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A Comparison of Inventory Strategies for a Manufacturer within the Air Conditioning Industry

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Authors' contributions

This work was carried out in collaboration between both authors. Author MdCMP designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author SOCM revised the study, the statistical analysis, and wrote the final draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The present manuscript describes the application of two inventory strategies to optimize the supply process within an air conditioning manufacturing facility. These approaches were considered as the air conditioning industry involves variable demand patterns due to its large market (automotive, home, cooling/heating systems, among others). Because the components which are assembled in this factory involve 45 components which have different demand, lead times and inventory management costs, the strategies were adjusted to reduce costs and management complexity. First, inventory management costs were optimized according to the classification of the most important components. Then, periodic and continuous review models were adapted to optimize the management costs of these components. Validation of these strategy through discrete-event computer simulation led to determine their suitability for this case study, significantly reducing

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inventory management costs while increasing service level. Simulation also led to determine that for specific components, a model can lead to better (and feasible) results than the other and showing no stock-out events. This is an outcome which can be considered by companies to make a better evaluation of the supply strategies during the planning process.

Keywords: Inventory management; continuous review; service level; computer simulation.

1. INTRODUCTION

To satisfy the demand requirements of a market, companies need appropriate inventory replenishment strategies to ensure the availability of components, raw materials and end products. Inventory control is aimed to support the managerial decisions to minimize the costs associated to maintain the inventory and satisfy the clients demand.

Inventory replenishment and compliance of demand requirements is performed through the frequent ordering of product lots of size Q. Thus, the inventory control models respond to the following questions: when this order of size Q must be placed? and what size for Q must be considered to minimize inventory management costs? [1,2].

To address these questions, it is important to identify the behavior of the customers' demands. If demand is (almost) constant, *Q* must be estimated through deterministic models such as the standard Economic Order Quantity (EOQ) model. In contrast, if there is high variability, inventory replenishment must be performed through stochastic or non-deterministic control models such as Periodic Review (P), Continuous Review (Q, R) or News Vendor (one-shot demand) model [3].

Note that stochastic approaches are required when there is a significant uncertainty in customers' demands. This uncertainty is addressed through the use of probability distributions which are integrated within the estimation of Q to reduce stock-out risks while minimizing inventory management costs. In practice, both P and (Q, R) models have been studied for different application cases. Sarkar & Mahapatra [4] extended the P model to include variability within the delivery time. Minner & Transchel [5] presented a P model for perishable products under service-level constraints and validated their results with simulation. An application of both models was reported by Alim [6] where it was determined that the (Q, R) model could lead to better management of costs. This finding also was reported by Rizkya et al. [7]. Singha et al. [8] also studied both models and added the storage space with backlog and lost sales restrictions. They found that regardless of the additions, both models lead to similar results. Here it is important to mention that most of reported works evaluate the models with single-product numerical data not associated with a case study (i.e., not from a real case scenario). Also, the validity of Q and R is not assessed with dynamic data as it is performed by simulation.

In our case study, the enterprise manufactures multi-product components for heating and cooling systems for different industries where demand is highly variable. Thus, the present work aims to apply P and (Q, R) models with the real data of the components manufactured by this enterprise. To evaluate the suitability of these models the methodology consisted of the following steps:

- Standardization of costs through ABC classification;
- Estimation of the economic order quantity Q with the P and (Q, R) models;
- Assessment of Q considering dynamic behavior of demand through computer simulation.

This led to the determination that important savings in inventory management costs can be obtained with these techniques. Also, we found that for specific components, a model can lead to better (and feasible) results than the other. In example, no stock-out events are presented with P when compared to (Q, R), and vice versa.

Our manuscript is structured as follows: in Section 2 we present the details of the periodic (P) and continuous (Q, R) inventory control models. Then in Section 3 we present the details of the enterprise. Section 4 presents the application of the inventory control models including an analysis and discussion of their results. Finally, our conclusions and future work are presented in Section 5.

2. TECHNICAL BACKGROUND

2.1 Periodic Review (P)

In the periodic review (*P*) model the inventory is planned through a review of the same which is performed every fixed period of time *T* [9,10]. At the time of the review, the estimate of the required inventory is estimated by:

$$Q = d(T + LT) + z\sigma\sqrt{T + LT} - I, \quad (1)$$

where *d* is the average demand during the smallest unit of time within *T*, *LT* is the lead (or delivery) time (*T* > *LT*), *σ* is the standard deviation of the demand during the delivery time, *z* is the number of deviations considered for a required service level, and *I* is the inventory level at the time of the review [11]. The inventory management cost function *IC*, which provides insight regarding the suitability of the lot size *Q* to minimize costs, is presented as follows:

$$IC = C_h \times \frac{dT}{2} + C_o \times \frac{D}{dT} + C_h \times z \times \sigma \times \sqrt{T + LT}, \quad (2)$$

Where C_h is the unit holding cost, C_o is the lot ordering cost, and *D* is the cumulative demand through the planning horizon (if *d* is a weekly demand, then *D* = weeks × *d*). Because the inventory at the time of review *I* can be variable given the non-deterministic nature of the demand, the lot size *Q* can be different for all periods. Fig. 1 presents a description of the inventory supply and consumption patterns. Note that Q1≠Q2 depending on *I* at the review time.

