A modified cross-ABC analysis for direct inventory management

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Abstract: Data analytics represents an important step for manufacturing companies aiming at optimizing warehouse management. Moreover, in a Decision Support System perspective, companies require automated methods and processes for warehouse activities planning able to identify the most appropriate inventory management policy. Moving towards a data-driven environment, a deeper understanding of data provided by warehouse operations and supplier's orders is needed. In this context, a procedure aiming at reducing the problem of out of stock and overstock by developing a *Decision Support System* is deployed through a data-driven approach. The standard cross-ABC analysis is revised as a top-down methodology: in this way, cross-ABC analysis is applied iteratively by ranking items according to their physical features, e.g., color or size, in order to identify the weight of the items for each attribute classification, then combining the results for the final rating. The first step of the proposed procedure requires the identification of a weight for each feature, based on the influence of its importance. Then, a Decision Support System is developed in order to customize and automate the following daily activities: (a) application of the revised cross-ABC analysis, (b) warehouse management, and (c) orders planning. The main contribution of this work is the development of a versatile and dynamic procedure applying the well-known cross-ABC analysis in a different way, also developing and integrating a direct warehouse management system. A case study of a manufacturing company is also presented to explain the proposed procedure, as well as to analyze its performance and the different results compared to the standard analysis.

Keywords: ABC analysis, inventory management, Decision Support System.

1.Introduction

Inventory management is one of the largest and most significant aspects of a manufacturing business (Ciarapica et al. 2008). In this regard, ABC analysis is one of the most widely used techniques in for inventory classification. As defined by Douissa and Jabeur (2016), ABC analysis classifies the items into three ordered categories called A, B, and C: class A contains the most important items while class C includes the least ones. Usually, only one criterion is considered by the traditional ABC method for the classification of the inventory items, namely the annual dollar usage (Liu et al., 2016). It is well known that several aspects, such as demand, unit cost, criticality, lead time, substitutability, and so on, are used for inventory classification with multiple-criteria (Ramanathan, 2006; Stoll et al., 2015). Usually, the procedure consists of calculating the weighted average of the attributes, then applying the traditional ABC classification.

Our idea is instead to apply ABC cross analysis directly on each attribute, then developing a model for multiple analyses integration. The paper aims to study how the main intrinsic features of a product (color, thickness, diameter, etc.) can influence the ABC classification by using a *top-down* approach (*e.g., could an article be more critical simplistically because characterized by a high demand color?*). Based on the data collected through original equipment manufacturer, the necessary analysis was carried out. So, a modified cross-ABC analysis approach for items prioritization and inventory classification is applied. Finally, Visual Basic for Application (VBA) is used to create a dynamic Decision Support System (DSS) for a Periodic Review Policy (PRP) of items classification, warehouse management, order planning, and user interface to access, edit, and add information easily.

The remainder of the paper is organized as follows: after this brief introduction and a review of the most relevant contributions on similar topics since the 1980s (Sec. 2), the procedure is developed in Sec. 3, additionally describing our DSS. Moreover, in Sec. 4, a case study is presented to better clarify the application of the procedure and compare the results of the well-known ABC cross analysis with a new method. Lastly, in the same section, conclusions and future research directions are presented.

2.State of the art

In literature, several approaches are designed to eliminate unwanted activities by simplification or standardization, such as reducing process changeover time (Bevilacqua et al., 2015). There is also great interest in spare parts logistics and, according to Stoll et al. (2015), ABC analysis is used to divide them in individual classes. In this regard, warehouse and inventory strategies can be derived through several criteria.

As shown in Table 1, because countless process management applications are based on ABC classification and data analysis, a literature review is conducted to identify the main practices and techniques.

