

ARTICLE

Research on the Comparison between the Different Policies by Service Level and Inventory Level Performance of Auto Parts in N.A.C.C. (North Automobile Components Company)

Sory Ibrahima Cisse^{1*}  Jianwu Xue¹ Moussa Sali²

1. School of Management, Northwestern Polytechnical University, Xi'an, 710072, China

2. School of Information Engineering, Chang'an University, Xi'an, China

ARTICLE INFO

Article history

Received: 4 April 2022

Revised: 12 May 2022

Accepted: 23 May 2022

Published: 4 July 2022

Keywords:

Classification

Policies

Auto parts

Forecast

Performance analysis

Comparison

ABSTRACT

As after sales services become more and more popular, particularly preventive or corrective maintenance, the intervention and repair of the customer's goods in a timely and efficient manner ensure customer satisfaction and contribute to the establishment of brand image in the market of the suppliers. The availability and quality of spare parts are key elements of this strategy while ensuring minimal management costs. The reuse of spare parts retrieved from customer systems is a growing maintenance strategy practice which impacts the traditional spare parts supply chain. This reuse is primarily driven by extending the economic life of goods, initially regarded as waste and therefore without added value, by transforming them into valuable spare parts that can be reused; secondly, for environmental or regulatory reasons, demanding responsibility for the treatment of products at the end of their life; and thirdly, to improve the availability of parts for maintenance, especially parts that the organization can no longer purchase or that are impacted by other issues. It also involves the analysis of their condition and their eventual return to working order as they are retrieved from the customer's systems in a defective condition. In this paper, we will identify and classify the different customers and spare parts by estimating the critical level of rationing policy based on forecasts, identify the thresholds of inventory management policies, and finally, compare the different policies by service level and inventory level performance for the N.A.C.C. company.

1. Introduction

As spare parts manufacturing industries expand at an accelerated pace, the business challenge of customer de-

mand is becoming more and more acute. In the past few years, auto parts manufacturing companies are forced to pay more labor and material resources to deal with a variety of problems due to the gap between customer demand

*Corresponding Author:

Sory Ibrahima Cisse,

School of Management, Northwestern Polytechnical University, Xi'an, 710072, China;

Email: sorycisse771@gmail.com

DOI: <https://doi.org/10.30564/jmser.v5i2.4593>

Copyright © 2022 by the author(s). Published by Bilingual Publishing Co. This is an open access article under the Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License. (<https://creativecommons.org/licenses/by-nc/4.0/>).

and actual demand, the operation schedule is ahead or behind. The shortage of customer resource management has greatly damaged the business of automotive component manufacturing enterprises, and automotive component manufacturers in some parts of the world have begun to carry out these aspects in general, some common shortcomings are such as weak theoretical basis, poor feasibility, and lack of learning of index classification and secrecy of data sources, etc.

If an effective customer demand forecasting model is not implemented, it can result in huge losses of investment for the manufacturing company. Therefore, the relevance of this paper arises from the need to implement the most appropriate model for the spare parts manufacturing industry by classifying different customers and spare parts by estimating the critical level of rationing policy based on the forecast, finding the thresholds for inventory management policies at threshold levels and finally comparing between the different policies by the service level and inventory level performance for N.A.C.C. (North Automobile components company).

In today's competitive manufacturing environment, to meet changing demand quickly, organizations are transitioning to a more efficient demand-driven supply chain. The market has morphed into a "pull" environment, with increasingly demanding and selective customers dictating to the supplier what products they want and when they should expect them. Demand forecasting is critical to inventory management, as inventory levels are also dependent on demand forecasts.

An inadequate estimate of demand can result in significant out-of-pocket costs, proving that the process is not efficient. As a result, many systems make significant investments in inventory to avoid "stock-outs". Another layer of complication is that some demands may be intermittent, meaning that there is a time when we have no demand and sometimes, we have successive demands. Intermittent demands have emerged as a major challenge in today's competitive manufacturing environment, and in the pursuit of a rapid response to changing demands, organizations are moving toward a more efficient demand-driven supply chain.

These points reflect the fact that the market has evolved into a "pull" environment, with increasingly demanding and selective customers dictating to the supplier what products they expect and when they expect to receive them.

2. Literature Review

In some environments, such as petrochemistry, the same spare part for the same type of equipment can be installed in various types of implementations. The latter could be critical or non-critical, hence the need for different service levels for the same part to cover different types of implementations. (we are talking here about the criticality of the implementations/systems using the part, not the criticality of the part itself). The supply chain degree: the differentiation is based on the position of the actor who requests the part in the supply chain. The example we can provide here is the differentiation between requests from the retailer's store and direct requests from the final customer. In this case, prioritization is a function of the company's strategy. Outside of industry: the necessity of inventory differentiation is not limited to the industrial domain; we can give here the example of managing the availability of hotel rooms or airplane seats. Differentiation also seems to be useful in the medical domain, such as for the management of organ transplants and the need for stocks of blood depending on the severity of the patient's condition.

2.1 Inventory Management Policies at Different Service Degrees

To meet this need for inventory differentiation is reflected by the application areas that were presented above, inventory management policies are used in:

Traditional policies: in the absence of dedicated differentiated management policies, industries tend to apply one of the following two practices in an attempt to meet the priority customer's service degree. Common service level. In this case, the highest service level of the highest priority customer class is established as the only service level for the part. In other words, all other customer classes receive an overestimated service level.

- **Advantages:** ease of management and implementation, availability requirements for different types of contracts are met.
- **Disadvantages:** large inventory, priority customers do not feel they have priority over others, and non-priority customers do not see the value in asking to be upgraded.

Separate inventory: in this case, for each class of customers, a dedicated inventory and management are created. It is almost a matter of replacing each reference with sub-references in the number of customer classes. For the

same reason, a customer class, even if it has priority, has no visibility of the stocks of other classes.

- **Advantages:** easy to set up and for each customer class a different service degree.
- **Disadvantages:** high inventory, multiplication of the supply manager's portfolio, desynchronization of order management, and logistic transport.

2.2 Inventory Rationing Policies and Quantity Rationing

It also called the policy of the critical degree, it is a kind of intermediate solution between the two traditional practices, between the non-separation and the separation of the stock and the part. It consists in reserving a part of the common stock for certain priority classes and depriving other fewer priority ones of this reservation. If we assume that there are two classes of customers, one with priority and the other with lower priority, only one critical level is decided, often noted as **k** or **cl** (critical level). Both customers are served in the same way, but as soon as the stock level is lower than the critical level, we stop serving the lower priority customer and the remaining stock is reserved for the higher priority customer, as long as the stock is replenished.

In the meantime, in the case of **N** classes of customers, **N-1** critical levels are decided, only the priority customer does not have a critical level imposed. The value of the critical level assigned to each class decreases with the growth of the priority associated with this class.

