An Optimized System to Reduce Procurement Risks and Stock-Outs: A Simulation Case Study for a Component Manufacturer

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Featured Application: Procurement planning adapted to suppliers' behavior and the related risks for procurement based on the appropriate selection of procurement order quantities.

Abstract: In the current global system; supply chains are at risk due to increasing procurement shortages, supply disruptions, and the reliability of on-time deliveries with the original order quantities. As a result, an anticipated management model is of vital importance to provide companies with the productive flexibility necessary to adapt quickly to supply changes, in order to ensure the quality and delivery time through efficient management of stocks and supply costs. In this context, this research aims to develop a system to complement classical procurement planning based on inventory management methods and MRP (material requirements planning) systems by considering suppliers' behavior regarding procurement risks. For this purpose, a system is developed that seeks to simulate the impacts of procurement shortages of different natures. Moreover, the research investigates the development of a system that performs procurement planning of a component manufacturer to determine the supply orders necessary to meet the master production schedule. The system is analyzed based on a set of indicators in the event that the supplier of a material needed for production does not supply on time or has short-term problems. Several scenarios are simulated, and the results are quantified by changing the procurement order quantities, which may or may not follow the economic order quantity (EOQ) model, and the potential procurement disruptions or shortages. The results show how the simulation and anticipation of potential suppliers' procurement behavior concerning potential shortages and their probability are key for successful procurement within a joint strategy with classical procurement methods.

Keywords: economic order quantity; inventory management; MRP systems; procurement order quantity; procurement risks; supply crisis management; component manufacturing; simulation

1. Introduction

Humans have managed inventory problems since we began utilizing the planet's resources [1]. The first mathematical approach to inventory planning was the economic lot size or economic order quantity (EOQ) model, carried out by Harris in 1913, who developed the EOQ model, where the bases for integrating storage and other costs when determining the size of the batches to be produced [2]. Although the EOQ model was developed and initiated a development process that can be seen in Figure 1, it was not until the 1950s and 1960s that other important advances were made to meet logistics needs, such as consideration of surpluses, shortages, and order costs, to determine inventory parameters [1]. Furthermore, computerized forecasting and inventory control began in the 1960s and 1970s [3].
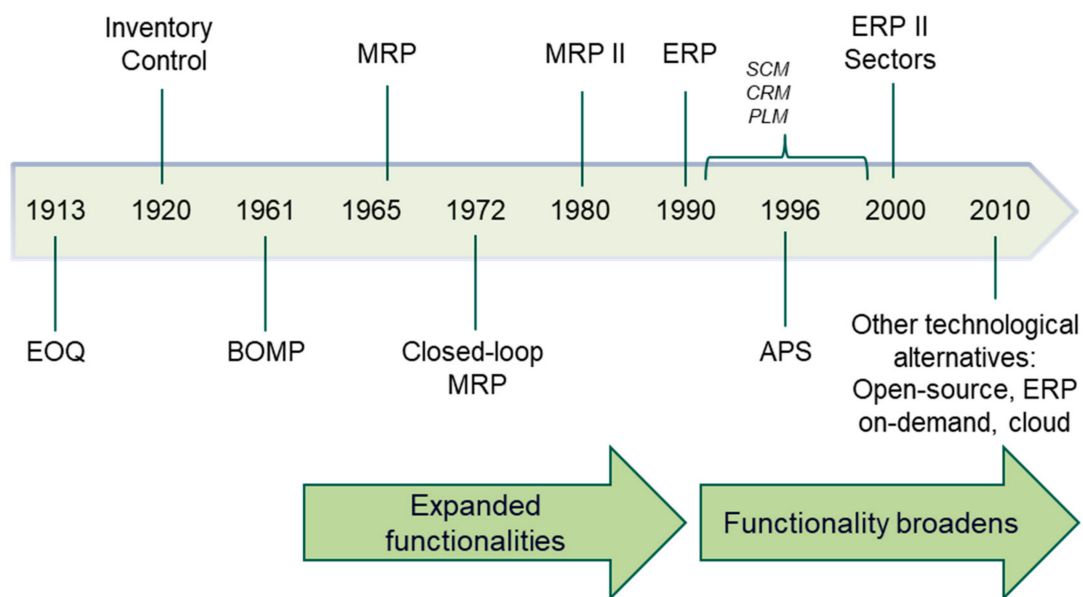
Figure 1. Evolution of planning models and systems: From the EOQ model to ERP systems (own Elaboration based on [4–6]).

Since the 1980s, great effort has been made to develop inventory planning software solutions with the goal of reducing operating costs and capital employed due to stock levels in storage. However, in the day-to-day life of most manufacturers in the process industries, inventory planning continues to be driven by databases of "manual" spreadsheets [7]. Furthermore, the EOQ model after a century is still analyzed and expanded by researchers and is used in practice [1]. MRP II (manufacturing resources planning) emerged in the 1980s and was aimed at identifying problems of productive capacity, considering the availability of resources and production orders in such a way that the planner was able to correct possible deviations. However, it was not until the late 1980s that an attempt was made to integrate support software for automatic decision-making that suggested corrective actions. In the 90s, ERP (enterprise resources planning) emerged—given the need to integrate different areas of the company.

In this context, in supply management, several authors have developed various models based on the EOQ model, as well as other models [8]. Most of the models developed consider the demand for an item as a parameter with static product specifications, that is, they do not change over time [8]. In contrast, as markets have become more complex, inventory management is also now more complex [9] and market conditions have changed more rapidly than the rate at which researchers could respond [1]. Moreover, managers in practice have been able to provide effective and efficient solutions for the global supply chain.

In this way, conventional planning methods based on average values are highly extended in practice [10]. An update of the planning parameters is carried out with long intervals of time [11]. In this context, the business success of the actors in a supply chain will be determined in the future by the ability to identify disturbances early and to compensate for them with adequate planning models that ensure a high quality of planning [12].

World logistics flows have increased dramatically [13] with an international competition in meeting the service level in terms of the delivery date, delivery reliability, and nature of delivery, which increases pressure on supply flexibility [14]. Furthermore, demand volatility in almost all industry sectors appears to be higher than in the past due to shorter product and technology life cycles, sales promotions, rearranged quantities, and unplanned outages [15]. The conventional response to this challenge when dealing with uncertainty is to increase the safety stock of products in order to ensure the expected level of service [16].

In this context, being able to cope with the changing needs of customers, the volatility of demand, and new product launches, it is becoming increasingly important to gain a competitive advantage [17]. The need to respond to the uncertainty of demand is a necessity. The current situation, characterized by epidemic crises, product changes, and deviations in replenishment time, can lead to stockouts and a high level of inventory required to provide a given level of service. People affected by the potential lack of supplies are at great risk [18], as experienced with the global COVID-19 crisis when companies speculated on the supply of demand—reducing supply to increase margins due to client demand. Therefore, theoretical developments are required with methods that determine inventory levels based on measures other than cost [1].

The COVID-19 pandemic has had significant global economic consequences [18]. This situation demonstrated the future risks and current fragility [19] of supply chains. The consequences have included production stoppages due to a lack of supply of raw materials, while other producers had to decrease or interrupt production because finished products could not be shipped abroad. In addition, there can be an increase in obsolete products and materials when demand is low or products cannot be shipped, as has occurred during the COVID-19 pandemic, causing risks associated with oversizing of stock levels and causing an increase in waste. Therefore, there is an urgent practical need to increase the adaptability of manufacturing and procurement systems in order to react to unforeseen events, such as COVID-19 [20].

