LDNST: A PROTOTYPE SUPPLY CHAIN SIMULATION TOOL FOR EVALUATING THE SUPPLY CHAIN DISTRIBUTING STRATEGIES

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ABSTRACT
LDNST (Logistical Distribution Network Simulation Tool) has been modeled and developed to assist of studying the alternative stocking locations, distribution strategies, and the daily routing schedule in a food supply chain. The model represents the distribution network of a German food producer. The company produces thousands of product types and serving a lot of distribution centers in Germany and Europe. This paper describes the specific logic details of the developed simulation tool along with its effectiveness in comparing distribution strategies for locating inventory and minimizing total logistic costs within the supply chain levels.

One of the main objectives of this paper was to present the design and development steps of a real life supply chain simulation model of a German food supply chain firm, which will used in assisting the logistics supply chain managers in evaluating the distribution supply chain performance measures. Therefore, some theoretical and practical operational modeling logics have been considered in the developing the Logistical Distribution Network Simulation Tool (LDNST) according to a conceptual supply chain framework was developed before utilizing the SCOR level 1 and 2 and The use case map (UCM) notation method. In this paper detailed operational elements proposed in SCOR 6.1 model levels 3 and 4 more see in [1,2].

KEY WORDS
Supply Chain Modeling, Simulation, Logistical Distribution Network

1. Introduction
Distribution network design problems have received increasing attention from the research community in recent years because great savings are expected from a better-designed network. Work has been performed at the modeling and solving levels simultaneously [1,2]. Supply chain network design decisions have a significant impact on performance because they determine the supply chain configurations and set constraints in which inventory, transportation and information can be used either to decrease distribution network costs or increase responsiveness [3,4].

Early work on designing distribution networks focused on locating warehouses in relation to customers. The warehouse location problem was the first issue in the distribution network design because it accounts for the transportation costs from the central warehouses to the customers (outbound transportation, direct shipments), but it does not account for the transportation costs between suppliers and the central warehouses (inbound transportation). Accounting for the location of suppliers increases the complexity of the problem and brings it to the class of network design problems.

The simulation based heuristics methodologies were selected as solution methodology utilized in this paper to quantify how well alternative networks would function through variation in demand and supply. The simulation models assists in answering to the following questions:

1. What are the relationships between inventory policies and the resulting safety stock inventory levels, customer service levels, and redeployment of stock?
2. Does the location of inventory storage for different classes of products have an effect on total inventory levels and redeployment of stock?

Our aim contribution in this paper is presenting and discussing our details modular and reusable logistic activities according to a conceptual supply chain framework developed utilizing the UCM and SCOR ver. 6.1 model considering several real life logistic business processed and strategies. Those selected logistic business processed and strategies effects on the performance of the supply chain in terms of objectives such as delivery time, order picking processes, order fulfillment strategies and cost minimization. As a result, the proposed sub models
based on SCOR level 3 and 4 were discussed in details in section 3.

2. Modeling Supply Chain with DOSIMIS-3

DOSIMIS-3 was developed by SDZ GmbH [5]. The DOSIMIS-3 is a discrete event simulator for material flow and logistic aspects, enabling the user to intuitively analyse production and assembly, material flow and transport and other logistic systems.

The first DOSIMIS-3 version was launched in 1984 with new versions released every year, with an intuitive and interactive graphical user interface that is easy to use. Hidden behind the surface, DOSIMIS-3 offers a specific functionality for simulating production and logistic processes. That allows the building of material flow models based on a process-oriented model, an event oriented model or a combination of both.

A specialized supply chain library policy controller was developed considering the supply object library proposed by Biswas and Narahari 2004 [6], and real life business processes (such as order-picking and consolidation process), with the help of the conceptual SCOR models, that were integrated with the DOSIMIS-3 tool to construct the Logistical Distribution Network Simulation Tool (LDNST).