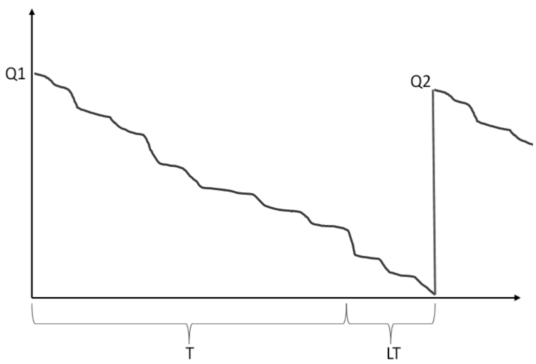


Fig. 1. Parameters and inventory supply/consumption pattern under the periodic review (P) model
(Sánchez-Vega et al. [11])

2.2 Continuous Review (Q, R)

In the Continuous Review (*Q, R*) model, the inventory level is frequently reviewed until a Reorder Point (R or RP) is reached [10]. When this happens, a fixed lot of size *Q* is ordered. In contrast to the *P* model, the time between revisions is variable because reaching the RP depends on the variable consumption rate. Fig. 2 presents a description of the inventory supply and consumption patterns under this model.

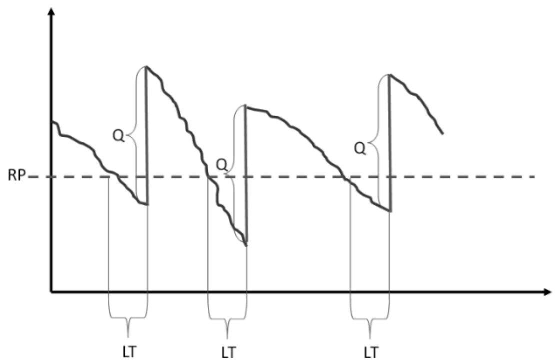


Fig. 2. Parameters and inventory supply/consumption pattern under the continuous review (Q, R) model
(Sánchez-Vega et al. [11])

The lot size Q is frequently estimated through iterative methods or linear programming. In such case, Q must minimize the following inventory management cost function:

$$IC(Q) = C_h \times \frac{Q}{2} + C_o \times \frac{D}{Q} + C_h \times [R - \mu_{LT} + \sigma LT \times L(z) + p \times \sigma LT \times L(z) \times DQ, \quad (3)$$

Where μ_{LT} and σ_{LT} are the mean and standard deviation of the demand through the lead time ($\mu_{LT} = d \times LT$ and $\sigma_{LT} = \sigma \times \sqrt{LT}$), *p* is the unit cost of non-supplied product, *R* is the level of the reorder point (=$\mu_{LT} + z \times \sigma_{LT}$), and *L(z)* is the loss function.

Note that *R* is the inventory unit quantity on hand that triggers the purchase or ordering of *Q* units. If the purchase process is performed as planned, *R* should result in the accurate replenishment of the inventory as the last of the on-hand inventory is consumed. Because every item may have a different demand, and involve different lead times, R can be different for each one of them [2].

2.3 ABC Inventory Classification

This classification system for inventory is based on the concept that only some products within the inventory are responsible for most of its value. This considering their unit value and usage or demand rate. Hence, these products are considered very important or belonging to an "A" category. Table 1 presents an overview of the remaining categories under this system [10,7].

The steps to perform the ABC classification are the following:

- For each type of product *i* within the inventory (where *i*=1,..., *N*), compute Y_i = *usage* $(demand_i)$ × *value* $(unit\ cost_i)$;
- Sort all products from highest to lowest Y_i
- Compute the relative frequency for each product as $\frac{Y_i}{\sum_{i=1}^{N} Y_i}$
- Compute the cumulative frequency
- Classify the products according to the following cumulative frequencies: 0 to 0.50/0.70 as A, 0.50/0.70 to 0.90/0.95 as B, and 0.90/0.95 to 1.0 as C.

2.4 Computer Simulation

Computer simulation has been an important tool to evaluate and improve industrial processes. Discrete-event simulation enables the modeling of large and complex processes, permitting throughput increase, bottlenecks identification, logistics improvement and the evaluation of potential changes in live processes.

All simulation models must be developed based on a methodology with rigorous criteria because we must ensure that, within statistical parameters, it accurately represents the real process. Fig. 3 shows the steps and stages of the simulation modeling process [12]. First, a conceptual model is performed, which is followed by its validation. This process is repeated until this conceptual model is fit. Second, the computer model is developed from the conceptual model, which is consequently validated. If any changes on the conceptual or computer models are needed, then verification and validation processes must be completed for all stages [13].

Different software is available for simulation, among these, the following can be mentioned: SIMIO, Rockwell Arena, PROMODEL, etc. In this case we used the simulation code described in [3] for deterministic and non-deterministic inventory control techniques.

Table 1. Characteristics of products within the ABC system

Classification	Importance
A	10% of the inventory is responsible for 50-70% of its use-value
B	30-40% of the inventory is responsible for 20% of its use-value
C	50% of the inventory is responsible for 5-10% of its use-value