Table 1: Practices and techniques commonly used for ABC analysis

Practices or techniques	**ABC analysis literature**[a]																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ABC analysis	x		x		x		x			x		x							x		x			
Cross-ABC analysis		x						x						x			x							
Joint criteria matrix	x	x																						
Analityc Hierarchy Process			x						x				x	x			x							
Multicriteria approach			x	x		x	x		x		x	x	x	x	x	x	x	x	x	x		x	x	x
ABC/XYZ analysis																x						x	x	x
Qualitative and quantitative criteria			x											x	x		x							
Simulations			x	x															x	x				
Case study		x		x	x					x	x		x	x			x		x		x			x
Mathematical programming						x												x						
VED analysis														x			x							
DEA model													x		x									
Fuzzy classification								x			x		x											
Artificial Neural Network					x													x		x	x			

[a]References: (1) Flor. and Why., (1986); (2) Flor. and Why., (1987); (3) Par. and Bur., (1993); (4) Güv. and Erel, (1998); (5) Part. and Ananda., (2002); (6) Ramanathan, (2006); (7) Wan Lung (2007); (8) Bidermann, (2008); (9) Chu et al., (2008); (10) Syntetos et al., (2008); (11) Cebi et al., (2010); (12) Hadi-Vencheh, (2010); (13) Hadi-Ve. et Moh., (2011); (14) Molenaers et al., (2012); (15) Torabi et al., (2012); (16) Bulinski et al., (2013); (17) Stoll et al., (2015); (18) Dou. and Jab., (2016); (19) Liu et al., (2016); (20) Nallusamy et al., (2017); (21) Lopez-Soto et al., (2017); (22) Stoj. and Reg. (2017); (23) Zen. et Kaba., (2018); (24) Aktunc et al., (2019).

It should be noted that three main groups of techniques are often used in any ABC classification model (Douissa and Jabeur, 2016): Mathematical Programming, Artificial Intelligence, and Multi-Criteria Decision Making (MCDM). Syntetos et al. (2008) applied the ABC analysis for the entire European spare parts logistics network of an electronics manufacturer. However, the traditional ABC analysis may not be able to provide a good classification of inventory items in practice (Portovi and Anandarajan, 2002). Flores and Waybark (1987) first presented the joint criteria matrix approach to overcome the standard ABC limits by using consumption value and lead time as criteria. Many approaches have been proposed in literature to address the problem of MCDM, such as meta–heuristic techniques. In this regard, Güvenir and Erel (1998) developed a genetic algorithm for inventory classification of a university purchasing department, considering items request, consumption value, lead time, and replaceability. The ABC classification problem is also solved using a discrete Artificial Neural Network (ANN) (Lopez-Soto et al., 2017). Unit price, demand, ordering costs and lead time are usually used, e.g., by Portovi and Anandarajan (2002) to present an ANN for a pharmaceutical company based on back propagation and genetic algorithm. Ramanathan (2006) proposed the R-model as a weighted linear optimization method for MCDM, however, an item with high value in a negligible criterion could be inappropriately classified as a class A item. Similarly, the NG-model is an alternative weight linear optimization model (Ng, 2007), where the score calculated is independent of the item weights (Torabi et al., 2012). The NG-model application process classified inventory items without a linear optimizer, who seems not suitable to be applied to models involving the measurement of criteria with categorical data. To address the problem of inadequate classification, Hadi-Vencheh (2010) presented an extended version of the NG-model as a non-linear programming model, consisting of a common set of weights for all the items. It should be noted that both NG and HV models need subjective information to provide the order of importance of the criteria (Torabi et al., 2012). However, mainly in the case of large inventory size, it is very time-consuming to solve MCDM by using mathematical programming techniques. Liu et al. (2016) combined the clustering analysis and the simulated annealing algorithm to search for the optimal classification. Incorporating both quantitative and qualitative criteria is essential to have more realistic results in ABC analysis (Torabi et al., 2012), as well as the Analytic Hierarchy Process (AHP). It should be noted that the most of ABC analyses in the literature used the AHP-method to identify the attribute weights. AHP is a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales (Saaty, 2008). Molenaers at al. (2012) used AHP based on three several criteria, i.e., replenishment time, number of potential suppliers, and technical specifications. Portovi and Burton (1993) proposed AHP with rating mode to classify inventory items based on multiple criteria. Many attributes are usually hard to define precisely, and in literature, the fuzzy set theory is often used to overcome the problem. In this regard, Cebi et al. (2010) suggested the usage of a multi-attribute ABC classification model by using fuzzy AHP alternatively, incorporating imprecision and subjectivity. Hadi-Vencheh et Mohamadghasemi (2011) proposed instead an integrated fuzzy AHP-data envelopment analysis (FAHP-DEA). In recent years, also the combined ABC-XYZ analysis is common in several studies, mainly for inventory control, marketing and logistics developing individual procurement and inventory strategies (Bulinski et al., (2013); Stojanovic and Regodic, (2017); Zenkova and Kabanova, (2018); Aktunc et al., (2019)). AHP is also used as a decision supporting methodology for the VED analysis (Molenaers et al., 2012; Stoll et al., 2015), while, according to Stoll et al. (2015), the AHP in combination with a decision tree is a suitable methodology basing on criticality. Finally, Nallusamy et al. (2017) highlighted the importance of a periodical review policy for sustaining the inventory level in a manufacturing industry.

