Design of a conceptual model for a maintenance object within a producer: impact on distribution network - a simulation case study

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Abstract: Nowadays, logistics can be described as an interdisciplinary strategy to optimize the production system. Availability is, therefore, the link between logistics and industrial maintenance. To manage this paradigm, maintenance management for a production process plays a key role. Therefore, the purpose of this paper is to design a holistic process-oriented approach to assess the impact of maintenance management on the distribution network and end-customer. As a result, impacts and interrelationships between maintenance and distribution towards the end-customers are derived. Based on the conceptual model, a simulation case study in a supply chain with a producer and its distribution network is developed. Goal is to observe the results of a certain maintenance strategy and its related maintenance characteristics in the subsequent steps of the production process and in the end-customer through the distribution network. The analysis of the case study is performed by means of simulation. The simulation model is built using System Dynamics (SD). Thanks to the scenarios and their results the impact of the maintenance strategy of one object could be observed. The impact depends also on other factors than only maintenance of the object such as customer demand, stocks, supply chain steps and proximity to end-customers.

Keywords: Maintenance Management, Supply Chain Management, Distribution Network, System Dynamics, Simulation Case Study.

1. Introduction

Over the last 50 years, a transition from the producers’ market to the customers’ markets has occurred [1]. During the 1950s and 1960s each operation within each stage of the supply chain tried to minimize its own costs, which defined an intracompany intraoperation scope [2]. In the 1970s the scope was expanded including the optimization of cross-functional processes [3]. Moreover, quality problems came to the forefront of enterprise management and Total Quality Management (TQM) was established [1].

The cost pressure already established in the 1980s caused by the saturation of markets and an increasing competition situation, created new quality and efficiency requirements on the enterprise process management [4]. Later in the 1980s and 1990s, companies were challenged by a high product variety and shortened time-to-market (TTM). But it was in the 1990’s, when firms recognized the necessity of looking beyond the borders of their own firms to their suppliers, suppliers’ suppliers, and
customers to improve overall customer and consumer value. This movement, titled supply chain management or demand chain management, changed the companies' focus from the internal management of business processes to managing across enterprises [5]. The development of SCM (Supply Chain Management) was driven in the 1990s by three main trends: customer orientation, markets globalization and establishment of an information society [1]. This led to a worldwide integration of value chains and to the optimization of global logistics networks in the 2000s [5].

Nowadays, logistics can be described as an interdisciplinary strategy to optimize the production system. This means that all business areas are affected by the interdisciplinary logistics strategy. Areas of logistics, such as procurement logistics, distribution logistics, reverse logistics, transportation logistics, information logistics, plant logistics, and maintenance logistics allow the aforementioned objectives to be achieved [6].

Currently there are already approaches for optimizing individual areas. However, these are usually suboptimal from a global perspective. Therefore, partial concepts and improvements are potential sources for conflict. In addition, in recent years, the importance of the orientation towards the added value process has increased considerably. Maintenance should not be isolated in this regard, but rather should be "integrated" and dependent on all functional areas involved in added value [7]. Maintenance processes are closely linked to the rest of the value-added processes such as production and procurement, as well as materials management. Production as a "customer" of the maintenance department requires the necessary availability and reliability of machines and systems. Due to this strong interconnection of the different functional areas within the company, a comprehensive maintenance consideration is essential [7]. Therefore, this research paper pursues the analysis and design of an integrated and holistic process-oriented approach with the goal to derive the impacts and interrelationships between maintenance and distribution towards the end-customers.

2. Methodology
The methodology used starts by reviewing the literature based on reference books and articles of:

- Logistics Management
- Distribution Network
- Maintenance Management

Based on the above-mentioned research a case study in a supply chain with a producer and its distribution network is designed. The producer has several production steps with their associated maintenance strategies. With this basis framework, the case study is studied by parametrizing the maintenance strategy of a maintenance object in the production process of the producer. Goal is to observe the results of this strategy and its related maintenance characteristics in the subsequent steps of the production process and in the end-customer through the distribution network. The analysis of the case study is performed by means of simulation. The simulation maintains the producer and the distribution network as well as end-customer demand with the same scheme and values in all scenarios. By doing so, it can be analysed the impact of the maintenance strategy in each step of the production process in the end-customer. Only a variation in demand is analysed with a high-demand scenario and a low-demand scenario. The simulation model is built using System Dynamics. The use of System Dynamics (SD) Modelling in Supply Chain Management has re-emerged in the recent years after a long-stagnated period [8]. SD is a rigorous method for qualitative description of exploring supply chains as far as their processes, information, strategies, and organizational limits are concerned [9]. SD can, should and will be more used to improve supply chain management in practice [10].

