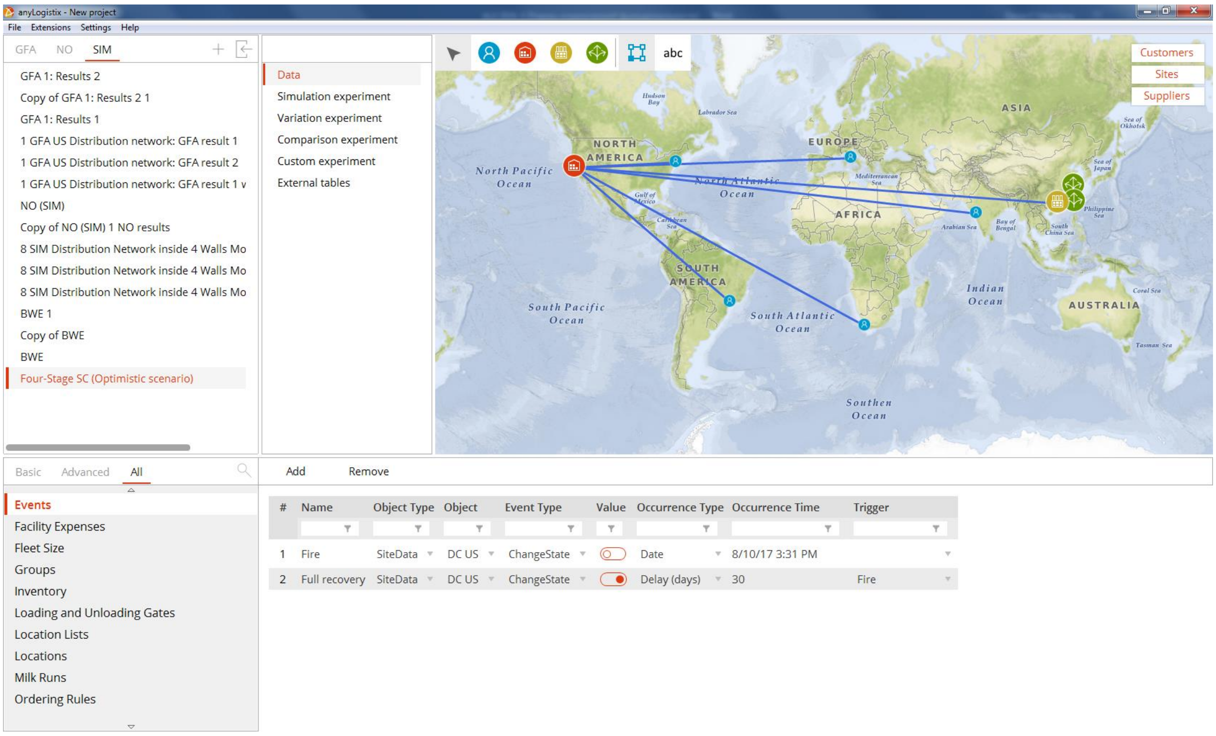


Fig. 158. Events as disruptions in the SC

Table "Events" is used to dynamically open/close SC sites or change demand

- Name – name of the event
- Object type – to which object this event is related (demand or site)
- Object – a particular site of the SC. Works only if "Object type" is "SiteData"
- Event type – define what event does. Depends on "Object type"
- Value – Value which event will assign. Depends on "Object type"
- Occurrence type – defines when event happens
  - *Date* – a particular date when event should happen
  - *Random* – event may occur randomly according to uniform distribution
  - *Delay* – event happens after some delay (see trigger)
- Occurrence time – used to define date or delay
- Trigger – reference to another event which serves as a trigger

Events is a powerful function that allows us to model for conditions such as:

- Seasonality
- Closing/opening sites
- Closing/opening paths
- Ex. Some paths may be available only during winter time
- Change the demand for a particular customer
- One Event may be triggered by another Event that allows you to model very complex behavior
- We may add their own Event through extension of anyLogistix with AnyLogic Professional Software

In our case, we created two events. The first event – "Fire" – occurs at the DC according to a specified occurrence time on August 10, 2017. In the column "Value", we switch off the DC on this date. The second event – "Full recovery" switches on the DC after a delay of 30 days triggered by the first event "Fire".

8.3. Simulation experiment for ripple effect

Let's analyze how the disruption at the DC will affect the following KPI:

- Products received (incoming orders)
- Products delivered (outgoing orders)
- Expected magnitude (i.e., lost sales)
- Customer service level

First, we run the simulation experiment for the non-disruption case (i.e., we switch on the slider in the column "Value" for the event "Fire"), see Fig. 159.

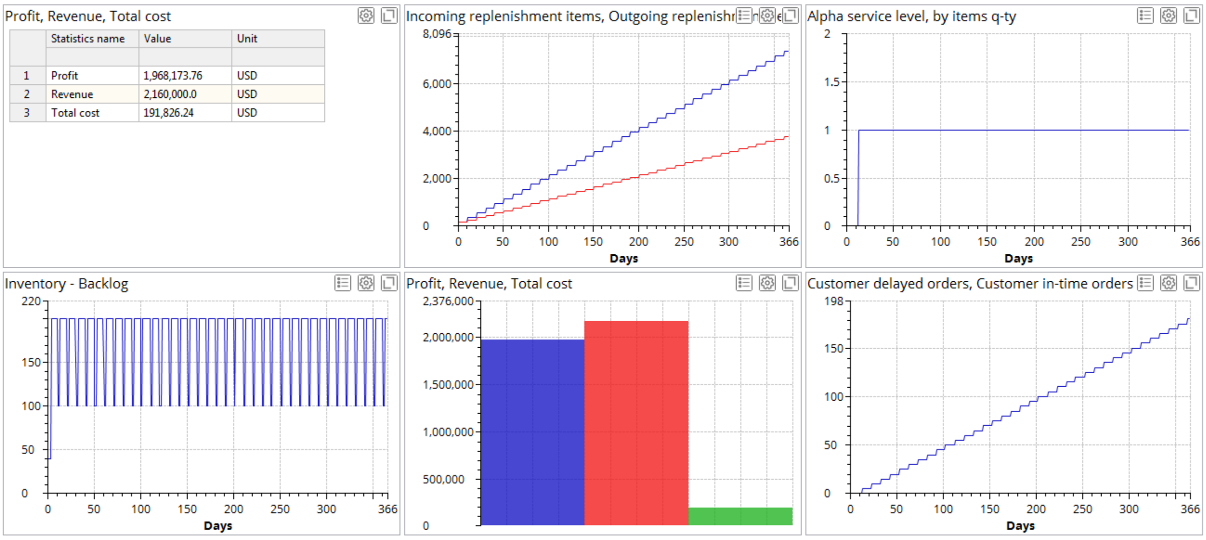


Fig. 159. Simulation results for the non-disruption case

It can be observed that Profit of $1,968,173.76 and total revenue of $2,160,000.0 can be achieved. Service level is 100% and there is no interruption in replenishment and customer-in-time orders.

Second, we perform the simulation experiment for the disruption case (i.e., we switch off the slider in the column “Value” for the event “Fire”), see Fig. 160.

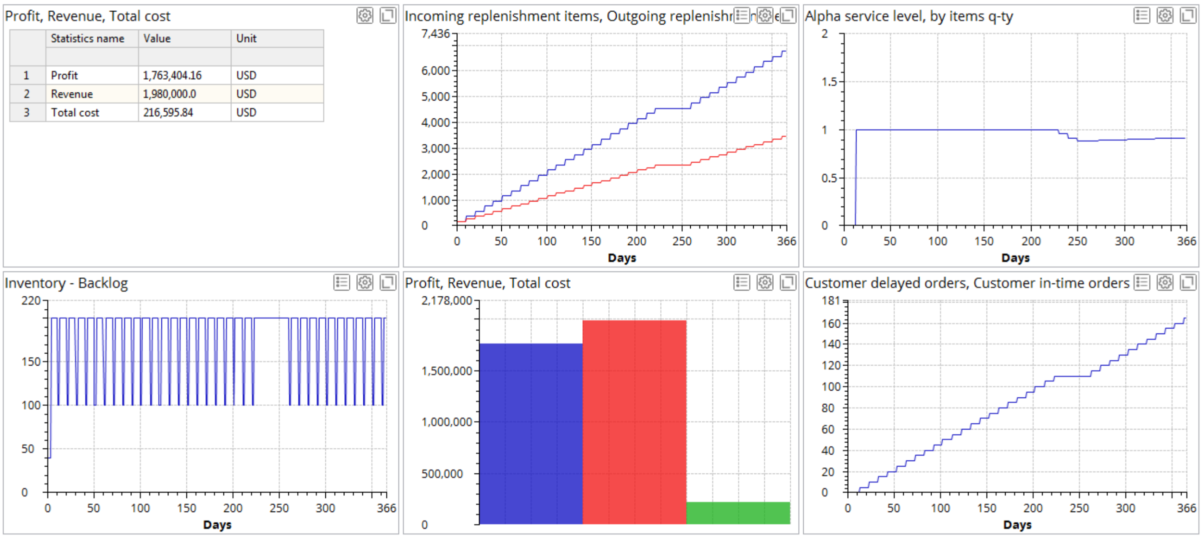


Fig. 160. Simulation results for the disruption case

It can be observed that Profit of $1,763,404.16 (instead of $1,968,173.76) and total revenue of $1,980,000.0 (instead of $2,160,000.0) can be achieved. Service level wasn’t changed and there is an interruption in replenishment and customer-in-time orders.

8.4. Analysis of proactive and reactive policies

The SC manager needs to select the most efficient proactive and reactive strategies. In particular, two proactive strategies can be applied: inventory increase in the SC and a back-up DC. Two reactive strategies can be applied: fast and expensive DC recovery and slow and efficient DC recovery.

8.4.1. Impact of inventory increase

We change the inventory policy at DC from s=100, S=200 to s=100, S=400. The simulation result is shown in Fig. 161.