Based on the literature, an attempt was made to create and implement an ongoing review of ABC classification in order to improve inventory management in manufacturing. According to existing literature contributions, the research gap involving the development of a new method for inventory items classification, for istance, implementing and integrating multiple cross-ABC analysis based on the intrinsic characteristics of the products, and not the usual aspects such as lead time, demand or unit cost. Due to the continuous improvement nowadays available, the identified research gap could also be addressed developing a DSS to automatize the PRP of the new methodology, also including dynamic inventory management and planning activities.

3.Methodology

The current research approach is a review of several methods, aiming at developing a procedure to continuously manage stock items: a modified cross-ABC analysis and Decsion Support System are developed for stockouts and overstocking prevention by using VBA. The main steps of our DSS includes *descriptive analytics* to describe the current and past situations, *predictive analytics* for data analysis and future estimation, and *prescriptive analytics* to propose operational/strategic solutions. Specifically, our procedure consists of a cyclical multi-layer model (Fig. 1): a) Data mining, b) Modified cross-ABC analysis, c) Warehouse management system, and d) Order planning.

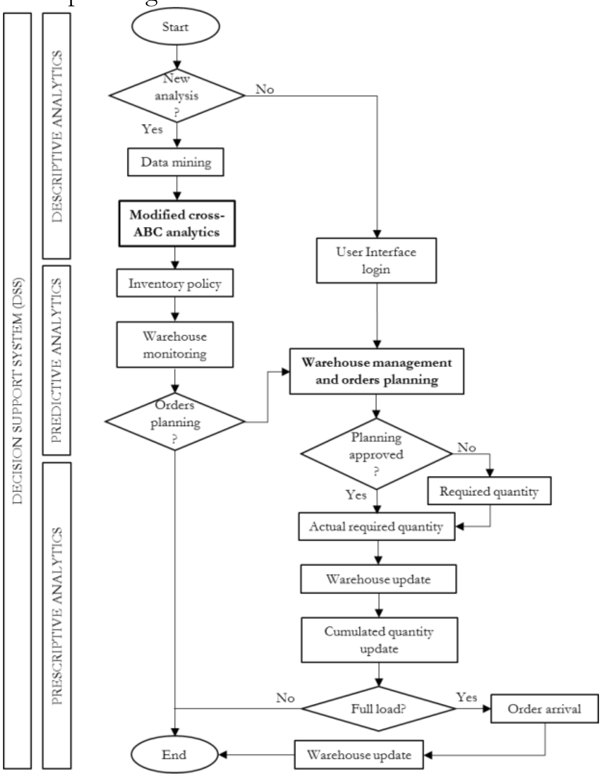

Figure 1: DSS flow chart

The methodology is the use of the indicator of the process concerned with data collection and analysis, carried out automatically by our Decision Support System. In order to correctly define the functionality of the software, it is designed with the *step-wise refinement* technique, i.e., a methodology for the analysis, design and implementation of programs based on the principles of "divide et impera" and "abstraction". Our software consists of 3 main workbooks, including 29 spreadsheets orderly interacting and 17 integrated macros. The Decision Support System first studies the existing scenario by implementing a new ABC methodology. The ABC analysis is carried out to classify the inventory system, while the inventory PRP is developed accompanied by continuous stock monitoring and planning.