Moreover, new technologies have led to increasingly recurring changes in product specifications, which has led to high volatility in demand for products in a finite life cycle [1]. Therefore, as product life cycles are shortened, the randomness of demand increases [21]. As a result, logistics managers and supply planners must make decisions with a higher level of uncertainty about demand. It is at this point that new models and concepts should contribute to providing solutions to this challenge [20].

In this context of fluctuating demand, long lead times, inaccurate forecasts, the large variety of products, and the impact of complex networksthe current methods of production planning and inventory control have shortcomings. MRP, as a production control system, is appropriate for the deterministic environment. Therefore, in a stochastic condition, research has proposed a modified MRP to anticipate the demands and lead time with demand-driven material requirements planning for the MRP to adapt to the variability of demands and supplies. However, there are few studies on the benefit of this type of approach [4]. Companies that have had experience with MRP have chronic problems and the risk of large variations, overstocks and shortages for customer supply. These conditions affect three main factors: inventory performance, service level performance, and higher levels of expenses and waste [4].

In the current global system, procurement planning in the process and assembly industries acquire vital importance to provide companies with the productive flexibility necessary to adapt quickly to changes through efficient management of stocks and supply costs. Scenario simulation can help to solve manufacturing and inventory planning challenges [22] combined with classical materials requirements planning. To date, many models have been developed to deal with uncertainty and determine the optimal inventory policy [23]. However, most inventory models are related to the classical cost analysis approach with uncertain input data precision [1]. The cause of the uncertainty has several reasons [23] such as the procurement risks of a certain supplier that can produce stock-outs and production losses. Therefore, how to balance the procurement strategy and cost optimization while considering potential procurement shortages is a key decision for managers.

In this context, this research aims to develop a methodology for materials requirement planning by means of scenario simulations in order to improve the future procurement order quantities based on the impacts of target indicators. The scenarios vary depending on the procurement order quantity and on the procurement shortages from suppliers. The final goal of the developed system is to provide adaptability and flexibility mechanisms to

industrial organizations by determining a differentiated strategy based on the supplier's procurement behavior. This is pursued to provide managers with a tool to select the procurement order quantity needed to meet required service levels while optimizing inventory costs.

The hypothesis is that EOQ models need to be considered together with the procurement shortage risks, along with the service and cost goals, in order to determine the best-fit procurement order quantity for a specific supplier's behavior.

As a result, the system contributes to improving management capabilities within the company to act early and appropriately as well as optimizing information systems to be a crucial support for processes and decision making in volatile environments resulting from a lack of transparency regarding planning and control of production systems as one of the greatest weaknesses of ERP supply chain management (SCM) systems—as they are insufficiently integrated with each other to ensure holistic planning and control across all networks. The consequences of this problem include: unrealistic delivery dates and consequent inadequate compliance with delivery dates for customers [24]. In this context, the problem is delimited to the management of production and supplies and more related to the determination of supply needs based on the master production program.

Companies are faced with the challenge of having to master an increasing number of individualized product solutions and short delivery times at the lowest possible cost with high market dynamics leading to fluctuating customer demand and increasing short-term order changes. To successfully produce despite increasing external volatility, flexible and adaptable production systems are required that can be adapted to new requirements in a short period of time [25,26].

The novelty of the research is that it can support decision making by complementing MRP planning with a simulation of scenarios with different procurement order quantity policies, enabling prediction of the results in cases of procurement shortages based on unexpected non-reliable behavior of suppliers. It also supports preparing preventive planning, applying, and verifying lessons learned, providing an easy-to-use decision-making and continuous improvement tool for managers to direct their decisions in the best way possible.

2. Methodology and Fundamentals

2.1. Methodology

In this paper, the methodological approach is as follows:

1. Literature research on:

    (a) Production planning and control;
    (b) Inventory management;
    (c) Target and monitoring systems;
    (d) Materials requirements planning and systems evolution and challenges.

2. Development of a conceptual model describing an integrated system for materials management with an MRP approach. It aims to serve as a framework for optimal procurement planning, enabling better decision making and continuous improvement of the system target indicators and capabilities.
3. Design of a simulation model for modeling and assessing the different scenarios and the system flexibility and adaptability depending on the MRP settings and policy configuration.
4. Discussion of results with regard to the potential benefits and outcomes for managerial positions.
5. Critical reflection of the research performed, and outlook of potential future research based on the study.

2.2. Production Planning and Control

The task of production planning and control involves the planning and control of deadlines, capacities, and quantities of manufacturing and assembly processes [27]. Within

a company, the production planning and control systems consist of structured levels of planning that include both aggregate plans, master plans, materials management, as well as the levels of execution, referring to production planning [28]. In a first step, within the annual sales planning, a strategic alignment with the product offer is carried out based on the evolution of market demand, as well as considering the results of the commercial planning network at the company level. The result is the annual sales plan which includes the sales quantities for each of the periods at the product family level. With this plan, independent requirements planning is calculated, which becomes a production proposal for each of the periods. Subsequently, in the planning of the gross needs, this proposal is disaggregated with the help of proportional factors at the product family and total needs per product level are determined for each period based on the annual sales planning [27]. This total demand is adjusted with the help of demand forecasts that are continuously updated for periods of time. Stochastic methods are normally used for forecasting future primary needs, as well as heuristics for forecasting demand for a certain future time horizon. In rough resource planning, it is assessed whether sales planning and production schedules can be carried out with available resources, that is, product and/or component requirements determined according to the type, quantity, and date on which they are planned and compared with available resources [27].

2.3. Inventory Management

Inventory management plans and controls stocks. It supplies the stored goods based on the expected sales [29] and fixes the repositioning point and the safety inventory. Inventory management includes the functions of demand planning, inventory planning, and procurement planning [30]. Other instruments are order planning defining the optimal quantity and frequency, as well as the selection of the order policy [31]. This refers to the management of existing inventory at present, and its main task is the definition of the optimal order point.

Inventory planning includes the determination of the necessary safety stock (SS) and the stock for the release of the supply order [32]. This requires consistent forecasting and inventory management from demand planning [32].

Procurement planning takes care of procurement initiation, order quantity selection, and lot size selection. In different supply policies, the two parameters, quantity and frequency of the order, can be variable or constant [33]. If the four characteristics of the two parameters—size and frequency of the order—are combined, there are four different procurement ordering strategies [31]. In the reorder point method, the inventory level is checked after each stock movement to assess if the remaining inventory is below the reorder point. If this is the case, then an order is placed [34]. A third method, called the control rhythm, arises from another combination of parameters. These are the policies (t, s, q)—y (t, s, S) [35]. The three methods used here are for make-to-stock (MTS), while a fourth method depends on the demand and is, therefore, make-to-order (MTO).

