An Integrated Maintenance policy for delivery vehicles in its supply chain

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Abstract – In this study, we involve a problem of optimization of integrated maintenance policy for vehicle routing. We are considered several reliability constraints in basic vehicle routing problem. Our goal in this study involves the establishment of an optimal maintenance strategy in the context of transport vehicle in its supply chain. The problem of vehicle routing purposes to find the shortest path at a minimal cost that beginning and ending the route at the manufactory, so that the known demand of all nodes are satisfied. Consequently, an optimal preventive maintenance strategy is applied on the vehicle takes into account the influence of crossed distances on transport vehicle degradation. An objective function characterized by transport and maintenance costs, is developed analytically and optimized in order to determine the ordered set of tours for the delivery means before performing fixed tours and the vehicle routing distance as well as the maintenance strategy, defined by the optimal number of preventive maintenance to do over the defined vehicle routing. A numerical example proposed in order to proof the analytical model.

***Keywords* – Maintenance policy, supply chain, proportional hazard, optimization, vehicle routing problem.**

1 INTRODUCTION

The economic development requires companies to be more reactive and organized in front of a competitive market. The challenge is how to satisfy customers' demands with a high quality level and a minimum costs. So, being a pioneer company in the market requires a well-managed supply chain with minimum expenses. In this context, the notion of the supply chain is highlighted.

The management of the supply chain is one of the success keys in a competitive market. Corporations try to handle it by raising the quality level of their services and reducing expenses. Industrials manage their supply chain from the provision to the delivery. In fact, the supply chain covers the coordination between supply and demand and organizes production, storage and distribution.

In the present context the main aims for many enterprises are adapting to the market and customer satisfaction, which usually depends on the overall performance of their supply chain. Today, the attention of enterprise is focused on the management of flows between actors of supply chain. Often companies ignore the mobile resource management, these resources can increase costs. Consequently it is important to think about the good management of mobile resources and to take them into consideration when designing a logistics network, which provides a comprehensive visibility and control over these resources. In this context, looking the f supply chain management frame, the research works are generally interested in optimizing costs related to the conception of logistics network in order to estimate the optimal quantity transported and also the costs of the location of the various elements of supply chain seeking to minimize the distance and maximize profit from this work are cited the following:

The research work of (Pan et al. 2011) aims to study the environmental and economic challenges of logistics pooling. They considered that it is an emerging strategy to improve logistics performance. The authors noted that to develop the concept of services supply chain and aims to reduce inventory. In the article the authors have introduced some researchers that link between transport and sustainable development, this link enables logistics providers and carriers to participate not only in the reduction of logistics costs, but also to the reduction of CO_2 emissions. Benoist (2010) is interested of an optimization problem of vehicle tours with inventory management. In this paper, the seller is responsible for the inventory of its customers; the objective of this paper is to minimize logistics costs. The authors demonstrated that their model could reduce costs by 20% compared to what was done by the experts of the logistics domain.

Wassila and Riad, (2010) is interested in a recent problem of the green logistics. The purpose of this article is to provide a mathematical model to minimize the overall economic costs of the supply chain i.e. direct traditional logistics costs, in closed loop and reverse logistics costs, Then they proposed another model that minimizes the effects of carbon dioxide these costs are considered in the article as external transport costs.

Many researchers devoted their studies to develop an optimal maintenance strategy. As example, we can take Murthy and al (1981). and Nakagawa (1981) studies. The purpose of these studies is to reduce maintenance costs by using the reliability of the system. In this context, we can take the methods of the maintenance age type and block type from the article of Barlow and al (1960). After that, researchers formulated new integrated maintenance strategies. Hajej and al.(2012) took the influence of production rates in the equipment failure rate under subcontracting and retraction constraints into consideration. Dellagi et al (2006), presented an integrated maintenance in a subcontracting context. In order to avoid the subcontractor unavailability, Improved Maintenance Policy (IMP) was developed to find the appropriate delay of the preventive maintenance task to avoid lost order.

Generally, we notice that many studies are interested in the problem of the transport routing and treat only the economic aspect by minimizing the transport costs and delays as well as Eckhardt and al (2012), and Iannone (2012), without taking the maintenance of the vehicle into account.

Hajej et al. (2014) interested in determining a maintenance policy with an optimal cost to enable the company to generate significant profits, often the means of transport travelled different paths, they are characterized by their distance flown.

Concerning the operating conditions of an industrial or logistics problems, several works are interested in the type of this problem, the researchers are always considered that these conditions are constant normal over time.

For (Schutz et al., 2009), the operating conditions have an influence on the choice of maintenance policy conducted and system reliability, he defined, that these conditions are environmental or operational associated for each mission are estimated by experts naval field. According to (Schutz et al., 2009), the environmental conditions depend on the environment and the place of performance of the mission; these environmental conditions have an influence on the rate of system failure. The modelling of the influence for operating conditions is given by the proportional risk model.

In the works of (Hajej et al., 2011) concerning the operating conditions, they determined that the variation of the production rate leads to a degradation of the system and increase the failure rate. Pan et al. (2011) studied the impact of operating conditions on the choice of maintenance action, the aim of the author is to determine after each changing operating conditions the maintenance actions to apply.