- **Time Rationing:** Also known as the critical-time policy, it follows the same approach as the critical degree policy, except that the differentiating parameter, in this case, is time rather than quantity. This time is often reduced to the time remaining when the order is received. So, if the remaining time is long, a prioritization is set up and then lifted as soon as the reception approaches. This is an additional problem in the case of inventory management at different degrees of service when the order management mode is "backorder" and not "lost sales". The problem is called "backorder management" or "backorder elimination process". Indeed, as in any inventory management policy, the occurrence of a backorder shortage is likely. The implementation of a priority management mechanism between these backorders is necessary to define to whom the stock should be allocated at reception. If in the absence of customer differentiation, the management of stock shortages is

often done according to the principle of first-come, first-served, in the case of customer differentiation and when the stock shortages concern several classes of customers, a problem arises: defining how to distribute the order recently received from the supplier between the different classes. Indeed, in the case of two classes of customers: one priority and the other less priority, a backorder will be created for the priority customer if and only if the stock is zero but will be created for the less priority customer as soon as the critical degree is crossed. So, there are two degrees of prioritization decisions to be taken in this situation: first, between backorders in the priority class and those in the lower priority class: first-come, first-served management: in this case, no prioritization is done in backorder management.

- **Management with priority:** In this case, all the backorders in the priority class are eliminated before processing those in the lower priority class. If the second decision is made, then another choice is made between backorders of the lower priority class and replenishing the stock: serve the backorders in the second class, before replenishing the inventory. Fill the inventory to the critical degree, then eliminate the backorders from the lower priority class. Schuh and Stich, McKinsey & company, forecast growth in production, including component activity for the next several years.

In addition, Dombrowski and Schulze attest to the fact that parts management accounts for a significant portion of aftermarket revenues. All these points underline the economic necessity of spare parts management and its optimization. Demand forecasts are used for many purposes, such as negotiating contracts with suppliers. The more accurate the forecast, the better the starting position for negotiations.

Unused spare parts are a limited capital asset that generates storage and maintenance costs instead of revenue. Therefore, an overestimate should be considered a negative. Underestimating demands could lead to bottlenecks in component supply. In the worst case, this could lead to unnecessary car downtime, reducing customer satisfaction and hurting the brand as a whole. According to Klug, a good supply of auto parts is now an important factor in customers' purchasing decisions. These points summarize the economic need for accurate forecasting of auto parts demand for an automotive manufacturer.

Many works have proposed models for forecasting

component demand. An improvement of Croston's estimator was done "by simply adding a smoothing parameter for forecasting" Syntetos and Boylan (2007) ^[1].

After several tests, some good results have been achieved when "the bootstrapping method was applied to forecast component demand" Willemain et al. ^[2].

"Grey systems theory has been employed to forecast material equipment in the Taiwan Navy" proving its effectiveness Chiou et al. ^[3].

Propositions of models based on "support vector machines have been employed in several domains of forecasting" such as (computing, motors, car parts, etc...) which has also proven handy Hua Zhang ^[4].

Implementation of "Neural networks have proven their effectiveness in forecasting auto parts, airplane parts, etc..." dealt with large scale data more effectively than most methods to forecast parts demand Gutierrez et al. ^[5].

The "Kano model principle examined personalized demands, built a hierarchical model of personalized demands for products, and established the priority order of importance of personalized demand" based on the hierarchical model and the ranking of importance, the customizable attributes of the product, and their priorities for customization were determined ^[6].

"Large-scale spectral clustering with landmark-based representation selected K-means clustering of large customers" based on the dimensions of electricity, electricity prices, and capacity to classify customers into five categories. Second, customer requirements were identified based on large customer service orders, customer surveys, etc., and the requirements were hierarchically classified according to business types and customer perceptions. Finally, based on the findings of the customer cluster analysis, the specific electricity demands of customers in each category were identified, and demand stratification and resource allocation were proposed ^[7].

"System optimization method for customer demand prediction based on support vector regression analysis in the process" They proposed a three-step algorithm including mathematical model formulas of nonlinear programming (NLP) and linear programming (LP) to obtain the regression function, and the last step used a recursive method to predict customer demand effectively ^[8]. "Demonstrations of the ability of self-organizing maps (SOMs) were used to classify customers and their responsiveness potential using merchants, trade, and customer flow demand databases, and helped load response modeling as supporting tools". "Customer suitability searches are limited to daily

and real-time products, and interest in such products is growing in developing countries. Therefore, customer demand and responsiveness (demand response and distributed generation strategies) were tested and compared to the price curve".

The results significantly demonstrated the ability of the method to improve data management, and it is easy to find a systematic strategy to achieve clear demand ratios in different price scenarios ^[9].

Studies have been done on the optimal inventory management of some companies. "The price of products sold by the companies was driven by an exogenous stochastic pricing process" that impacts the customer acquisition rate between ordering cycles, the author also analyzed the backlog and turnover of optimal ordering decisions. The research results show that the price-based inventory strategy is optimal under certain conditions ^[10].

Based on the results of real Amazon datasets, forecasting the demand for remanufactured products is a complex nonlinear problem. "With the help of advanced machine learning techniques, we can achieve highly accurate predictions of product demand" ^[11]. Another proposition to model customer demand using evaluation data has been made to firstly, address the concern that the number of issues in the clustering analysis is not easy to determine, a product performance dictionary was provided to ascertain the clustering issues. The TF-IDF method was improved for the dictionary creation and based on product performance the dictionary completed customer demand mining. Secondly, given the lack of a demand analysis process in existing product review studies, a "Kano analysis method based on product review data was proposed". On this basis, the matter-element representation was introduced to quantify the customer demand model ^[12].

Most of these works used statistical models for demand prediction, "machine learning approaches have achieved promising results in time series forecasting over the past decade". This trend is not recognizable for automotive spare parts demand forecasting, which is a related field. Despite the advantages, the overall picture of customer demand forecasting methods influenced by improved classical methods remains unclear according to Borempi et al. ^[13].

This motivates the identification of spare parts classification management and policy characteristics to conduct a literature review to determine possible approaches applicable to the spare parts forecasting problem in N.A.C.C.

2.3 The Emergence of Service and the Notion of Service Quality

Historically, the value-added of industrial production was mainly in the form of material products (goods). So, industry-focused principally on the design and production functions. Meanwhile, services were seen as mere support functions and regarded as cost factors rather than sources of economic benefit. “Traditionally, the after-sales service function has been viewed as a necessary evil in companies.”

This product approach of companies explains the limits of material, human and technological investments in the field of services; we talk about “product-centric” companies. It is with the evolving needs of customers in terms of services (the so-called post-industrialization period), and the change in customer habits, the result of new economic strategies and competitive issues for companies, that the service orientation of industries has appeared. “The change is in favor of a vision that considers after-sales service as a source of competitive advantage and a business opportunity”. Figures can confirm the emergence of service to an international degree, such as “among the 25 largest economies in the world, all but one country is dominated by services (more than 50% of gross domestic product)”.

Today, some industries offer after-sales service contracts with product-independent pricing. This is a measure of the importance of the intangible to the consumer. In addition, marketers are increasingly aware of the similarity of products in certain markets, most of which fulfill their primary functions. This similarity is the result of increasingly pronounced competition, of which the automotive market is an example. The difference between these competitors often lies in a few optional features, sometimes hardly visible to the customer.

This fine difference can at the same time imply very expensive technological and material investments. The marketing function of companies, however, finds that the degree to which they differ from the competition can be in the quality of the service offered with the product.