There are many available formulas to select the optimal lot size that is prescribed in many new studies. Although these formulas are available, few companies attempt to arrive at an explicit quantitative balance of inventory and procurement costs [36]. The economic order quantity (EOQ) plays an important role in the total profit of the factory in all respects [37]. A constant order quantity (q), the most widely used, in practice, is the classical EOQ with the Andler–Harris formula for the optimal lot size [38] which minimizes the total cost of the inventory [37]. The optimal lot size is always calculated for a certain period [38]. The economic order quantity (EOQ) used in the paper finds the optimal quantity to order among three components: the cost per unit, the procurement order cost, and the inventory holding costs [39] as it can be seen in detail in Appendix A. This order quantity strategy can be applied with a dynamic calculation in each period or with a discrete calculation valid for a period, such as a year. For a variable order quantity, the inventory is filled to a target level [33]. This is one of the options for the dynamic or feedback-dependent model [32].

2.4. MRP Systems

Starting from the production program, the productive elements, such as production means, labor, and materials, necessary for the manufacture of primary needs are made available within the framework of the planning of production needs [40]. In this way, the planning of the production factors ensures the capacity to implement the production program through adequate supply programs [27]. These can be made based on consumption- or production-oriented planning. While the consumption-oriented determination of secondary needs is conducted through forecasts, the secondary needs are based on a production schedule-oriented requirements planning, calculated by disaggregating the product structure of primary needs considering the relationships between quantities. Through the planning of production factors, the gross secondary requirements are determined based on the production plan and through disaggregation of the bill of materials, as well as a net comparison with the warehouse inventory [27]. The net comparison is made dynamically by considering the planned inflows and outflows for demand at a certain time point. Through inventory management, gross secondary requirements are covered through raw materials stock. The determination of net dependent requirements generates supply orders. Supply orders are grouped into a supply program, either produced within the company itself or subcontracted. Based on the supply orders that are in the subcontracting program and considering the information from the purchasing departments in relation to the available contracts, the planning of the production factors is defined, such as the calculation of the procurement order quantity. In this process, secondary needs are grouped for a given period to determine optimal order quantities from the economic point of view through the use of methods for their calculation [27].

Materials requirements planning (MRP) is an inventory management system designed to help production managers schedule and order items dependent on demand. Demand-dependent items are components of the finished product such as raw materials, components, and sub-assemblies or the amount of inventory required depending on the level of production of the final product [41]. MRPs have undergone various developments of MRP and closed-loop MRP, including manufacturing resource planning (MRP II), advanced planning, and scheduling systems (APS), and ERP enterprise resource planning systems [4]. Materials requirements planning assumes that demand and delivery times are deterministic. Unfortunately, most production systems are stochastic. Therefore, the deterministic assumptions of the MRP are usually too restrictive [4].

3. Conceptual Model: Procurement Order Quantities Regulation for Shortage Scenarios

The vision of this work is to provide a conceptual model that provides a framework on how to design procurement policies based on the regulation of the order quantities to face procurement shortage scenarios, thus enabling management levels to decide and select the optimal order quantity based on the specific scenario and characteristics of the company and its goals. As a result, the conceptual model seeks to serve as a basis for decision making for future procurement improvement projects capable of increasing service levels towards end-customers and reducing operational costs to secure the long-term viability of their organizations.

3.1. Target System

This subsection aims to define the requirements of the model to be built, that is, to identify the system's capabilities. To achieve this, the target parameter system is developed and consists of the following six blocks shown in Figure 2. The first block refers to the final customer demand that must be monitored to evaluate its changes, as well as its implications in the needs of the products on other levels obtained by exploiting the bill of materials. Second, another parameter to control is the stock level for the different types of flows in relation to an industrial organization, so that the value of available material is known. Third, the service level that is being provided to the client must be known in terms of quantity and date. In addition, the fourth block seeks to analyze the procurement costs.

The fifth block of parameters deals with the supply orders, how many, of what quantity, when, and how long it takes to physically arrive and be ready so that the model always knows at any time the capacities and supply options to subsequently determine which are optimal for the target service level and thus optimize the stock levels and associated costs. Sixth, the block from which the deviations versus the initial schedules are analyzed. In this sense, the objective is to know and trace the supply deviations and their implications over time.
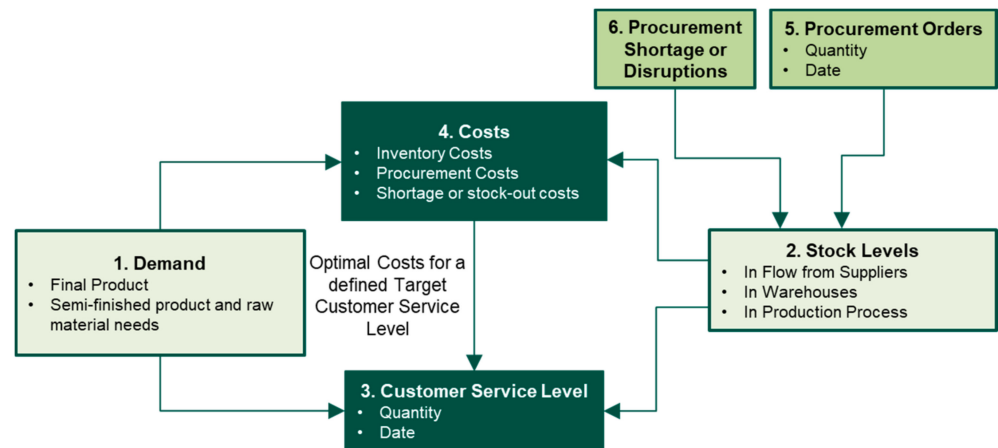

Figure 2. Target parameter system (own elaboration).

In addition, the parameter system works by comparing the target and actual values with a predefined frequency; so that, in each period, it is determined whether the evolution is positive or negative, converging or diverging from the objective of the logistics system. If evolution presents explanatory cause–effect relationships, an attempt is made to prevent the causes that originate from the divergences and to promote or enhance the causes or effective measures that enable the system's convergence to the logistical objective. In the absence of explanatory cause–effect relationships, new measures must be analyzed and defined to help determine the behavior and causes of the results obtained.

3.2. MRP Planning and Shortage Impacts

The logic of an MRP system starts from the master production plan that determines the quantity to be produced since it considers orders and sales forecasts. The list of materials contains all the information related to the articles and the composition of the finished products. The purchase and production orders are given by the materials requirements planning (MRP), for which the replenishment times and the availability of the necessary materials are needed, allowing for inventory control. In turn, purchasing and production also feed the system with information on the receipt of orders, which helps determine availability in the near future. MRP systems allow the production system to anticipate strategies for different supply shortage scenarios to determine the steps to follow to achieve a pre-defined goal set.