The remainder of the paper is organized as follows: In Section II, we present the originality of our study. In section III we detailed the problem and Section IV presents the maintenance strategy. In section V we developed the optimization approach. In section VI, we presented a numerical example, in order to apply the analytical results. Finally we conclude in section VII.

2 ORIGINALITY STUDY

It's easy to see that several interested works in logistic frame help companies in the establishment of the economical supply chain. In spite of the success of these studies, we noted that searchers neglected several constraints which can impact on the optimal supply chain established. As constraint, we can cite the maintenance strategy adopted for the transport mean ensuring the mission. In fact, it's evident that every transport mean, ensuring the execution of the mission, need maintenance task in order to face randomly failures. It's noted in literature, that by adopting a preventive maintenance strategy we can reduce the failure rate. More then, recent studies were involved to integrated maintenance policy. These studies aim to extend traditional maintenance policies by developing new maintenance strategies with taking into account new constraints. In this way, we presented our study dealing with new integrated maintenance logistic strategy. In fact, the originality of our work consists to establish simultaneously the optimal supply chain and maintenance strategy adopted in order to ensure a predefined mission. The optimization is expressed by minimizing simultaneously a total cost integrating maintenance and logistic costs. We noted that we take into account the influence of the mean transport road type on the system degradation and consequently on the maintenance strategy adopted. An analytical study is developed in order to express an objective cost function integrated maintenance and logistic data. By optimization of the objectives function we can deduce the optimal variable decisions related to maintenance and logistic frame.

3 PROBLEM STATEMENT

Our study deals the case of a firm composed by the transport means ensuring the delivery of merchandises between the different elements of the supply chain (plants, distribution centers, customers).

In this study we consider only one means of transport is required to ensure a set of tours during over finite horizon. The tours are characterized by their roads as well as the time required to complete a tour. Similarly, a tour is generally generates a degradation process of delivery means, which can cause failures where the maintenance cost will be high, which reduces the profit generated by the tour.

We assume that a single vehicle index v ensures the delivery of products from the factory k to distribution center then from distribution center to the customer and finally back to the factory from the customer. This loop builds a tour to the delivery means, then a tour begin to the factory and returning eventually to the same plant or from another.

Our objective is to establish a jointly maintenance policy and an ordered set of tours for the delivery means before performing tours, which decrease a total cost integrating maintenance.

The specification of this problem lies, by the fact, the impact of the distance travelled by delivery means in the number of failures and preventive actions to maintenance.

The problem is illustrated in figure 1.

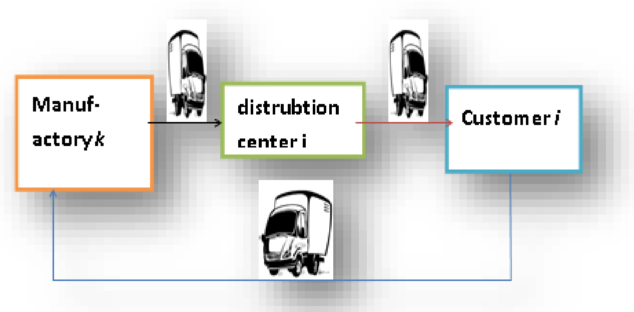

Figure 1. Problem Description

3.1 Notation

✓ The subscript:

k∈ K : index of manufactories k= {1,2,…, K}
j∈ J : index of the distribution centers j= {1,2,…, J}
i∈ I : index of Customers i= {1,2,…I}
v∈ V : index of vehicles v= {1,2,…, V}
Y : tours number
q : index of the tours q= {1, 2,3,…, Y}

✓ The model parameters :

rj : demand of distribution center j
ri : demand of customer i
cjiv : cost of transport from the distribution center j to the customer i by the vehicle v
ckjv : cost of transport from the manufactory k to distribution center j by the vehicle v
ukjv : cost of displacement from manufactory k to distribution center j by displacement unity for vehicle v.
ujikv : cost of displacement from distribution center to customer and from customer to manufactory by displacement unity for vehicle v
capaj : capacity of distribution center
capak : capacity of manufactory k
dkjv : distance between manufactory k and the distribution center j traveled by the vehicle v.
djikv : distance between distribution center j and customer i and the customer i to manufactory k traveled by the vehicle v.
Mcv : cost of corrective maintenance for vehicle v
Mpv : cost of preventive maintenance for vehicle v
mu: monetary unit

✓ The decision variables :

xjiv : transported quantity from distribution center j to customer i by the vehicle v
xkjv : transported quantity from manufactory k to distribution center j by the vehicle v
yjikv =1 if the distance djik traveled by the vehicle v, 0 if no
Nv : number of the preventive maintenance intervals for the vehicle v.

3.2 Total function cost

The idea is to minimize the cost of the transport between the different elements of the logistic network and the road cost thus that the cost of maintenance actions.