So whenever, the developed supply chain library policy controller DLL is called, the supply chain location input data is read. All functions and algorithms procedures are written in visual C++ programming language, which takes care of the planning activities proposed by the SCOR 6.1 model. The overall proposed integrated LDNST simulation model framework is demonstrated and broken into several main sequential steps and phases. The developed supply chain library policy controller DLL and DOSIMIS-3 tool are linked by a designed interface simulation cockpit as shown in Figures 1 and 2 See more in [1].

Each supply chain location has been assigned to a specific controller with associated control policy and input data files. In such a way, LDNST was employed using different sets of input data without affecting the model code.

This approach offers more flexibility in implementing more experimental distribution scenarios without the need of reprogramming. The DOSIMIS-3 model is responsible for managing the logic by which the model entities and resources interact dynamically with each other; each group of blocks has a corresponding representation, and these can be combined into a sequential block diagram Figure 3 depicts a screen dump of a simple supply chain consisting of 1 supplier and 5 distribution centers with 10 demand point locations represented by an appropriate abstraction of DOSIMIS-3 module as seen in Figure 4. (For more details on other DOSIMIS-3 modules see in [5]). The developed supply chain library policy controller DLL considers the complex decision algorithms and presents them by the decision table symbol.
2.1 The Supply Chain Simulation Model Characteristics

1. Entities represented as examples of the orders, shipments, tours, product types.
2. Attributes are the characteristics of the entities with a specific value that can differ from one to another e.g. orders are assigned to shipment delivery and vice versa.
3. Resources are the things like space in storage area of limited size, truck capacity, etc

2.2 The Supply Chain Validation Methodology

One of the most important aspects in the simulation studied is the validation of the model. If the model is not valid, then any conclusions derived from the model will be doubtful some authors like Law and Kelton [7] described that the validation phase passes through 3 important steps:

1. Verification determines that the simulation model performs as programmed.
2. Validation is concerned with the modeling of the concept in capturing the real system representation.
3. Credibility, the end phase, describes that the owner believes in the simulation model results.

Hover and Perry [8] present the following approach to model validation: after the model is developed, it is necessary to observe the system for a period of time before collecting data for all variables and performance measures; then the same previous variables are input into the build simulation model collecting the model performance measures from the model output.

The decision on model validation is based on the degree to which the performance means are produced by the model and those means then collected from the real system. Van der Vorst [] mentions that it is impossible to perform a statistical validation test between the model output and the real system output due to the nature of these data, where the output process of most real systems and simulation are non-stationary, and auto corrected, which means that the distribution of those data changes every time with different values and they are not correlated.

Law and Kelton [7] mentioned that it is most useful to ask whether or not the difference between the system and the model output is considered to affect any conclusions.

3. Description of the Developed Supply Chain Simulation Model

In the developed Logistical Distribution Network Simulation Tool (LDNST), the supply chain planner enters or imports data of the supply chain distribution network, and LDNST predicts the performance, operationally and financially, of the proposed network. If the current network is entered in, alternative scenarios can be tried, in order to see how the current operation will function if e.g. demand falls, rises, spikes seasonally, for one product, several products, or entire product classes See [1,2].

LDNST also lets the user try out changes to the existing distribution network configuration, to see what the impact will be. Thus, users can evaluate what the effect would have been on the last scenarios financially if they had implemented make to order (MTO) instead of make to stock (MTS), or if one of the logistic center hubs had been closed, or if inventory had been consolidated on full trucks prior to shipping them [1,2].

The following network specifications were considered in LDNST:
• **Network Structure:**
  - Products - weight, size, sales price,
  - Sites - location, type of site, capacities,
  - Real demand, forecasted or distribution - time and place it occurs, order quantity and required product.

• **Network Policy:**
  - Inventory Policy - where (if at all) inventory is stocked, how often it is counted, when it is reordered, handling, holding inventory costs.
  - Replenishment Policy – how much quantity should be ordered and based on what concept (pull, push, hybrid),
  - Sourcing Policy - where orders for re-supply get handled, and which site supplies which products,
  - Transportation Policy - how products are transported, Less than Truck Load (LTL), Full Truck Load (TL), direct shipments or hybrid and how much shipment costs are affected

• **Raw materials Sourcing and Production:**
  - Raw materials suppliers and production policies are modelled using the black box: simple production lead-time and quantities estimated.