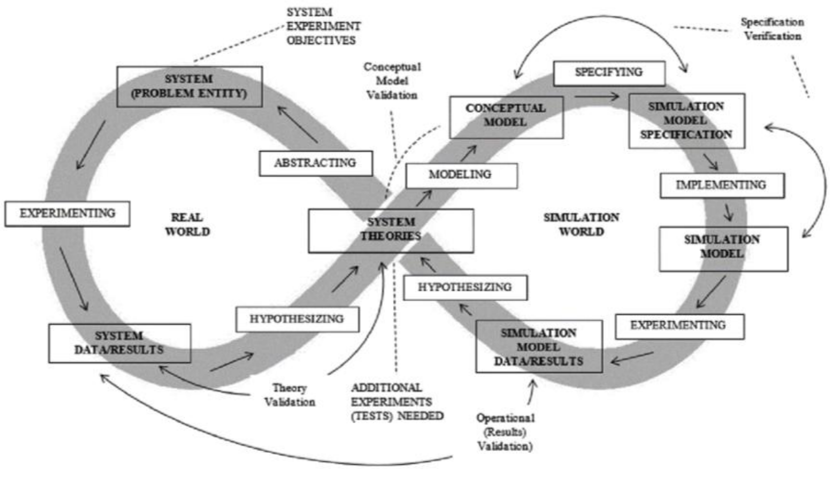


Fig. 3. Stages of problem modeling through computer simulation [adapted from *(Schriber et al. [12])*

3. PROBLEM DESCRIPTION

Table 2. Source data for the case study: Wk(s) = Week(s), SL = Service Level

Product	*LT* (Wks)	Unit Value	*d* (Wk)	σ (Wk)	C_o	C_h	*p*	SL
1	2.0	$0.80	3036	679	6000	18	$1.44	0.98
2	2.0	$0.60	3036	679	6000	18	$1.08	0.98
3	2.0	$0.80	800	179	6000	18	$1.44	0.98
4	2.0	$0.60	800	179	6000	18	$1.08	0.98
5	1.0	$1.20	2108	472	5500	18	$2.16	0.98
6	2.1	$0.40	3836	858	3500	18	$0.72	0.98
7	2.1	$0.30	3836	858	3500	18	$0.54	0.98
8	2.1	$0.50	2108	472	3500	18	$0.90	0.98
9	2.1	$0.50	2108	472	3500	18	$0.90	0.98
10	2.1	$0.40	2095	469	3500	18	$0.72	0.98
11	2.1	$0.40	2095	469	3500	18	$0.72	0.98
12	1.8	$0.10	6285	2800	6000	22	$0.18	0.98
13	1.6	$0.40	7673	3418	5000	14	$0.72	0.98
14	1.6	$0.60	4216	1878	5000	14	$1.08	0.98
15	1.6	$0.50	4190	1867	5000	14	$0.90	0.98
16	1.6	$0.30	4216	1947	5000	14	$0.54	0.98
17	1.6	$0.30	4190	1935	5000	14	$0.54	0.98
18	1.6	$0.50	2108	974	5000	14	$0.90	0.98
19	1.6	$0.50	2108	974	5000	14	$0.90	0.98
20	1.6	$0.40	2095	934	5000	14	$0.72	0.98
21	1.6	$0.40	2095	469	5000	14	$0.72	0.98
22	1.0	$3.80	1128	253	6000	30	$6.84	0.98
23	1.0	$3.80	652	302	6000	30	$6.84	0.98
24	1.0	$3.30	713	318	6000	30	$5.94	0.98
25	1.0	$3.80	476	213	6000	30	$6.84	0.98
26	1.0	$3.30	352	157	6000	30	$5.94	0.98
27	2.1	$1.50	2095	968	4500	16	$2.70	0.98
28	2.1	$0.40	3836	1771	4500	16	$0.72	0.98
29	2.1	$0.30	3836	1771	4500	16	$0.54	0.98
30	2.1	$0.30	3836	1709	4500	16	$0.54	0.98
31	2.1	$0.30	2108	939	4500	16	$0.54	0.98
32	2.1	$0.30	2095	968	4500	16	$0.54	0.98
33	2.1	$0.30	2095	968	4500	16	$0.54	0.98
34	2.1	$0.30	2108	974	4500	16	$0.54	0.98
35	2.1	$0.20	2108	974	4500	16	$0.36	0.98
36	2.1	$0.20	2095	1447	4500	16	$0.36	0.98
37	2.1	$0.20	800	553	4500	16	$0.36	0.98
38	1.8	$0.10	4216	2912	3500	30	$0.18	0.98
39	1.8	$0.10	7673	3504	3500	30	$0.18	0.98
40	1.8	$0.10	4190	1867	3500	30	$0.18	0.98
41	1.0	$0.20	57706	25702	6000	25	$0.36	0.98
42	0.6	$0.10	2108	939	5000	18	$0.18	0.98
43	0.6	$0.10	3100	380	5000	18	$0.18	0.98
44	0.6	$0.10	890	267	5000	16	$0.18	0.98
45	0.6	$0.10	2235	1117	5000	16	$0.18	0.98