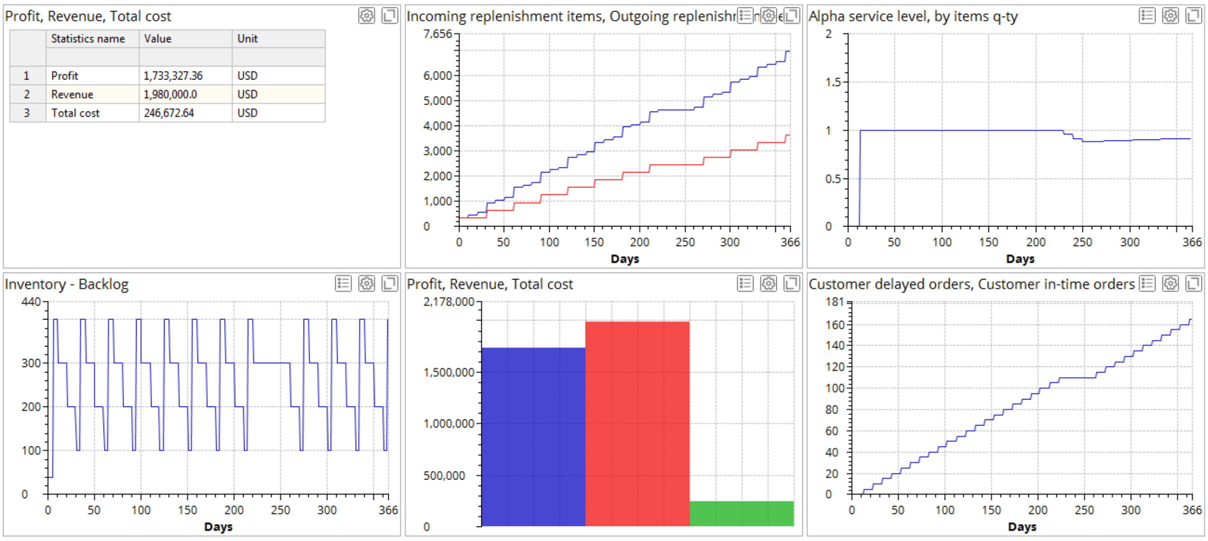


Fig. 161. Impact of the change in the inventory policy at DC from s=100, S=200 to s=100, S=400 on the SC performance

It can be observed in Fig. 161 that no performance improvement could be achieved. Even more, the SC performance became worse due to higher opportunity costs. We can observe that inventory increase is sensible downstream a risky disruption point in the SC, but not at this point.

Think about a situation if only the incoming area of the DC would be destroyed, but the storage and outgoing areas would operate in the normal mode. What effect of the inventory increase would you expect in this situation? How would you simulate such a case in ALX using events?

8.4.2. Impact of a back-up DC

We introduce now a back-up DC in the SC close to the main DC. This DC is not operating in the SC under normal conditions, but it can be used in the case of need. We define this policy by new events 3 and 4 (Fig. 162).

#	Name	Object Type	Object	Event Type	Value	Occurrence Type	Occurrence Time	Trigger
1	Fire	SiteData	DC US	ChangeState		Date	8/10/17 3:31 PM	
2	Full recovery	SiteData	DC US	ChangeState		Delay (days)	30	Fire
3	In back-up DC	SiteData	Back-Up DC	ChangeState		Date	8/10/17 3:31 PM	Fire
4	Out back-up DC	SiteData	Back-Up DC	ChangeState		Delay (days)	30	In back-up DC

Fig. 162. New events for back-up DC

This capacity *flexibility* is costly because the back-up DC creates an initialization costs of $40,000 (Fig. 163).

#	Facility	Expense Type	Value	Cost Unit	Time Unit	Product Unit	Time Period
1	Back-Up DC	Initial cost	40,000	USD			(All periods)

Fig. 163. Data for back-up DC

We also need to extend the sourcing, inventory, and transportation policies for the back-up DC (Figs 164-166)

#	Delivery Destinat...	Product	Type	Parameters	Sources	Time Period	Inclusion Type
1	Factory	Display	Closest (Multiple..	No parameters	Supplier China	(All periods)	Include
2	Factory	Chip	Closest (Multiple..	No parameters	Supplier Taiwan	(All periods)	Include
3	DC US	Smartphone	Closest (Multiple..	No parameters	Factory	(All periods)	Include
4	(All customers)	Smartphone	Closest (Multiple..	No parameters	Back-Up DC, DC US	(All periods)	Include
5	Back-Up DC	Smartphone	Closest (Single s...	No parameters	Factory	(All periods)	Include

Fig. 164 Extended sourcing policy

#	Facility	Product	Policy Type	Policy Parameters	Initial Stock, ...	Periodic Check	Period	Policy Basis	Stock Ca...	Time Unit	Time Period
1	DC US	Smart..	Min-max policy	s=100, S=200	150		0	Quantity	0	day	(All periods)
2	Factory	Smart..	Min-max policy	s=30, S=60	40		0	Quantity	0	day	(All periods)
3	Factory	Chip	Unlimited invent.	Unlimited	∞		0	Quantity	0	day	(All periods)
4	Factory	Display	Unlimited invent.	Unlimited	∞		0	Quantity	0	day	(All periods)
5	Back-Up DC	Smart..	Min-max policy	s=100, S=200	50		0	Quantity	0	day	(All periods)

Fig. 165 Extended inventory policy

#	From	To	Cost Calcula...	Cost...	Cost Unit	Distance	Dista...	Transpor...	Time Unit	Straight	Vehicle Type	Transpo...	Mi...	Aggregate Ord...
1	Supplier C...	Factory	Distance-ba.	0.5 ...	USD	0	km	0.0	day		Truck	LTL	0	
2	Supplier Ta.	Factory	Distance-ba.	0.8 ...	USD	0	km	0.0	day		Ferry	LTL	0	
3	Factory	DC US	Volume&di..	0.01...	USD	0	km	2.0	day		Airplane	LTL	0	
4	DC US	(All locations)	Volume&di..	0.01...	USD	0	km	2.0	day		Airplane	LTL	0	
5	Back-Up DC	(All locations)	Volume&di..	0.01...	USD	0	km	2.0	day		Airplane	LTL	0	

Fig. 166 Extended transportation policy

The simulation result is shown in Fig. 167.

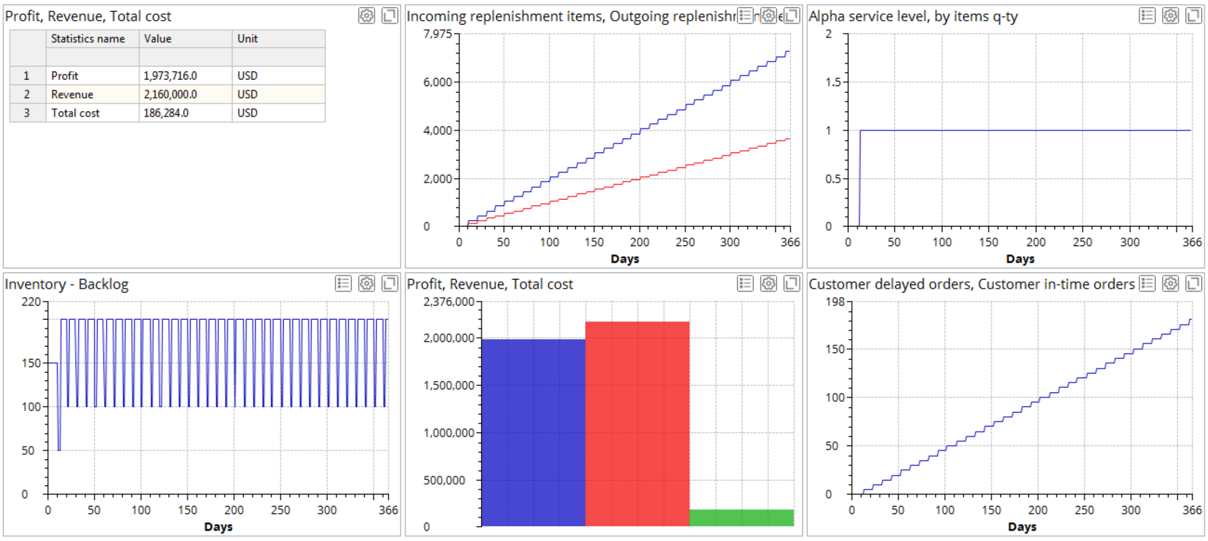


Fig. 167. Impact of the back-up DC on the SC performance

We compare this result with Fig. 160. It can be observed that Profit of $1,973,716.0 (instead of $1,763,404.16) and total revenue of $2,160,000.0 (instead of $1,980,000.0) can be achieved. Service level is 100% and there is no interruption in replenishment and customer-in-time orders.

It is now the task of the SC manager to decide either avoid investments in the SC protection hoping to achieve the highest possible profit in the case of the disruption-free scenario or to invest in the SC protection (i.e., back-up DC). This investment would bring higher profit if disruption happens, but if nothing happens, this over-investment would reduce the profit.

8.4.3. Impact of recovery strategies

Instead of or jointly with proactive actions, different recovery strategies may be considered and analysed regarding their performance impact. Two reactive strategies can be analysed in our example: a fast and expensive DC recovery and a slow and efficient DC recovery.

Assume that using the back-up DC is referred to as the fast and expensive DC recovery (Sect. 8.4.2). Further assume that recovery in 30 days without any pro-active strategy (Sect. 8.3) is referred to as the slow and efficient DC recovery. In this case, we follow the discussion in regard to Fig. 167 and observe that we can recommend the fast and expensive DC recovery strategy using the back-up DC.

8.5. Variation experiment

Simulation experiments runs the model only once but which experiment you would use if you would like to do 20 iterations and look at min, max, mean and standard deviation? The goal of this section is to demonstrate how to use “Variation” experiment and what kind of problems that can be addressed here. We will create a variation experiment, vary the initialization costs for the back-up DC and measure the performance impact.