Service has become a key sales criterion and a way for

the company to build its brand image. Moreover, it allows the company to stay in touch with its customers even after the sale of the product. It becomes a good way to ensure feedback on the quality of the product and a follow-up on the evolution of the customer’s needs. Ideally, this feedback can be used to improve the design of new products, so it is clear today that the services that accompany a product can generate benefits that are a direct and indirect source of profit for companies, direct because these services are often more profitable than the products they surround, and indirect because expected by customers, they are inducers of product demand and a source of differentiation of the company’s offering. The profit generated by after-sales services is often greater than that obtained from sales, and the market for services can be 4 or 5 times larger than that for products.

This rise in power of the immaterial (service) offered with the material (product), so that the requirements of societal and environmental responsibility are in full swing, which has given rise to the notion of use: in this case, the responsibility of the product is not transferred with the sole act of sale, but the company remains responsible for its product in its different life phases through the services, until the return and recycling of the product. In this configuration, the customer becomes a user and no longer a consumer. So, the industrialization of the product is now accompanied by the industrialization of the service, which can commence even before the act of sale.

In this case, as for products, services can be represented in a life cycle. As we presented the main types of services in the Figure 1 below.

We can notice that the services of this cycle can be immaterial like the training of the user, or accompanied by material like the maintenance.

However, the common link between these services consists in the creation of added value by providing a useful service to the user without necessarily calling upon a technological transformation of the material.

We are talking about the production of service around a product, through the creation of new services, as well as the maintenance and improvement of existing service levels.

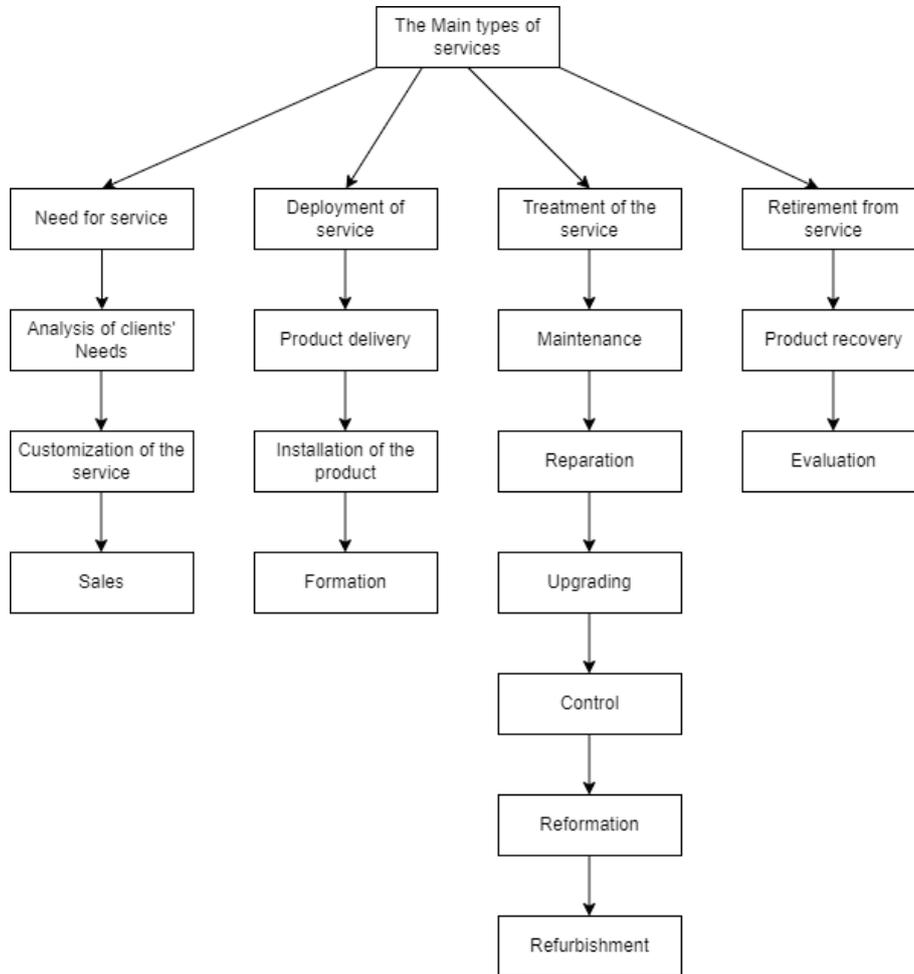


Figure 1. The prominent types of services in N.A.C.C.

3. Research Methodology and Framework

This chapter will present the industrial context of the application of the work of this paper, passing from the general presentation of the company and going through the spare parts supply chain department, before performing an analysis of the inventory management processes of its planning team.

As such, efficient spare parts supply chain is required to ensure the availability of spare parts to serve technicians through transportation and warehousing solutions while optimizing and rationalizing inventory.

The planning team is responsible for centralized inventory management. Its tool provides plans based on forecasts to the procurement staff. One of the first things that stand out of our analysis is the need to standardize practices which today are too often based on individual initiatives that do not offer the control of the spare parts management and distribution process desired by the company. This standardization of practices, to be adopted and effective, should not be positioned in total rupture of

practices, especially since the experience of the suppliers remains preponderant. Thus, from our point of view, the standardization of these practices will have to be based on a rationalization of current practices in terms of spare parts inventory management.

An additional point that we can emphasize here is that, although the amount of data that supply houses has to deal with, the amount of data specific to the management of a reference is very small and its variability is important. The quality of the estimates of the forecast of each reference is then strongly degraded.

It is then difficult to measure in practice the effects of the quality of the demand forecasting models currently used at N.A.C.C. on the actual results. We propose in the work of this paper to analyze the relationships in terms of efficiency on purely statistical considerations and stock management indicators based on the scientific positioning of this problem which will be carried out in the following chapter.

Below is a graphical representation of the conceptual framework in Figure 2.

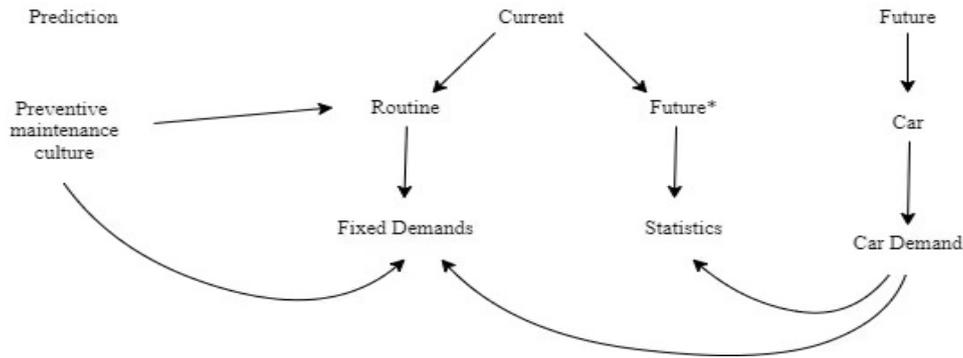


Figure 2. Conceptual framework

4. Spare Parts Management Solutions and Expectations at N.A.C.C.

N.A.C.C. uses a push/pull management of its spare parts flows through dedicated tools and teams. Each supply manager is in charge of a portfolio according to the maintenance technician. This consists of executing the plan proposed by planning software. This plan is based on demand forecasts. Each supply manager is responsible for all the parts in a specific portfolio by placing orders with suppliers, ensuring that suppliers and carriers respect delivery times, and placing the required quantity of parts in stock in the required warehouse: this is a “push” flow logic.