Table 3. ABC classification of the case study inventory

Product	C_h	Unit Value	*d* (Wk)	usage × value	RelFreq	CumFreq	Class
41	25	$0.20	57706	$11,541.20	0.1760	0.1760	A
22	30	$3.80	1128	$4,286.40	0.0654	0.2414	
27	16	$1.50	2095	$3,142.50	0.0479	0.2893	
13	14	$0.40	7673	$3,069.20	0.0468	0.3361	
5	18	$1.20	2108	$2,529.60	0.0386	0.3747	
14	14	$0.60	4216	$2,529.60	0.0386	0.4133	
23	30	$3.80	652	$2,477.60	0.0378	0.4511	
1	18	$0.80	3036	$2,428.80	0.0370	0.4881	
24	30	$3.30	713	$2,352.90	0.0359	0.5240	
15	14	$0.50	4190	$2,095.00	0.0320	0.5560	
2	18	$0.60	3036	$1,821.60	0.0278	0.5837	
25	30	$3.80	476	$1,808.80	0.0276	0.6113	
6	18	$0.40	3836	$1,534.40	0.0234	0.6347	B
28	16	$0.40	3836	$1,534.40	0.0234	0.6581	
16	14	$0.30	4216	$1,264.80	0.0193	0.6774	
17	14	$0.30	4190	$1,257.00	0.0192	0.6966	
26	30	$3.30	352	$1,161.60	0.0177	0.7143	
29	16	$0.30	3836	$1,150.80	0.0176	0.7319	
30	16	$0.30	3836	$1,150.80	0.0176	0.7494	
7	18	$0.30	3836	$1,150.80	0.0176	0.7670	
8	18	$0.50	2108	$1,054.00	0.0161	0.7830	
9	18	$0.50	2108	$1,054.00	0.0161	0.7991	
18	14	$0.50	2108	$1,054.00	0.0161	0.8152	
19	14	$0.50	2108	$1,054.00	0.0161	0.8313	
10	18	$0.40	2095	$838.00	0.0128	0.8440	
11	18	$0.40	2095	$838.00	0.0128	0.8568	
20	14	$0.40	2095	$838.00	0.0128	0.8696	
21	14	$0.40	2095	$838.00	0.0128	0.8824	
39	30	$0.10	7673	$767.30	0.0117	0.8941	
3	18	$0.80	800	$640.00	0.0098	0.9038	C
34	16	$0.30	2108	$632.40	0.0096	0.9135	
31	16	$0.30	2108	$632.40	0.0096	0.9231	
32	16	$0.30	2095	$628.50	0.0096	0.9327	
33	16	$0.30	2095	$628.50	0.0096	0.9423	
12	22	$0.10	6285	$628.50	0.0096	0.9519	
4	18	$0.60	800	$480.00	0.0073	0.9592	
35	16	$0.20	2108	$421.60	0.0064	0.9656	
38	30	$0.10	4216	$421.60	0.0064	0.9721	
36	16	$0.20	2095	$419.00	0.0064	0.9785	
40	30	$0.10	4190	$419.00	0.0064	0.9849	
43	18	$0.10	3100	$310.00	0.0047	0.9896	
45	16	$0.10	2235	$223.50	0.0034	0.9930	
42	18	$0.10	2108	$210.80	0.0032	0.9962	
37	16	$0.20	800	$160.00	0.0024	0.9986	
44	16	$0.10	890	$89.00	0.0014	1.0000	

The considered case study is an enterprise within the air conditioning industry which involves variable demand patterns due to its large market (automotive, home, cooling/heating systems, among others). Currently, the company is present in 21 locations around the world including China, North America, Mexico, Thailand, Australia, Europe and India. In

Mexico, the manufacturing facility mainly produces cooling components, like radiators and heat exchanges, for the automotive industry.

The components which are assembled in this factory involve 45 components which have different demand, lead times and inventory management costs. Table 2 presents the source data of these products: *LT* = lead time (in weeks), unit *cost value*, *d* = demand (weekly), σ (weekly standard deviation of demand), order cost per lot (C_o), holding cost per unit (C_h), unit cost of non-supplied unit (*p*), and required service level (*SL* = probability of complying with demand requirements on time).

By considering the unit *cost value* and the weekly demand (*d*), we computed the *usage* × *value* metric to perform the ABC classification of the inventory which is presented in Table 3. Note that only 12 products (27%) represent 61.13% of the inventory's value, 17 products (38%) represent 89.41%-63.47%=25.94% of the inventory's value, and the last 16 products represent 100.00%-90.38% = 9.62% of the inventory's value.

The ABC classification helps to identify which products, due to their importance, must be kept with higher priority and care. As this is associated to their holding costs, "A" products should have the highest C_h while "B" and "C" products should have the lowest C_h. As presented in Table 3, there are products within the "B" and "C" classes with high C_h and this must be reduced to make better use of the economic resources. After an analysis, the following C_h costs were considered for each product within the categories A, B and C respectively: $25, $16 and $8. Note that this classification also can improve the application of the inventory policy as observed by Rizkya et al. [14].

4. APPLICATION OF THE INVENTORY MODELS AND DISCUSSION ON FINDINGS

As previously mentioned, the periodic (*P*) and continuous review (*Q, R*) inventory control models were considered for the present case. For the implementation, a planning horizon of 52 weeks (one year) and *T* = 4 weeks were considered. Note that, with this data, *D* = *d*×52 for the *P* and (*Q, R*) models.

Also, for both models, z was estimated with the inverse normal standard distribution of the service level which, for all products, is considered as 98.0%. This led to *z* = 2.054 which has a *L(z)* value of 0.0073.

Finally, *Q* for the (*Q, R*) strategy, was computed through linear programming (LP) using the Solver tool of Microsoft Excel ® and the cost function *IC(Q)* (see Eq. (3)). The LP model is described as follows:

Objective Function:

$$Min\ \sum_{i=1}^{N} C_{hi} \times \frac{Q_i}{2} + C_{oi} \times \frac{D_i}{Q_i} + C_{hi} \times [R_i - \mu_{LTi} + \sigma_{LTi} \times L(zi)+pi\times\sigma LTi\times L(zi)\times DiQi. \quad (4)$$

Subject to:

$$Q_i > 10\ \forall\ i \quad (5)$$

$$Q_i \in Integers \quad (6)$$

In (4), (5) and (6), *i* = 1, …, *N* where *N* is the total number of products within the inventory (thus, *N*=45). Table 4 presents the results of the (Q, R) strategy (the lot size $Q_{(Q,R)}$, *R* as described in Section 2.2, and the cost function associated to the lot size as described by *IC(Q)*- Eq. (3)-(4)), and the results of the *P* strategy (the lot size $Q_{(P)}$ – Eq.(1) and the cost function as described by *IC*-Eq. (2)).

