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Design and simulation of a logistics distribution network applying the Viable System Model (VSM)

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Abstract

Designing viable and integrative distribution networks is challenging for big companies. Researchers often fail to holistically design distribution networks. Thus, the aim of this study is to propose a holistic approach how distribution networks can be designed. Hereby the Viable System Model was applied. Standardized communication channels were able to be defined. In conclusion this proposed approach enables companies to reduce necessary stocks, lead times, manpower allocation and leads to an increase of the service level.

Keywords: Cybernetics; System dynamics; Viable system model; Distribution network

1. Introduction

Developing organizations capable of coping with the present competitiveness needs is not easy. Nowadays, technological development cause lags in systems of implementation, which are not able to manage efficiently the new technological impacts. Achieving sustainable long-term advantages will no longer ensure the competitiveness of companies. Clearly it is essential to focus on successive temporary competitive advantages. This fact also increases the complexity of manufacturing and assembly processes, so that the planning and control of both production and logistics becomes more difficult. This situation results in a significant increase of information which the company has to face.

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Actually it can be said that the information is the glue in organizations. It is needed for policy, decision-making, control, coordination, etc. Problems with information flows lead to negatively impact in the organization, and if these management problems with the information are not solved, finally it will become dangerously harmful to the whole system.

Then apparently it is not easy for management models nowadays to adapt themselves to present needs. To deal with this situation the biological sciences can provide more substantial guidance than the economic sciences. The main target is to adjust companies to become more flexible, so that this increased flexibility will give them the capacity to deal with problems and will increase considerably its ability to survive in a hostile environment. Thus, the paper will focus on the science called Cybernetics. This science is originally defined as the science of control and communication in animals, men and machines. Information, processing and control can be extracted from any context by science. This science extracts, from whatever context, that which is concerned with information processing and control. And inside this science, the paper will specially focus on one particular Model, the Viable System Model (VSM). Creating this Viable System Model, the organization is transformed into an autonomous system capable of adapting to those constant environment changes. The Viable System Model also exhibits many other features including spontaneous behavior and social harmony within hierarchically ordered relationships. To do this, the powerful weapon (VSM) ought to be really useful.

Distribution refers to every step taken to move and store a product from the supplier stage to a customer stage in the supply chain. Distribution is a key driver of the overall profitability of a firm because it affects both the supply chain cost and the customer experience directly.

At the FIR (Institute for Industrial Management) at the RWTH Aachen University an approach is developed in order to solve the problem of demand and supply distribution planning with the help of the Viable System Model. The aim of the research is to propose a self-regulating approach how to design distribution networks.

2. Viable system model

In order to implement the VSM in a distribution network the method of System Dynamics is applied, which is a powerful method to gain useful insight into situations of dynamic complexity. It is increasingly used to design more successful policies in companies and public policy settings [6].

System dynamics structure consists of the feedback loops, stocks and flows, and non-linearities created by the interaction of the physical and institutional structure of the system with the decision-making processes of the agents acting within it [6].

The VSM is built on three main principles: viability, recursivity and autonomy. Viability is a property of every system that is able to react to internal and external perturbations in order to maintain separate existence [1]. Thus, the aim of the project is to propose a self-regulating approach how to design distribution networks. For this reason, the VSM is applied for distribution network. The cybernetic model of every viable system consist always in a structure with five necessary and sufficient subsystems that are in relation in any organism or organization, that is able to conserve its identity (Fig. 1) [2].
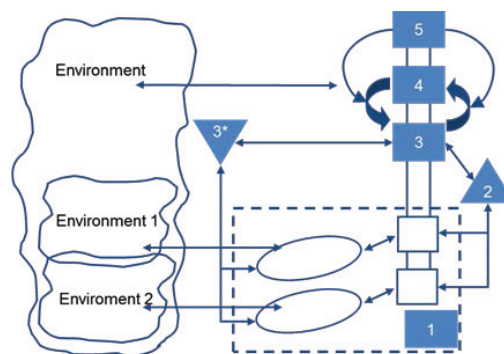

Fig. 1. The Viable System Model.

