CHEMICAL INDUSTRY SUPPLY CHAIN OPTIMISATION USING AGENT-BASED MODELLING

Jan Škvor, Jakub Dyntar

Abstract: *In this paper we present an application of Supply Chain Spread Sheet Simulator (SCSS) in a task dealing with chemical industry supply chain redesign and optimisation. SCSS uses principles of Agent-Based Modelling combining 4 types of agents with 3 algorithms to control their behaviour. Location Algorithm is used to place the logistics objects satisfying the demand of customers, Clarke&Wright's Savings Algorithm is applied to plan the routes and Past Stock Movement Simulation is used to control the stock levels. SCSS is developed in MS Excel using programming language Visual Basic for Applications. Its basic functionality is discussed simulating a real task dealing with the redesign of the distribution system for goods coming from chemical industry in the Czech Republic. We test 6 different structures of the distribution system differing in number of located logistics objects ranging from 1 to 6. Based on the outputs of SCSS recalculated to distribution costs we suggest decreasing the number of located warehouses from 6 to 1 estimating almost 33 % distribution costs savings per year.*

Keywords: *Supply Chain Redesign, Agent Based Modelling, Spread Sheet Simulation, Distribution, Logistics.*

JEL Classification: *C61.*

Introduction

Supply chain is considered as integrated process which involves a set of business entities, e.g. suppliers, producers, distributors etc. Their collective goal is to find a solution to efficiently meet customer requirements such as high product variety, high quality, and short lead times [15], [17]. Supply chain is characteristic with a forward flow of materials and a backward flow of information [13]. The forward flow means all activities which must be done to offer the goods to customers at the right quality, right amount, right place and right time. Only by fulfilment of these requirements at the same time we can talk about effective distribution system [5], [2]. Backward flow of information serves to discover customer requirements and opinions on provided level of services. At its highest level, the supply chain is comprised of two basic, integrated processes [1]. First process involves suppliers of raw material and producers of final goods. This part is called Production planning and inventory control process. Second part called Distribution and logistics process represents distribution of final goods from producers to consumers. This activity is provided by various business entities. As published by [14] it is necessary to design the supply chain already during the process of designing final goods, which will be distributed by proposed system. Although we are able to design the perfect distribution system at the very beginning for known requirements we have to check the changes in demand or important constraints in the course of time. The result is that high percentage of companies has to make decision about redesigning of current distribution system [10], [12]. Because the distribution costs can represent even 40 % of sale price the optimization of distribution system offers quite a large scope for final price reduction, which is still more important competitive criterion for consumers [3]

The complex model of designing or redesigning distribution systems tries to find answers on following questions:

- How many distribution centres to select,
- where to place these objects,
- what is an appropriate storage capacity of these objects,
- how to deliver goods to customers and
- how to control stock level in distribution centres,

while minimizing the distribution costs in compliance with requiring level of services (mainly in the form of lead time). To search for the answers on these questions we design Supply Chain Spread Sheet Simulator (SCSS). SCSS is based on the principles of Agent-Based Models (ABM), the alternative modelling paradigm considered to be suitable for design and optimization of the real distribution systems. ABM is a class of computational models for simulating the actions and interactions of autonomous agents, individual or collective entities such as organizations or groups, with a view to assessing their effects on the system as a whole. The models simulate the simultaneous operations and interactions of multiple agents, in an attempt to recreate and predict the appearance of complex phenomena [7], [8], [18]. SCSS is developed in MS Excel environment using programming language Visual Basic for Applications (VBA). Its basic functionality is discussed simulating a real task dealing with the redesign and optimisation of the distribution system for goods coming from chemical industry in the Czech Republic.

1 Material and Methods

SCSS consists of a group of agents controlled by a set of algorithms which together represents an effective tool for designing and optimisation of distribution systems.

1.1 Agents

The **production agent** is designed to deliver products into the simulated supply chain. It is characteristic with available amount of products that is willing to provide to transportation agents during a certain period of time. In SCSS the production agent represents the production plant which produces goods.