The total inventory management costs achieved with these strategies are $10'134,416 and $16'014,404 for (*Q, R*) and *P* respectively. If no adjustments on C_h were performed, the costs would be $11'220,233 and $17'575,833 respectively. Thus, the adjustments based on the ABC classification represent average savings of 12%.

Finally, these results were validated through the simulation codes described in (Bonilla-Enriquez & Caballero-Morales, 2020). The adapted codes are presented in Fig. 4. Note that demand (*d*) and standard deviation (σ) data were converted from weekly to daily data. This was performed to simulate more accurately the replenishment process which depends of the lead time, which as presented in Table 4, was available on weekly format

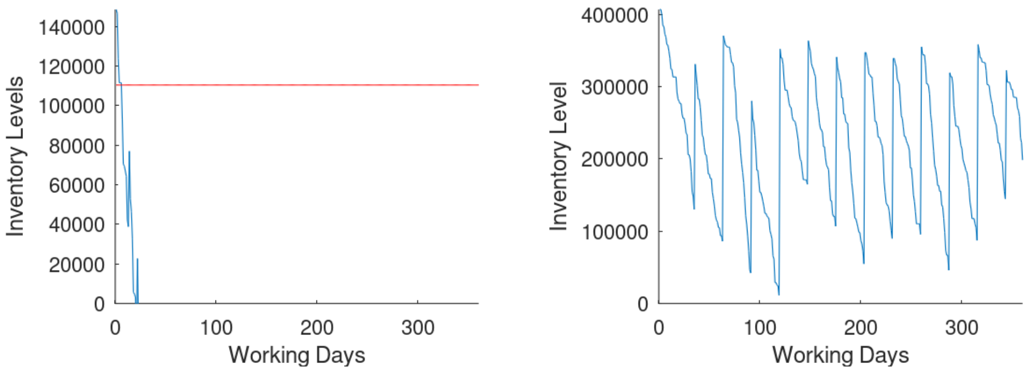
Table 4. Results of the (*Q, R*) and *P* strategies

Product	Source Data								Analyzed Data					Results (*Q, R*) Strategy			Results (*P*) Strategy	
#	*LT*	*d*	σ	C_o	C_h	*p*	*SL*	*CV*	μ_{LT}	σ_{LT}	*D*	*z*	*L(z)*	$Q_{(Q,R)}$	*R*	*IC(Q)*	$Q_{(P)}$	*IC*
41	1.0	57706	25702	6000	25	$0.36	0.98	0.45	57706	25702	3000712	2.054	0.0073	38165	110491	2278508	406562	5914097
22	1.0	1128	253	6000	25	$6.84	0.98	0.22	1128	253	58656	2.054	0.0073	5311	1648	145830	6802	163446
27	2.1	2095	968	4500	25	$2.70	0.98	0.46	4400	1403	108940	2.054	0.0073	6281	7280	229325	17690	286002
13	1.6	7673	3418	5000	25	$0.72	0.98	0.45	12277	4323	398996	2.054	0.0073	12662	21156	539328	59580	863942
5	1.0	2108	472	5500	25	$2.16	0.98	0.22	2108	472	109616	2.054	0.0073	6949	3077	198060	12708	231089
14	1.6	4216	1878	5000	25	$1.08	0.98	0.45	6746	2376	219232	2.054	0.0073	9382	11624	356955	32737	503980
23	1.0	652	302	6000	25	$6.84	0.98	0.46	652	302	33904	2.054	0.0073	4039	1272	116541	4647	145272
1	2.0	3036	679	6000	25	$1.44	0.98	0.22	6072	960	157872	2.054	0.0073	8712	8044	267290	21632	315195
24	1.0	713	318	6000	25	$5.94	0.98	0.45	713	318	37076	2.054	0.0073	4223	1366	121972	5025	150159
15	1.6	4190	1867	5000	25	$0.90	0.98	0.45	6704	2362	217880	2.054	0.0073	9350	11554	355438	32538	501343
2	2.0	3036	679	6000	25	$1.08	0.98	0.22	6072	960	157872	2.054	0.0073	8710	8044	267244	21632	315195
25	1.0	476	213	6000	25	$6.84	0.98	0.45	476	213	24752	2.054	0.0073	3449	913	97224	3358	126254
6	2.1	3836	858	3500	16	$0.72	0.98	0.22	8056	1243	199472	2.054	0.0073	9350	10609	190612	27752	237886
28	2.1	3836	1771	4500	16	$0.72	0.98	0.46	8056	2566	199472	2.054	0.0073	10608	13326	254371	32383	324983
16	1.6	4216	1947	5000	16	$0.54	0.98	0.46	6746	2463	219232	2.054	0.0073	11716	11804	268688	33072	351312
17	1.6	4190	1935	5000	16	$0.54	0.98	0.46	6704	2448	217880	2.054	0.0073	11680	11731	267607	32868	349547
26	1.0	352	157	6000	16	$5.94	0.98	0.45	352	157	18304	2.054	0.0073	3707	674	64493	2481	100800
29	2.1	3836	1771	4500	16	$0.54	0.98	0.46	8056	2566	199472	2.054	0.0073	10604	13326	254307	32383	324983
30	2.1	3836	1709	4500	16	$0.54	0.98	0.45	8056	2477	199472	2.054	0.0073	10604	13142	251338	32068	319951
7	2.1	3836	858	3500	16	$0.54	0.98	0.22	8056	1243	199472	2.054	0.0073	9348	10609	190577	27752	237886
8	2.1	2108	472	3500	16	$0.90	0.98	0.22	4427	684	109616	2.054	0.0073	6929	5832	133429	15253	151263
9	2.1	2108	472	3500	16	$0.90	0.98	0.22	4427	684	109616	2.054	0.0073	6929	5832	133429	15253	151263
18	1.6	2108	974	5000	16	$0.90	0.98	0.46	3373	1232	109616	2.054	0.0073	8283	5903	173170	16538	208195
19	1.6	2108	974	5000	16	$0.90	0.98	0.46	3373	1232	109616	2.054	0.0073	8283	5903	173170	16538	208195
10	2.1	2095	469	3500	16	$0.72	0.98	0.22	4400	680	108940	2.054	0.0073	6907	5795	132929	15158	150603
11	2.1	2095	469	3500	16	$0.72	0.98	0.22	4400	680	108940	2.054	0.0073	6907	5795	132929	15158	150603
20	1.6	2095	934	5000	16	$0.72	0.98	0.45	3352	1181	108940	2.054	0.0073	8256	5778	171067	16271	204669
21	1.6	2095	469	5000	16	$0.72	0.98	0.22	3352	593	108940	2.054	0.0073	8254	4570	151629	14011	168510
39	1.8	7673	3504	3500	16	$0.18	0.98	0.46	13811	4701	398996	2.054	0.0073	13223	23466	366613	61834	568333
3	2.0	800	179	6000	8	$1.44	0.98	0.22	1600	253	41600	2.054	0.0073	7901	2120	67383	5700	98004
34	2.1	2108	974	4500	8	$0.54	0.98	0.46	4427	1411	109616	2.054	0.0073	11111	7326	112167	17799	131752