System 1 reacts to the development of the relevant operative unit´s environment and it coordinates itself with the other operative units with the objective of own stability and whole company´s stability [3].

System 2 enables the units of System One to solve their own problems allowing decentralized decision-making and solve conflicts between those units [2]. It also carries out the coordination of the operative units regulatory centres. It is an interface between Systems One and Three [3].

System 3 realizes the control of the orders that are taken in the current operations [2]. It checks the strategic activities provided by system 4 and converts them into tactical operations [4]. Systems One, Two and Three constitute an autonomic system that regulates internal stability and tries to optimize performance within a given structure and criteria [3].

System 4 does an analysis of the external environment and the internal ability to deal with it. It also makes strategic decisions [4]. The internal stability has only sense if the external factors are considered. Reception, elaboration and transmission of information from the environment are tasks of System Four in order to provide external stability [5]. It is a set of activities, which feeds the highest level of decision making. It must contain a model that represents the idea of the firm in order to inform the top management about which type of firm they are running [3].

System 5 represents the normative level that makes the balance between current operations (System Three) against future´s needs (System Four). When there is no balance, System Five plays the role of judge [2]. System Five for the firm is the top management and it determines policies and establishes the goals to take decisions [3].

3. Simulation of the logistics distribution network

The initial hypothesis is that the VSM simulation model will be able to meet customer demand with more accuracy than the Non-VSM simulation model with a better allocation of the available resources. It is expected due to its ability to implement measures in order to meet on going customer demand.

In Figure 2 you can see the different simulation models. One the left side the Viable System simulation model and on the right side the Non-VSM simulation models: Economic Order Quantity (EOQ), Reorder Point and Push until Regional Warehouse.

To sum up supply chain simulation generates supply chain knowledge by developing and validating improvements using what-if analysis and quantifying benefits supporting decision making at the strategic decision level [7].

To analyze the interaction between parameters, its impact on the KPI´s and to quantify the influence of the different models experiments with random combination of the input parameters were conducted. The purpose of the investigation is to compare the answer of the models when dealing with different input demands and to analyse how the variation of the input parameters influences the KPI's.

The VSM simulation model considers all planning tasks of a distribution network. These tasks are allocated in the different systems of the VSM (System 1-5). However the Non-VSM simulation model contains some major differences to the VSM-simulation model. In the Non-VSM simulation model it is not possible to generate demand forecasts. Even other functions as the switch between different or applying different procurement methods (System 3) are not existent. This means that a system 4 function is not correctly developed.
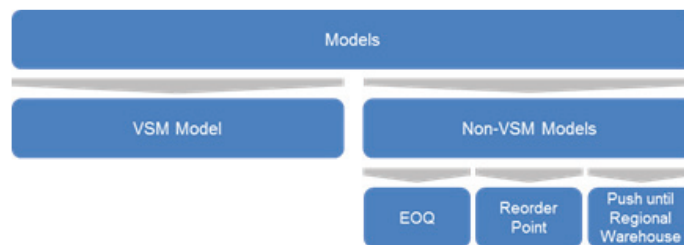
Fig. 2. Different simulation models.

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4. Structure of the model

The goal of the research is to study the behavior of different models, the VSM and the Non-VSM models:

The objective is to analyze how these models respond to different input demands. The respond is evaluated according to the following *Key Performance Indicators (KPI)*:

- Service level (%)
- Quantity delivered on time (%)
- ∑ Customer backlog (products)
- Customer backlog (days)
- Utilization ratio of employees (%)
- ∑ Total stocks (products)
- ∑ WIP (total stocks + shipments) (products)

To explain how the models works an adapted Ishikawa Diagram of Hypothesis is shown in Fig. 3. On the right side the objectives of the simulation can be seen. Point 1 to 8 indicate the conditions of the model.