When a customer request is triggered (via the maintenance technician), an algorithm automatically searches for the part in the warehouse closest to the maintenance technician in question. If the requested part is not available in the supply chain network, a dedicated team takes charge of the response to this “backorder” (pending request). In the event of a lack of availability of the requested part in the supply chain network, a dedicated team takes charge of the response to this “backorder” (pending request) by the suppliers via emergency routing solutions while ensuring contact with the maintenance department: this is a case of “pull” flow logic, as seen in the below Table 1.

Table 1. Flow management of Spare parts in N.A.C.C.

Types of flows	Flow generation tools	Implementation team and flow monitoring
Push flows Push	Planning tool	Procurement Managers (Contact with the supplier)
Pulled flows Pull	Request management tool	Customer Solution Managers (Contact with the maintenance technician)

The primary measures of the performance of this supply chain are: the availability of spare parts in the logistics network is expressed as the number of backorders at the

global “backorders” level and the level of unfilled orders at the regional or local level. The level of inventory is expressed as the quantity of inventory and the value of on-shelf and by the level of excess inventory. Among the teams in this department, we find the planning team, which is mainly responsible for defining the rules for the supply and distribution of parts between the various warehouses. It, therefore, defines inventory management policies for the type of push flow management. It bases its management on a commercial planning software that proposes recommendations for the team of supply managers. It is also in charge of maintaining and improving the recommendations of this tool. The availability of spare parts, as well as the inventory levels, are therefore highly dependent on their recommendations.

These recommendations must be based on efficient planning practices and models. The performance of this team is therefore measured by its ability to provide plans to the procurement team (recommendations in orders...) that both improve parts availability and reduce the risk of overstocking. These performances depend on the quality of the forecasts, and therefore on the associated models, and the proposed supply thresholds. Let’s recall here the conflicting nature of the management of availability and overstock risks, essentially controlled by the dependent values of supply thresholds and safety stocks.

N.A.C.C. expressed its need to improve its planning processes and its associated tool. To improve its performance indicators and meet the multiple challenges of reactivity and efficiency of its supply chain. In this context, the research project work started with the conduct of a rigorous analysis of the team’s planning processes with the objectives of formalizing the current solutions and identifying their limitations. This analysis led to the following conclusions: we note, is for each industrial solution and instance for each industrial expectation that was identified during this analysis, to summarize this study in Table 2 below.

4.1 Segmentation

The planning process uses segmentation of the spare parts to define the planning rules and differentiate the actions (for example the service level of the inventory management model). This segmentation is a combination of demand quantity, part cost, and criticality (industrial solution). However, the company's stakes and expectations in terms of supply chain performance indicators change according to the part's life cycle and the influence of the demand profile on the achievement of its objectives has been noted. If, on the one hand, there is a dedicated team that manages punctual actions according to the part's life cycle, on the other hand, the planning processes do not take into account these phases of the part's life cycle. This finding was identified as critical and induces the need to evolve the segmentation of the parts according to the characteristics related to their life cycles. Also, the classification of the demand is limited to one of the quantities of the demand and does not consider its variability and its frequency (industrial expectation). Nature of input data: the operating context of N.A.C.C does not allow today to enrich the input data to migrate to new reliability-oriented approaches. The origin of the demand for spare parts comes from the failure of the product itself, a forecasting method based on the analysis of the lifetimes of these products could thus be conducted. However, it should be noted that this analysis would be difficult to carry out, on the one hand, because these lifetimes are highly dependent on the conditions of use and environment of the products specific to each customer, and on the other hand, because of the great uncertainties on the management practices of each distribution center as well as the great variability of the routing processes. The current input data for the demand forecasting models contained in the software can be summarized as the supply orders and therefore the demand for spare parts. The performance improvement here will therefore be achieved through a transition to advanced demand-based methods.

Forecasting methods: the planning tool uses classical demand forecasting models. However, these models are known to be not very efficient for low or erratic demands, properties generally verified for spare parts. Our objective will be to analyze the efficiency of current approaches in the global process of demand forecasting and spare parts management and to propose advanced methods adapted to these demand characteristics.

4.2 Performance Indicators

It is not possible to assign a total cost function for evaluation. This is due to the difficulty of assigning a cost

of stock shortages (backorders). These have an impact on customer satisfaction and the organization's image, as well as the additional workload of the dedicated team. The main measures of N.A.C.C. are essentially the number of stock shortages and the inventory level. It will be necessary to propose a global approach based on the differentiation in terms of inventory and service level performance evaluation for which the construction of these metrics remains independent but analyzed commonly according to the service/inventory priorities of the part in question. Selection of forecasting methods: the selection of forecasting methods for parts is based on the forecasting error, a purely statistical quantity. The question is then is it not possible to try to qualify a demand forecasting model based on its performance, which is no longer purely statistical but translated by the global inventory management process according to the stocking levels of WIP or in terms of demand satisfaction? Customer differentiation: today the management of spare parts requests is done on a first-come-first-served basis. N.A.C.C's maintenance department has launched an initiative to differentiate standard maintenance contracts, and as a result, differentiation in terms of service technician assignment and availability is now offered to customers. The final objective of this differentiation is to reduce the downtime of the system, so the availability of the maintenance technician can be without any added value if it is not accompanied by the availability of spare parts.

Thus, it becomes necessary that the logistic chain of spare parts and in particular the management of stocks aligns with this initiative through the implementation of differentiation of the availability of spare parts in stocks as well as in the speed of the solutions of transport of these parts. The following table summarizes these N.A.C.C. solutions and their industrial expectations in scientific inventory management solutions which are well stated in Table 2 as follows.

4.3 Definition of the Number of Customer Classes

The majority of literature on rationing proposes either a 2-customer or N-customer model, or two independent studies, the first with 2 classes and then a generalization to n classes. However, no article in the literature proposes a methodology to decide how many customer separations can be carried out without impacting the common performance indicators.

Introducing the issue of the number of customer classes, one can imagine that if the number of customer classes increases significantly, the available inventory degree may increase (due to bookings), without improving the service level to desired levels and may generate a significant in-

Table 2. Resolutions and anticipations of N.A.C.C. Inventory management

Subject	Current NACC solution/constraint	Industrial expectation of NACC
Segmentation	Classical segmentation: in quantity of the demand/part cost/criticality	Taking into account the variability of the demand Taking into account the life cycle of the part
Input data	Lack of reliability data	Use of models based on demand history
Forecasting methods	Classical methods	Methods considering low and erratic demand
System performance indicators	Inadaptability of the measure by a total cost function	Double evaluation of the level of backorders and inventory
Selection of methods forecasting methods	Selection by statistical methods	Selection of the final indicators of N.A.C.C.
Customer differentiation	First come, first served demand management	Consideration of demand differentiation in the N.A.C.C. SYSTEM

crease in inventory.

4.4 Separation Policies of Performance Evaluation

For most inventory management articles at different service degrees, the evaluation is limited to a sensitivity analysis of the policy concerning several parameters and employing the same policy. Rare articles extend this evaluation to a comparative analysis between several policies and in particular with the classic policies, such as the common service level policy and the separate inventory policy. Whereas we can determine in the case of a demand hypothesis according to the fish law of a backorder model and for two customer classes, corresponds to the separation policy with the basic service level policy and the separate stock policy between the two classes. Which is represented in Figure 3 below.