8.5.1. Create new variation experiment

The following steps are needed to create a new variation experiment (Figs 168-170):

1. Create the experiment
2. Replications number, e.g., 20
3. Configure statistics
4. Select parameters to vary and the variation range and step
5. Run the variation experiment

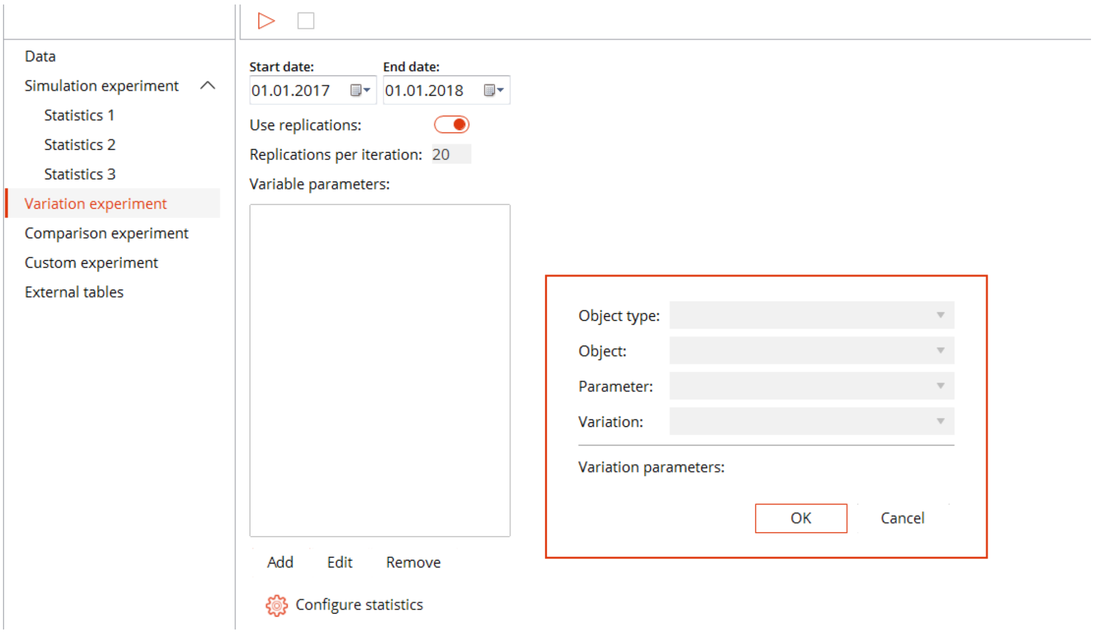


Fig. 168. General framework of the variation experiment

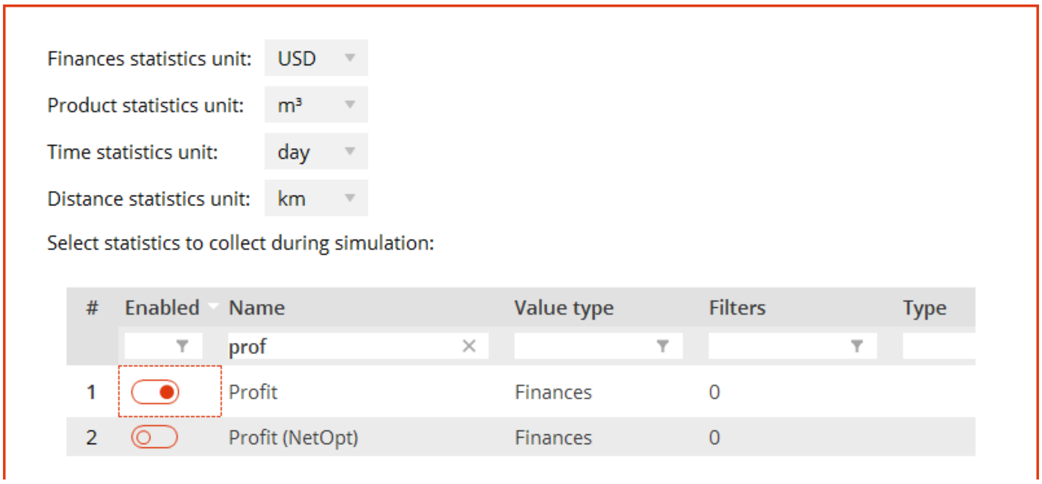


Fig. 169. KPI selection

→ Note: the column „Enabled" can be filtered according to the activated statistics. Just write "True" in the field below the column name. This helps you to find quickly the enabled statistics and avoid the representation of undesired statistics in the experiment results.

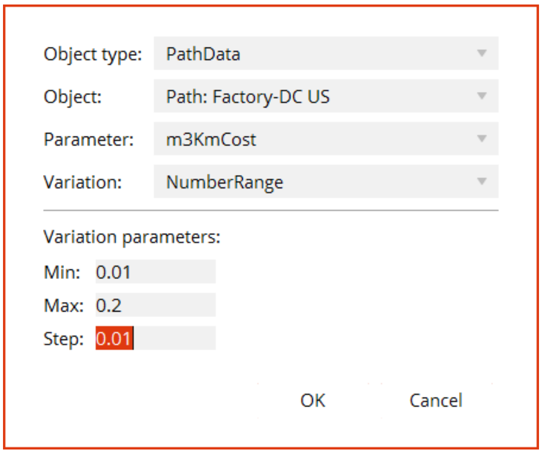


Fig. 170. Variation parameter and range selection

8.5.2. Performing a variation experiment

We run the variation experiment to observe the impact of the transportation costs. The result in shown in Fig. 171.

	Description	Profit mean
1	m3KmCost: 0.01	1,973,716
2	m3KmCost: 0.02	1,972,314.4
3	m3KmCost: 0.03	1,970,912.8
4	m3KmCost: 0.04	1,969,511.2
5	m3KmCost: 0.05	1,968,109.6
6	m3KmCost: 0.06	1,966,708
7	m3KmCost: 0.07	1,965,306.4
8	m3KmCost: 0.08	1,963,904.8
9	m3KmCost: 0.09	1,962,503.2
10	m3KmCost: 0.1	1,961,101.6
11	m3KmCost: 0.11	1,959,700
12	m3KmCost: 0.12	1,958,298.4
13	m3KmCost: 0.13	1,956,896.8
14	m3KmCost: 0.14	1,955,495.2
15	m3KmCost: 0.15	1,954,093.6
16	m3KmCost: 0.16	1,952,692
17	m3KmCost: 0.17	1,951,290.4
18	m3KmCost: 0.18	1,949,888.8
19	m3KmCost: 0.19	1,948,487.2
20	m3KmCost: 0.2	1,947,085.6

Fig. 171. Variation results

It can be observed from Fig. 171 that we have a linear relation between the transportation costs and profit.

9. Literature

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10. Summary and discussion questions

Chapter 1

In Chapter 1, we learned how to create new SC model in ALX, design the KPI dashboard, and perform simulation, network optimization, and simulation-based optimization experiments. In particular, we learned how to create a new scenario in ALX and define the customers, products, SC facility locations, sourcing and transportation policies. As an application, we used the created SC model to facility location planning and network optimization tasks. We learned how to apply ALX to green field analysis in regard to single and multiple warehouse locations and different objectives, i.e., costs and service distance. Subsequently, we extended our analysis towards network optimization using mathematical programming models. We learned similarities, differences, and application areas of both simulation and optimization methods in SC design. Using ALX, we learned major trade-offs between the number of facilities in SC design, facility costs, transportation costs, and response time. Finally, we learned how to create new KPI dashboard, collect statistics, prepare and run simulation and network optimization experiments of SC design analysis improvement.

Discussion questions:

- Just imagine that you are selling lithium batteries for electric vehicles. How would you create a scenario for GFA analysis? What parameters will you need? What optimization criteria can you use?
- Now imagine that you are responsible for reverse logistics at this company and you need to design the closed-loop supply chain. You need to define optimal number and locations of collection centers for the lithium batteries. Next, you need to analyse dynamics of collection processes. How can you use ALX for these decisions?
- If you want to invest into building two DCs in the US and use a GFA experiment to find the suggested areas, will you get the same results for the following experiment settings:
  - ✓ Number of DCs –2
  - ✓ Service distance – 2100 km (data about US: West to East –4200 km, North to South-2500 km)
- What is the difference between Network Optimization and Simulation-based Network Optimization experiments?
- What is the difference between alpha, beta and ELT service levels?
- When does it make sense to use simulation-based network optimization instead of analytical network optimization?
- How can you include capacity limitations in the analysis?

Chapter 2

In Chapter 2, we included different inventory control policies (e.g., fixed period or re-order point policies) and transportation policies (such as FTL – full truck load and LTL – low truck load) into consideration. In practice, inventory control and transportation policies may significantly impact decisions on SC design and operations. In this Chapter, we got skills on impact of inventory control and transportation policies on SC and logistics performance. We created a three-stage SC structure, performed experiments and measured performance in ALX. Using this model, we learned major trade-offs between the inventory control policies, transportation frequency, and lead time. We also learned how to extend ALX by AnyLogic.

Discussion questions:

- Just imagine that you need to increase the frequency of transportation from your suppliers to your DC in order to become more flexible and responsive in regard to customer demand changes. How would you model this situation in ALX? What trade-offs should you consider in regard to inventory control and warehouse capacity?
- How can you analyse capacity utilization at your warehouse in dynamics using ALX?
- Just imagine that we want to ship a product to the US from China. Which experiment should we use to decide which port is the best option?
- Just imagine that your chief asks you to analyse the impact of currently used inventory control policy on the total SC costs. How would you model this situation in ALX?
- Is there any difference in NetOpt results if you use LTL or FTL transportation policy?
- Let's assume you supply luxury goods and you want to analyze the service level you will be able to provide to your customers with the given SC structure. How could you estimate it with ALX?

Chapter 3

In Chapter 3, we included production and sourcing policies into consideration. We created a four-stage SC structure, performed experiments and measured performance in ALX. Using this model, we learned major trade-offs between the single and multiple sourcing, production time, transportation frequency, inventory control policies, and lead time. We also learned how to create BOM (bill-of-materials) in ALX. Finally, we learned how to transit from model-based result to a management decision by inclusion of soft facts.

Discussion questions:

- Just imagine that you need to increase the production quantity from your factory to your DC in regard to higher customer demand. How would you model this situation in ALX? What trade-offs should you consider in regard to transportation policy, inventory control and warehouse capacity?
- How can you analyse lead time at your customers in dynamics using ALX?
- Just imagine that you may ship a product to the US from China and from India. How would you decide if single or dual sourcing is more efficient?
- Just imagine that your chief asks you to analyse the impact of currently used sourcing policy on the lead time. How would you model this situation in ALX?