The procurement system in consideration can be generated as a closed-loop regulated system as shown in Figure 3 in which target service levels and costs are defined. Based on them, the MRP system is executed and its result is implemented operatively in the procurement process. In the implementation of the planned procurement process according to the output of the MRP, the process presents disturbances such as procurement shortages. As a result, the actual values are measured and are different in comparison to the expected indicators. Therefore, in each cycle, optimization needs to be performed. In the case of the developed model, the improvement is made on the procurement order quantity. Based on the simulation of scenarios, the different options can be assessed thanks to the previously defined target system of indicators. Finally, the procurement order quantity is then adjusted to meet target service levels and costs considering the deviations between plan and actual indicator values and based on the simulated scenarios.
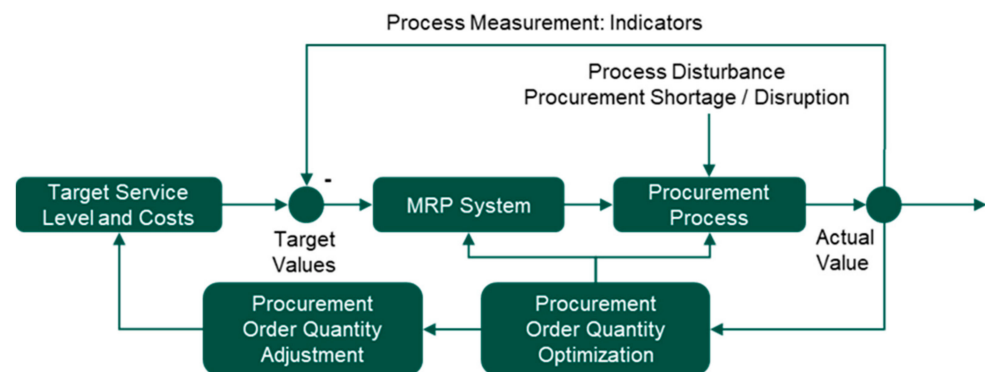
Figure 3. Parameter system target (own elaboration).

3.3. Factors in Relation to the Procurement Order Quantity, Service and Cost Levels

These factors determine the speed and effectiveness with which external changes to the system, such as changes in demand, are absorbed and attenuated by the planning model so that effectiveness is not compromised and efficiency, e.g., cost or service oriented, that is, quality and time, in that situation is maximized. Critical factors for supply management for a manufacturing company are:

- Expected demand for the final product;
- Current inventory/stock level;
- Supplier replenishment time;
- Supplier procurement lot size.

These factors may suffer from the following deviations that are a source of uncertainty for planning:

- Deviations in the expected demand for the final product (forecast error and/or lack of firm customer orders);
- Inventory deviations;
- Deviations in the procurement order lead time (supplier delivery date);
- Deviations in the procurement order quantity (quantity delivered from supplier).

These deviations are compensated with stock-outs and supply failures that trigger production losses of available capacity or the need to make changes in planning and therefore increase the needs of other procurement goods. To avoid these effects, there are two mechanisms to compensate for these potential negative effects that nevertheless have a cost (time, space, material):

○ Safety stock;
○ Security times.

In these regard, Figure 4 shows how the the procurement order quantity is determined depending on the planning type and on the need of compensation factors:

These factors will then be the determining factors to analyze the model's responses in the simulation; for example, an already placed procurement order that changes from level 1 to level 2 in the form of a step change due to a procurement shortage and how the system responds to different procurement order quantity configurations.

The inventory function can be described from two different perspectives. From a classical planning perspective, a high level of stock allows for trouble-free production, short delivery times, overcoming production failures, constant production utilization, and thus economical production. However, the idea of efficient management is based on the view that stocks are generally used only to hide processes deviations and failure, uncoordinated capacity, lack of flexibility, waste, and lack of reliability and delivery. Flexibility and adaptability can be understood at different levels—stock transfers, supply synergies, capacity coordination, and production networks—thanks to an MRP approach. A factory is intended to be classified at different levels. Optimization, to improve efficiency, must be performed at all levels. The lower level is the process level, where losses are due to

the physical movement of the machine or of materials or people in relation to the process itself. Moreover, at the production or transport machine level; the line level that contains many machines and the factory level must also be considered and optimized to provide a comprehensive result [42].
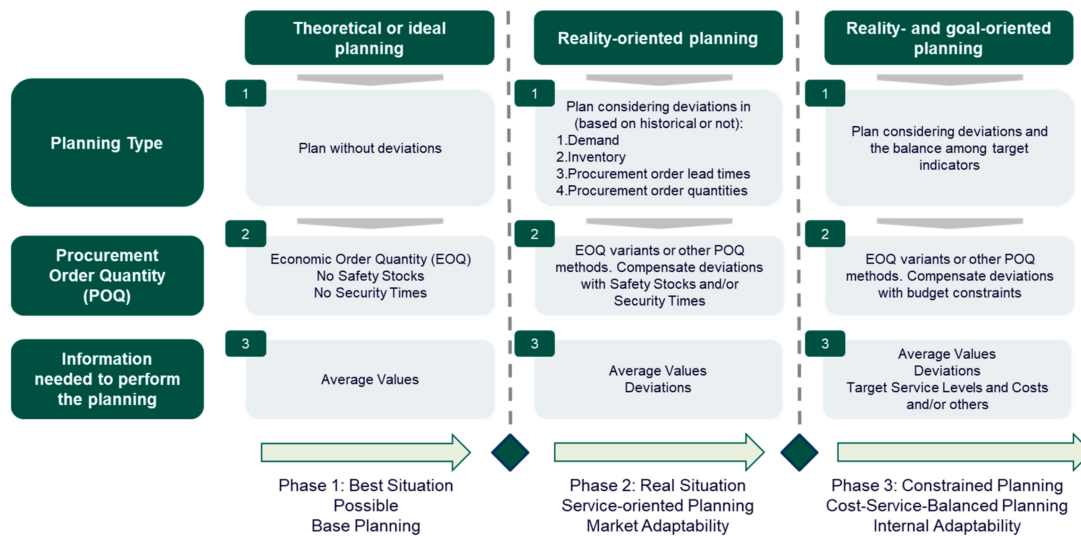
Figure 4. Procurement order quantity planning based on deviation and compensation factors in three incremental adaptability phases (own elaboration).

4. Methodological Simulation Approach Depending on Supplier's Behavior and Procurement Order Quantity

According to the "VDI-Richtlinie", simulation is the reproduction of a system with its dynamic processes in an experimental model capable of acquiring knowledge that can be transferred to reality. In particular, processes which develop over time [43]. In contrast to analytical models that offer the possibility of reaching an optimal solution, the main problem with simulation models is that these models do not provide a closed set of solutions [44]. Simulation models are used mainly to support decision making as they reveal a system's dynamic behavior [45]. On the other hand, simulations are the only practical way to test models, because our mental models are dynamically deficient, omitting evaluations, lags, accumulations, and nonlinearities [46].

With the help of technical simulation models, results can be transferred to reality. The objectives of a simulation are, among others, the assurance of the methodology, as well as the planning, management, and control of the flows of people, materials, energy, and information [47]. Simulation models are increasingly used in logistics, which have been actively applied in the supply chain context [44]. On the other hand, this allows us to evaluate the possible scenarios before implementing a plan and to make better planning decisions with additional information provided by the simulation. Therefore, the development of supply chain management simulation models has become a necessity [48] to gain competitiveness.

The simulation is carried out through the Microsoft Office package, specifically in Excel since it includes additional programmable functionalities with standard tools and allows the storage and interconnection of databases for their calculation and processing and for the management of manufacturing needs and supplies.