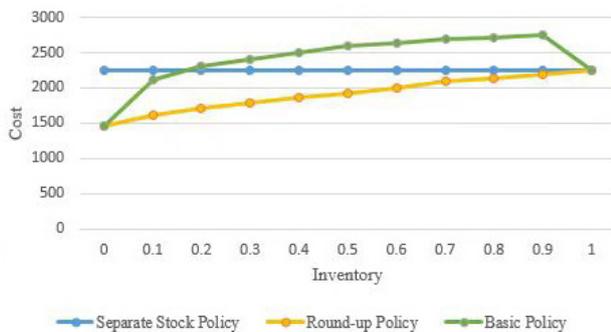


Figure 3. Comparison of costs between differentiation policies

4.5 The Policy of Inventory Management at Different Levels of Service on Forecasts in N.A.C.C.

In what follows, we consider only the scenario of 2 classes of customers, a priority class noted class 1 and a less priority class 2, and other customers, presented in the Figure 4 below.

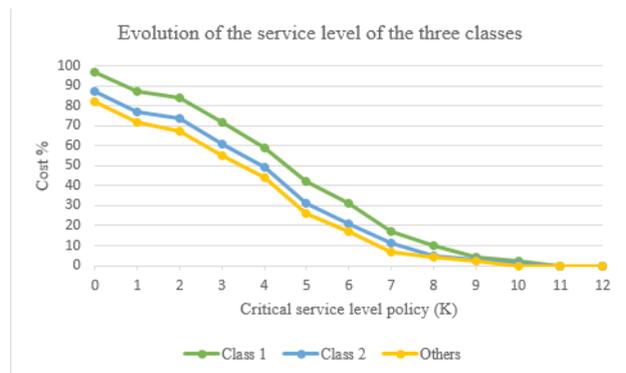


Figure 4. General comparison between the service degrees of three types of classes

According to this figure, the performance of the differentiating policy is superior, particularly as the priority class demand ratio increases. The performance is in terms of the total cost that includes the penalty costs related to each contract, which are inherently larger for priority customers, thus justifying the performance of rationing in the case of a large ratio of penalty costs for each contract.

Regardless, from a service level point of view, as illustrated in the above Figure 4 it is vital to note a slight improvement in the service level of the priority class when

already at high levels can thoughtfully tarnish the service level of the non-priority class. This is owed to the exponential nature of the service level expansion.

In the table that follows are the notations for the different service levels of inventory management for the different customer classes as in Table 3 below.

Table 3. Inventory management model ratings for different service levels

Notation	Meaning.
SL:	Required public service level
SL1:	Service level required for class 1
SL2:	Service level required for class 2
RSL:	Common real service level
RSL1:	Actual service level 1
RSL2:	Actual service level 2
BO _j :	The number of Backorders generated in period j for the two classes
BO _{1j} :	The number of Backorders generated in period j for class 1
BO _{2j} :	The number of Backorders generated in period j for class 2
MSE _i :	The common forecast error calculated at period i
MSE _{1i} :	The forecast error of class 1 calculated at period i
MSE _{2i} :	The forecast error of class 2 calculated at period i
OH _i :	The common stock level at period i
OH _{1i} :	Level 1 inventory level in phase I (in case of separate inventory)
OH _{2i} :	Level 2 inventory level in phase I (in case of separate inventory)
L:	Supply time
N:	Duration of comparison/ performance evaluation
D _i :	The common real demand in period i
D _{1j} :	The value of the alternative j by the criterion k
2 _i :	The real demand at period i of class 2
γ:	The ratio of demand 1 $\gamma = \frac{\sum_{i=1}^N D1_i}{\sum_{i=1}^N D_i}$
F _{i+k} ⁽ⁱ⁾ :	The common forecast for the period i for the period i+k
F _{1+k} ⁽ⁱ⁾ :	The forecast at period i for period i+k of class 1
F _{2+k} ⁽ⁱ⁾ :	The forecast at period i for period i+k of class 2

a) Estimating the critical level of rationing policy on forecasts (k)

We consider common service level policies on forecasts as the basis for these policies. In the case of two customer classes with the need to differentiate the service level between the two classes, while using a common inventory, the policies (S, k, s), (t, k, s), and (t, r, KR, q) must evolve to new policies (Si, ki, si), (t, ki, si), (t, ri, kri, qi). Let us note the critical level which will be equal to Ki, ki, or kri depending on the policy used.

We keep the same threshold calculations for Si, si, ri,

and qi and we propose a method to calculate these critical levels. We assume a backorder management model and the following backorder management mode: if the stock level is above the degree, no distinction is made between backorders, otherwise, only first-class backorders are processed. When an order is placed by the supplier, the first-class backorders are served first, then the second-class backorders, before replenishing the inventory.

For all policies we consider below the order initiation threshold, we consider this classic assumption in the literature that we could not stop serving the least valued customer if no order is initiated. Estimation of cli calculations the concept of this estimation is to ensure that the available stock is enough to satisfy the priority customer during the period preceding the receipt of the order according to the required service level s11.

Let us note **m** the time remaining to the reception of the order triggered by the replenishment thresholds of the common degree.

$$m \in \{1, \dots, L\} \tag{1}$$

The calculation of the thresholds of the classical inventory policies enables the fulfillment of the demand. During the period of the supply time L. By the same logic, we consider that the objective of the critical level is to satisfy the service level of class 1 during the remaining period at order receipt m.

We stop serving class 2 when the inventory level is less than the estimated amount needed to cover the required service level for class 1 during that period. Thus, based on these considerations, the table of policies on common service level forecasts and the assumption that cli <, if we can reconcile the estimate of the critical level during period m to cover customer class 1, with the calculation of the common safety stock for the supply period L:

We note:

$$S_i = f^{-1}(1-SL) * \sqrt{L} * \sqrt{MSE_i} + \sum_{K=0}^{L-1} F_{i+k}^{(i)} \tag{2}$$

Thus, we can estimate **ki** by this formula in the case of the policy (Si, ki, si)

$$K_i = \min (f^{-1}(1-SL1) * \sqrt{m} * \sqrt{MSE_{1i}} + \sum_{K=0}^{m-1} F_{i+k}^{(i)}, s_i) \tag{3}$$

b) Thresholds for inventory management policies at different service levels

We consider Table 4 of the forecasting policy on (si, Si) forecasts and adjust it in the case of differentiation of two customers, so the table below provides a summary of the threshold estimates of the following inventory management policies: the rationing policy (at the critical degree), the common stock policy, and the separate stock policy.

Presented in the following Table 4 below.