The LDNST supply chain library policy controller DLL main elements will be explained in the next sections.

### 3.1 Developed Supply Chain Library Elements

The supply chain library controller is a collection of system elements; algorithms and processes that together control and manage the system dynamics. The model consists of the basic elements representing all the activities and supply chain business processes that are performed in each location according to the supply chain network, items (materials), inventories, retailers and customers’ allocation and shipments in the network. Table 1 summarizes the main library control classes within LDNST supply chain simulation framework; in addition, it is discussed how they are organized and how they behave. The current developed library consists mainly of 14-object classes representing various elements and components in the distribution supply chain under study.

<table>
<thead>
<tr>
<th>Class Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABC and XYZ Products Class</td>
</tr>
<tr>
<td>Products Information Class</td>
</tr>
<tr>
<td>Order Management Class</td>
</tr>
<tr>
<td>Truck Capacity Class</td>
</tr>
<tr>
<td>Spedition Type Class</td>
</tr>
<tr>
<td>Spedition (Shipping Cost) Class</td>
</tr>
<tr>
<td>Locations and Customers Class</td>
</tr>
<tr>
<td>Facility Location Type Class</td>
</tr>
<tr>
<td>Inventory Control Management Model Class</td>
</tr>
<tr>
<td>Transportation Strategy Class</td>
</tr>
<tr>
<td>Tour Management Model Class</td>
</tr>
<tr>
<td>Shipping and Warehousing Activities Class</td>
</tr>
<tr>
<td>Global Supply Chain Controller</td>
</tr>
<tr>
<td>General Simulation Class</td>
</tr>
</tbody>
</table>

### 3.2 Selected LDNST Supply Chain Simulation Components

The following were the main supply chain components utilized in the LDNST:

• **Supply Chain Locations:** The model prototype simulates the network of plants, central warehouses, distribution centers, and transshipment points that respond to consumer demand points of finished goods SKUs; suppliers are not considered.

• **Materials and Inventories:** Each plant produces only a specific range of finished goods stocked in central warehouses directly utilizing a push concept; no product is produced in more than one production plant. Several product types could be held in inventories at logistic center hubs (distribution center). Raw materials are not modelled in this system.

• **Transportation Methodology:** Several integrated approaches of modeling transportation shipments were considered. The transportation
lead-time is modelled as a delay time associated with moving material from one location to another (dock to dock). This delay time is assumed to be uniformly distributed between 1 to 4 working days.

- **The Packaging Unit Load:** Four forms of unit load were modelled as follows:
  - Form-1 Individual consumer product unit, which represents the smallest unit in the simulation model, customer demands are received in this form e.g. (boxes, bags, bottles,...).
  - Form-2 Cartons which pack several identical consumer product units, and forming a bigger unit load than for an individual consumer,
  - Form-3 Production Product full pallets form, packs several identical one product cartons together in one full standard European pallet with maximum of 2.4 m height indicated as \( Q_{IP} \), and
  - Form-4 Mixed pallet forms, packing several different product types together function in desired filling degree (set as 90% of the total pallets volume) and desired customer pallet height.

### 3.3 The LDNST Supply Chain Simulation Input Data Mask

A significant amount of historic data from the company’s SAP/ERP system could be integrated and transferred to the LDNST simulation model through an input data mask, such as product lists, product ABC-XYZ classification. Moreover, the global supply chain system parameters could also be defined.

Figure 5 shows both designed supply chain location input data masks linked to the LDNST model divided into 7 input blocks as follows:

1. Location information: number, type and name
2. Product information: products list, products reorder point, products up to level stocking quantities, and customer allocation, ABC-XYZ classification
3. Flow information: production, order flow in terms of customers’ demand
4. Cost information: activities location costs and shipping costs
5. Inventory policy: allowed to keep inventory or not allowed
6. Transportation policy: Pull replenishments, SF-PCR-VMI-1, SF-ADI-VMI-2
7. If allowed to have a lateral transshipment between distribution centers
8. The global system parameter reads the dimensions of the mixed pallets and the standard pallet height, pallet packing type, maximum number of pallets that can be stacked above each other, working days on the calendar and finally, whether direct shipments are allowed or not.