4.1. Methodological Approach

Model building consists of knowing how to simplify the complexity to reflect only the essential characteristics to fulfill the model's purpose [49]. Since the scope and limits are wide, the model should include a large number of variables. However, the model is limited to those factors and conditions that are considered relevant to answer the research

question. Furthermore, this research has a single simulation model. However, it allows for simulating scenarios and is therefore parameterizable. In this way, it would allow planners to compare different procurement policies to decide on planning in the considered horizon. The objectives of the simulation are to: (1) Compare the influence on the indicators of the potential deviations such as the procurement order lead times and procurement order quantities; (2) observe the impact of these sources of uncertainty, as well as of the parameters in the target indicators so that decision making—in a manufacturing and supply process chain—can be optimized. The hypothesis is that the simulation model applying an optimal supply policy will present better results in terms of the study parameters compared to the model that does not apply or perform simulations of different policies. Starting from the conceptual model in Chapter 3 as a basis, the methodology for the design of the simulation model is:

1. Definition of the objective, hypothesis, and methodology;
2. Number of simulation models;
3. Definition of quantitative parameters to obtain results and compare the models;
4. Simplification of the complexity of the conceptual model through assumptions;
5. Criteria enabling comparison of simulation scenarios;
6. Definition of the product and the supply chain;
7. Development of the model based on an MRP approach;
8. Validation of the behavior of the simulation model;
9. Determination of scenarios, simulation, and extraction of results;
10. Evaluation of results and derivation of conclusions.

4.2. Target System: Key Performance Indicators

Some major reasons for organizations to undertake activities are to save money or increase profit, or influence other important factors, such as quality, delivery time, or delivery reliability, which are essential for competitiveness [1]. The results will be quantitative to evaluate the responses according to the following performance indicators, and the detailed mathematical formulation can be found in Appendix B:

1. Gross demand/needs (final product units): The sum of the final product demand, and therefore represents the gross needs as an input parameter of the simulation model;
2. Service level (% over quantity): The percentage of products produced on time according to planning;
3. Service level (% on days): The percentage of the days in which the production manufactured the required quantity. It is declared at the end of the production process and is considered as a demand not satisfied on time in those cases in which the quantity sent is less than the demand of the clients on the current day plus the delays of the previous days;
4. Delays (product units): The quantity of products delivered late to the customer according to planning;
5. Delays (days): The days in which the customer deliveries did not reach the required quantity;
6. Average stock level (units of materials/products): The average value of units in the inventory;
7. Number of orders (number of orders): The number of orders placed during the simulation time horizon;
8. Total inventory costs (USD): The sum of the procurement costs from an external supplier, the warehousing costs, the materials planning, and the handling costs;
9. Procurement management costs (USD): The total procurement cost minus the cost of the parts or materials from which it is procured. It is the value of planning, ordering, and handling management;
10. Procurement costs (USD): In the model, this is applied as external procurement costs and not as in-house production. Therefore, the external procurement costs depend on

the order quantity and cost price as direct costs and the order costs and cost rate of the order initiations [32];

11. Warehouse storage costs (USD): The sum of capital commitment costs and storage costs [32];
12. Capital commitment costs (USD): The function of the interest rate, inventory quantity, and its inventory value and storage time;
13. Storage costs (USD): The components of shortage costs are lost contribution margins, reduced revenues, and additional costs, such as contractual penalties [32]. For the model, it is considered as a penalty per unit not delivered on time in each period;
14. Stock-out costs (USD): The model considers a fine for each unit of product not delivered on time for each period of delay in delivery.

4.3. Development of a MRP Simulation System

First, a series of assumptions are defined to simplify the model so that we can focus on the objective of the simulation.

- Manufacturing process not considered;
- Final demand without deviations;
- Material receipts can be used on the day of receipt for manufacturing;
- Quality failures not considered;
- Demand does not change if customer service is better or worse;
- Infinite warehouse, manufacturing, and procurement capacity.

The defined points will be listed to make a comparison between the different scenarios within the simulation model possible.

- Same demand, same demand patterns, and replicas;
- Same deviations in days of delivery delays;
- Same cost parameters.

The simulation case study manufactures an item A from three units of component B and one unit of component C. Moreover, the simulation considers the procurement planning for the production plant of the Tier-1 supplier as shown in Figure 5. Therefore, the Tier-2 suppliers are suppliers of the Tier-1 manufacturer for the items B and C. Finally, the original equipment manufacturer is the client of the production plant in focus.

The next step is to develop the simulation model based on the previous information. The simulation model is built based on data inputs, the simulation execution, and the data output as shown in Figure 6. Moreover, a new parametrization of the POQ to execute further scenarios is possible enabling the comparison of policies and the continuous improvement of the planning while considering disturbances.

Based on the previous Figure 6, the model is developed consisting of six different areas or sub-models as is shown in Figure 7.

Given a defined demand and production strategy, the modeler must define a time horizon and time units. In the case study, it has been decided to simulate a horizon of 11 weeks to evaluate influences at the tactical and operational levels with a time pass of 1 day.

Moreover, behavior validation of the simulation model was performed with extreme-value tests such as, for instance, if there is no reception of components, then stocks will be zero and the service level will decrease or as, for instance, when there are double the procurement order quantities ordered, then there is an accumulation of stocks. Based on these facts among others, the simulation is validated.
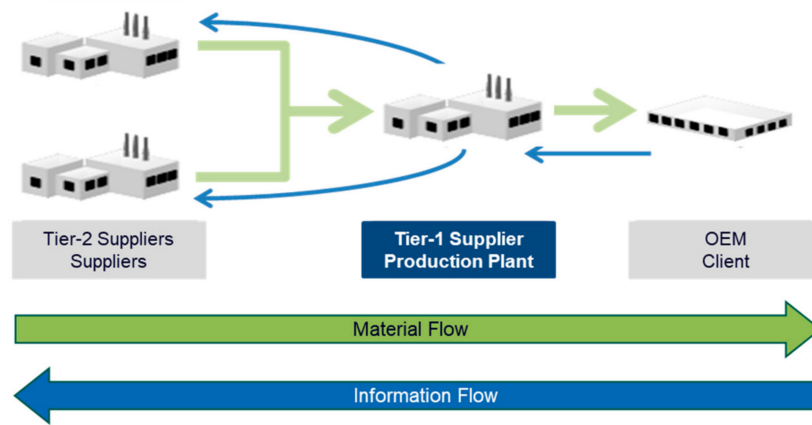
Figure 5. Production flow of the simulation (own elaboration).
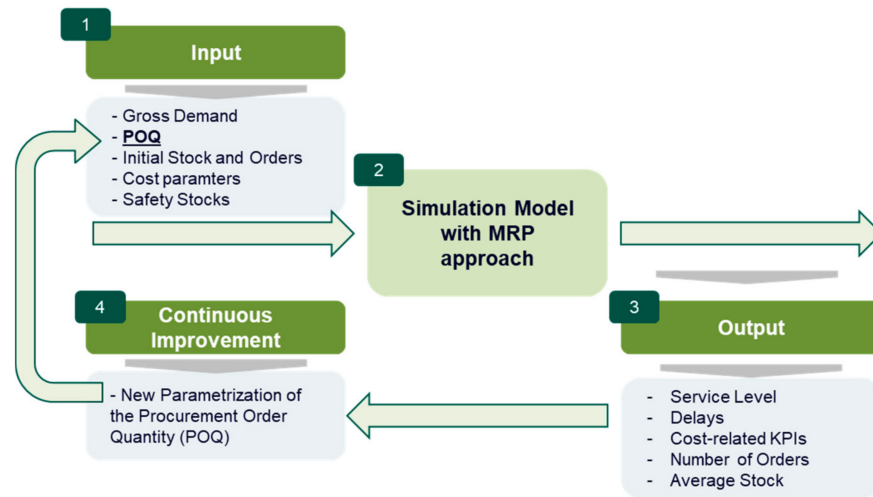
Figure 6. Input–output diagram of the simulation model (own elaboration).
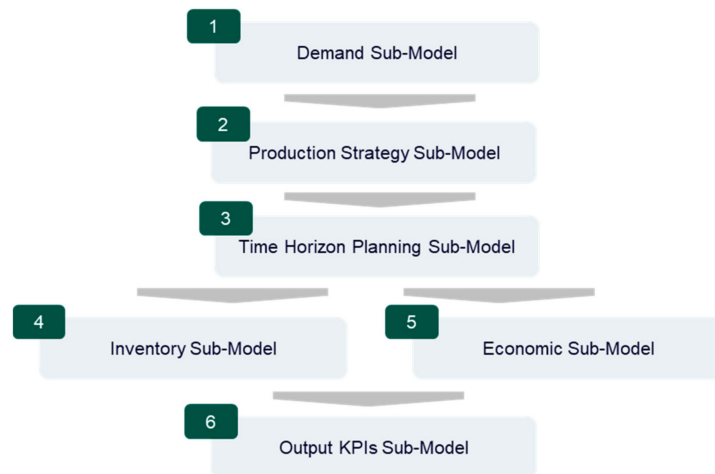
Figure 7. Sub-models areas of the simulation model (own elaboration).