The **storage agent** ensures the storing of goods provided by a transportation agent until it is transported to retailer agents by other transportation agents. Storage agent is characteristic with the storage capacity and geographic location. In SCSS the storage agent represents a warehouse.

The **transportation agent** connects production agents, storage agents and retailer agents. Its task is to ensure the physical flow of goods to the right place at the right time. Transportation agent is characteristic with transportation capacity and speed of transportation. In SCSS the transportation agent represents any means of transport.

The **retailer agent** takes the products from transportation agents. It is characteristic with a plan of the delivery where the requirements on a certain amount of a product are specified during the simulated period of time. Each retailer agent is also characteristic with a geographic location and the lead time representing the maximum of time that a retailer agent is willing to wait for goods delivery. In SCSS the retailer agent represents customers.

1.2 Algorithms

According to purpose and mathematical background the set of algorithms used in SCSS to control agents can be divided into the three phases each relating one another.

The goal of Phase 1 is to find optimal location of $i = 1,2,...,m$ selected logistic objects (storage agents) serving a set of $j = 1,2,...,n$ customers (retailer agents). In Phase 1 **Location Algorithm (LA)** is applied in a way described in [16]. As input data GPS coordinates of served customers and total amounts of products demanded by customers during certain period of time are specified. The objects are placed in a way leading to the minimization of function Z in the form of Eq. (1):

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} q_{ij} \cdot d_{ij} \tag{1}$$

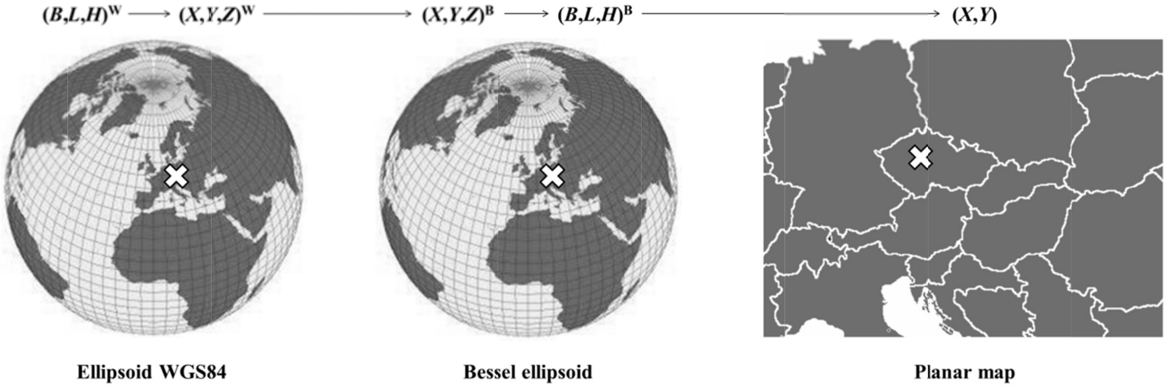
where d_{ij} is shipping distance and q_{ij} is the total amount of products which is transported among located object and customers in the selected period of time.

Shipping distances d_{ij} are obtained using Eq. (2):

$$d_{ij} = k_s \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \tag{2}$$

where (X_i,Y_i) represent new object coordinates, (X_j,Y_j) served customer coordinates and k_s is the correction of a straight distance depending on a density of road network. According to [16] is for the Czech Republic value of k_s set to 1.235. (X_j,Y_j) are obtained from GPS coordinates using the transformation to plane. This process ensures that shipping distances correspond to real values. The longer the distances the more important to use the transformation because of curvature of the Earth. As SCSS is particularly suitable to optimize the distribution systems placed in Central Europe (namely in the Czech Republic and Slovakia) transfer to coordinate system valid for this area is used and its basic principles are illustrated in Fig. 1. Input values of GPS coordinates, northern latitude $(B)^W$ and eastern longitude $(L)^W$, represent geodetic coordinates which has to be at first transformed to rectangle coordinates $(X,Y,Z)^W$ in geocentric system in Ellipsoid WGS84. Although value of altitude $(H)^W$ has no importance for final location in planar coordinates it is necessary to use it in first three steps of transformation. Therefore in the beginning its value is defined to zero. Next step is transformation to system of Bessel ellipsoid $(X,Y,Z)^B$ and reverse transformation from rectangle coordinates to geodetic coordinates $(B,L,H)^B$. Last step is the transformation to planar coordinates. The result of transformation is the projection of location of any site in rectangular coordinates in the form of (X,Y). System of transformed locations is given in meters. Additional information can be found for example in [9] and [11].