![Figure 5: LDNST Simulation Model Input Data Parameter Masks [1]](image)

### 3.4 LDNST Supply Chain Product Assortment and Inventory Model

The developed LDNST model invokes a multi independent items inventory model, each product facing stochastic demand and supply conditions. There is no supply–demand link between them, and their supply and demand processes are distinct. Such assumptions are actually used in commercial inventory control programs.
Zipkin [10]; Elsayed [11], and Silver et al. [12] stated different methodologies for analyzing the behavior of the multi item multi location (such as Aggregate Performance Measure, Inventory–Workload Trade off Curve, Cost Estimation and Optimization, Aggregate Sensitivity Analysis, ABC Analysis, Exchange curves).

LDNST characterizes the multi products performance with the aid of ABC-XYZ analysis which is constructed based on the demand forecasted data for each product type.

### 3.4.1 Designing of Two-Dimensional ABC-XYZ Product Classifications

It is another tactic for coping with a large number of items in a multi location problem. Essentially, it means dividing the items into a few groups. Commonly, three groups are used, labeled A, B and C on the basis of sales volume or number of orders per period, where A class has the highest value of the total supply delivered volume or the most demanded items in the supply chain during the study period or in general based on the decisions made by the management. B items represent medium values and C class is the smallest added value to the supply chain location.

Normally the A class includes only a few items, say 10 %, while the B class is large at 30 % and the C group is the largest at 60 %. Even so, the A class items typically account for the bulk of the total sales (often as much as 80 %), while the C items cover only a small fraction with the B class items somewhere in between.

Flores and Whybark [13] recommended using a two dimensional classification where the first was the traditional ABC analysis and the second based on criticality as cited in Cohen and Ernst [14]. The XYZ will be utilized as a second multi product classification scheme.

The XYZ analysis classifies the product according to an extra three categories based on the dynamic of their demand consumption rate or coefficients of variation $v(d^k_p)$ see more in Silver et al., [12]; Kljajic et al.[15].

The XYZ analysis also divides stock in classes, which differ in their prognosticating bareness. So it is guaranteed that despite the different need processes, the correct supply principles are used. X-Products are those products with homogeneous and constant demand behaviors; Y-products follow trending or seasonal patterns, while Z-products are characterized by irregular or sporadic demand behaviors and difficult to prognosticate. Table 2 summarizes suggested multi product families and classe characteristics according to ABC-XYZ classification stated by Alicke [16]. According to Table 2 the combination of ABC-XYZ classification clusters the products into nine basic families as (AX, AY, AZ...CZ) categories.

The XYZ analysis classified the products in each supply chain location based on the product coefficients of variation $v(d^k_p)$ see more in Kljajic et al.[15]; Johannes and Posten [17] as follows:

$$v(d^k_p) = \frac{\sigma(d^k_p)}{\mu(d^k_p)}$$

Such that:

- Products family X: if $v(d^k_p)$ less than or equal 0.5
- Products family Y: if $v(d^k_p)$ between 0.5 and 1.0
- Products family Z: if $v(d^k_p)$ greater than 1.0

### Table 2: Multi Products Classes Characteristics According to ABC-XYZ Classification. Alicke [16]

<table>
<thead>
<tr>
<th>Product Class and Family</th>
<th>Product Class A</th>
<th>Product Class B</th>
<th>Product Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Class X</td>
<td>Constant demand</td>
<td>High added value</td>
<td>Low added value</td>
</tr>
<tr>
<td>Product Class Y</td>
<td>Fluctuant Demand</td>
<td>Medium added value</td>
<td>Medium added value</td>
</tr>
<tr>
<td>Product Class Z</td>
<td>Sporadic Demand</td>
<td>Low added value</td>
<td>High added value</td>
</tr>
</tbody>
</table>