4.4. Simulation Scenarios

Based on the developed simulation model, multiple scenarios can be designed, executed, and analyzed. However, to check the hypothesis of a model that is able to respond to supply disturbances by applying a feedback control loop based on the definition of different POQ policies, the research proposes the following scenarios as shown in Figure 8:

- Scenario 1, a reliable supply behavior: The supply execution of the suppliers is 100% aligned in time and quantity with the planning;
- Scenario 2, non-reliable supply behavior—week disruptions: The supply execution of the suppliers is not aligned with the planning. Disruptions of one week without supply in each four weeks in the planning horizon exist. As a result, the supply for this week is delayed by one week;
- Scenario 3, non-reliable supply behavior—2 weeks disruptions: the supply execution of the suppliers is not aligned with the planning. Disruptions of two weeks without supply in each four weeks in the planning horizon exist. As a result, the supply for these two weeks is delayed by one week.
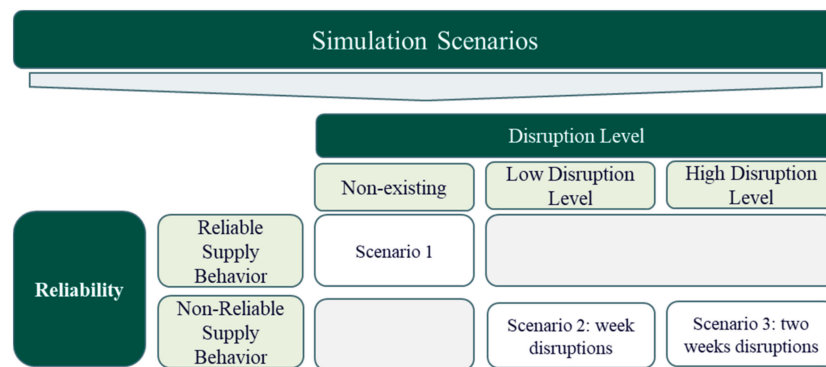

Figure 8. Simulation scenarios based on supply reliability and disruption level (own elaboration).

5. Results

In this section, the simulation results for the simulation model for the three scenarios with different POQ and the same demand are presented in the following tables (Tables 1–3).

As shown in Table 1, five different POQ are evaluated for the first scenario. As this scenario represents the ideal or theoretical planning that reproduces the supply as expected, the simulation model provides a 100% service level without backlogs for all values of the POQ. In addition, inventories are lower as the POQ reduces, being almost 10 times lower for a POQ of 4 units than for a POQ of 96 units. On the other hand, the number of procurement orders placed follows a contrasting trend with 54 orders for a POQ of 4 and 4 orders for a POQ of 96 units. Moreover, in relation to cost, it can be seen how the minimum inventory costs and also procurement management costs are for a POQ of 24 units, which represents the economic order quantity (EOQ) for the input parameters.

Table 1. Simulation results for scenario 1: A reliable supply behavior.

No.	Key Indicator	Procurement Order Quantity (POQ), # Units				
		POQ 1 4 Units	POQ 2 16 Units	POQ 3 EOQ = 24	POQ 4 48 Units	POQ 5 96 Units
1	∑ Demand (# products)	356	356	356	356	356
2	Cumulated Service level (%, products)	100.0%	100.0%	100.0%	100.0%	100.0%
3	Cumulated Service level (%, days)	100.0%	100.0%	100.0%	100.0%	100.0%
4	∑ Backlog (# products)	0	0	0	0	0
5	∑ Backlog (# days)	0	0	0	0	0
6	Ø Stocks (# units)	6.6	12.7	16.8	30.1	57.2
7	∑ Procurement Orders (# orders)	54	22	15	8	4
8	∑ Inventory costs (USD)	216,010	214,961	214,838	215,063	215,931
9	∑ Procurement management costs (USD)	2410	1361	1238	1463	2331
10	∑ Procurement costs (USD)	215,760	214,480	214,200	213,920	213,760
11	∑ Warehouse storage costs (USD)	250	481	638	1143	2171
12	∑ Capital commitment costs (USD)	83	160	213	381	724
13	∑ Storage costs (USD)	167	320	425	762	1447
14	∑ Stock-out costs (USD)	0	0	0	0	0

Table 2. Simulation results for scenario 2: Non-reliable supply behavior—week disruptions.

No.	Key Indicator	Procurement Order Quantity (POQ), # Units				
		POQ 1 4 Units	POQ 2 16 Units	POQ 3 EOQ = 24	POQ 4 48 Units	POQ 5 96 Units
1	$\sum$ Demand (# products)	356	356	356	356	356
2	Cumulated Service level (%, products)	89.9%	93.3%	95.5%	95.5%	95.5%
3	Cumulated Service level (%, days)	69.0%	74.1%	75.9%	86.2%	91.4%
4	$\sum$ Backlog (# products)	36	24	16	16	16
5	$\sum$ Backlog (# days)	18	15	14	8	5
6	Ø Stocks (# units)	5.1	10.0	13.4	25.6	50.8
7	$\sum$ Procurement Orders (# orders)	54	22	15	8	4
8	$\sum$ Inventory costs (USD)	231,153	224,260	222,510	219,091	218,888
9	$\sum$ Procurement management costs (USD)	17,553	10,660	8910	5491	5288
10	$\sum$ Procurement costs (USD)	215,760	214,480	214,200	213,920	213,760
11	$\sum$ Warehouse storage costs (USD)	193	380	510	971	1928
12	$\sum$ Capital commitment costs (USD)	64	127	170	324	643
13	$\sum$ Storage costs (USD)	129	253	340	647	1285
14	$\sum$ Stock-out costs (USD)	15,200	9400	7800	4200	3200

Table 3. Simulation results for scenario 3: Non-reliable supply behavior (two weeks disruptions).