Fig. 1: Illustration of transformation GPS coordinates to planar coordinates



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The outputs of Phase 1 represent the locations of objects, shipping distances summed up to the matrix of the distances and the territories assigning each customer to one located object. For interpretation of results at the end of Phase 1 has to be done reverse transformation of planar coordinates to GPS coordinates. After this transformation, is possible to identify locations of new logistic objects on regular map. Reverse transformation is described in [9], [11]. Important part of searching locations for new objects is also evaluation results due to real geographic conditions when has to be verified if proposed location is suitable in terms of landscape, commercial premises or required infrastructure.

The goal of Phase 2 is to plan the transportation routes connecting storage agents with retailer agents in a way that transportation agents ensuring the flow of goods achieve the highest savings $s(j,j')$ of travelled distance in the form of Eq. 3 while respecting the requirements of retailer agents on lead time.

$$s(j,j') = d(D_i,j) + d(D_i,j') - d(j,j') \qquad (3)$$

where storage agent's coordinates represent a depot D_i, retailer agents represent $j = 1,2,...,n$ demand startpoints, $j' = 1,2,...,n$ demand endpoints, $d(D_i,j)$ represents the distance between a demand point and the depot and $d(j,j')$ represents the distance between two different demand points ($j \neq j'$). In Phase 2 **Clarke&Wright's Savings Algorithm (CWS)** is applied in a way described in [4]. As input data number of located storage agents, territories and matrix of the distances are used all coming from Phase 1. Furthermore, lead time required by retailer agents, retailer agents' lead time demand observations in a certain period of time and the maximal capacity and average speed of transportation agents' carriers are used. The outputs of Phase 2 represent routes characteristic with travelled distance, amount of transported goods and number of served demand points.

The goal of Phase 3 is to select a stock control policy of $i = 1,2,...,m$ storage agents ensuring $j = 1,2,...,n$ retailer agents' demand satisfaction on $k = 1,2,..,o$ items in $t = 1,2,..,T$ periods in a way leading to the minimization of average stock. Furthermore, the storage capacities of storage agents and the requirements on goods deliveries from $l = 1,2,...,q$ production agents are specified. In Phase 3 **Past Stock Movement Simulation (PSMS)** is applied in the structure described in [6]. As input data number of located storage agents and territories are used coming from Phase 1. Furthermore, retailer agents' demand observations, production agents' lead times and package receipt for all demanded items, the maximal capacity and average speed of transportation agent's carriers and the required fill rate is used. The territories are specified using $w_{j,i} = 1$ if j^{th} retailer agent is served by i^{th}

storage agent or $w_{j,i} = 0$ otherwise. Aggregated demand of i^{th} storage agent on k^{th} item (i.e. $Demand_{k,t,i}$) is evaluated for $t = 1,2, .., T$ periods as:

$$Demand_{k,t,i} = \sum_{j=1}^{n} Demand_{k,t,j} w_{j,i} \tag{4}$$

where $Demand_{k,t,j}$ represents j^{th} retailer agent's demand on k^{th} item. In each t^{th} period stock movements are represented by met retailer agents' demands (stock decrease) and the arrival of replenishment orders delivered from production agents by transportation agents (stock increase). Replenishment orders are of constant size when using reorder-point, reorder-quantity stock control policy (Q-system) or of variable size in case that reorder-point, order-up-to level stock control policy (PQ-system) is employed. During the simulation run missing quantities $MQ_{k,t,i}$ of k^{th} item as well as the final stock levels $FS_{k,t,i}$ in each t^{th} period are recorded. To assess the efficiency of storing and ordering the average stock $x_{avg,k,i}$ is evaluated from the final states of all simulated periods as:

$$x_{avg,k,i} = \frac{\sum_{t=1}^{T} FS_{k,t,i}}{T} \tag{5}$$

The ability to satisfy the demand is evaluated in the form of the fill rate ($FL_{k,i}$) representing the demand that can be satisfied right from the currently available stock. To evaluate the fill rate for the stored item the missing quantities obtained during the simulation run are used in a way leading to Eg. (6):

$$FL_{k,i} = 1 - \frac{\sum_{t=1}^{T} MQ_{k,t,i}}{\sum_{t=1}^{T} Demand_{k,t,i}} \tag{6}$$

Evaluated fill rate is compared to the fill rate required by retailer agents and for the combinations of control parameters of available stock control policy that complies with requirements the one with minimal average stock is chosen. Based on the placed replenishment orders and with the respect to production agents' lead times goods deliveries from production agents to storage agents are planned trying to fully utilize transportation agents' carriers with the maximal capacity. The flow of goods incoming to a storage agent (planned goods deliveries based on replenishment orders) decreased by the flow of goods outgoing from a storage agent (met retailer agents' demand) provides the information about the maximal quantity of goods stored by a storage agent during a certain period of time which can be easily recalculated to necessary storage capacity with help of the package receipt.

1.3 Distribution system efficiency assessment

To assess the efficiency of a distribution system represented by a selected number of located storage agents distribution cost analysis is employed. Input data represents the outputs coming from Phase 1−3 such as number and locations of located storage agents, routes connecting storage agents and retailer agents characteristic with travelled distance, amount of transported goods and number of served demand points, storage agents' storage capacities, average stock levels of stored items and plan of goods deliveries from production agents to storage agents

Based on $q = 1,2,...u$ routes obtained in Phase 2 transportation costs C_1 are evaluated as:

$$C_1 = \sum_{q=1}^{u} RD_q r_t \tag{7}$$

where RD_q represents route distance (for example in km) and r_t is transportation rate addicted to the capacity of used carrier.

Similarly based on $x = 1,2,...y$ routes obtained in Phase 3 as the plan of goods deliveries among production agents and storage agents transportation costs C_2 are evaluated as:

$$C_2 = \sum_{x=1}^{y} RD_x r_t \tag{8}$$

Based on the Storage agents' storage capacities operating costs C_3 are evaluated as:

$$C_3 = \sum_{i=1}^{m} S_i r_s \tag{9}$$

where S_i represents storage capacity (for example in palette sites, m^2 etc.) and r_s is storage rate (for example in € per one palette site, m^2 etc.) addicted to the storage capacity.

Based on average stock levels of k stored items held by m storage agents' capital costs C_4 are evaluated using Eq. (10):

$$C_4 = APR \sum_{i=1}^{m} \sum_{k=1}^{o} x_{avg,k,i} p_k \tag{10}$$

where APR represents adequate annual percentage rate reflecting the possibility of alternative investment of money otherwise bounded in stock and p_k is the sell price of stored item.

Total distribution costs C can be evaluated as:

$$C = C_1 + C_2 + C_3 + C_4 \tag{11}$$

2 Results and Discussion

We apply SCSS on a real task dealing with redesign of a distribution system of products coming from chemical industry. These products are distributed in small size consumer packaging within area of the Czech Republic. The goal of the project is to redesign the current distribution system while minimizing the distribution costs and respecting required service level of retailer agents in the form of the fill rate and lead time.