Product	**Source Data**							**Analyzed Data**						**Results (*Q, R*) Strategy**			**Results (*P*) Strategy**	
#	***LT***	***d***	σ	C_o	C_h	***p***	***SL***	***CV***	μ_{LT}	σ_{LT}	***D***	***z***	***L(z)***	$Q_{(Q,R)}$	*R*	*IC(Q)*	$Q_{(P)}$	*IC*
31	2.1	2108	939	4500	8	$0.54	0.98	0.45	4427	1361	109616	2.054	0.0073	11111	7221	111329	17622	130332
32	2.1	2095	968	4500	8	$0.54	0.98	0.46	4400	1403	108940	2.054	0.0073	11077	7280	111749	17690	131301
33	2.1	2095	968	4500	8	$0.54	0.98	0.46	4400	1403	108940	2.054	0.0073	11077	7280	111749	17690	131301
12	1.8	6285	2800	6000	8	$0.18	0.98	0.45	11313	3757	326820	2.054	0.0073	22150	19028	239144	50302	289352
4	2.0	800	179	6000	8	$1.08	0.98	0.22	1600	253	41600	2.054	0.0073	7900	2120	67380	5700	98004
35	2.1	2108	974	4500	8	$0.36	0.98	0.46	4427	1411	109616	2.054	0.0073	11109	7326	112149	17799	131752
38	1.8	4216	2912	3500	8	$0.18	0.98	0.69	7589	3907	219232	2.054	0.0073	13860	15613	175302	38856	228180
36	2.1	2095	1447	4500	8	$0.36	0.98	0.69	4400	2097	108940	2.054	0.0073	11077	8706	123194	20119	150738
40	1.8	4190	1867	3500	8	$0.18	0.98	0.45	7542	2505	217880	2.054	0.0073	13813	12686	151813	33536	186415
43	0.6	3100	380	5000	8	$0.18	0.98	0.12	1860	294	161200	2.054	0.0073	14195	2465	118418	15934	127991
45	0.6	2235	1117	5000	8	$0.18	0.98	0.50	1341	865	116220	2.054	0.0073	12054	3118	110702	15201	140121
42	0.6	2108	939	5000	8	$0.18	0.98	0.45	1265	727	109616	2.054	0.0073	11706	2759	105646	13833	131817
37	2.1	800	553	4500	8	$0.36	0.98	0.69	1680	801	41600	2.054	0.0073	6842	3326	67955	7685	93740
44	0.6	890	267	5000	8	$0.18	0.98	0.30	534	207	46280	2.054	0.0073	7606	959	64259	5270	88649