### 3.4.2 Modeling LDNST Independent Inventory Control Management Model

This section discusses practical inventory control models that are often used in conjunction with the developed supply chain simulation model LDNST. The proper application of an independent demand inventory system can mean significant savings. Independent demand inventory systems are based on the premise that the demand or usage of a particular item is independent of the demand or usage of other items. [10]; [11], [12]

Inventory types that can be managed with independent demand systems including most finished goods, spare parts and resale inventories. Items whose demand or usage is related to other products such as raw materials, component parts, and work-in-process inventories are often better managed using the dependent demand systems. Independent demand inventory systems were modeled as pull systems; two factors classify independent demand inventory systems, based on a review mechanism...
and the type of order quantity. The review mechanism deals with when to check the inventory to see if more stock is required. There are two basic approaches: continuous and periodic review.

The second factor was whether the order quantity is fixed or varies from order to order. Within each of the four classes of models these two factors create, the manager must also be concerned with the determination of the reorder point and the safety stock.

The simulation model was designed as \((S^k_p, S^k_p)\) multi products continuous review with variable order quantity. \((S^k_p, S^k_p)\) continuous review systems are inventory control systems that monitor the level of inventory \(I_p\) every time an inventory transaction takes place. When the inventory of an item reaches a critical level, called the reorder point \(S^k_p\), a variable replenishment order is placed. These models are often called reorder point models reflecting the order process. Figure 6 illustrates the behaviour of the theoretical \((S^k_p, S^k_p)\) product (p) inventory system.

Figure 6: Theoretical \((S^k_p, S^k_p)\) of Product (p) Continuous Review Systems with Variable Order Quantity

The advantage of the variable order quantity model is that special circumstances such as seasonality or large sales can be taken into account when placing orders. Ballou [18] classified the estimation of the \((S^k_p, S^k_p)\) pull inventory model parameters considering the safety stock as follows:

- Statistical Reorder Point (CSL \(S^k_p\))
- Stock-to-demand Reorder Point (STD \(S^k_p\))

These models and methods were the most frequently described in the literature and observed in practice for perpetual demand patterns that are projected in the short run from historical time series.

3.4.2.1 Designing the Statistical \(S^k_p\) Using CSL Method

The reorder point safety stock (safety inventory) is designed based on the desired Cycle Service Level (CSL) of decision makers. Cycle Service Level (CSL) is the fraction of replenishment cycles that end with all the customer demand being met [3,4,18]. A replenishment cycle is the interval between two successive replenishment deliveries. Therefore, CSL is equal to the probability of not having a stock out in a replenishment cycle, several suggested CSL levels could be investigated such as 99%, 95%, 90%, and 80%.

3.4.2.2 Designing the \(S^k_p\) Using STD Method

Unlike the statistical estimation of the \(S^k_p\), Stock-To-Demand is an empirical and practical approach to inventory control whereby a forecast is made at specified intervals based on such factors as convenience, requirements of multiple items in inventory, workload scheduling when orders emanate from multiple inventory locations, and supplier order-size or product lot-size minimums. Then, inventory levels are managed according to desired goals, such as a particular turnover ratio or number of days of inventory. It is usually executed in a manner similar to the periodic review method with the exception that most of the parameters of the method are set based on judgment, experience and goals for inventory.

3.5 Modeling LDNST Transportation Rates Profiles (SCNT)

Transportation rates are the prices of hiring carriers for their service. Various criteria are used in developing rates under a variety of pricing situations. The most common rate structures are related to volume, distance, and demand [18]. Two supply chain transportation rates were modeled such as: the unit outbound long haul shipping and outbound short haul shipping cost associated with the distribution to customer demand.

The non-linear dependencies of the costs from shipment sizes, and transportation distance; third-party in the supply chain transportation costs adds another dimension of complexity to the problem of the cost modeling and calculations. The transportation cost was modeled as close to reality as possible; however, function in distance and
shipment size rates with extra-related rates considering the transportation to fixed defined location in the supply, the following shows an example of transportation shipping cost types of the real supply chain network costs which motivated this paper work.