Chapter 4

In Chapter 4, we considered ALX applications to risk management and control in SCs. Risks in SCs are characterized by different frequency and performance impact. High-frequency-low-impact disruptions are typically considered in light of bullwhip-effect and refer to demand and lead-time fluctuations. Bullwhip effect considers weekly/daily demand and lead-time fluctuations as primary drivers of the changes in the SC which occur at the parametric level and can be eliminated in a short-term perspective. In light of low-frequency-high-impact disruptions, ripple effect has been considered. We learned how to model and to quantify both bullwhip effect and ripple effect using ALX. We developed technical skills on batching, ordering rules, and events. Subsequently, we learned how to prepare and run variation and comparison experiments in ALX. Finally, we focused on understanding of major trade-offs in SC risk management in regard to efficiency and resilience. We included proactive and reactive recovery strategies in analysis.

Discussion questions:

- What is the difference between bullwhip effect and ripple effect?
- How can you explain the meaning of the “Products Bullwhip Effect” statistics in ALX?
- Just imagine that you need to increase the sales batch size because of transportation policy optimization. What impacts can this decision have on other decisions or policies in the SC? How can you analyse these impacts using ALX?
- What is the meaning of BWE? Why does it allow to identify a bullwhip effect?
- What does it mean if BWE = 1?
- Does it make sense to measure BWE for a number of products?
- How does the BWE depend on the inventory control policy?
- Create three scenarios with different demand distributions. Use “Comparison” experiment to compare the scenarios
- What kind of events can you add to your model?
- Just imagine that you need to analyse performance impacts of three different disruptions, i.e., a strike of a transportation company, a fire at a DC, and an explosion at a factory. How would you model this in ALX? Which experiment(s) would you use?
- How can you analyze different ways an event may happen?
- If you would like to vary the location of a factory how would you do this?
- If you would like to vary suppliers in sourcing policy how would you do this?
- What is the difference between “Variation” and “Comparison” experiments?
- Which parameters of the SC can be varied and in what decisions?

11. Typical conceptual mistakes and how to avoid them

1. Simulation experiment does not start; the SC objects are not connected on the map.

Sourcing rules need to be defined.

2. Simulation experiment does not start or starts, but terminates quickly.

Please check maximum warehouse or factory capacity

Too long production time or processing time

Check the assignments of objects and products to groups

Inventory policies need to be defined for all sites

Paths need to be defined for all stages in the SC

3. In the network optimization experiment, not all sites for optimization can be selected.

In “Factory/DCs”, the “Inclusion type” should be “Consider”

4. After an order aggregation in transportation policy, the simulation experiment does not run.

Since we increase the transportation quantity, we also need to increase the MAX-Level in the inventory control policy. Otherwise, the simulation experiment will stop because of insufficient warehouse capacity. It is also advisable to increase the MIN-level since the replenishment interval will be increased.

or

Please ensure that the aggregation policy is aligned with Max value in inventory control policy

5. In an experiment with BOM, no activities are shown in the simulation experiment between suppliers and assembly factory.

In “Inventory”, inventory policy needs to be defined for all products of BOM, not only for final product.

6. In an experiment, the results are not shown fully.

Click any other experiment or scenario and then return to your experiment. The results should be shown full.

7. Transportation costs is shown in the experimental results for the connection between the customers and DC only, no costs is shown for the connection between the DC and factory.

Activate transportation costs for factory in “Configure statistics” in your experiment.

8. In simulation experiment, the time is running but nothing is shipped.

Check demand parameters, backorder policy, and initial inventory.

9. Orders are not shipped to customers.

Check LTL and FTL policies and the corresponding minimum ratio, aggregation periods as well as product characteristics and transportation capacities.

10. Orders are not shipped to customers.

The inventory policies, the types of vehicles and the transportation policies are not compatible with each other. For example, some large vehicles with a LTL policy of min. load 0.8 and an aggregation period of 10 days waste a lot of time waiting for the loading the vehicles. By reducing the size of vehicles and increasing the parameters of inventory policies it is possible to fulfill more orders placed by the customers.

12. Appendix 1: Examples of case study problem statements for student projects

12.1. Example 1: Consolidation effects in the retail supply chain

Learning objective of this case: students become familiar with model-based decision-making principles in supply chain management on the example of optimization and simulation application to analysis ofa real-life location-allocation problem in a global retail supply chain.

1. Management problem statement

1.1 Object of investigation

A global retail company comprises producers of fruits and vegetables and regional distributions centers (DC).

1.2 Process of investigation

We investigate the process of fruit and vegetable delivery from suppliers to regional DCs.

1.3. Problem to be solved and its relation to the literature

Currently, the products are shipped from suppliers to regional DCs directly using LTL policy with an average of 15 pallets per delivery. This results into high coordination complexity, low fleet capacity utilization, higher transportation costs, and higher inventory holding costs.

The retail company aims at establishing some central DCs between the suppliers and regionals DCs (Fig. 1).

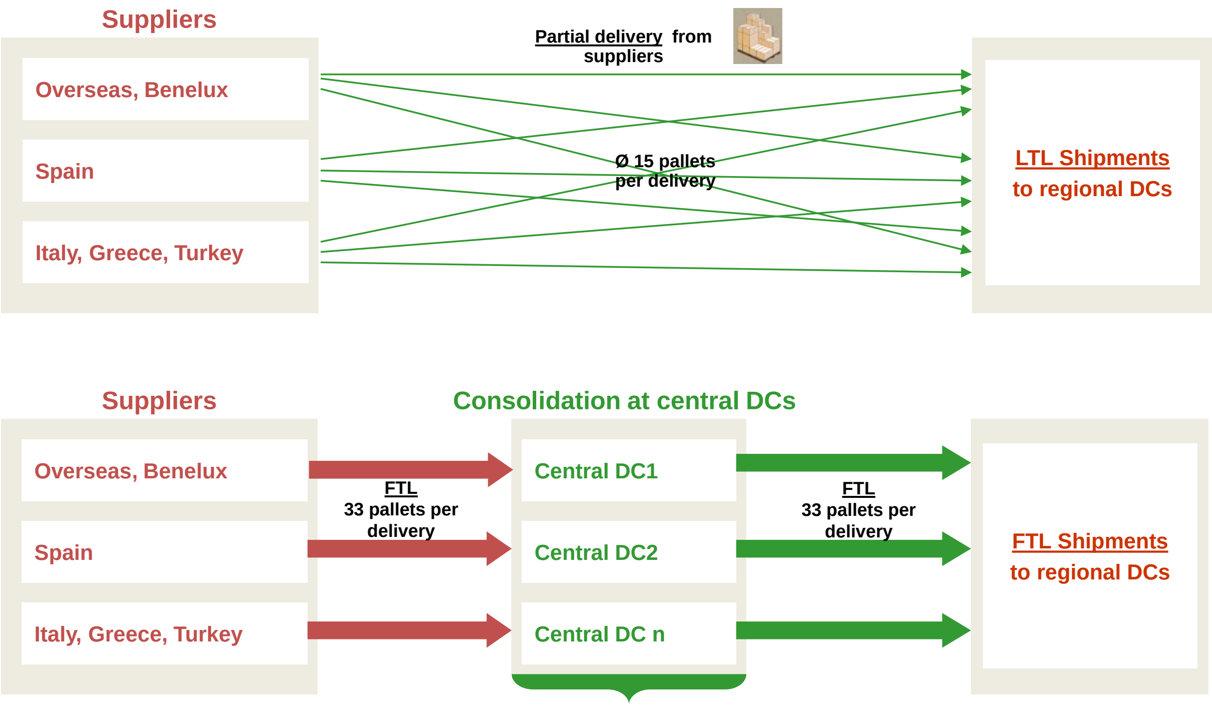


Fig. 1. Initial and planned supply chain design

The problem consists in the determination of the number of central DCs, their locations, and the allocation of regional DC demands to central DCs. It is to balance the DC capacities, transportation policy, sourcing policy and inventory control policy in the most efficient way subject to a pre-determined customer service level.

This problem statement corresponds to the standard location-allocation problem in the literature.

Two scenarios need to be analysed and compared subject to Fig. 1:

- Direct shipments
- Shipments via central DCs

In addition, future shifts in demand up to 30% to 50% at some regional DCs in regard to population growth forecasts and local farmer market development forecasts need to be taken into account.

1.4 Main goal of investigation

The main goal of investigation is to increase supply chain efficiency without decreasing the customer service level.

1.5. Decision to be taken

The main decision is to determine the number of central DCs, their location, and the allocation of regional DCs to central DCs.

In addition, it is to decide on:

- what capacity at the DCs should be used
- fleet size and transportation policy
- inventory control policy and its parameters
- sourcing policy
- resilience policy

1.6. Research question

The main research question is to analyse the impact of supply chain re-design in regard to (i) location-allocation options, (ii) impact of transportation, sourcing, and inventory control policies as well as (iii) future capacity and demand changes on supply chain financial, customer, and operational performance.

1.7. Sub-questions to be answered to take the decision

- compare supply chain without central DCs and with central DCs in regard to supply chain financial, customer, and operational performance
- compare different location-allocation variants in regard to supply chain financial, customer, and operational performance
- compare the impact of LTL and FTL shipment policies on supply chain financial, customer, and operational performance
- compare inventory control policies in regard to supply chain financial, customer, and operational performance
- compare the impact of sourcing policies on supply chain financial, customer, and operational performance
- analyse the impact of future demand changes on supply chain financial, customer, and operational performance
- analyse the impact of capacity disruption risks on supply chain financial, customer, and operational performance
- analyse the impact of DC capacity changes on supply chain financial, customer, and operational performance

1.8. KPI to measure the results of investigation

Financial DC performance:	*Customer performance:*
total profit (EBIDTA), $	Maximum lead time, days
total revenue, $	Min-Max Service level, %
opportunity costs, $	OTD (on-time delivery), orders
production costs, $	Total incoming orders from customers
inventory holding costs, $	Total outgoing orders to customers
transportation costs at suppliers, $	Total orders shipped to customers
transportation costs at DC, $	*Operational performance:*
profit and lost statement, $	Maximum capacity usage at DCs, m^3
total costs at DC, $	Maximum inventory in the SC, units

2. Data needed to solve management problem

The following data is needed to solve the problem above-described:

2.1. Demand at regional DCs:

Regional DC	**Forecasted Demand (pallets per day)**	**Initial Inventory (Pallets)**
Bulgaria		
Hungary 1		
Hungary 2		
Romania 1		
Romania 2		
Romania 3		
Croatia		
Slovakia 1		
Slovakia 2		
Czech Republic 1		
Czech Republic 2		
Czech Republic 3		
Czech Republic 4		
Czech Republic 5		
Poland		