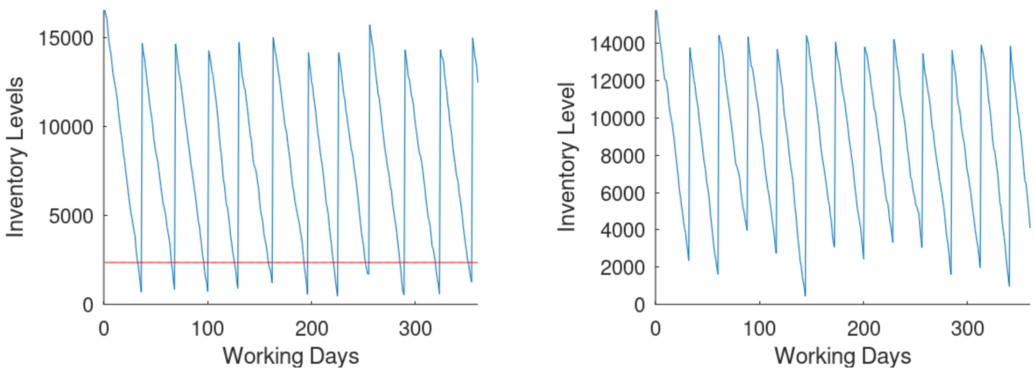
```
clear all; clc; pkg load statistics
%                1      2      3      4       5
%               LT      d    std      Q       R
source_data=[  7.0   8243   9714  38165 110484;  7.0   161    95   5311   1643;
              14.0    299    365   6281   6991; 11.0  1096  1291  12662  20850;
               7.0    301    178   6949   3074; 11.0   602   709   9382  11451;
               7.0     93    114   4039   1270; 14.0   433   256   8712   8029;
               7.0    101    120   4223   1359; 11.0   598   705   9350  11380;
              14.0    433    256   8710   8029;  7.0    68    80   3449    911;
              14.0    548    324   9350  10162; 14.0   548   669  10608  12813;
              11.0    602    735  11716  11628; 11.0   598   731  11680  11557;
               7.0     50     59   3707    671; 14.0   548   669  10604  12813;
              14.0    548    645  10604  12628; 14.0   548   324   9348  10162;
              14.0    301    178   6929   5582; 14.0   301   178   6929   5582;
              11.0    301    368   8283   5818; 11.0   301   368   8283   5818;
              14.0    299    177   6907   5546; 14.0   299   177   6907   5546;
              11.0    299    353   8256   5693; 11.0   299   177   8254   4495;
              12.0   1096   1324  13223  22571; 14.0   114    67   7901   2111;
              14.0    301    368  11111   7042; 14.0   301   354  11111   6934;
              14.0    299    365  11077   6991; 14.0   299   365  11077   6991;
              12.0    897   1058  22150  18291; 14.0   114    67   7900   2111;
              14.0    301    368  11109   7042; 12.0   602  1100  13860  15050;
              14.0    299    546  11077   8382; 12.0   598   705  13813  12192;
               4.0    442    143  14195   2355;  4.0   319   422  12054   3009;
               4.0    301    354  11706   2658; 14.0   114   209   6842   3202;
               4.0    127    100   7606    919];
for h=1 %Product #
  %% CONTINUOUS REVIEW (Q,R)
  LT=source_data(h,1); d=source_data(h,2); std=source_data(h,3);
  Q_qr=source_data(h,4); R_qr=source_data(h,5); T=4*7; k=360; Z_p=2.054;
  Inventory = Q_qr+R_qr; count_LT=0; inv_consumption=[];
  for i=1:k
    inv_consumption=[inv_consumption; Inventory]; dt=d+norminv(rand)*std;
    if dt<0 dt=0; end;
    if Inventory - dt > R_qr Inventory = Inventory - dt;
    else Inventory = Inventory - dt; count_LT=count_LT+1; end
    if count_LT == LT+1 Inventory=Inventory+Q_qr; count_LT=0; end
  end
  figure; hold on;
  vect_R_qr=ones(length(inv_consumption),1)*R_qr;
  plot(inv_consumption); hold on; plot(vect_R_qr,'-r'); axis([0 k 0 Q_qr+R_qr]);
  xlabel('Working Days'); ylabel('Inventory Levels');

  %% PERIODIC REVIEW (P)
  I=0; Q_p=d*(T+LT)+Z_p*std*sqrt(T+LT)-I; Inventory=Q_p; count_T=0; count_LT=0;
  inv_consumption=[];
  for i=1:k
    inv_consumption=[inv_consumption; Inventory];
    dt=d+norminv(rand)*std;
    if dt<0 dt=0; end
    Inventory=Inventory-dt; count_T=count_T+1;
    if count_T==T; I=Inventory; count_T=0; count_LT=LT+1; end
    if count_LT>0
      count_LT=count_LT-1;
      if count_LT==0; Inventory = Inventory+(Q_p-I); end
    end
  end
  figure; hold on;
  plot(inv_consumption); axis([0 k 0 Q_p]);
  xlabel('Working Days'); ylabel('Inventory Level');
end
```

Fig. 4. Simulation code for the results of the (Q, R) and P strategies
[adapted from (Bonilla-Enriquez & Caballero-Morales [3])]



a) (Q, R) Strategy **b) P Strategy**

Fig. 5. Simulation results of the (Q, R) and (P) strategies for Product 1



a) (Q, R) Strategy **b) P Strategy**

Fig. 6. Simulation results of the (Q, R) and (P) strategies for Product 41

Table 5. Simulation-verified strategies for all products

Class	#	(Q,R)	P	Class	#	(Q,R)	P	Class	#	(Q,R)	P
A	41	Yes	Yes	B	17	Yes	Yes	C	34	Yes	Yes
	22	Yes	Yes		26	Yes	Yes		31	Yes	Yes
	27	Yes	Yes		29	X	Yes		32	Yes	X
	13	Yes	Yes		30	Yes	Yes		33	Yes	Yes
	5	Yes	Yes		7	Yes	Yes		12	Yes	Yes
	14	Yes	X		8	Yes	Yes		4	X	Yes
	23	Yes	Yes		9	Yes	Yes		35	Yes	Yes
	1	X	Yes		18	X	Yes		38	Yes	X
	24	Yes	Yes		19	X	Yes		36	Yes	Yes
	15	Yes	Yes		10	Yes	Yes		40	Yes	Yes
	2	Yes	Yes		11	Yes	Yes		43	Yes	Yes
	25	Yes	Yes		20	Yes	Yes		45	Yes	Yes
B	6	Yes	Yes		21	Yes	Yes		42	Yes	Yes
	28	Yes	Yes		39	Yes	Yes		37	Yes	Yes
	16	Yes	Yes	C	3	Yes	Yes		44	Yes	Yes

Interestingly, the adapted code helped us to evaluate the suitability of one strategy over another while evaluating each one independently. Fig. 5 presents the simulated inventory consumption / replenishment patterns for Product 1. Note that the (Q, R) strategy leads to stockout within the first 30 days. In contrast, the P strategy reduces this risk. This is caused by the high demand variability (coefficient of variability, CV = σ/d > 0.20) and high lead time. From Table 4, for Product 1 CV = 0.22 and LT = 2 weeks (or 7 days). Thus, for this product, the periodic review strategy is a better approach. Note, however, that this strategy involves larger lot sizes.