2.1 Task characteristic

Nowadays, distributed chemical products are produced by 2 production agents with sufficient manufacturing capacity to satisfy all customer requirements. The total produced amount is about 30 000 tons per year. The products are offered in about 1300 retailer stores placed in the whole area of the Czech Republic (see Fig. 2) with total demand density displayed in Fig. 3. Retailer stores are supplied from 6 warehouses trying to reach required retailer agents' lead time of the length of 2 days and required fill rate 98 %. The available storage capacities range from 600 to 7200 palette sites yearly consuming storage capacities operating costs displayed in Fig 4. Production agents guaranteed lead time is of the length of 14 days. Transportation agents' carrier capacities range from 1 to 7 tons with the transportation rates ranging from 0.345 €/km to 0.711 €/km. Annual percentage rate is suggested to be 1.53 %.

Fig. 2: Contemporary structure of distribution system

Source: Authors

Fig. 3: Customer demand density

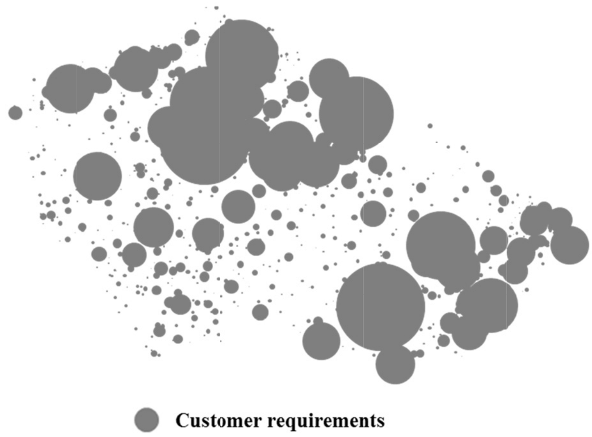

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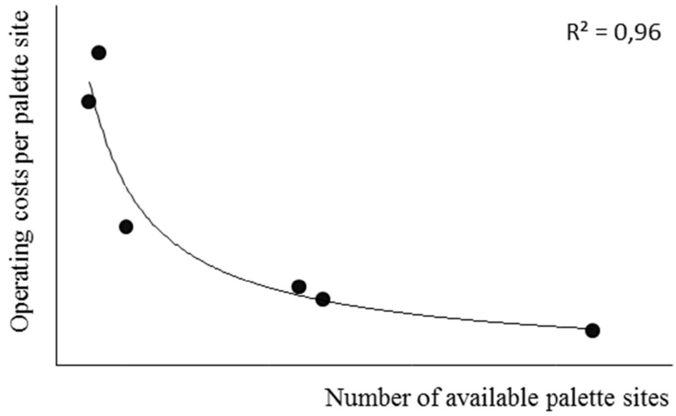
Fig. 4: Storage capacities operating costs depending on number of available palette sites



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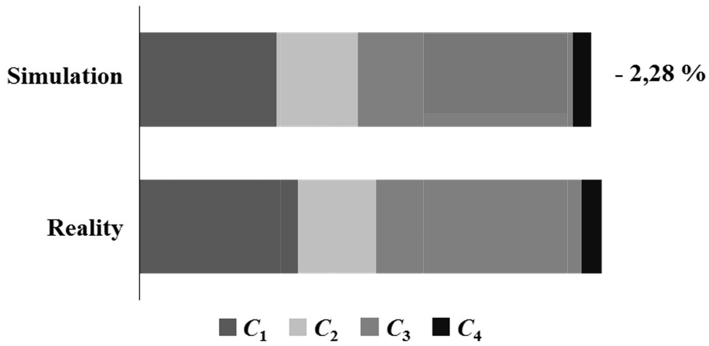
2.2 Contemporary distribution system simulation and SCSS validation

Omitting Phase 1 in SCSS (i.e. warehouse location) we simulated contemporary state of the distribution system using known warehouses locations. The outputs of the simulation recalculated to partial distribution costs C_1–C_4 are compared with the real distribution costs spent in simulated period (see Fig. 5).