- **Note 1:** similarly, standard policies (T, SI) and (T,

Table 4. Calculations of predicted strategy differentiation in the threshold

Parameters	Rationing Policy (si, ki, Si)	Common Stock Policy (si, Si)	Separate Stock Policy (s1i, s2i, S1i, S2i)
Si	$f^{-1}(1 - SL) * \sqrt{L} * \sqrt{MSE_i + \sum_{k=0}^{LT-1} F_{i+k}^{(i)}}$		
S1i			$f^{-1}(1 - SL1) * \sqrt{L} * \sqrt{MSE_i + \sum_{k=0}^{LT-1} F_{i+k}^{(i)}}$
S2i			$f^{-1}(1 - SL2) * \sqrt{L} * \sqrt{MSE_{2i} + \sum_{k=0}^{LT-1} F_{i+k}^{(i)}}$
Si	$f^{-1}(1 - SL1) * \sqrt{L} * \sqrt{MSE_i + \sum_{k=0}^{LT} F_{i+k}^{(i)}}$		
S1i			$f^{-1}(1 - SL1) * \sqrt{L} * \sqrt{MSE_{1i} + \sum_{k=0}^{LT-1} F_{i+k}^{(i)}}$
S2i			$f^{-1}(1 - SL1) * \sqrt{L} * \sqrt{MSE_{2i} + \sum_{k=0}^{LT-1} F_{i+k}^{(i)}}$
Ki	$\min[f^{-1}(1 - SL1) * \sqrt{m} * \sqrt{MSE_{1i} + \sum_{k=0}^{m-1} F_{i+k}^{(i)}}, Si]$		

RI, Qi) can be constructed.

- **Note 2:** if a common inventory policy with no difference is used, but priority needs to be given to customer satisfaction, it is assumed that the overestimated service level is regarded as $SL = SL1$. **Note 3:** $F_i \neq F1_i + F2_i$; $MSE_i \neq MSE_{i1} + MSE_{i2}$; if $\neq s1 + s2$; $Si \neq Si1 + Si2$ Equality constraints are not enforced unless the simulation randomly generates equations.
- **Note 4:** parameter m can be calculated by triggering the Z counter when placing an order. In this case, $M = L - Z$, or by using the order database, which usually contains the information of the expected receipt date (due date) of the order, In this case, $M = dd - cd$ (ED expiration date and CD current date).

Lastly, it is worth noting that in the configuration of the presently proposed solution, we adopt the objective of satisfying the service degree of the priority classes, while simultaneously maintaining the same public service level objective between the two classes. This configuration is common in industrial applications, and companies are willing to give priority to their customers (for commercial reasons...) in order to meet the contract requirements and to sustain a good global measure of its service level (company image, internal indicators...) but avoiding to increase the inventory.

c) Performance measurement in case of difference between two customers impact measurement on prediction error

In order to measure the impact of differentiation on the prediction error, we measured the ratio of the prediction error of the two types of demand to the prediction error of ordinary demand.

Prediction error ratio of differential prediction error ratio

$$DFER_i = \frac{MSE_{1i} + MSE_{2i} - MSE_i}{MSE_i} \tag{4}$$

Service measures

In the same way as the calculation method of actual service level, under the condition of no difference inventory management, we continue to calculate the actual service level of level 1 and level 2 and the common actual service level:

$$RSL1 = 1 - \frac{\sum_{i=1}^N 1^{BO1_i}}{\sum_{i=1}^N 1^{D1_i}} \tag{5}$$

$$RSL1 = 1 - \frac{\sum_{i=1}^N 1^{BO2_i}}{\sum_{i=1}^N 1^{D2_i}} \tag{6}$$

$$RSL1 = \frac{\sum_{i=1}^N 1^{BO1_i} + \sum_{i=1}^N 1^{BO2_i}}{\sum_{i=1}^N 1^{D1_i} + \sum_{i=1}^N 1^{D2_i}} = 1 - \frac{\sum_{i=1}^N 1^{BO_i}}{\sum_{i=1}^N 1^{D_i}} \tag{7}$$

Inventory measures

We measure the impact on the common stock level in the same way as in the case of management without differentiation by the measure of inventory relative to demand.

Relative inventory level:

$$RIL = \frac{\sum_{i=1}^N 1^{OH_i}}{\sum_{i=1}^N 1^{D_i}} \tag{8}$$

Only the case of the policy has separate stock that it is necessary to consolidate the two levels of stock in the measure, in this case, we will note in addition $OH1_i$ and $OH2_i$.

$$RIL = \frac{\sum_{i=1}^N OH1_{i_t} + \sum_{i=1}^N OH2_{i_t}}{\sum_{i=1}^N D_{i_t}} \quad (9)$$

4.6 Test Plan and Results

a) Experimental plan

We consider the same experimental plan as the previous chapters, using the same requirements profile segments and part maturity level segments.

We consider a fixed supply time of 5 cycles.

We consider three priority demand ratio scenarios:

$$\gamma = \{0.3, 0.5, 0.7\}.$$

We consider three common theoretical service level scenarios: 90%, 95%, and 97%. For each scenario, the theoretical priority service level requirements (Level 1) we used increased by 92%, 97%, and 99% respectively.

For a separate inventory strategy, a theoretical service level of non-priority (Level 2) must also be defined. In this case, the service levels we used were reduced by 5 percentage points to 85%, 90%, and 92%, respectively in Table 5.

Table 5. The 3 implemented theoretical levels of service scenarios

Scenarios	Common theoretical service level	Theoretical service level class 1	Service level Theoretical class 2 (for split stock policy)
Scenario 1: Low level of service	90%	92%	85%
Scenario 2: Average level of service	95%	97%	90%
Scenario 3: High level of service	97%	99%	92%

We measure the impact of differentiation on the forecast error ratio for the different segments of demand variability and part maturity level.

Different segments of demand variability and part maturity level

We measure the actual service level of classes 1, and 2 as well as the common actual service level **RSL1**, **RSL2**, and **RSL** respectively, and measure the common relative inventory level **RIL**. We compare the results of the service and inventory measurements of the three policies, critical level, common inventory, and separate inventory: **(si, ki,**

Si), **(si, Si)**, and **(s1i, S1i, s2i, S2i)** for the different demand profile and spare part maturity level segments.

b) Comparison of the impact of differentiation on the forecast error

Here we represent the results of the DFER measure over the comparison period N for the experimental plan that was detailed above in the following Tables 6 and 7.

By demand profile segmentation

Table 6. Impact of differentiation on forecast error by demand category

	$\gamma:0.3$	$\gamma:0.5$	$\gamma:0.7$
Stable	9%	6%	8%
Sporadic	20%	18%	21%
Erratic	15%	12%	16%

Stable parts are the least impacted by differentiation, but the forecast error deteriorates significantly for sporadic parts. The scarcity of demand in this case results in much worse forecast quality when separating demand. This is even more significant when the demand ratio between the two classes is not in balance, making the demand for one class very low and thus harder to forecast.

Table 7. Impact of differentiation by part maturity level on prediction error

	$\gamma:0.3$	$\gamma:0.5$	$\gamma:0.7$
Introduction	16%	14%	17%
Mature	7%	5%	8%
End of life	19%	17%	19%

Mature parts are less affected by differences, and even if there are differences in demand, these are more predictable. In comparison, for imported and aftermarket parts, the prediction error is significantly reduced. In this particular circumstance, the changes in demand are more significant, and it is more complicated to identify these changes when the demand is separated. This is more significant when the ratio of demand between the two categories is uneven, making the demand very low categories more challenging to predict.

c) Comparison between different policies by performance

Service and inventory levels

The following Figures 5-10 show the comparison results of three policies: common stock, critical level stock, and separated stock. For different demand ratios and theoretical service level scenarios, for different types of demand profiles and parts maturity levels.