2.2. Supply to regional DCs in the initial SC with direct shipment

	BG1	H1	H2	RO1	RO2	RO3	CR	SK1	SK2	CZ1	CZ2	CZ3	CZ4	CZ5	P
Albania															
Argentina															
Austria															
Belgium															
Brazil															
Bulgaria															
Chile															
China															
Columbia															
Costa Rica															
Croatia															
Cyprus															
Czech Republic															
Ecuador															
Egypt															
France															
Germany															
Greece															
Honduras															
Hungary															
India															
Israel															
Italy															
Mexico															
Moldavia															
Morocco															
Netherlands															
New Zealand															
Overseas															
Panama															
Peru															
Poland															
Romania															
Senegal															
Serbia															
Slovenia															
South Africa															
Spain															
Turkey															

2.3. Costs and profits

Costs and profits	**$**
DC inbound operating costs	
DC outbound operating costs	
Initial costs for building DC	
Facility operating costs	
Opportunity costs	
Inventory carrying costs	
Fixed DC costs	
Transportation costs	
Sales price	

2.4. Further estimations

Parameters	
Lead time	
Transportation mean capacity	
DC capacity	
Expected lead time	
…	

3. Description of experiments

3.1. Direct shipment analysis

*It is to compute for initial scenario s*upply chain financial, customer, and operational performance subject to KPI in §1.8 for

- AS-IS parametric setting
- Changed parametric settings subject future shifts in demand up to 30% to 50% at some regional DCs in regard to population growth forecasts and local farmer market development forecasts
- Changed parametric settings subject to severe disruptions in supplier and regional DC capacities

Experiment used: Simulation (inventory control policy parameters can be computed analytically prior to simulation)

3.2. Central DC shipment analysis

It is to analyse for scenario with central DCs:

- How many central DCs should be used
- DC locations

- allocation of regional DCs to central DCs

Experiments: Analytical: Green Field Analysis and Network Optimization

- what capacity at the DCs should be used
- fleet size and transportation policy
- inventory control policy and its parameters
- sourcing policy
- resilience policy

Experiment: Simulation (inventory control policy parameters can be computed analytically prior to simulation)

3.3. Comparison of two scenarios

- compare supply chain without central DCs and with central DCs in regard to supply chain financial, customer, and operational performance
- compare different location-allocation variants in regard to supply chain financial, customer, and operational performance
- compare the impact of LTL and FTL shipment policies on supply chain financial, customer, and operational performance
- compare inventory control policies in regard to supply chain financial, customer, and operational performance
- compare the impact of sourcing policies on supply chain financial, customer, and operational performance
- analyse the impact of future demand changes on supply chain financial, customer, and operational performance
- analyse the impact of capacity disruption risks on supply chain financial, customer, and operational performance
- analyse the impact of DC capacity changes on supply chain financial, customer, and operational performance

Experiments: Comparison and Variation

Project report structure

1. Management problem statement (object of investigation, process of investigation, main goal of investigation, decision to be taken, sub-questions to be answered to take the decision, KPI to measure results of investigation)

2. Data needed to solve management problem

3. Model description (objective function, constraints, parameters, variables; if optimization models: set of equations, if simulation model: process diagrams and schemes)

4. Description of software

5. Implementation in software

6. Description of experiments

7. Presentation of computational results

8. Analysis of results

9. Recommendations on the solution of the management problem stated in 1) in regard to main goal of investigation, decision to be taken, sub-questions to be answered to take the decision, and KPI to measure results of investigation.

12.2 Example 2

ETC is a wine manufacturing company. ETC company produces two types of wine for export: Pinot Gris and Traminer. Both of these are of high quality and expensive. These two products are sold to customers from Europe, Asia, South and North Americas. Because of high demand ETC management decided in the past to build distribution centers in Europe, Asia, South and North Americas. Since demand starts fluctuating, ETC management is striving to answer the following questions:

- Determine where would be the best locations for their DCs taking into consideration customer locations, distances from warehouses to customers and customer demand.
- Management has some doubts about the cost-effectiveness of the DC located in South America. They want to know whether it would be more rational to run 3 instead of 4 DCs.
- Finally, the CEO wants to compare the most important KPIs of the overall supply chain between scenario 1 (4 DCs) and scenario 2 (3 DCs)

12.3 Example 3

ZSE is a European e-commerce company which was founded in 2008. The company maintains a cross-platform online store that sells shoes, clothing and other fashion items and it is based in Berlin. In Germany it is one of the most successful online-shops, but ZSE is also operating in fourteen European countries and worldwide with spin-offs and subsidiary companies.

Online-shopping is getting more and more popular so that ZSE wants to be the most successful online-shopping platform in the EU. At the moment they have one factory in China and one distribution centers (DC) in Germany. ZSE needs to focus on developing solutions. For a successful foray into Europe, the retailer would need to highlight its unique selling points in comparison to its competitors. ZSE is focussing on a four years strategy with the aim of fast delivery, excellent customer service and an efficient supply chain. To expand the business in Europe they need to decide whether to open new DC or to expand the xapacity of the existing DC in Germany in anticipation of increasing demand. If they decide to open new DC, it is to determine where to locate it to minimize the supply chain costs subject to miniomum service level requirements

12.4 Example 4

Consider a company that ships everything one expects to find in a drug store. They sell almost 25,000 different products and ship 570,000 orders a month, have agreements with 16 suppliers. By developing a new pricing management software over the years, the founders of the company have found an extremely effective way to dominate the market they operate in, as the software is able to calculate the best price as well as to manage their whole stock and sales/demand forecasts. They have managed to increase their sales. However, when looking at the performance indicators, the delivery time is quite long, which is caused by having only one warehouse, located in New York City.

Therefore we need to decide if it would be sensible to open a second warehouse on the Westcoast in order to speed up delivery to the West side of the US and therefore fulfill customer expectations?

13. Appendix 2: Simulation and analytical methods in supply chain facility location modelling

In this Section, we provide an additional example of how to apply both optimization and simulation methods to SC facility location problem. The objective of this case study is to learn what we can how we can apply simulation and optimization modelling to SC design decisions. In Figs A1-A2, basic features of optimization and simulation methods in ALX are summarized.

- NetOpt is used to find:
  - Locations for facilities
  - Sourcing policies
  - Product flows
- To conduct the NetOpt experiment you must specify:
  - Locations – the “Locations” table
  - Periods – the “Periods” (basic period is used by default) table
  - Customers – the “Customers” table
  - Products – the “Products” table
  - Demand – the “Demand” table
  - Initial, outbound/inbound processing, other monthly costs – the “DCs and Factories” and “Facility Expenses” tables
  - Supplier – the “Suppliers” table
  - Storage constraints – the “Linear Site Constraints” table
  - Flow constraints – the “Linear Flow Constraints” table
  - Transportation cost and option to use real routes – the “Path” table
- About NetOpt:
  - Optimization method: Mixed Integer Linear Programming
  - Criteria: solution cost = transportation cost + sites associated costs + penalties - revenue
- NetOpt Results (Tables)
  - DCs and Factories – the best sites have “inclusion type” included
  - Sourcing – defines where and which product to buy
  - Inventory – NetOpt creates and parameterizes “S”&”s” inventory policies
    - *s = average daily demand * lead time*
    - *S = 2*s*
  - Overview of solution costs, revenues
- Notes
  - NetOpt operates with flows

Fig. A-1. Analytical framework summary NetOpt

- Analytical Optimization
  - To solve a **particular** problem you create the system of equations which are only relevant to this problem – analytical model
  - You can only consider aggregated flows
  - **Optimization** means minimization/maximization of an objective function meeting constraints, e.g.:
    - *F(X1, X2, X3) -> MIN*
    - *X1 = X2 + X3*
    - *X2 = X1 + X3*
    - *X3 = X1 + X2*
    - *X1 < 120*
    - *X3 > 400*
  - Criteria
    - *As system of equations and inequalities is developed for a particular problem the criteria is also related to this particular problem*
- Simulation Optimization
  - A Simulation model describes how the system works. It makes sense without the problem.
  - You can consider events, stochastics and changes of the system over time
  - **Optimization** means a number of simulation runs with different input parameters
  - Criteria
    - *Everything that is measured by simulation model can be a criteria*

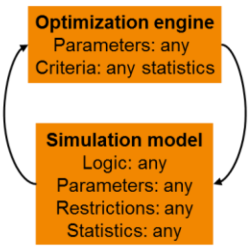


Fig. A-2. Application of simulation and optimization modelling

Consider the following example. An SC in Germany comprises Supplier, three DCs and ten Customers (Fig. A-3).

Fig. A-3. Supply chain structure

The following input data is used (Fig A-4).

Periods (3)
Processing Cost (3)
Processing Time (0)
Product Groups (0)
Production (0)
Production Batch (0)

#	Name	Start	End	Demand Coefficient
1	First quarter	1/1/17	4/30/17	1
2	Second quarter	5/1/17	8/31/17	1.3
3	Third quarter	9/1/17	1/1/18	0.8

BOM (0)
Customers (10)
DCs and Factories (3)
Demand (10)
Demand Forecast (0)
Events (0)

#	Name	Type	Location	Initially Opened	Inclusion Type	Capacity	Capacity Unit	Interests, ratio ...	Aggregate Orders...	Additional Param...
1	Site 1	DC	Site 1 location	on	Consider	0	m³	0	off	Additional parame...
2	Site 2	DC	Site 2 location	on	Consider	0	m³	0	off	Additional parame...
3	Site 3	DC	Site 3 location	on	Consider	0	m³	0	off	Additional parame...