No.	Key Indicator	Procurement Order Quantity (POQ), # Units				
		POQ 1 4 Units	POQ 2 16 Units	POQ 3 EOQ = 24	POQ 4 48 Units	POQ 5 96 Units
1	$\sum$ Demand (# products)	356	356	356	356	356
2	Cumulated Service level (%, products)	83.1%	88.8%	88.8%	95.5%	95.5%
3	Cumulated Service level (%, days)	32.8%	37.9%	39.7%	53.4%	72.4%
4	$\sum$ Backlog (# products)	60	40	40	16	16
5	$\sum$ Backlog (# days)	39	36	35	27	16
6	Ø Stocks (# units)	2.9	6.1	8.1	16.2	41.0
7	$\sum$ Procurement Orders (# orders)	54	22	15	8	4
8	$\sum$ Inventory costs (USD)	283,869	269,911	265,308	253,534	237,516
9	$\sum$ Procurement management costs (USD)	70,269	56,311	51,708	39,934	23,916
10	$\sum$ Procurement costs (USD)	215,760	214,480	214,200	213,920	213,760
11	$\sum$ Warehouse storage costs (USD)	109	231	308	614	1.556
12	$\sum$ Capital commitment costs (USD)	36	77	103	205	519
13	$\sum$ Storage costs (USD)	73	154	205	410	1037
14	$\sum$ Stock-out costs (USD)	68,000	55,200	50,800	39,000	22,200

As can be seen in Table 2, five different POQ are also evaluated for the second scenario. As this scenario represents planning that reproduces a reality in which the supply reliability is affected, there are deviations that imply delays reducing the service levels for the different POQ options. Service levels increase, as does the POQ, however, a significant increase in the service levels in the number of products is realized up to POQ that equals the EOQ. In addition, inventories are also lower as the POQ reduces—being almost 10 times lower for a POQ of 4 units than for a POQ of 96 units. Moreover, in relation to cost, it can be seen how the minimum inventory costs and procurement management costs are for a POQ of 96 units. However, the relevant cost reduction occurs in the change from a POQ of 4 units to a POQ of 24 units, almost USD 9000, while the change from 24 to 96 units represents less than USD 4000.

As can be seen in Table 3, five different POQ are also evaluated for the third scenario. As this scenario represents planning that reproduces a reality in which the supply reliability is affected, there are deviations that imply delays, reducing the service levels for the different POQ options. Service levels increase as does the POQ, however, a significant increase in the service levels in the number of products is realized up to a POQ that equals

the maximum POQ level, which represents a difference with scenario 2. In addition, inventories are also lower as the POQ reduces—being almost 15 times lower for a POQ of 4 units than for a POQ of 96 units. Moreover, in relation to cost, it can be seen how the minimum inventory costs and procurement management costs are for a POQ of 96 units. In this case, on the contrary, as for the second scenario, the relevant cost reduction occurs in the change from a POQ of 24 units to a POQ of 96 units, almost USD 30,000, while the change from 4 to 24 units represents less than USD 20,000. This can be explained by the fact that the service level in days for a POQ equal to the EOQ is almost half than the service level with a POQ of 96 units. This implies that the delivery reliability of the plant is low and therefore the stock-out costs are a relevant factor in the scenario. This scenario presents the lower levels of inventories for all POQ due to the fact that the raw materials are not in the warehouse for long lead times as the backlog needs to be recovered and as soon as the raw materials are available, they are assembled and sent to the client.

6. Discussion

Being able to select the most appropriate procurement order quantity can lead to relevant implications on service and cost performances. However, as syndicated with the simulation results, the most suitable procurement order quantity for the same demand depends on the supply reliability, i.e., the supply behavior. As a result, for the same demand and for the same product, there should be different procurement order quantities based on the procurement reliability of the supplier. By doing so, a manager can secure operations in the plant under their responsibility with complete planning that includes the supply deviations.

Based on the need to consider the supplier's behavior, in the sense of their procurement reliability (in quantity and time) to generate robust procurement plans, the selection of differentiating procurement order quantities represents a key factor for logistics managers to design, optimize, and secure operations. To provide a framework for managers on how to select the most suitable POQ, Figure 9 presents a methodological sequence for this purpose while considering a given master production schedule and organizational strategy. With this information, five steps are to be followed to enable a continuous improvement process in the selection of the POQ that implies a global optimization of the supply chain. The first step consists of executing the planning—assuming a reliable supply. Then, in the second step, the expected supplier´s behavior is to be considered to simulate what-if scenarios. With the results and the probability of different kinds of behaviors and reliability levels, in the third step, the selection of the suitable POQ can be performed. Afterward, in the fourth step, the execution in the planning time horizon, providing actual indicators, can be compared with the target indicators. Finally, after the comparison, the deviations with target goals influence the continuous improvement process based on the organizational strategy, which will imply, for instance, the need for more or less safety stocks in the next procurement planning cycle. Based on the current global situation, in which supply chain disruptions and shortages, production stoppages, and stock-outs are becoming increasingly common and are developing into a global supply crisis, the trend for procurement order quantities and related factors is expected to be as follows:

- One expected strategy is to increase procurement order quantities as producers will try to secure operations considering the supply uncertainty, thus leading to increased ordering to cover the potential future lack of supplies;
- Another strategy is to maintain procurement order quantities with orders being placed in advance as producers expect supply delivery delays;
- A third strategy might be to order the same or more procurement order quantities distributed in lower order quantities assigned to different suppliers while considering the supply risk of each supplier and potential order cancellations.
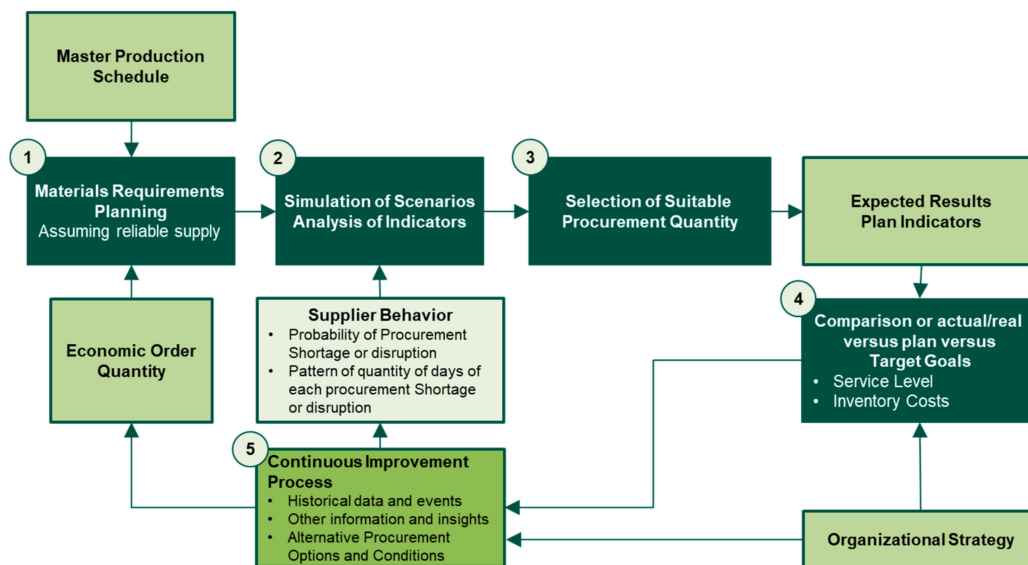
Figure 9. Methodological sequence for the selection of the most suitable procurement order quantity based on the supplier's behavior (own elaboration).