3.1 Data mining

With the aim to conduct the modified cross-ABC analysis and to develop the periodic review policy; the following data are collected from the existing source: bill of materials, standard cost of materials, customer demand, route sheet, supplier information, order statistics, and so on. In order to increase readability, universal elements such as common components to all codes for sheets declaration, *For* cycle counters, and variables and parameters for temporary storage are used in our software. For better understanding, the main variables/parameters are listed in **Errore. L'origine riferimento non è stata trovata.** according to the software area: (1) *User interface* contains all the aspects user-modifiable (i.e., calendar, one push-button panel for programs activation), and three main domains such as "Item Code", "Quantity" and "Date"; (2) *ABC analysis* contains all the aspects for the item's classifications; (3) *Warehouse management* contains all the information for continuous monitoring and PRP; (4) *Orders planning*, for purchasing schedule in order to calculate the required quantity, delivery time, supplier code, and so on.

Finally, several binary variables are used for software verification and control activities, e.g., consistency checking of the reorder policy.

Table 2: DSS variables and parameters

Work area	Variables and parameters	Description
All	Check	Binary verification variable
All	Found	Binary search variable
All	Database/Warehouse/Schedule	Binary variable of belonging
User interface	GgLav	Working days in the period
User interface	LT/FLT	Lead Time/Lead Time Factor
User interface	O	Order issue cost (%)
User interface	H	Stockpiling cost (%)
User interface	Nmax	Transport capacity
ABC Analysis	Article/ArticleAA/…/ArticleCC	Items code
ABC Analysis	nAA/nAB/…/nCC	Number of items per class
ABC Analysis	Loading	Loading items quantity
ABC Analysis	Unloading	Unloading items quantity
ABC Analysis	Existence	Items existence
ABC Analysis	Average stock	Items average stock
Warehouse management	SS	Safety stock
Warehouse management	PR	Reorder point
Warehouse management	Sum1/Sum2/Sum3	Cumulative amount of items in in/out/unload
Warehouse management	EOQ	Economic Order Quantity
Warehouse management	Smax	Maximum stockpile
Warehouse management	Availability	Items availability
Warehouse management	Control	Next check date
Warehouse management	RimI	Initial stock
Warehouse management	RimF	Final stock
Warehouse management	Committed	Committed items quantity
Orders planning	NO	Optimal Order Number
Orders planning	T	Reorder Cycle
Orders planning	Supplier	Supplier code
Orders planning	ML	Linear meters
Orders planning	Quantity	Required quantity
Orders planning	Ordered	Ordered quantity
Orders planning	Q	Order quantity
Orders planning	QR0	Request quantity
Orders planning	QR	Actual request quantity
Orders planning	Qrcum	Cumulated request quantity
Orders planning	GG	Delivery time
Orders planning	Surplus	Surplus quantity
Orders planning	Nord	Order number

3.2 The modified cross-ABC analysis

According to a Top-Down approach, our cross-ABC analysis is first applied to the attributes of items, and then to the articles as well.
Simplistically, as many cross-ABC classifications as the main attribute are developed for each item. If the main attributes are three (e.g., color, thickness and diameter) for each item three cross-ABC classifications are achieved. Firstly, the main attributes "types" are also classified, in order to associate them a weight according to their *consumption* and *stock value*. The procedure is then repeated until the final classification of all the items. Considering *m* starting attributes, for each item *m* cross ABC analyses are developed, integrated then through a weighted average. Therefore, each item is classified differently depending on the attribute studied. As shown in Figure 2, a splitting procedure is required for each *x-th* attribute according to its characteristics.

In Table 3, an example the modified ABC analysis output is shown, by considering *n* items and *m* attributes. Finally, all the analyses are integrated according to the weight and the importance of each attribute, aiming to provide final classification.