- **Demand (10)**
- Demand Forecast (0)
- Events (0)
- Facility Expenses (3)
- Fleet Size (0)
- Groups (1)
- Inventory (1)
- Loading and Unloading Gates (0)
- Location Lists (0)
- Locations (14)
- Milk Runs (0)
- Ordering Rules (0)
- Path Selection Mode (0)
- Paths (1)

#	Customer	Product	Demand Type	Parameters	Time Period	Expected Lead Ti...	Time Unit	Backorder Policy
1	Hamburg	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
2	Berlin	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
3	Hannover	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
4	Dresden	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
5	Frankfurt	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
6	Erfurt	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
7	Munchen	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
8	Stuttgart	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
9	Cologne	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total
10	Nurnberg	Water	Periodic demand	Period=5.0, Quant...	(All periods)	30	day	Allowed total

- **Facility Expenses (3)**
- Fleet Size (0)
- Groups (1)
- Inventory (1)
- Loading and Unloading Gates (0)
- Location Lists (0)

#	Facility	Expense Type	Value	Cost Unit	Time Unit	Product Unit	Time Period
1	Site 1	Other costs	666	USD	day		(All periods)
2	Site 2	Other costs	666	USD	day		(All periods)
3	Site 3	Other costs	666	USD	day		(All periods)

- **Inventory (1)**
- Loading and Unloading Gates (0)
- Location Lists (0)
- Locations (14)

#	Facility	Product	Policy Type	Policy Parameters	Initial St...	Periodic Check	Period	Policy Basis	Stock Calc...	Time Unit	Time Period	Inclusion Type
1	(All sites)	Water	InventoryPolicy...	Order on demand	100		0	Quantity	0	day	(All periods)	Include

- **Paths (1)**
- Period Groups (0)
- Periods (3)
- Processing Cost (3)

#	From	To	Cost Calculation	Cost Calculation ...	Cost Unit	Distance	Distance Unit	Transportation Ti...	Time Unit	Straight	Vehicle Type	Transporta
1	(All locations)	(All locations)	Distance-based c.	1.2 * distance	USD	0	km	0.0	day		Truck	LTL

- **Processing Cost (3)**
- Processing Time (0)
- Product Groups (0)
- Production (0)
- Production Batch (0)
- Products (1)
- Sale Batch (0)

#	Source	Product	Type	Units	Cost	Cost Unit	Time Period
1	Site 1	Water	Outbound ship...	m³	20	USD	(All periods)
2	Site 2	Water	Outbound ship...	m³	20	USD	(All periods)
3	Site 3	Water	Outbound ship...	m³	20	USD	(All periods)

- **Products (1)**
- Sale Batch (0)
- Site States Changes (0)
- Sourcing (2)
- Suppliers (1)

#	Name	Unit	Selling Price	Cost	Cost Unit
1	Water	m³	500	250	USD

- Products (1)
- Sale Batch (0)
- Site States Changes (0)
- **Sourcing (2)**
- Suppliers (1)

#	Delivery Destinat...	Product	Type	Parameters	Sources	Time Period	Inclusion Type
1	Customers	Water	Closest (Fixed So.	No parameters	(All sites)	(All periods)	Include
2	(All sites)	Water	Closest (Fixed So.	No parameters	Supplier	(All periods)	Include

- Unit Conversions (0)
- Units (0)
- **Vehicle Types (1)**

#	Name	Capacity	Capacity Unit	Speed	Speed Unit
1	Truck	50	m³	80.0	km/h

Fig. A-4. Input data

First, we perform a simulation experiment for three DCs. The result is shown in Fig. A-5.

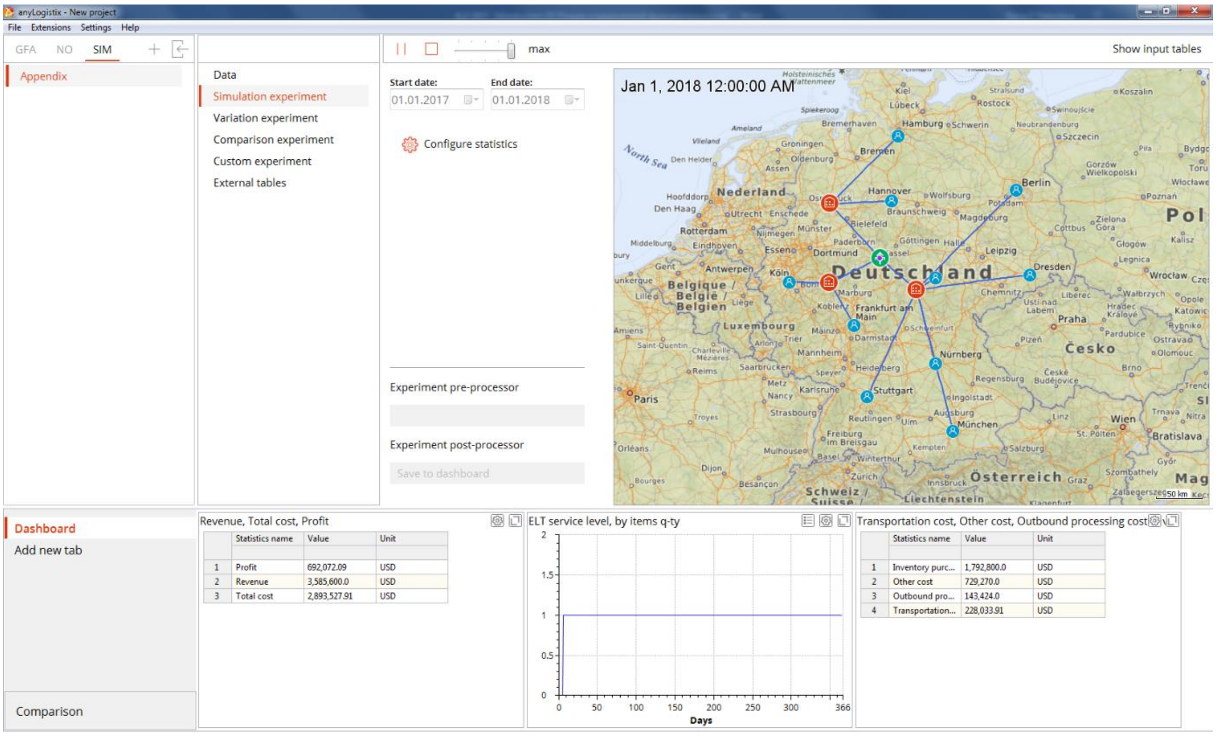


Fig. A-5. SC performance with three DCs

Then convert current simulation scenario to NO scenario put the following data to “Demand” table:

Table 16 Demand distribution

Customer	Product	Demand Type	Time Period	Revenue	Down Penalty	Up Penalty
Hamburg	Water	PeriodicDemand[period:5.0;quantity:10.0]	First quarter	500	5000	5000
Berlin	Water	PeriodicDemand[period:5.0;quantity:12.0]	First quarter	500	5000	5000
Hannover	Water	PeriodicDemand[period:5.0;quantity:8.0]	First quarter	500	5000	5000
Dresden	Water	PeriodicDemand[period:5.0;quantity:8.0]	First quarter	500	5000	5000
Frankfurt	Water	PeriodicDemand[period:5.0;quantity:10.0]	First quarter	500	5000	5000
Erfurt	Water	PeriodicDemand[period:5.0;quantity:7.0]	First quarter	500	5000	5000
Munchen	Water	PeriodicDemand[period:5.0;quantity:13.0]	First quarter	500	5000	5000
Stuttgart	Water	PeriodicDemand[period:5.0;quantity:8.0]	First quarter	500	5000	5000
Cologne	Water	PeriodicDemand[period:5.0;quantity:12.0]	First quarter	500	5000	5000
Nurnberg	Water	PeriodicDemand[period:5.0;quantity:8.0]	First quarter	500	5000	5000
Hamburg	Water	PeriodicDemand[period:5.0;quantity:13.0]	Second quarter	500	5000	5000
Berlin	Water	PeriodicDemand[period:5.0;quantity:15.6]	Second quarter	500	5000	5000
Hannover	Water	PeriodicDemand[period:5.0;quantity:10.4]	Second quarter	500	5000	5000
Dresden	Water	PeriodicDemand[period:5.0;quantity:10.4]	Second quarter	500	5000	5000
Frankfurt	Water	PeriodicDemand[period:5.0;quantity:13.0]	Second quarter	500	5000	5000
Erfurt	Water	PeriodicDemand[period:5.0;quantity:9.1]	Second quarter	500	5000	5000
Munchen	Water	PeriodicDemand[period:5.0;quantity:16.9]	Second quarter	500	5000	5000
Stuttgart	Water	PeriodicDemand[period:5.0;quantity:10.4]	Second quarter	500	5000	5000
Cologne	Water	PeriodicDemand[period:5.0;quantity:15.6]	Second quarter	500	5000	5000
Nurnberg	Water	PeriodicDemand[period:5.0;quantity:10.0]	Second quarter	500	5000	5000
Hamburg	Water	PeriodicDemand[period:5.0;quantity:8.0]	Third quarter	500	5000	5000
Berlin	Water	PeriodicDemand[period:5.0;quantity:9.6]	Third quarter	500	5000	5000
Hannover	Water	PeriodicDemand[period:5.0;quantity:6.4]	Third quarter	500	5000	5000

Dresden	Water	PeriodicDemand[period:5.0;quantity:6.4]	Third quarter	500	5000	5000
Frankfurt	Water	PeriodicDemand[period:5.0;quantity:8.0]	Third quarter	500	5000	5000
Erfurt	Water	PeriodicDemand[period:5.0;quantity:5.6]	Third quarter	500	5000	5000
Munchen	Water	PeriodicDemand[period:5.0;quantity:10.4]	Third quarter	500	5000	5000
Stuttgart	Water	PeriodicDemand[period:5.0;quantity:6.4]	Third quarter	500	5000	5000
Cologne	Water	PeriodicDemand[period:5.0;quantity:9.6]	Third quarter	500	5000	5000
Nurnberg	Water	PeriodicDemand[period:5.0;quantity:6.4]	Third quarter	500	5000	5000

In the second step, network optimization experiment is run (Fig. A-6).