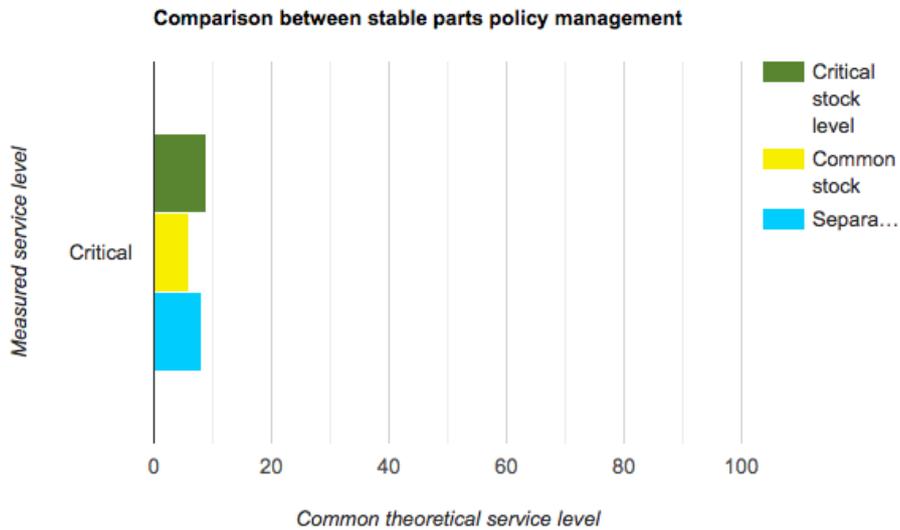


Figure 5. Comparison of different stock levels with the measured service level of stable parts

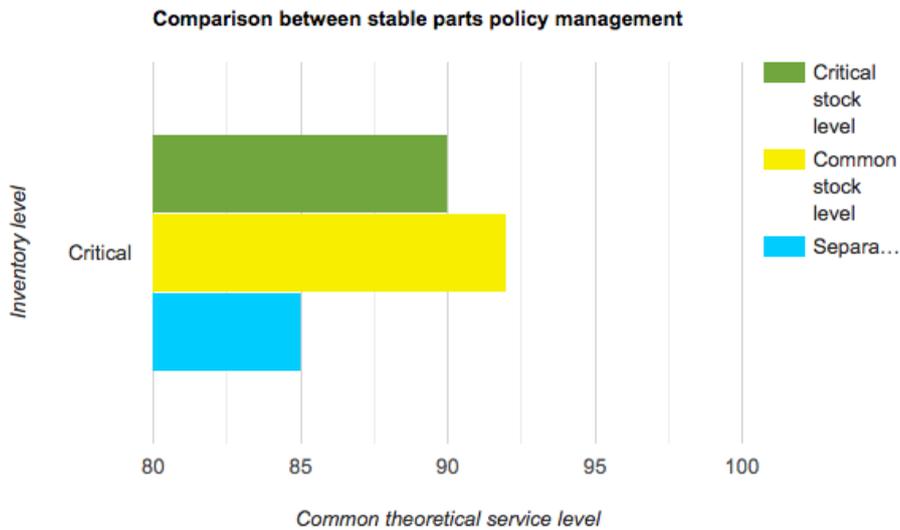


Figure 6. Comparison of different stock levels with different inventory levels of stable parts Comparison between policy management for stable parts

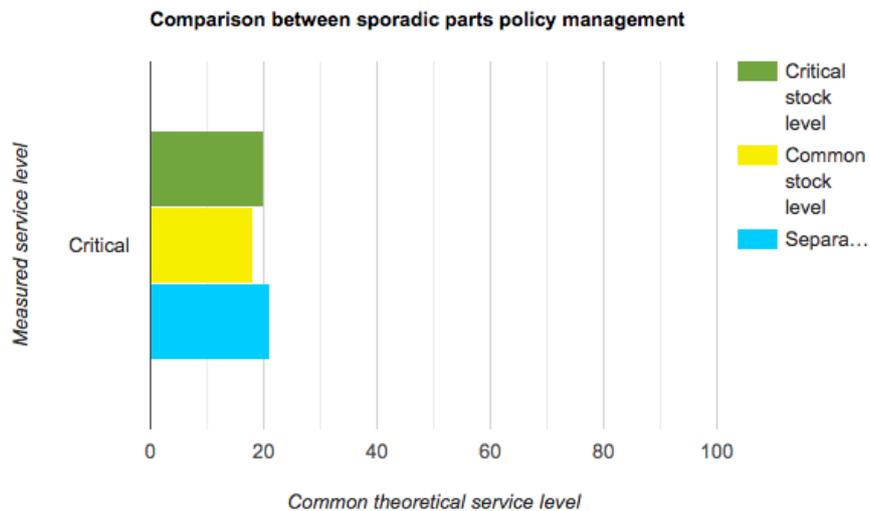


Figure 7. Comparison of different stock levels with the measured service level of sporadic parts

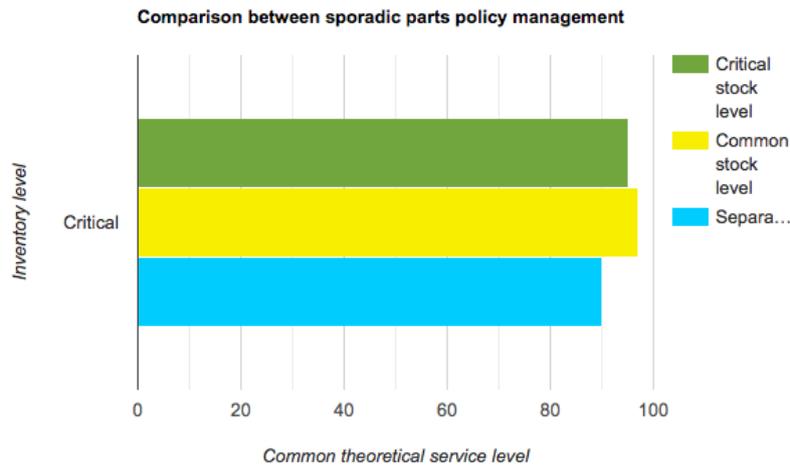


Figure 8. Comparison of different stock levels with different inventory levels of sporadic parts Comparison between policy management for sporadic parts

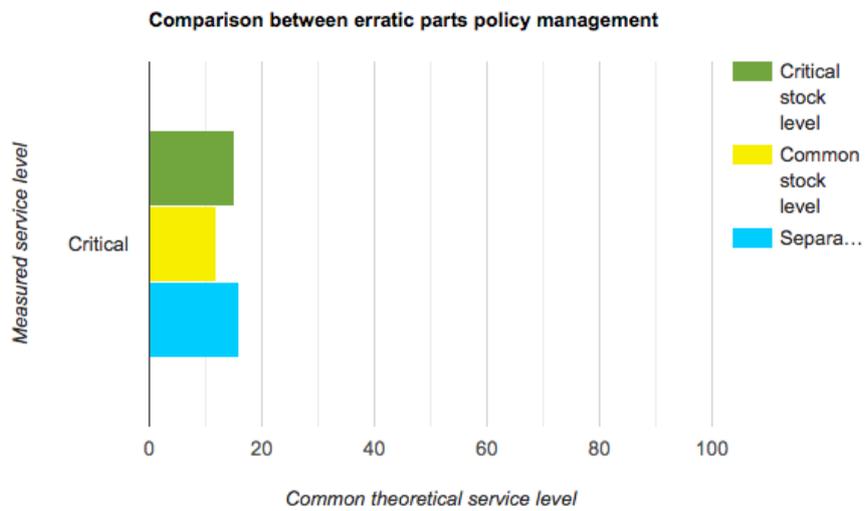


Figure 9. Comparison of different stock levels with different inventory levels of erratic parts