3.5.1 Modeling Long-Haul Transportation Cost Function

A sophisticated long haul transportation cost function was considered and developed where the transportation cost offered by the transportation 3rd party was classified into three main categories: 1) specific destination (e.g. logistic center hubs); 2) based on the customer location according to location zip code e.g. direct shipments; 3) special orders delivery (e.g. weight, volume, heights).

Those rates and classes were developed based on shipment quantity discount concept function in the number of transported pallets between the sources and destinations. The cost rates profiles are different from one location to another; an example of supply chain long haul transportation rates is presented and illustrated in Figure 7. If the plant central warehouse decides to send shipments less than truck capacity, a higher unit cost per pallet per class will be considered.

3.5.2 Modeling Short-Haul Transportation Cost Function

The short-haul transportation cost function was modelled and classified into two main classes: 1) distance-related freight rate; 2) special orders delivery (function in shipment weights). In Figure 8 this diagram shows an example of the short haul transportation cost as distance-shipments size related freight rate.

3.6 Modeling LDNST Replenishments Orders Cycle Time

The orders were considered as simulation entities and scheduled to be received on a daily basis. The downstream replenishments order are received by the upstream supply chain locations such as the central warehouse at 8:00 clock; in the central warehouse picks and preparing the delivery order within 6 hours such that the shipments to downstream supply chain locations will be ready at 18:00 clock in the plant central warehouses shipping area.

The customers’ orders are scheduled to be delivered in the morning at 6:00 clock only when the whole customer order is satisfied, otherwise a partial shipment order is placed depending on the order fulfiment strategy discussed later, the maximum replenishments order delay between downstream locations and upstream locations can not exceed more than 5 working days and between downstream and customer locations not more than 1 delivery day as shown in Figure 9. Figure 10 depicts the modelled order activity delay. Only abstracted main supply chain activities are modeled. The order cycle time considered the weekend period in account.
3.7 Modeling Handling and Order-Picking Activities

It is easy to think of the warehouse as being dominated by product storage. There are many activities that occur as part of the process of getting material into and out of the warehouse. Most warehouses engage in the these activities (receiving, pre-packaging, put away, storage, order picking, packaging and or pricing, sorting and/or accumulation, and finally packing ad shipping).[19]

Consider put away activity as the act of placing merchandise in storage. It includes both transportation and placement component, and the order picking activity as the process of removing items from storage to meet specific demand requirements represents the basic service that the warehouse provides for the customer, and is the function around which most warehouse designs are based. In a real life supply chain customer demand may be met with a desired specific pallet height and quantity $Q_{fp}$ that is differ in amount of the production product full pallets $Q_{fp}^p$. Such a case results in extra order picking activities. A perceptual Negative Order-Picking Policy (NOPP) was modelled in case the customer full pallet less than standard full product pallet $Q_{fp}^p < Q_{fp}$ which results minimizing the number of picked cartons in the warehouse. For example, the proposed negative order-picking strategy mechanism of three customer orders cases is summarized in Table 3.

### Table 3: An Example of Negative Order-Picking (NOPP) Policy

<table>
<thead>
<tr>
<th>Customer Full Pallet Quantity</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pal</td>
<td>1x 24 cartons --&gt; 12 cartons picked down</td>
</tr>
<tr>
<td>1.5 Pal</td>
<td>1x 16 cartons --&gt; 8 cartons picked down</td>
</tr>
<tr>
<td>2 Pal</td>
<td>2x 12 cartons --&gt; 2x 12 cartons picked to new pallet</td>
</tr>
</tbody>
</table>

### 4. Selected and Proposed Supply Chain Performance Measurers

The SCOR model classified performance measures in terms of effectiveness and efficiency in accomplishing a given task in relation to how well a goal is met. In the logistics and supply chain context, effectiveness is concerned with the extent to which goals are accomplished and they may include lead-time, stock out probability, and fill rate. Efficiency measures how well the resources are utilized, for which the measures may include inventory costs and operation costs [20].