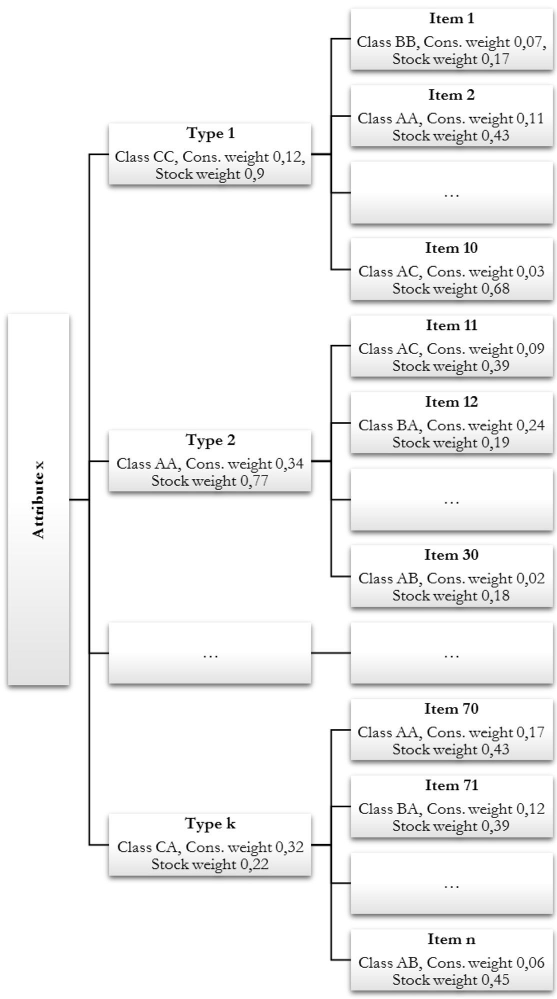

Figure 2: Example of the splitting procedure

Table 3: An example of our multiple cross-ABC classification por items

Multiple cross-ABC classification por items				
Items	Attribute 1	Attribute 2	…	Attribute m
1	AB	AC	…	CB
2	CB	BB	…	BA
…	…	…	…	…
n	AA	CB	…	AC

In such splitting procedure, the following aspects are defined for each *i-th* item and *k-th* attribute:

- Stock Class (A, B, or C);
- Consumption Class (A, B, or C);
- Relative Stock Value y_i;
- Relative Consumption Value x_i.

Our modified cross-ABC analysis execution method includes the following for each *i-th* item:

Total Consumption Value c_i, the average weight of the attribute consumption values.

$$c_i = \frac{\sum_{j=1}^{m} w_j * z_j}{m} \qquad (1)$$

With,
$i = 1, \dots, n$
$j = 1, \dots, m$
n = *Number of the items*
m = *Number of the attributes*

c_i = *Total Consumption Value i-th items*

w_j = *Weight of consumption of the attribute j*

x_j = *Consumption Value attribute j*

Total Stock Value s_i, the average weight of *the* attribute stock values.

$$s_i = \frac{\sum_{j=1}^{m} z_j * y_j}{m} \qquad (2)$$

With,
$i = 1, \dots, n$
$j = 1, \dots, m$
n = *Number of the items*
m = *Number of the attributes*

s_i = *Total Stock Value i-th items*

z_j = *Weight of stock of the attribute j*

y_j = *Stock Value attribute j*

Standardization

$$C_i = \frac{c_i}{TC} \qquad (3)$$

$$TC = \sum_{i=1}^{n} c_i \quad (4)$$

$$S_i = \frac{s_i}{TS} \quad (5)$$

$$TS = \sum_{i=1}^{n} s_i \quad (6)$$

With,

C_i = *Total normalized consumption value of attribute i*
TC = Sum of the consumption values of all items

S_i = *Total normalized stock value of attribute i*
TS = Sum of the stock values of all items

Cumulative frequency, of both consumption and stocks values.

Final cross-ABC classification, items combination based on the integration of stock and consumption values of each attributes. It is assumed that: **'A'** items – 20% of the items accounts for 80% of the annual value; **'B'** items – 15% of the items accounts for 25% of the annual value; **'C'** items – 50% of the items accounts for 5% of the annual value.

3.3 Warehouse management system

Based on our modified-cross-ABC analysis, Total and average consumption, Standard deviation, Average stock, Rotation index, and Coverage index are calculated automatically by the software. Since the warehouse policy is to operate in economic stock size, the following are defined: Service Level, Service Factor, Safety stock and, depending on the management technique, Reorder interval and Maximum stock or Reorder point, and Economic Reorder Quantity, too. Therefore, the procedure of our software is different according to the class of articles analyzed, as follows:

- *Continuous control*, for medium to high consumption items belonging to classes AA, BA, CA, BB, CB. The Economic Order Quantity model (EOQ) is usually suitable for high consumption items.