In the market there are different software packages that enables system dynamics modelling. Out of them, VENSIM simulation software was selected for this project. Vensim (Vensim is a registered trademark of Ventana Systems Inc.) provides high rigour for writing model equations allows to determine most convenient policy options by parametrising these policies. As a final step, the research
is analysed in terms of consequences as well as develop towards a guide for manufacturing and supply chain managers independently of their industry.

2.1. Logistics management
Logistics can be defined as market-oriented, integrated planning, design, processing and controlling of the whole associated material and information flows between a company and its suppliers, within a company as well as between the company and its customers [11]. The main goal of logistics is to be able to provide the right products in the right quantity and quality with full information at the right time at the right place [3]. Availability is, therefore, the central concern of logistics, which in turn is the link between logistics and industrial maintenance [6].

2.2. Distribution network strategy
Distribution logistics includes all storage and transport activities of the distribution of goods to the customer and the related information, control, and inspection activities [12]. It is the link between the entrepreneurial production logistics and the customer’s procurement logistics [13]. Distribution logistics is a key driver of the overall profitability of a firm because it affects directly both the supply chain cost and the customer service [2]. A distribution network strategy can be explained by the following factors:

- Cost efficiency vs. responsiveness [3];
- Centralized vs. decentralized [3];
- “Push” vs. “pull” [2].

The distribution network of a company depends on the number of different storage levels, the number of warehouses at each stage as well as on their locations and spatial association between the warehouses [12]

2.3. Maintenance strategies
The DIN EN 13306 maintenance standard defines the existing maintenance strategies: corrective maintenance, preventive maintenance, condition-based maintenance, and predictive maintenance [14]. Moreover, a further maintenance strategy, called prescriptive maintenance – still not yet standardized, but already used in practice – was also included [15]:

- Corrective Maintenance;
- Preventive Maintenance;
- Condition-based Maintenance;
- Predictive Maintenance;
- Prescriptive Maintenance.

3. Conceptual model design for a maintenance object within a producer

3.1. Description of a maintenance object within a producer’s supply chain
Given a machine defined as an object that requires maintenance activities to maintain its functionality, figure 1 represents a production process with \( n+m \) steps in which the maintenance object is one of the machines within a machine group \( n \) in a producer’s supply chain. Also, the storage steps of the distribution network are depicted until the delivery to the end-customer. Any maintenance object within a producer’s supply chain has upstream and downstream production steps, distribution network steps for the transportation towards the end-customers. In this context, the challenge that arises is which is the impact of the maintenance strategy of the maintenance object into the distribution network as well as on the customer service level. Moreover, the maintenance can or not be part of a production process with alternative resources being part of a machine group or be the only machine in a specific production step:
3.2. Conceptual model elements

The elements of the conceptual model refer to those factors that have a role in the maintenance object related environment towards the fulfilment of customer orders. These elements are needed to analyse, develop, and improve the existing maintenance strategy. Figure 1 shows the elements of the conceptual model and their characteristics.

![Figure 1. Conceptual model elements of a maintenance object within a producer’s supply chain.](image)

![Production system elements for the maintenance object:](production-system-elements)

| Production system elements for the maintenance object: |
|--------------------------------------------------------|
| • Capacity available & utilization                     |
| • Order book & capacity control                       |
| • Production-control strategy & Sequence building      |
| • Maintenance object parameters: Quality, Performance, Availability |
| • Maintenance strategy for a machine within machine group n (maintenance object) |
| • Organizational factors: shift planning, employees, other additional resources, IT-Systems stability, etc. |
| • Asset condition, life cycle and economic strategy    |

| Distribution elements: |
|------------------------|
| • Distribution storage levels |
| • Distribution warehouses at each level |
| • Spatial distribution of warehouses |
| • Distribution strategy |
| • Inventory management methods |
| • Transport planning |
| • Alternatives distribution channels and transport means |

| Delivery elements: |
|-------------------|
| • Time, place, type, quantity, quality, cost, composition |