Fig. 6 presents the simulated inventory consumption / replenishment patterns for Product 41. As presented, both strategies are suitable with no stock-out periods. In this case, the strategy with the lowest IC must be selected. Table 5 presents the recommended strategies for all 45 products.

5. CONCLUSIONS

In the present work an improvement in inventory management was achieved with a structured analysis of inventory classification and inventory control strategies. As inventory management is focused on reducing operative costs while keeping high service levels, a standardization of inventory management costs was performed through ABC classification.

Then, two non-deterministic inventory strategies were implemented to determine the optimal lots. While common practice imply confidence in the parameters of the inventory strategies, the dynamic assessment must be performed to validate their performance. As highlighted by our simulation approach, under some circumstances, the (Q,R) strategy can lead to better performance than the P strategy and vice versa (this is, to avoid stock-out periods which severely affect service level).

Discrete-event simulation is an important tool to evaluate the performance of any strategy, particularly when there is significant variability in the parameters (i.e., demand). In such case, while commercial software has powerful tools, open-source programming can provide the means for fast implementations and assessment.

As future work it is considered to perform simulation of the distribution mechanisms of the end products as transportation times also have significant variability. This can provide important insights regarding the performance of two-echelon and three-echelon supply chains under vendor managed inventory (VMI), which is the current architecture of global supply chains.

As reported in Carreon-Nava & Caballero-Morales [15], the integration of vendors and providers in a two-echelon supply chain involves additional costs and sensitivity to variable demand patterns. Thus, simulation must be performed to reduce the impact of variability in service levels.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hugos MH. Essentials of Supply Chain Management. Hoboken, New Jersey: John Wiley & Sons, Inc.; 2011.
2. Bragg SM. Inventory Management. Centennial, Colorado: Accounting Tools, Inc.; 2018.
3. Bonilla-Enriquez G, Caballero-Morales SO. Simulation Model for Assessment of Non-Deterministic Inventory Control Techniques. Asian Journal of Research in Computer Science. 2020; 5(3):63-70.
4. Sarkar B, Mahapatra AS. Periodic review fuzzy inventory model with variable lead time and fuzzy demand. International Transactions in Operational Research. 2015;1-31.
5. Minner S, Transchel S. Periodic review inventory-control for perishable products under service-level constraints. OR Spectrum. 2010;32:979-996.
6. Alim MH. Analisa Persediaan Bahan Baku Menggunakan Metode Continuous Review System dan Periodic Review System di PT XYZ. Jurnal Teknologi dan Manajemen Industri Terapan. 2022;1(3): 163-172.
7. Rizkya I, Syahputri K, Sari RM, Anizar, Siregar I, Ginting E. Comparison of Periodic Review Policy and Continuous Review Policy for the Automotive Industry Inventory System. IOP Conference Series: Materials Science and Engineering. 2017;288: 1-6.
8. Singha K, Buddhakulsomsiri J, Parthanadee P. Mathematical Model of (R, Q) Inventory Policy under Limited Storage Space for Continuous and Periodic Review Policies with Backlog and Lost Sales. Mathematical Problems in Engineering. 2017:1-9.
9. Chen Y, Ray S, Song Y. Optimal Pricing and Inventory Control Policy in Periodic-Review Systems with Fixed Ordering Cost

and Lost Sales. Naval Research Logistics. 2006;53(2):117-136.

10. Teunter RH. ABC Classification: Service Levels and Inventory Costs. Production and Operations Management. 2010;19(3): 343-352.
11. Sánchez-Vega MdR, Caballero-Morales SO, Sánchez-Partida D, Martínez-Flores JL. Risk-based Strategic Inventory Supply Model for New Products. In: García Alcaraz J et al. (eds). Best Practices in Manufacturing Processes. Springer, Cham; 2019.
12. Schriber T, Brunner DT, Smith JS. Inside discrete-event simulation software: How it works and why it matters. In Proc. of the 2013 IEEE Winter Simulations Conference (WSC). December 2013, Washington D.C., USA. 2014;8-11.
13. Caballero-Morales SO, Sánchez-Partida D, Barreto-Maceda MF. Improvement of Public Cab Transportation System through Computer Simulation. Asian Journal of Economics, Business and Accounting. 2022;22(17): 1-9
14. Rizkya I, Sari RM, Erwin, Sari RF. Determination of Inventory Policy based on ABC Classification. IOP Conference Series: Materials Science and Engineering. 2020;851:1-5.
15. Carreon-Nava LF, Caballero-Morales SO. Multi-retailer Sales Model under Uncertain Demand in a Pharmaceutical Two-Echelon Supply Chain with Vendor Managed Inventory System. International Journal of Combinatorial Optimization Problems and Informatics. 2022;13(2): 114-125.

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