All three strategies lead—if orders are delivered according to planned dates—to an increase in the average stock levels. In an uncertain context, an increase in stocks up to a certain level will be beneficial when considering the opportunity costs of stock-outs that might arise. However, if there is no collaboration regarding transparency among supply chain partners, it could lead to the generation of a bullwhip effect that could then develop into a supply crisis. In this situation, suppliers and producers will give priorities depending on product margins or strategic factors as they might have a higher quantity in their order books than they are able to process. This prioritization leads to the supply of goods with differentiated strategies depending on the product margin, product characteristics, sector, geographical location, etc., which may imply there will be some products or sectors suffering more from the lack of supplies than others.

To balance this situation for producers, the proposed methodology provides a reliable method to balance stocks and stock-out consequences based on the selection of appropriate procurement order quantities based on the supplier´s behavior. Moreover, it should be complemented with transparency among supply chain partners and with alignment to the organizational strategy. As a result, and based on the potential supply crisis and related risks, this methodology is key to securing operations, balancing stock levels and opportunity costs, and building trust in the relationships among supply chain partners.

7. Conclusions

This section is divided into theoretical, managerial, and empirical conclusions, and explains the limitations of the research as well as describing the potential research work derived.

Theoretical conclusions: This research provides syndication of the need for models and systems to respond to the increasing global risks of supply that are creating major disruptions in international supply chains. Moreover, it provides a contribution via the methodology and developed system to deal with this challenge:

- The current challenges of procurement methodologies and supply planning systems were described;
- A new methodology for assessing and improving procurement order quantities was developed;
- A system enabling the simulation of scenarios for determining the best-fit procurement order quantity depending on the supply risk pattern was developed.
- Managerial conclusions:

- The methodology can support managers in the management and distribution of functions in production and procurement planning departments;
- The system for materials requirements planning with simulation capabilities can provide managers with short-term procurement insights to deal with the pressure of managerial decision making;
- Steps for assessing, selecting, and improving the procurement strategy were described in the discussion section.

Empirical conclusions: To prove the utility of the new concept a simulation of a component manufacturer´s materials requirement planning was performed. In the simulation, planning data are reliable, with the exception of the procurement risk of the supplier responsible to supply a material needed to produce the final product. The simulated scenarios analyze the procurement order quantity for different supply disruption or shortages scenarios. The benefits of the simulation—and its results—are:

- The results provide evidence that suppliers' behavior regarding supply risks is relevant for target indicators as a key factor when defining the procurement strategy of any producer;
- When suppliers' behavior, in terms of the delivery date, is reliable, the best set of target indicators are obtained for a procurement order quantity equal to the economic order quantity (EOQ);
- When suppliers' behavior, in terms of the delivery date, is not reliable the best set of target indicators are obtained for a procurement order quantity not equal to the economic order quantity (EOQ) and that will depend on the organization's goals concerning the service level to the customer and total inventory costs;
- When suppliers' behavior in terms of the delivery date is not reliable, a procurement order quantity lower than the economic order quantity (EOQ) provides higher backlogs and lower service levels with end-customers;
- When suppliers' behavior, in terms of the delivery date, is not reliable, a procurement order quantity higher than the economic order quantity (EOQ) provides lower backlogs and higher service levels with end-customers with a small increase in average inventory levels.

Limitations of this research work include:

- A product with two-component levels and with no great complexity;
- Factors as demand, replenishment times set as constant to isolate the factors in consideration in the research work;
- Lack of organizations working with this methodology;
- The tool developed does not include the connection with other related data such as demand planning or distribution management;
- The model does not consider its integration into a system landscape;
- The selection of the most appropriate procurement order quantity depends on the user, as the user decides on the different scenarios to be compared;
- The selection of the procurement order quantity does not consider other factors such as organizational strategy and other planning methods and horizons.

Future research: The potential research derived from this paper is:

- Combine or consider other procurement factors and policies;
- Apply in other product structures and production characteristics as case studies;
- Add the influence of intelligent capabilities based on data analytics;
- Integrate the methodology in a planning system with greater functionalities.

In summary, the research shows the potential benefits of differentiated order quantity strategies depending on suppliers' procurement behavior and their associated supply risk. As a result, the proposed methodology provides a useful tool for organizations and managers to align organizational strategies to the procurement performance and reliability to ensure greater flexibility and adaptability to secure supplies in procurement shortages and disruptions.

Appendix A. Formulae of the Economic Order Quantity

Calculation of the classic EOQ allowed [49]:

$$\text{EOQ [Units]} = Q_E = \sqrt{\frac{2 \times A \times S}{I \times C}}$$

where Q_E = EOQ; A = annual demand (units/year); S = procurement cost per order (USD); C = cost per unit depending on the batch size (USD/unit); I = inventory holding costs (1/year).

Appendix B. Formulae of Key Performance Indicators (KPIs)

KPIs are presented below.

Table A1. Target system: KPIs and formulae.

No.	Key Indicator	Formula
1	$\sum$ Demand (products)	$\sum_{t=1}^{n}$ *Demand at time period t*
2	On-time delivery (%)	$\frac{\sum_{t=1}^{n} Products\ delivered\ on\ time}{\sum_{t=1}^{n} Total\ products\ ordered} \times 100\%$
3	Service level (%)	$\frac{\sum_{t=1}^{n} Weeks\ without\ product\ backlog}{\sum_{t=1}^{n} t} \times 100\%$
4	Ø Customer backlog (products)	$\frac{\sum_{t=1}^{n} Customer\ backlog\ (products)}{\sum_{t=1}^{n} t}$.
5	$\sum$ Weeks with customer backlog (weeks)	$\sum_{t=1}^{n}$ *Customer backlog (weeks).*
6	Ø Stock (products)	$\frac{\sum_{t=1}^{n} Stock\ at\ the\ warehouses\ at\ time\ t}{\sum_{t=1}^{n} t}$
7	$\sum$ Procurement orders (orders)	$\sum_{t=1}^{n}$ *Procurement orders at time period t*
8	$\sum$ Inventory costs (mil. USD)	$\sum_{t=1}^{n}$ *Procurement costs + Warehouse Storage costs + Stockout costs.*
9	$\sum$ Procurement management costs (mil. USD)	$\sum_{t=1}^{n}$ *Orders Cost per Order + Warehouse Storage costs + Stockout costs.*
10	$\sum$ Procurement costs (USD)	$\sum_{t=1}^{n}$ *Units × Cost per Unit + Orders × Cost per Order*
11	$\sum$ Warehouse storage costs (USD)	$\sum_{t=1}^{n}$ *Warehouse Storage Cost per Unit*
12	$\sum$ Capital commitment costs (USD)	$\sum_{t=1}^{n}$ *Inventory value × Storage time × Interest rate*
13	$\sum$ Storage costs (USD)	$\sum_{t=1}^{n}$ *Units x Cost per unit*
14	$\sum$ Stockout costs (USD)	$\sum_{t=1}^{n}$ *Penalty per unit backlogged × units backlogged*

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