The conceptual model elements are divided in three parts: the production system elements, the distribution elements, and the delivery elements. Production system elements refer to the upstream and downstream steps as well as to the parameters and characteristics of the maintenance object such as the quality, performance, availability, maintenance strategy, organizational factors, asset condition, the life cycle and economic strategy for the asset. Moreover, the planning and control methods also play a key role as well as the availability of alternative resources for the maintenance object. Furthermore, stocks are also a key component. If the downstream operations have larger Work-In-Progress (WIP) stocks, then it means that the probability that a break-down in the maintenance object would have an impact on the end-customer would be lower.

The second part is related to the distribution elements, the distribution elements are related to the distribution network structure as well as to the distribution strategy and distribution planning. Finally, the third part consists of the target parameters to achieve a high service level.

3.3. Conceptual model design

To design a model for defining a suitable maintenance strategy for a specific maintenance object, it is needed to consider the planning horizons as well as the elements described previously. The planning horizons considered are the strategic, the tactical and the operative planning levels. The strategic considers a horizon of several years, the tactical horizon from 3 to 18 months and the operative horizon...
from days or weeks to three months [16]. In this context, the conceptual model provides a guide to select an appropriate maintenance strategy for a maintenance object that depends on different criteria for the different planning horizons, as it can be seen in figure 2. The maintenance strategies considered are the five strategies presented in the sub-chapter 2.3. Moreover, from all potential elements, four factors are taken into account to determine the maintenance strategy: the asset utilization life-cycle for the strategic planning level, the production planning for the tactical planning, the production control for the operative planning and the expected utilization rates of the maintenance object for all the planning levels. This utilization rate results from the division of the real or expected order book and the maximum available capacity of the maintenance object.

Using the factors considered and their combinations as well as the focus of the maintenance manager responsible for decision-making; short-, medium-, or long-term orientation, a defined maintenance strategy is suggested as shown in figure 2.

In the strategic level, if the machine as an asset is in its initial phase after commissioning, the suggested maintenance strategy is the predictive maintenance strategy if the expected utilization rate is high or mid-level. The predictive maintenance strategy implies the machine condition monitoring. In addition, if the utilization rate required is high, above 80%, and the asset is in its maturity or decline life-cycle phase, the maintenance strategy suggested is the prescriptive maintenance as it requires historical data to develop models using machine learning and data analytics. By selecting it, the most advanced models possible would be determined to maintain the maintenance object in operation enabling it to produce the required quantity. In this context, the model tries to avoid negative impacts on end-customer based on a non-proper maintenance planning of the maintenance object. A contrary situation is the corrective maintenance strategy that can be applied when the asset is on its decline phase and the expected utilization rate is lower than 50%.

In the tactical level, a pull production planning requires higher standards of maintenance system performance and complexity as it produces based on customer orders and normally in an optimized balance of lead times and stock levels. On the other hand, a push production planning system manufactures products in advance based on forecasts. As a result, the customer lead times when an order is placed are shorter and therefore the uncertainty and the consequences of a breakdown are smaller. A hybrid push-pull production planning defines a customer order decoupling point, until this point the production system produces based on forecast and later based on end-customer orders. In this context, the uncertainty depends on the position of this point.

In the operative level, a pull production control performs the release of orders only when it is needed to reach the customer order delivery date optimizing the stock levels during the manufacturing process while increasing also the pressure for avoiding long break-downs in the process. Based on this, the pull production control requires higher focus on the maintenance object to prevent failures and delays towards the end-customer.

Figure 2. Conceptual model design for a maintenance object within a producer.
After having described the three planning levels, it should be syndicated that the conceptual model provides a simplified tool to identify a suitable maintenance strategy. However, in reality other factors are to be considered such as product quality; in the model assumed as the same for all maintenance strategies; asset value and its strategic purpose for the manufacturing organization, the production step within the producer’s supply chain i.e. closer to raw materials warehouse or to distribution.