4.1. Time restrictions

The simulation model will take a time horizon of 4 years. By this it is possible to evaluate and demonstrate strategic decisions such as open a new warehouse or changes our distribution strategy. It is assumed that a month has 22 working days, a year 250 working days and four years have 1000 working days.
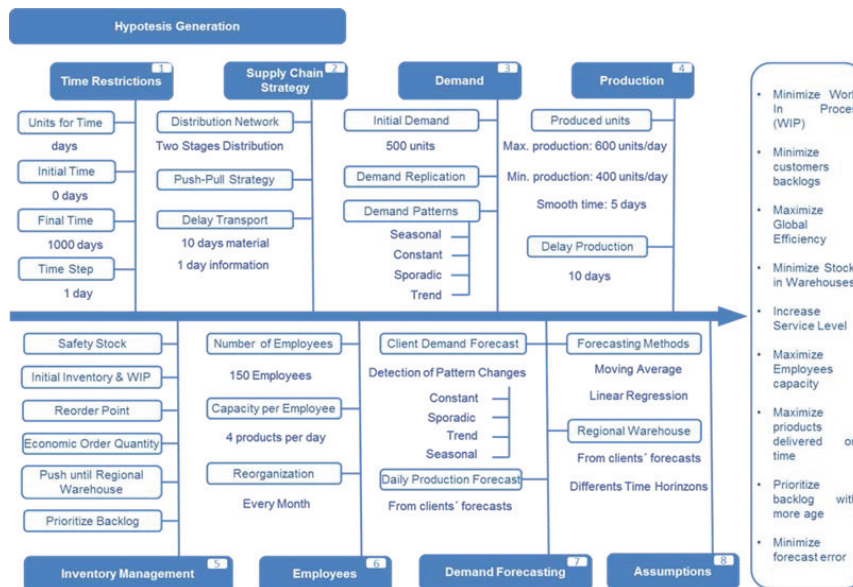

Fig. 3. Ishikawa Diagram of Hypothesis.

4.2. Supply chain strategy

The structure built is a decentralized distribution network with a hybrid push-pull approach from the production to the end customer. At the beginning of the simulation each warehouse has a certain level of inventory in each warehouse and with some quantity of products in their ongoing transportation between warehouses and customers (WIP). The distribution network presents a two stage distribution network with central warehouse. In the initial situation there are 15 customers with 3 regional warehouses opened with 5 customers per warehouse.

The decision to open a new warehouse is taken when certain backlog is reached (200 products) and this condition is maintained for more than a certain period (10 days). In this situation the decision is taken, but there is a necessary time to change the organization. In the standard this time is 30 working days. There are four different distribution networks according to the number of regional warehouses opened:

A. *Initial Situation:* Distributor one delivers to customers 1 to 5, distributor two to customers 6 to 10 and distributor three to customers 11 to 15. This is the permanent distribution network structure of the Non-VSM models.
B. *Distributor four closed and five opened:* distributor one delivers to customers 1 to 5, distributor two to customers 6 to 9, distributor three to customers 10 to 12 and distributor five to customers 13 to 15.
C. *Distributor four and five opened:* every distributor delivers to three customers. In this case customers 1-3, 6, 10, 13-15 are not delivered by the same distributor as initially. Therefore they are described with letter "b".
D. *Distributor four opened and five closed:* distributor one delivers to customers 4 to 6, distributor two to customers 7 to 10, distributor three to customers 11 to 15 and distributor four to customers 1 to 3.

4.3. Demand

In all the models the initial demand is a stationary demand, supposed normal distribution with mean and standard deviation equal to 33.3 and 5 respectively. In total the initial demand of all customers is 500 units per day. The customer demands have been created with a data generator in an Excel in order to have exactly the same demand in all the models. The demands patterns, steady, seasonal, trend, sporadic and mixed are introduce as customer demands in the models to show their behaviour when dealing with different demand situations and changes.

4.4. Production

Production can never be bigger than "600 units/day" or smaller than "400 units/day" even if the demand forecast is out of these limits. In every time period the daily production ordered is the sum of the demand forecast for every single customer with the failure that comes from the difference of the total demand and total production until this time period. This adjusting factor allows the system to regulate and to have always enough WIP products.

$$Daily\ production = \sum_{i=1}^{5} Demand\ Forecast\ for\ Distr\ i + Adjusting\ Factor \times Failure \tag{1}$$

After this order is placed the production of this batch is finished after 5 days (smooth time). Then there is a transport time until central warehouse of 10 days (delay production).