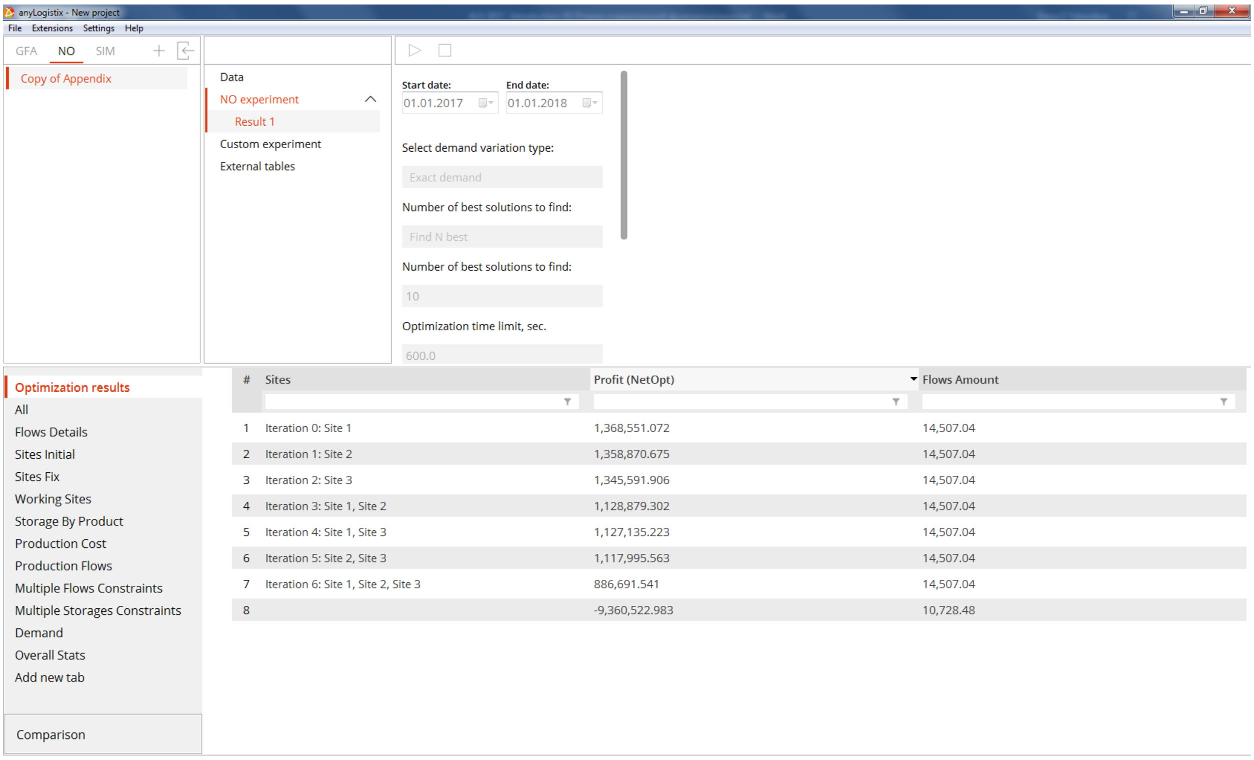


Fig. A-6. Network optimization experiment

Third, we use the best result of the network optimization that suggests having one DC as the most profitable SC design (profit of $1,368,551.072), convert it to the SIM scenario, change input data (delete all information about Supplier and don't forget about inventory policy) and run a simulation experiment with the optimal SC design subject to maximum profit (Fig. A-7).

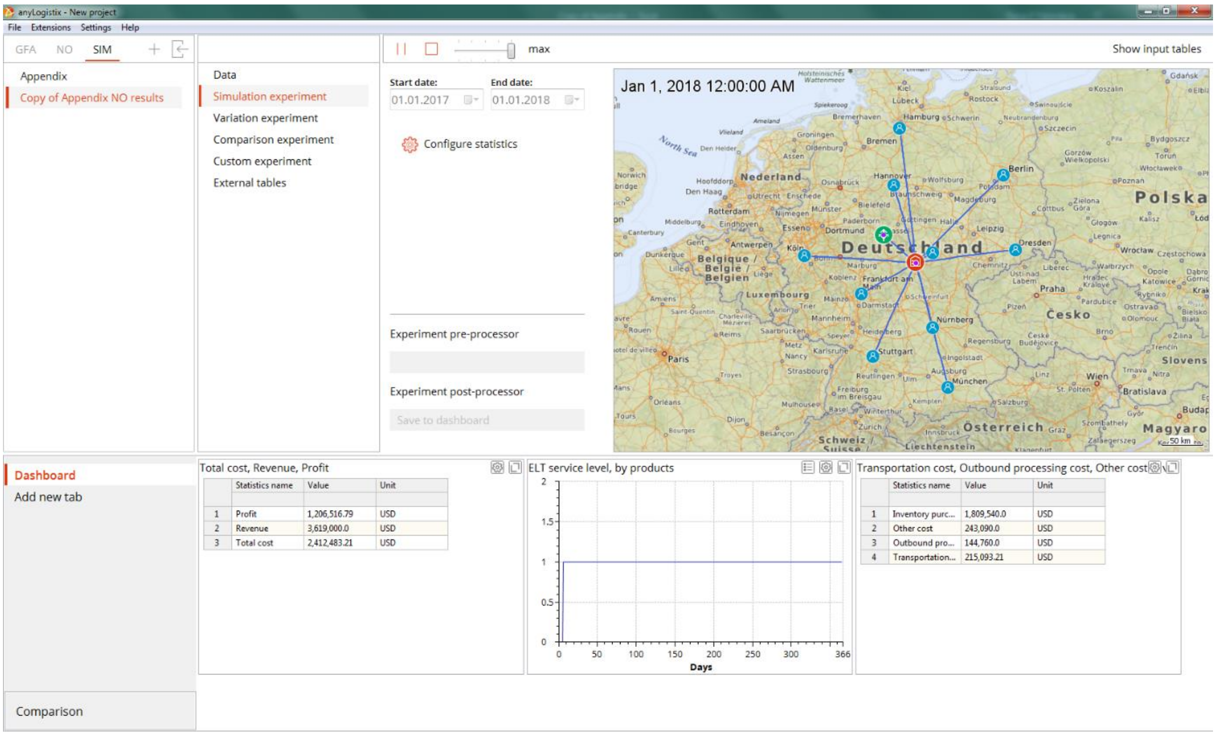


Fig. A-7. Simulation experiment with optimal SC design

We can observe that the sum of fixed warehousing costs is $ 243,090.0 and variable transportation costs equals $215,093.21.

We use “Comparison” experiment to compare the SC design with 3 DCs (scenario Appendix) and 1 DC (scenario Copy of Appendix 1 NO results) (Fig. A-8).

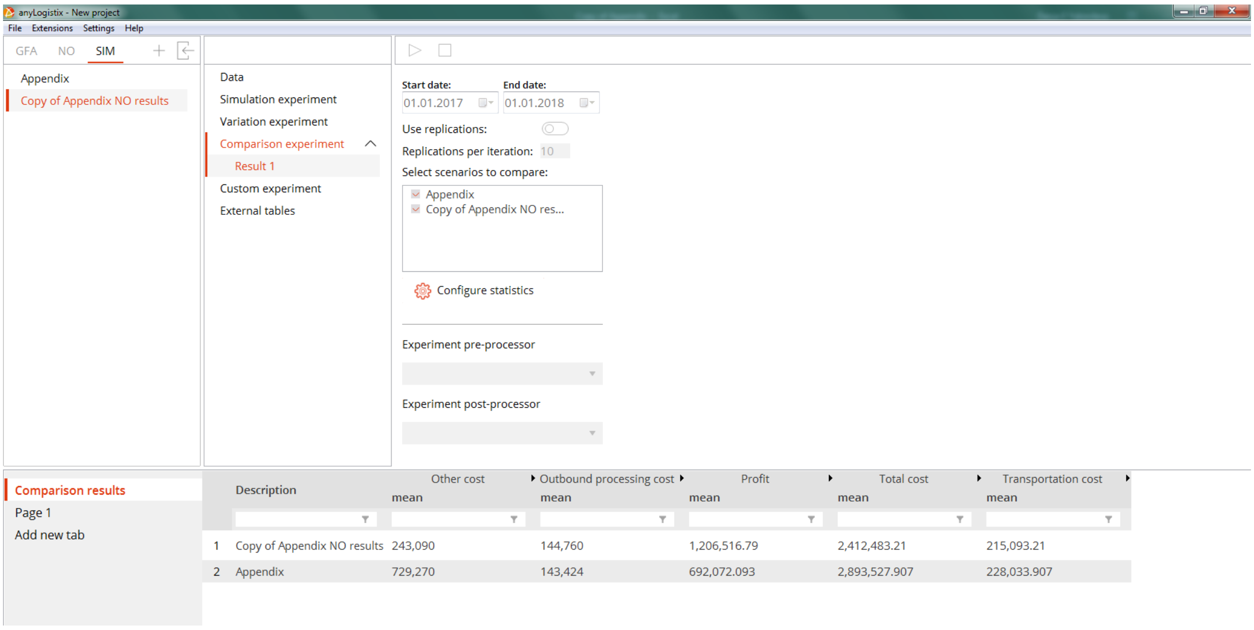


Fig. A-8. Comparison experiment

It can be observed in Fig. A-8 that transportation costs in the SC design with three DCs is lower than in the SC design with one DC. However, due to significant savings in fixed warehousing costs, the SC design with one DC is much more efficient and profitable as the SC design with three DCs.

Finally, we perform a variation analysis in order to analyze KPI sensitivity to the changes in transportation costs in range from $0.2 to $2.0 for a kilometer (Figs A9-A12).