Finally, it is important to point out that the superior planning, strategic has prevalence over the tactical planning and it over the operative planning. However, it is also possible to have a predictive maintenance strategy in the long-term but in a certain situation change to other maintenance strategy in the medium or short-terms. Moreover, this kind of decisions have to be taken without maintaining this situation as it does not follow the defined strategy of the higher planning level.

4. Simulation model, results and discussion

4.1. Simulation model development
To validate the hypothesis of the conceptual model a simulation model was developed. The simulation model consist of the following elements as shown in figure 3:

![Figure 3: Simulation Model Development: Supply Chain.](image)

The following assumptions were made related to the points to be fulfilled in order to conduct a comparison between the simulation models for a defined simulation demand scenario:

- The same demand using replication;
- Same production rate and total number of units;
- Same initial situation, that is, no backlog to begin with and the same conditions of WIP (products on their ongoing transportation to the customers), the same initial stock in the different warehouses, and initial stock ready to deliver to customers;
- Same number of employees with same initial distribution and same capacity to perform warehouse activities;
- Same supply chain distribution network (production facility, warehouses, etc.);
- Same material delays for production and transport processes
- Minimum quantity to deliver from central to regional warehouses. If this quantity is not reached, then the delivery does not take place;
• Same production limitations: Minimum and maximum levels;
• The warehouses have no stock capacity limitations;
• There were no transport limitation between the different production stages;
• Demand level is determined with an average of 30 units for the high demand scenario, and with 15 units per day for the low demand scenario, for the 2,000 days of the simulation.

The key performance indicators to evaluate the simulation results in the different models are:

• Quantity delivered on time (%);
• Service level (%);
• Backlog total (units and days);
• Work-In-Progress Stock (units);
• Breakdown time (days);
• Production availability (%);

4.2. Simulation Models and Simulation Scenarios

Four simulation models are analysed as shown in figure 4 considering two of the maintenance strategies, corrective and preventive maintenance as the two more common in practice, and two different production strategies, push and pull strategies. Preventive maintenance strategy considers that 70% of maintenance activities are performed with a preventive maintenance planning and in the same percentage for the corrective maintenance strategy. Push strategy syndicates that production and distribution is initiated based on a forecast while pull is based on customer orders:

![Simulation Models](image)

**Figure 4.** Simulation Models.

| No. | Key performance indicator | Model CP 1 | Model CP 2 | Model PP 1 | Model PP 2 |
|-----|---------------------------|------------|------------|------------|------------|
| 1   | Quantity delivered on time (%) | Middle (3) | Higher (1) | Middle (3) | Middle (2) |
| 2   | Service level (%)         | Lower (4)  | Middle (2) | Middle (3) | Higher (1) |
| 3   | Backlog total (units and days) | Middle (2) | Middle (3) | Higher (1) | Lower (4)  |
| 4   | Work-In-Progress Stock (units) | Middle (3) | Middle (2) | Lower (4)  | Higher (1) |
| 5   | Breakdown time (days)      | Higher (1) | Higher (1) | Lower (4)  | Lower (4)  |
| 6   | Production availability (%) | Lower (4)  | Lower (4)  | Higher (1) | Higher (1) |

For these simulation models, two different simulation scenarios are considered, named based on their demand level, the high demand scenario, and the low demand scenario.

4.3. Results

The following results in Table 1 can be observed. They are described in terms of ranking between the four models and for the two scenarios. Therefore, “higher (1)” means that the indicator has the higher
value for this simulation model in both scenario and as result its rank is one:

The following interpretations can be derived:

- Maintenance strategies play a significant role along the supply chain impacting the distribution network regarding the service level to end-customers.
- The maintenance object and its availability have more impact in case of a high-demand scenario than in a low demand scenario.
- The maintenance strategy is key for increasing the availability of production machines.
- Due to the level of initial stock parametrized, there are cases in which production breakdowns have no visible impact on end-customer specially in the low demand scenario.
- The push simulation models present the best results regarding end-customer service level while the pull simulation models have the worst results.