4.5. Inventory management

Different methods are used to order material such as the method of Economic Order Quantity (EOQ) or Reorder Point. Moreover the VSM simulation model is able to change between them depending on the variability of the demand, the demand pattern and the current backlog.

$$EOQ = \sqrt{\frac{2K\lambda}{iC}} * \sqrt{\frac{iC+\pi}{\pi}}; \qquad Reorder\ point = s = RT * d_{prog} + k * \sigma * \sqrt{RT} \tag{2,3}$$

Push until regional warehouse without customer backlog:

$$Stock\ sent\ Distr\ i = \frac{stock\ level\ Distr\ i}{\sum_{j=1}^{5} stock\ level\ Distr\ j} * stock\ level\ central\ warehouse \tag{4}$$

Push until regional warehouse with customer backlog:

$$Stock\ sent\ Distr\ i = \frac{customers\ backlogs\ Distr\ i}{\sum_{j=1}^{5} customers\ backlogs\ Distr\ j} * stock\ level\ central\ warehouse \tag{5}$$

4.6. Employees

There are initially 150 employees divided into 50 employees per warehouse. The Non-VSM simulation models have always the same amount of employees per warehouse while the VSM simulation model redistributes the employees every month according to the forecasted demand, the current backlog and the actual WIP.

4.7. Demand forecasting

The Non-VSM simulation model uses one method to forecast customer demand while the VSM simulation model can change between two models of forecasting depending on the pattern of the demand.

In addition the VSM simulation model can change the point of push-pull approach, move employees between warehouses and open new warehouses in order to improve its response to changes in customer demand. Moreover, by using Vensim we compare two different views of distribution networks, a Non-VSM simulation model and a VSM simulation model, which has been built applying the Viable System Model. The main difference between them is the fact that the VSM simulation model can take strategic decisions and observe its environment while the static can´t. The results were obtained by using Minitab and they show how the VSM-Model is able to meet customer demand and its changes with fewer backlogs than the Non-VSM models. It also allows lower stocks and better allocation of resources.

4.8. Assumptions of the simulation model

- The product is a finished product after the production facility.
- There is only one product in the distribution network.
- There is no stock limitation in the warehouses.
- There is no transport limitation or trucks limitation between the different stages.
- Distances between stages are constant.
- Steady supply of materials for the production process is given.
- Order information along the supply chain is available.
- Demand is not known, and historical data for all customers is available one day after the demand.
- Customers don´t change the company or order more if the last orders were not fulfilled on time.
- Customers can receive one order on different days.
- Distances between regional warehouses and customers are always the same and also when new warehouses are opened.
- New opened warehouses can be considered as a new physical warehouse or a part of the existing warehouse that takes care of its own customers.
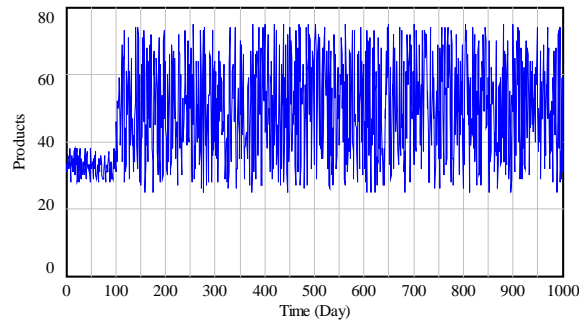
Fig. 4. Trend demand.

5. Results

First we consider a trend demand scenario which is characterized by a trendy demand, which can have a positive or negative slope. Here all the customers present a minimum of a trendy demand period over the simulation time (Fig. 4).

The VSM reached a service level of almost 99%, whereas the Reorder Point-method achieved 70%, the EOQ-method 68% and the Push-method only 30%. The amount of total units delivered not on time is more than 70 times higher for the Push-method (74,450 units), 22 times for the EOQ- and Reorder-Point-method than for the VSM (1,027 units). Also it is clear that 85-90% from the total units not delivered on time in the EOQ- and Reorder-Point-methods were caused due to a lack of employees to perform the warehouse activities. The VSM is able to solve this challenge because it can allocate the employees according to future demand. On the other hand in the Push-method 75% of the backlogs are due to lack of products in the regional warehouses that is generated by the push control logic.