Among the extant Supply chain performance conceptualizations, the SCOR model provides a useful framework that considers the performance requirements of member firms in a supply chain. Table 4 provides a useful framework for developing a construct and the corresponding instrument for supply chain performance measurement utilized in the simulation model. Several selected supply chain performance measures have to be distinguished between different simulation scenarios categorized by objectives that are based on as i) Cost or profit, ii) Measure of customer responsiveness, iii) Productivity.
Table 4: Selected SCOR Performance Measures [20]

<table>
<thead>
<tr>
<th>Supply Chain Process</th>
<th>Measurement Criteria</th>
<th>Performance Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer facing</td>
<td>Supply Chain Reliability</td>
<td>Delivery performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Order fulfilment performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Perfect order fulfilment</td>
</tr>
<tr>
<td></td>
<td>Flexibility and Responsiveness</td>
<td>Supply chain response time</td>
</tr>
<tr>
<td>Internal facing</td>
<td>Costs</td>
<td>Total logistics management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value added productivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Processing cost</td>
</tr>
<tr>
<td></td>
<td>Assets</td>
<td>Cash to cash cycle time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inventory days of supply</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assert turns</td>
</tr>
</tbody>
</table>

5. Distribution Network Case Study

In this paper, we consider a complex distribution network of a real life problem. The industrial company is located in Germany and produces 3 major brands of products and about 3000 SKU per day (stock keeping unit). Currently they have several production locations and for storing their products, they have central warehouses, about 30 regional distribution centers, and approximately 5000 retailers and customers spread over Germany. Figure 11 and 2 are showing the distribution network of the company inside Germany and locations. [1,2]

5.1 CASE STUDY Simulation Assumptions

The following are the most important assumptions considered in designing the simulation model:

- Dynamic process environments,
- The orders determine the flow of goods, in all orders, the sources are plant central warehouses and the sinks are the end customers demand type,
- Every plant central warehouse is assigned to all logistic center hubs (multi sourcing condition),
- Every customer demand point is assigned uniquely to one logistic center hub (No lateral transshipment allowed),

![Candidate Supply Chain Locations](candidate.png)

![Allocation of Supply Chain Locations](allocation.png)

**Figure 11: Logistical Distribution Network**

The logistics manager in the company would have to study some operating strategies to evaluate and improve the existing network. The LDNST model was designed to investigate these strategies.

**Figure 12: Plants Central Warehouses and Distribution Centers Locations**

- Standard European pallet (SEP) with maximum of 2.4 m height will be used to move the full pallet product from the warehouses to logistic center hubs with the following dimensions: (Length: 1.2 m * Width: 0.8 m * Height: 2.4 m),
- The mixed pallet of the following dimensions will be used to move the product from the logistic center hubs to retailers and customers: (Length: 1.2 m * Width: 0.8 m * Height: 1.8 m * Percentage of filling space: up 90%),
- Transportation costs based on the direct tour with one destination will be accounted for, with no routing allowed,
- The simulated truck capacity for long and short haul is (34-38) SEP,
- Transportation lead-time from plant central warehouse to logistic center hub is set to an internal delay of 1-4 days,
• No specific quantity or time temporal shipment consolidation procedure was implemented only the daily shipment consolidation algorithm based on pull principle,
• It is allowed to stack 2 pallets above each other (if possible) with a maximum height of 2.4 meter (truck consolidation strategy),
• The distribution supply chain network operated under the pure pull network concept, and the production operates under the push strategy.
• Standard European Pallet (SEP) with 2.4 m height will be used to move the full pallet product from the warehouses to regional distribution center. Length: 1.2 m * Width: 0.8 m * Height: 2.4 m
• The mixed pallet of the following dimensions will be used to move the product from the regional distribution center to retailers and customers : Length: 1.2 m * Width: 0.8 m * Height: 1.8 m * Percentage of utilized space: 70%
• Transportation costs based on the direct tour with one destination will be accounted, no routing allowed.
• Direct shipments from central warehouse to retailers or customers are allowed if the shipment size up to truck capacity.
• The used truck capacity is 38 SEP