Fig. 5 Comparison of the real distribution costs and the distribution costs obtained by simulation



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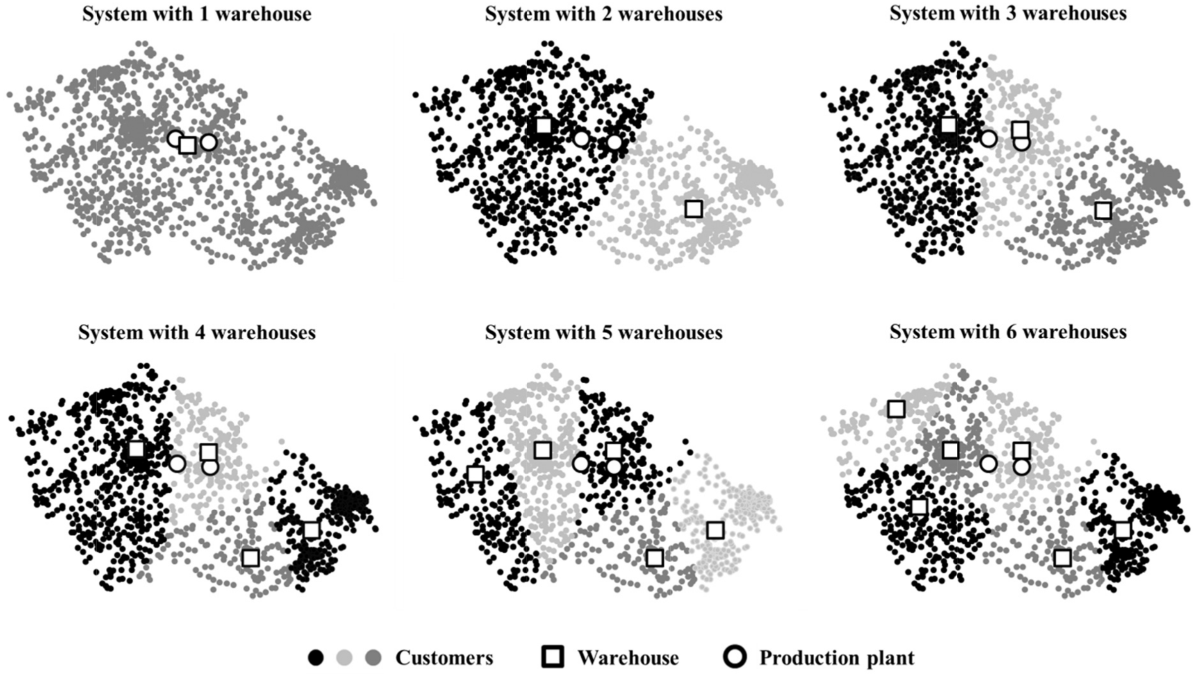
The results show the reserves in contemporary vehicle routing and stock management in about 2 %.

2.3 Distribution system redesign

In view of the current state of the distribution system and with the respect to the serviced geographic area we decide to examine 6 scenarios differing in the number of located warehouses that ranges from 1 to 6. For each simulated scenario we obtained the locations of warehouses and the territories carrying out SCSS Phase 1 (see Fig. 6).

Fig. 6 Warehouse locations and the territories of simulated scenarios



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Based on the warehouses locations and carrying out SCSS Phase 2 and Phase 3 we obtain the inputs to the distribution costs analysis. For each simulated scenario the transportation costs among storage agents and retailer agents C_1 and among production agents and storage agents C_2 are displayed in Fig. 7, storage capacities operating costs C_3 and storage agents' capital costs C_4 are displayed in Fig. 8, total distribution costs C are displayed in Fig. 9.

Fig. 7 Transportation costs C_1 and C_2

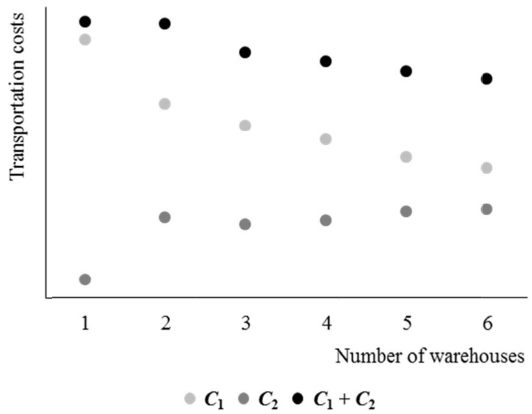

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Fig. 8 Storage capacities operating costs C_3 and storage agents' capital costs C_4