If the developments of backlogs are considered over several days, it can be seen that the long-term backlogs of the Non-VSM simulation models are much higher than the backlogs of the VSM-simulation model. Also the VSM has no backlog at the end of the simulation time while the other three models present backlog over 10,000 units.

Moreover total stocks in the VSM are 50% less than for Push-method and 25% less than EOQ- and Reorder Point-method. The utilization ratio of employees is also higher in the VSM even when the stocks in the regional warehouses are lower than in the other models as seen in Table 1. This is due to coordination between deliveries, allocation of employees and the future customers demand.

Table 1. Results trend demand.

Key Performance Indicators (KPIs)	Simulation Models			
	VSM	Reorder Point	EOQ	Push until CW
On time delivery (OTD) [%]	99.78	95.35	95.17	84.33
Service Level [%]	98.47	70.07	67.95	30.45
∑Customer backlog (products)	11,208	2.64 M	3.06 M	5.93 M
Backlog customers t=1000 days (products)	0	10,441	11,166	25,491
∑Customer backlog (days)	230	4,494	4,813	10,443
∑Backlog = 1 day (products)	1,027	22,108	22,957	74,450
∑Backlog = 2 days	925	21,871	22,761	74,186
∑Backlog ≥ 3 days	9,256	2.59 M	3.02 M	5,79 M
∑Backlog caused by missing manpower (products)	328	19,835	20,092	19,123
Utilization rate of employees (%)	78,78	76,88	77,37	74,35
∑Stocks central	3.64 M	6.84 M	3.21 M	0.16 M

warehouse (products)				
∑Stocks regional warehouse (products)	4.89 M	4.36 M	8.36 M	16.24 M
∑Total stocks (products)	8.54 M	11.20 M	11.57 M	16.4 M
∑WIP (stocks CW + shipments PF-CW) (products)	8.39 M	11.59 M	7.96 M	4.91 M
∑WIP (stocks RWs + shipments CW-RW) (products)	9.63 M	9.05 M	13.10 M	21.02 M
MAD Total demand – Forecast for production order	19.10	17.65	17.65	17.65
∑Demand of all customers (products)	475.012	475.012	475.012	475.012

6. Conclusion

From the results it is clear that in most cases the VSM approach gives us a better response in all KPI terms of delivery performance, stock, WIP, etc.. In the cases where the VSM simulation model doesn´t respond better than all the other three Non-VSM simulation models in all KPI´s are due to the following explanations:

- Non-proper demand forecast such as seasonal demand forecast due to a lack of forecast method for this kind of pattern.
- Low/Middle Demand with no significant changes: in these cases the response in terms of delivery performance from the Reorder Point (because the VSM change more to EOQ to be costly efficient and it has more chances to fail due its lack of dynamic response. When Push until regional warehouses the response is better due to the allocation of more stock close to the customers in the regional warehouses but involving high WIP & stock levels that lead to high costs.

Therefore the conclusion is not that the VSM has always the best performance because this decision depends on the classical conflict of interest of logistics. In terms of allocation of the available resources this study exposes clearly how the VSM provides the structure to allocate the products efficiently (controlling).In conclusion this proposed approach can increase the efficiency of distribution networks. Also it shows how a VSM approach is better when dealing with distribution logistics networks, because it allows meeting customer orders with higher delivery service with less stocks and more efficient manpower allocation than an approach with no recursive regulation.

This Viable System Model approach is the key to successful companies with complex distribution networks. The best way to face to the aforementioned problems is to adapt companies to this model. We reckon that would make the company better and even bring it to a new level. Through the analyzed examples and cases, it is clear that such a powerful tool like VSM must be taken advantage of. The results were obtained in the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" which has been funded by the German Research Foundation (DFG) as part of the Excellence Initiative. The authors wish to thank the DFG for their support.

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