4.4. Discussion

From the results, different maintenance strategies and views can be discussed as well as other factors can be introduced to analyse interrelationships. Moreover, the conceptual and simulation models provided can help managers to shape their maintenance strategies and to assess if those are aligned for the three planning levels. In this context, for brownfield scenarios the models can serve as a simulation tool to analyse the impact of a change in the maintenance objects and as well to identify potential maintenance strategies to be prepared to future events. On the other hand, for greenfield scenarios it can help to assign a preliminary maintenance strategy as well as to identify priorities and bottleneck resources that influences end-customer service levels.

5. Conclusions

The purpose of the paper is successfully achieved due to the following facts:

- The need for the analysis and consideration of the interrelationships between distribution networks, end-customer and maintenance management is presented.
- A supply chain is successfully designed with a producer with various production steps, with its distribution and its end-customers.
- The supply chain is implemented by means of simulation using System Dynamics with the Software Vensim allowing the study of scenarios in which the observation of the impact of maintenance management in the distribution network performance can be analysed.
- Thanks to the scenarios and their results the relevant role of maintenance management is concluded. Moreover, the impact of the maintenance strategy of one object depends on other factors than only maintenance of the object or of the system such as customer demand, stocks, supply chain steps and proximity to end-customers.
- Knowing the maintenance activities needed, the stock between production and supply chain steps can be also derived, as well as the other factors can be analysed from a supply chain perspective or from a maintenance management perspective.

Final goal of this research is to:

- Transfer the model to real organizations to increase their competitiveness by improving their strategies and planning methodology.
- Provide a guide for managers to decide on maintenance strategies based on the factors impacting the strategy of the organization.

References

[1] Ivanov D and Sokolov B 2010 Adaptive Supply Chain Management (London: Springer-Verlag)
[2] Chopra S, Meindl P and Kalra D V 2013 Supply chain management: strategy, planning, and operation (Vol. 232) (Boston: Pearson)
[3] Schuh G and Stich V 2013 Logistikmanagement 2. vollständig neu bearbeitete und erw. Auflage (Berlin: Springer Vieweg)
[4] Helmut BVL eV Baumgarten and Baumgarten H 2008 Das beste der Logistik (Berlin Heidelberg: Springer)
[5] Lummus R R, Duclos L K and Vokurka R J 2003 Supply chain flexibility: building a new model Global Journal of Flexible Systems Management 4 (4) pp 1-13
[6] Matyas K 2013 Instandhaltungslogistik–Qualität und Produktivität steigern 5. aktualisierte Auflage (München: Carl Hanser Verlag)
[7] Pawellek G 2016 Planung der Instandhaltung (Berlin Heidelberg: Springer Vieweg)
[8] Angerhofer B J and Angelides M C 2000 System dynamics modelling in supply chain management: research review Proceedings of the 2000 Winter Simulation Conference (IEEE) pp 342-351
[9] Campuzano F and Mula J 2011 Supply chain simulation: A system dynamics approach for improving performance. (London: Springer Science & Business Media)
[10] Akkermans H and Dellaert N 2005 The rediscovery of industrial dynamics: the contribution of system dynamics to supply chain management in a dynamic and fragmented world. System Dynamics Review: The Journal of the System Dynamics Society 21 (3) pp 173-186
[11] Schulte C 2008 Logistik: Wege zur optimierung der supply chain (München: Vahlen)
[12] Wannenwetsch H 2014 Integrierte Materialwirtschaft, Logistik und Beschaffung (Berlin Heidelberg: Springer-Verlag)
[13] Pfohl H 2010 Logistiksysteme. betriebswirtschaftliche grundlagen (8.th ed.) (Berlin, Heidelberg: Springer)
[14] DIN E 2010 13306: Instandhaltung–Begriffe der Instandhaltung. English: Maintenance terminology (Berlin: DIN Deutsches Institut für Normung e. V.)
[15] Merkt O 2019 On the use of predictive models for improving the quality of industrial maintenance: An analytical literature review of maintenance strategies Annals of Computer Science and Information Systems (IEEE) pp 693-704
[16] Bleicher K 2004 Das konzept integriertes management: Visionen-missionen-programme (Frankfurt/Main: Campus Verlag)