5.2 Modelled Logistics Costs
The total logistics costs consists of the following:
• Transportation costs: Depends on number of pallets and distance (ZIP code)
• inventory costs
• Order costs
• Order picking costs per pallet
• Warehouse outgoing goods costs per pallet
• Regional distribution centers incoming goods costs per pallet
• Toll fees per kilometre travelled

Thus the following variants and scenarios are:
• Scenario 1: Actual situation – 30 regional distribution centers and direct shipments to special customers from the central warehouses are allowed.
• Scenario 2: 30 regional distribution centers without inventory, no direct shipment, and the orders served by LTL strategy.
• Scenario 3: 30 regional distribution centers without inventory, no direct shipment, and the orders served by TL strategy.
• Scenario 4: 20 regional distribution centers without inventory, no direct shipment, the orders served by TL strategy and the remaining 10 regional distribution centers with inventory.

Table 5: Simulation Scenarios

<table>
<thead>
<tr>
<th>Operating Strategies</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Shipments</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(MTS)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution Centers</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>(MTO)</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cross Docking</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Transportation Policy</td>
<td>TL</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>LTL</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

TL: Full Truckload LTL: Less than Truckload

The above scenarios were proposed based on the discussion with the logistical department in the company.

5.4 Simulation Results
In this project the study period was regarded for one year. The data extracted from the real system of the company contained the demands, customers, orders, as well as export quantities. The scenarios described above and their strategies were implemented into the simulation model and accomplished experiments.

After the validation phase of variant 1 (actual situation), all further scenarios with the met standard attitudes were accomplished. By the help of supply chain reporter programmed in visual basic to assist in scrutinizing the output results, the results are summarized and described in the following diagrams. Figure 13, 14, 15 and 16.
The comparison and the evaluation of the different scenarios as shown in the figures 13, 14, 15 and 16, permit the following conclusions. All scenarios supply a reduction in the logistics costs. The outbound transportation costs have a highest percentage sharing in the total logistics costs as illustrated in figure 13 and 14. From figure 15 it is clear that the total logistics costs in the warehouses have been reduced while it has been increased in the distribution centers due to the reduction in the outbound transportation costs type 1. This means no more direct shipment to customers and increasing the outbound transportation type 2.

Scenarios 2, 3 and 4 proved that approximately 60-77% significant reduction in the total inventory costs has been achieved when the cross docking strategy on the distribution centers are applied as shown in Figure 14.

The scenarios 3, 4 (cross docking + truckload) gave the lowest logistics costs. Corresponding to scenario 1 results, about 1.8 - 2% cost savings have been achieved as shown in figure 16.

Scenarios 2, 3 and 4 proved that approximately 60-77% significant reduction in the total inventory costs has been achieved when the cross docking strategy on the distribution centers are applied as shown in Figure 14.

The scenarios 3, 4 (cross docking + truckload) gave the lowest logistics costs. Corresponding to scenario 1 results, about 1.8 - 2% cost savings have been achieved as shown in figure 16.

Scenario 3, 4 achieved minimum total transportation costs and highly utilized truck capacity comparing to scenario 1, this reduction was in the outbound transport part type1 while increasing in the outbound transport type 2 so to improve and reduce the total logistics costs could be done by optimizing the outbound transportation type 2. This can be achieved by the following methods:

- Reallocating the customers to the appropriate distribution centers.
- Increase of the truck filling degrees by making tradeoffs between the capacity and the costs.
- Applying the vehicle routing concept
6. Summary and Conclusion

The distribution operating strategies in the supply chain networks have a significant impact on the total logistics costs. The strategies that reduce system wide costs and improve the efficiency of the distribution networks should be more evaluated.

Discrete event system simulation is one of the most powerful tools for evaluating the dynamic aspects of the strategic distribution network design stage within a wide variety of production areas.

The simulation tool primary strength is its "self authoring" system in which each distribution network can be built for any specific manufacturing area. With its easy to use graphical interface users can quickly develop distribution network that accurately represent their system. Users are then able to evaluate “what if” scenarios with a variety of inputs to find the optimal solution. Using simulation to evaluate distribution network design can lead to better decisions saving money, increased productivity, and improved customer service.

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References