- *Discreet control*, for low consumption and high stock items belonging to classes AB, AC, BC, CC. The Period Order Quantity (POQ) management model is suitable for items with low consumption and high stock value.

3.4 Order planning

This software area is set as a "private" type macro, activated automatically when the software is opened. Our Scheduling and Control system supports the user in making decisions acting as orders reminder, too. The analytical tool is used in order to identify the raw materials order quantity, according to the following principle 'user is the final decision maker'. The historical data, user inputs and supplier data are analyzed for orders scheduling, including the capacity of the transport means. Simplistically, the order state could be '*open*' if the means of transportation is unsaturated, '*saturated*' if it is full, and '*closed*' if the order is coming in.

4.Case study

In this section, the case study of a Italian manufacturing company is analysed without ignoring the actual constraints. In current scenario, it is not following any warehouse management policies, ordering according to the changeable demand. In particular, the supplying cycle is the result of the commercial office's experience. Row material management is of the *look back* type (stock control), following the philosophy of stock recovery in depletion. There is no indicator of the reordering level, and the recovery is based only on the qualitative observation of past consumption. As mentioned in the previous paragraphs, the company's procurement method is not based on actual analyses but on entirely subjective parameters and rapid decisions, often causing *out of stock* and *overstock*.

In order to apply the modified ABC analysis correctly, only the most critical item, selected by experienced operators, are considered: every type of foam rubber in stock is analyzed. The foam rubber is purchased in a roll of different *density*, *thickness*, and *colour*, depending on the article type. There are two main suppliers of foam rubber, and the ordered items are stored in their warehouse until the saturation of the transport means: Full Truck Load (TL) type. Usually, the high demand allows the company to use a direct shipping network and, consequently, to access the following advantages: easy handling, independent shipments, no milk run, and relatively low delivery times. The procurement time is, in fact, almost two weeks varying according to the company needs.

In the next section, the results of the modified cross-ABC analysis and our Decision Support System and are presented.

4.1 Results

The supplier order planning and control of the studied company is hampered by the absence of an automated and well-organized information system. Aiming to address organizations as communicating entities (De Sanctis et al., 2018), requirements, indexes, ABC classification, and several crucial parameters for the supply activity (e.g., purchasing method and raw material transport) are defined.
Depending on company requirements three intrinsic features – *color*, *thickness*, and *diameter* have been employed for items classification. After the application of the modified cross-ABC analysis developed in this paper, the results are discussed with the managers of the company, founding an appropriate items classification.

As shown in Table 4, several items shifted from category B to A requiring a change of management policies, in order to avoid overstocking and understocking events: an excessive investment in stock is generally indicated by low stock turnover, while stock-out risk by a high rate. In Figure 3, instead, the comparison between both traditional and modified joint criteria matrices is shown in terms of percentage class of the items.

Table 4. ABC cross classification

Items	Traditional		Modified	
	Stock Class	Consumption Class	Stock Class	Consumption Class
1	A	C	A	C
2	A	B	A	B
3	A	B	A	C
4	A	A	A	A
5	A	A	A	A
6	A	A	A	A
7	B	A	A	A
8	A	B	A	C
9	A	B	A	B
10	A	A	A	A
11	A	B	A	A
12	C	B	A	A
13	A	A	A	A
14	B	B	A	A
15	B	B	A	B

The following results are achieved, highlighting improvements in the data analysis process:

- 6% decrease in opportunity for reduction articles;
- 12,57% increase in management consistency;
- 7,33% reduction in understock risk.

Items classification and their transition from *understock risk* to *consistency* class show how several articles could be better managed. Specifically, the current case study shows that 81% of these items have previously caused out-of-stock and over-stock problems, delivery delays and customer dissatisfaction. This is supported by the significant increase in the percentage of items in class AA from 6% to 18%, requiring a change in management policy from discreet to continuous control (Figure 3). The decrease in the number of items in *Opportunities for Reduction* also shows that 64% of items in transition are based on changing management policy and the consequent improvement in stock performance without requiring further changes. The remaining 36% consists instead of those items that do not allow a management improvement due to uncertain demand, product specificity or current company policies.