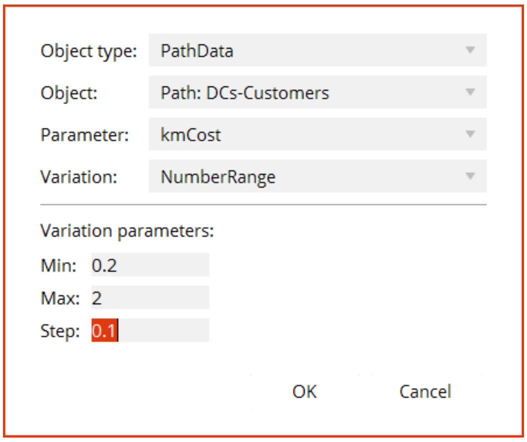


Fig. A-9. Setting the range for parameter change

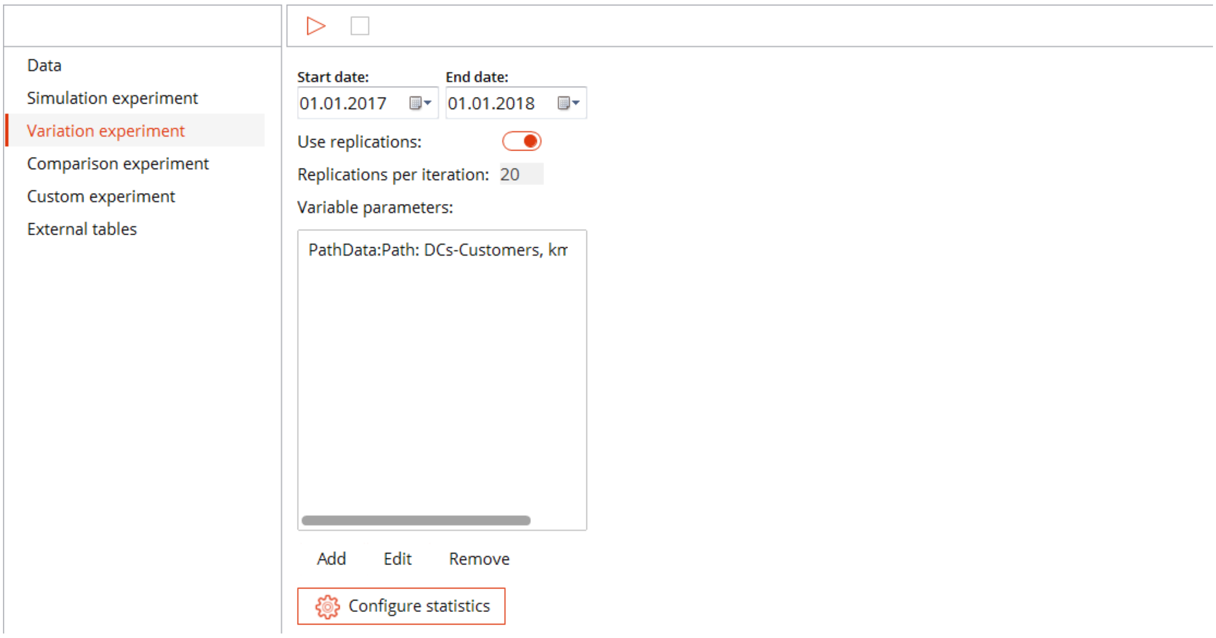


Fig. A-10. Setting the number of replications

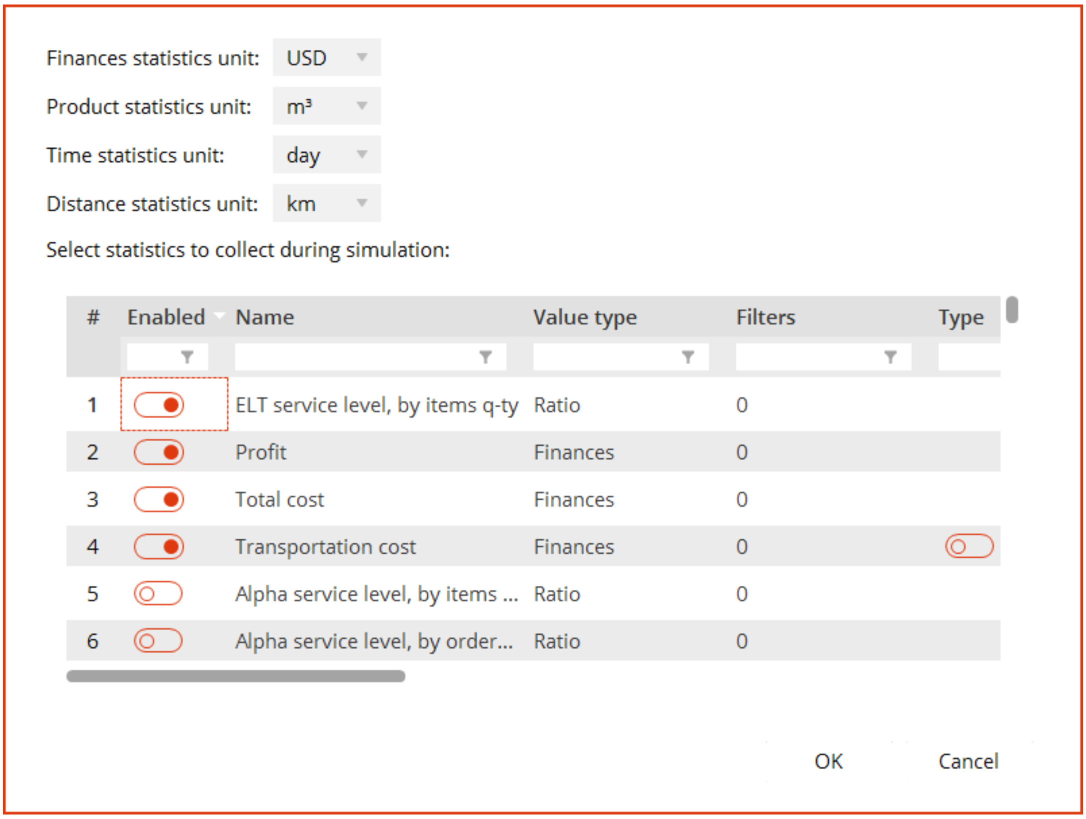
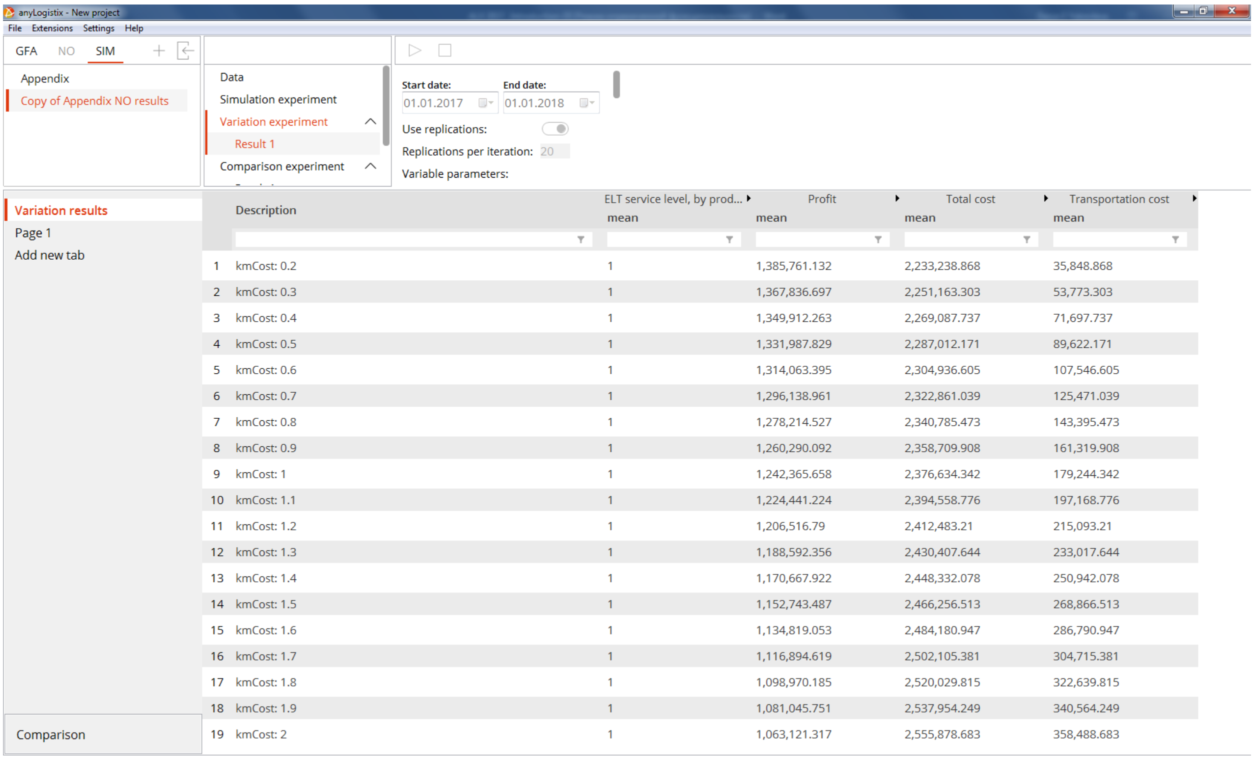


Fig. A-11. Configure statistics



#	Description	ELT service level, by prod... mean	Profit mean	Total cost mean	Transportation cost mean
1	kmCost: 0.2	1	1,385,761.132	2,233,238.868	35,848.868
2	kmCost: 0.3	1	1,367,836.697	2,251,163.303	53,773.303
3	kmCost: 0.4	1	1,349,912.263	2,269,087.737	71,697.737
4	kmCost: 0.5	1	1,331,987.829	2,287,012.171	89,622.171
5	kmCost: 0.6	1	1,314,063.395	2,304,936.605	107,546.605
6	kmCost: 0.7	1	1,296,138.961	2,322,861.039	125,471.039
7	kmCost: 0.8	1	1,278,214.527	2,340,785.473	143,395.473
8	kmCost: 0.9	1	1,260,290.092	2,358,709.908	161,319.908
9	kmCost: 1	1	1,242,365.658	2,376,634.342	179,244.342
10	kmCost: 1.1	1	1,224,441.224	2,394,558.776	197,168.776
11	kmCost: 1.2	1	1,206,516.79	2,412,483.21	215,093.21
12	kmCost: 1.3	1	1,188,592.356	2,430,407.644	233,017.644
13	kmCost: 1.4	1	1,170,667.922	2,448,332.078	250,942.078
14	kmCost: 1.5	1	1,152,743.487	2,466,256.513	268,866.513
15	kmCost: 1.6	1	1,134,819.053	2,484,180.947	286,790.947
16	kmCost: 1.7	1	1,116,894.619	2,502,105.381	304,715.381
17	kmCost: 1.8	1	1,098,970.185	2,520,029.815	322,639.815
18	kmCost: 1.9	1	1,081,045.751	2,537,954.249	340,564.249
19	kmCost: 2	1	1,063,121.317	2,555,878.683	358,488.683

Fig. A-12. Results of variation analysis

→ Note: Results of the variation analysis are presented in Fig. A-13 without filtering. To increase the result presentation clearness, the results can be filtered, e.g., in the column "Total costs" in order to depict the best result.

With the help of variation analysis, it becomes possible to observe the KPI change in dependence on the input parameter changes. This is helpful for sensitivity analysis.