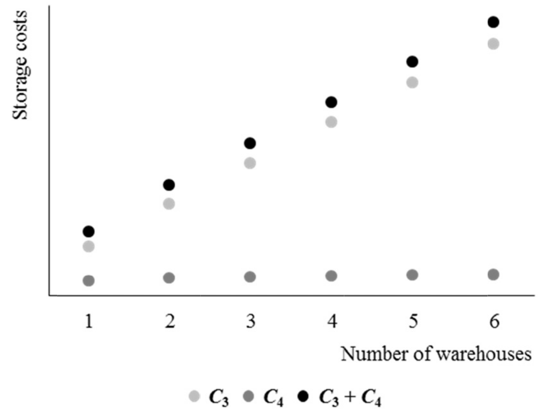

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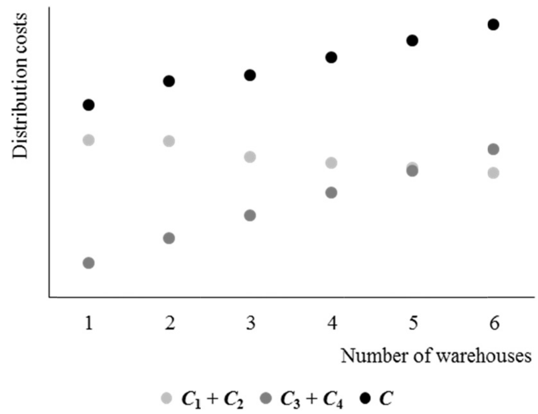
Fig. 9 Total distribution costs C



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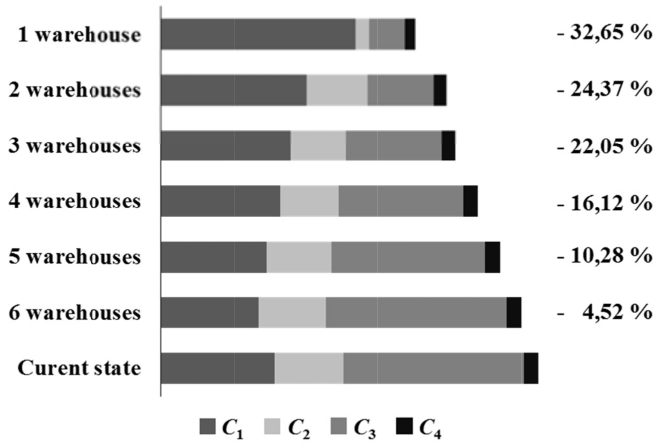
Finally, total distribution costs of all simulated scenarios are compared with the real distribution costs (see Fig. 10) achieving almost 33 % yearly distribution cost savings in case of the distribution system with 1 warehouse.

Fig. 10 Comparison of the real distribution costs and the distribution costs for 6 simulated scenarios differing in number of located warehouses



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Conclusion

SCSS represents the powerful tool for the distribution system redesign and optimisation. It has the ability to assess proposed structure of the system with help of the distribution costs analysis and therefore to compare its performance with contemporary state and estimate potential savings. Furthermore the parts of SCSS such as CWS and PSMS can be used individually in operative vehicle routing and stock management. However there are some possible improvements to become our simulator more complex. First, SCSS should be supported by a forecasting method to work not only with historical customer demand observations. We consider to implement forecasting methods for the time series with trend (i.e. Holt's method), time series with trend and seasonality (i.e. Winter's method) and time series with intermittent demand (i.e. Croston's method and their modifications). The selection of appropriate forecasting method should be performed using the measures of accuracy such as mean absolute deviation or root mean square error. Second, PSMS should be supplemented by the risk analysis of storing describing potential risks connected with intermittent demand items storing, very expensive items storing and items with high deviation of demand storing. These are the next challenges for our future work.

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