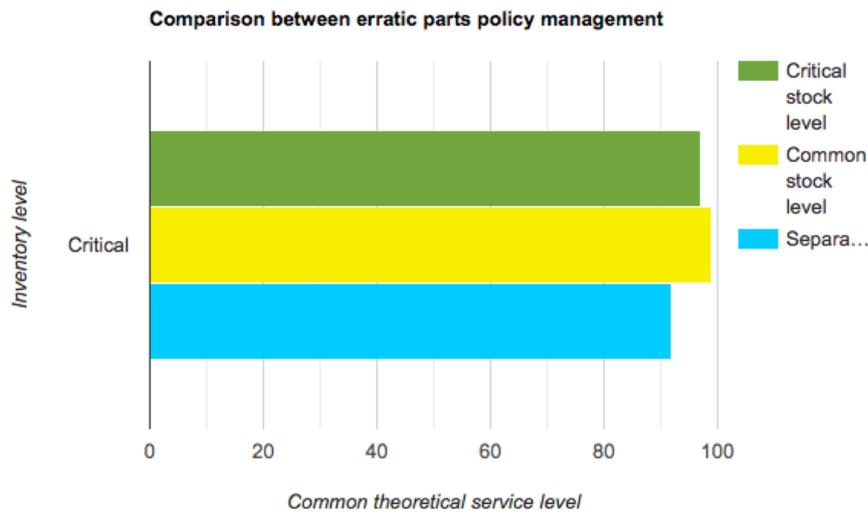


Figure 10. Comparison of different stock levels with different inventory levels of erratic parts

5. Conclusions

This paper addresses the problem of comparison between forecasting and inventory level management policies in the supply chain of spare parts at different service levels. The goal of this work was to provide insights into this issue in response to its purpose, i.e: to improve service levels and optimize inventories while considering some specific characteristics of spare parts. Spare parts supply chain management is both complicated and crucial. Complex, given the many flows in the chain, the demand profile, the risk of low turnover, stock depreciation, and the necessity to respond to different service levels according to the priority of the maintenance contract and the criticality of the parts. It is crucial because it ensures that the company can meet its commitments to rapid maintenance interventions by improving parts availability and minimizing transportation and inventory costs by synchronizing flows and allowing maintenance technicians to manage inventory. Forecasting and inventory management are key functions in this chain. This is because the quality of their production guarantees the best compatibility between service and inventory levels.

Inventory management process

Demand profile and part maturity level segmentations have been incorporated into this process to improve alignment with the forecasting process and to further determine the service level to be used in inventory management models.

Forecasting process and inventory management

In the case of customer classes: the inventory rationing policy was adjusted to the case of a forecast-based inventory management model and then compared with separate stock and common stock policies based on demand profile and part maturity level segmentations.

This research was developed in parallel with an industrial application to the case of N. A. C. C. This company manages the supply and deployment of a very large number of spare parts references throughout the world, for a large installed base of products and with a very high level of inventory, through a global and centralized supply chain. The mastery of its forecasting and inventory supply functions is consequently critical to achieving its objectives.

This work has led to a complete overhaul of its industrial logic of inventory management by the implementation of a new segmentation policy of the parts considering the aspects of variability and intermittence of the demand, the construction of a decision-making logic of parameteri-

zation of the models used according to this new segmentation, the improvement of the base of the methods used by scientific methods of forecasting and the implementation of the approach of forecasting and inventory management presented in this manuscript.

This has resulted in significant improvements in service and inventory levels and above all the alignment of the industrial process with a scientific methodology which constitutes a basis for a set of future enhancements. This work could motivate a variety of science-based perspectives in forecasting and inventory management of spare parts, including:

The combination of separation criteria

In this work, we analyzed the segmentation of demand profile and maturity level of parts in distinct ways. An extension by a combination of these two segmentations will allow strengthening the decision model given building matrices of forecasting methods and inventory management model dimensions appropriate to each combination.

Conflict of Interest

There is no conflict of interest.

References

- [1] Boylan, J.E., Syntetos, A.A., 2007. The accuracy of a Modified Croston procedure. *International Journal of Production Economics*. 107(2), 511-517.
DOI: <https://doi.org/10.1016/j.ijpe.2006.10.005>
- [2] Teunter, R.H., Duncan, L., 2009. Forecasting intermittent demand: a comparative study. *Journal of the Operational Research Society*. 60(3), 321-329.
DOI: <https://doi.org/10.1057/Palgrave.Jors.2602569>
- [3] Chiou, H.K., Tzeng, G.H., Cheng, C.K., 2004. Grey prediction model for forecasting the planning material of equipment auto parts in the navy of Taiwan. *Proceedings world automation congress*. 17, 315-320.
- [4] Zhang, H., 2019. Improved transudative support vector machine for a small labeled set-in motor imagery-based brain-computer interface. pp. 2-3.
- [5] Gutierrez, R.S., Solis, A.O., Mukhopadhyay, S., 2008. Lumpy demand forecasting using neural networks. *International Journal of Production Economics*. 111(2), 409-420.
DOI: <https://doi.org/10.1016/j.ijpe.2007.01.007>
- [6] Tang, Zh.J., Long, Y.L., 2012. Research on the method of acquiring individual demand based on kano model. pp. 127-131.
- [7] Chen, X., Cai, D., 2011. Large scale spectral cluster-

- ing with landmark-based representation. AAAI Conference on Artificial Intelligence. pp. 313-318.
- [8] Levi, R., Shi, C., 2005. Approximation algorithms for the stochastic lot-sizing problem with order lead times. <https://www.ResearchGate.Net/publication/260162679>. pp. 14-24.
- [9] Valero, M., Averkin, R.G., Fernandez-Lamo, I., et al., 2017. Mechanisms for selective single-cell reactivation during offline sharp-wave ripples and their distortion by fast ripples. *Neuron*, 94(6). pp. 1234-1247. DOI: <https://doi.org/10.1016/j.neuron.2017.05.032>
- [10] Canyakmaz, C., Özekici, S., Karaesmen, F., 2019. An inventory model where customer demand is dependent on a stochastic price process. *International Journal of Production Economics*, 212, 139-152. DOI: <https://doi.org/10.1016/j.ijpe.2019.01.039>
- [11] Van Nguyen, T., Zhou, L., Chong, A.Y.L., et al., 2020. Predicting customer demand for remanufactured products: a data-mining approach. *European Journal of Operational Research*. 281(3), 543-558. DOI: <https://doi.org/10.1016/j.ejor.2019.08.015>
- [12] Zhang, W.X., Xiao, R.B., Lin, W.G., 2020. Review data driven customer need model research based on product performance lexicon. *China Mechanical Engineering*, 31(15), 1866-1876. DOI: [10.3969/j.issn.1004-132X.2020.15.014](https://doi.org/10.3969/j.issn.1004-132X.2020.15.014)
- [13] Bontempi, G., De Stefani, J., 2017. Factor-based framework for multivariate and multi-step-ahead forecasting of large-scale time series. *Frontiers in Big Data*. pp. 14-27.