JOINT CRITERIA MATRIX				
LEGEND: *Opportunity for reduction*; *Management Consistency*; *Understock Risck*; x/y *Traditional/Modified*		Consumption Class		
		A (80%)	B (95%)	C(100%)
Stock Class	A (80%)	6,41%/18,07%	6,41%/4,81%	25,64%/18,07%
	B (95%)	7,69%/4,81%	7,69%/6,02%	14,1%/18,07%
	C (100%)	7,69%/2,40%	6,41%/7,22%	17,95%/20,48%

Figure 3: Joint Criteria Matrix: the comparison

Aiming to evaluate the efficacy of the new methodology, a comparison between the economic results of the current management and the application of the modified cross analysis has been developed. Specifically, a simulation model for "cost trend detecting" was implemented based on the historical data, setting the same boundary conditions of the current analysis and one year as the fixed time horizon. The Total Cost was detected considering both purchase and storage costs, items classifications and several parameters depending on the management policy of each item (e.g., existence, security stock, average and total consumption, EOQ, POQ). A decrease in stock management costs by using the proposed methodology is shown in Figure 4. However, since a decrease in stock-out events could also increase the number of orders, the economic trend of both traditional and new cross ABC analysis is similar. In conclusion, in addition to cost reduction, several results have been achieved such as optimization of batch size, reduction of human errors and delivery delays.

4.2 Discussion and conclusion

Based on the analysis, our software is effective if used continuously and dynamically for warehouse management, planning, and control operations. The aim of the paper is to answer the following question: *how to improve warehouse management and critical raw material supply in an automatic, simple and fast way?*. In order to be more effective than an approach that processes all items identically, a selective control for a modified ABC classification is implemented thorough software development. Our software analyzes and classifies stock items in a different way, defines management policies, and constantly monitors stock trend as a Decision Support System for order planning and scheduling, too. Specifically, the needs of an Italian company and its suppliers are addressed by reducing the supply process from arbitrariness and subjectivity, also making the user's tasks more and more timely. Our software is not to be considered universally applicable because more or less complex modifications and adaptations are necessary, depending on the needs. Based on the potential changes in items characteristics, in future studies our model can be improved, as follow:

- Proving the real effects of our modified cross-ABC analysis, for instance through inventory ratio changes and sensitivity analysis.
- Increasing the number of the selected items features, enhancing integration of several cross-ABC analyses.

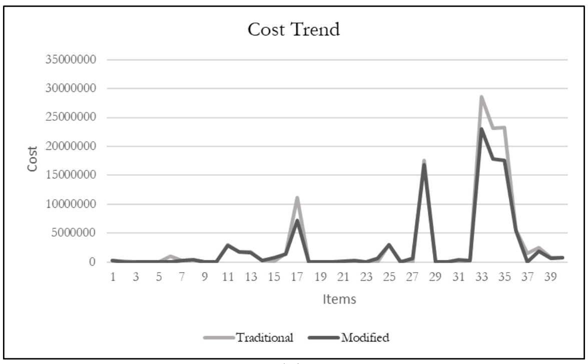

Figure 4: Economic Trend: the comparison

- Identifying potential criticalities for safety stock, through continuous model improvement.
- Including the study of the trend of class D articles (zero consumption and stock), which currently stands at 38.58%.
- Dividing the analysis period into smaller intervals, to better understand the evolution of items classification over time. It should be noted that a system capable of performing monthly our modified cross-ABC analysis has already been set up. The structure of the program is more complex than the previous one, by dividing the joint criteria matrix into 12 frames (one per month).
- Testing the methodology in at least another context.

Our paper provides a modified cross-ABC analysis procedure, classifying inventory based on the intrinsic items features. On the other hand, managers have been comfortable to use our software to score articles differently through a *drill down* procedure, aiming to improve data details. In conclusion, the results are consistent with initial expectations, according to which our approach would be useful not only to study a revised warehouse management procedure, but also to transform it into an automated system.

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