The total cost as follows:

$$\min(z) = \sum_{v\in V}[(\sum_{j\in J}\sum_{i\in I}(c_{jiv}x_{jiv}) + \sum_{k\in K}\sum_{j\in J}\left(c_{kjv}x_{kjv}\right) + \sum_{j\in J}\sum_{i\in I}\sum_{k\in K}(u_{jikv}d_{jikv} \times y_{jikv})$$
$$+\sum_{j\in J}\sum_{i\in I}(u_{jiv}d_{jiv}) + M_{cv}\phi_{cv} + M_{pv}(N_v - 1)]$$

Subject to:

$$\sum_{\mathbf{j}\in \mathbf{J}} \mathbf{x_{jiv}} \geq \mathbf{r_i} \quad \forall\ \mathbf{i}\in \mathbf{I} \qquad (1)$$

$$\sum_{\mathbf{k}\in \mathbf{K}} \mathbf{x_{kjv}} \geq \mathbf{r_j} \ \forall\ \mathbf{j}\in \mathbf{J} \qquad (2)$$

$$\sum_{\mathbf{i}\in \mathbf{I}} \mathbf{x_{jiv}} \leq \mathbf{capa_j} \ \forall\ \mathbf{j}\in \mathbf{J} \qquad (3)$$

$$\sum_{\mathbf{j}\in \mathbf{J}} \mathbf{x_{kjv}} \leq \mathbf{capa_k} \ \forall\ \mathbf{k}\in \mathbf{K} \qquad (4)$$

$$\mathbf{x_{jiv}} \geq 0 \forall\ \mathbf{j}\in \mathbf{J};\ \mathbf{x_{kjv}} \geq 0 \forall\ \mathbf{k}\in \mathbf{K} \qquad (5)$$

$$\mathbf{y_{jikv}} \in \{0,1\} \qquad (6)$$

Constraints (1) and (2) require the satisfaction of demands. Constraints (3) and (4) define the capacity bounds of the distribution canters and the manufactories. Constraint (5) denotes that the product flows are not negative. Constraint (6) is a binary constraint equally to 1 if the distance d_{jik}, traveled by the vehicle v.

4 MAINTENANCE STRATEGY

In this study, we will adopt the periodic policy of maintenance strategy; this policy is to perform preventive maintenance actions at constant time intervals. The maintenance strategy under consideration is the well-known preventive maintenance policy with minimal repair at failure.
The analytic expression of the total maintenance is expressed in literature as follows:

$$\mathbf{\Gamma(Y,N) = M_{cv}\phi_{cv} + M_{pv}(N-1)} \qquad (7)$$

Where ϕ_{cv} the average number of failures is expressed as follows:

$$\phi_{cv}(\mathbf{Y},\mathbf{N}) = \sum_{\mathbf{n}=1}^{\mathbf{N}}\left(\sum_{\mathbf{q}_v=\mathbf{d(n)}}^{\mathbf{f(n)}}\left(\int_{\tau_{q-1_v}}^{\tau_{q-1_v}+\sigma_{q_v}} \lambda_{q_v}(\mathbf{t})\mathbf{dt}\right)\right) \qquad (8)$$

$\lambda_{q_v}(\mathbf{t}) = g(z)_{q_v}\ \lambda_n(t)$ the failure rate associated to the tour q realized by vehicle v.
In the equation (8), the terms d(n) and f(n) that respectively represent the tours that beginning and finished the interval n with n= {1,2,3,…, N}. The realization of tours can be done in several intervals of preventive maintenance; therefore it is necessary to

determine the duration of these tours for each maintenance interval. This duration noted σ_{qv} is still less than or equal to the rotated length δ_{qv}.

- ✓ Proportional failure rate

In this work, we use the (Cox, 1972) that established a semi-parametric relationship between the risk factors for failure and distribution of lifetimes.
The Cox model is expressed by

$$\lambda(t,z) = g(z)\lambda_n(t) \quad (9)$$

with:

$\lambda_n(t)$ the function of nominal failure rate

$\lambda(t,z)$ The instantaneous risk of failure at time t, under the conditions z

In equation (9) the term g (z) is the risk function. It is an exponential function:

$$g(z) = e^{\sum_i b_i z_i} \quad (10)$$

The coefficient bi is the influence of zi factor, as in our case the factor zi represents the type of the path travelled by any transport means throughout the tour.

In our case there is only one factor i = 1, it has three levels of severity:
Z1c : the distance is a short path.
Z1M : the distance is a medium type.
Z1L : the distance is long type

In addition, the bi vector is estimated by maximizing the likelihood of Cox. We noted that V* the partial likelihood, from (Cox, 1972):

$$V^* = \prod_{i=1}^{n} V_i = \prod_{i=1}^{n} \frac{e^{b_i Z_i}}{\sum_{k \in n(t_i)} e^{b_i zk}} \quad (11)$$

We noted ti i= 1…n, with n is the number of observed failures and zi (i=1…n) the n associated constraints. n(ti) represent the entire population at risk, that is to say, all components with a lifetime greater than ti developed this expression and calculated the log-likelihood

$$L^* = \ln\left(V^*\right) = \sum_{i=1}^{n}\left[b_i z_i - \ln\left(\sum_{j \in n(t_i)} e^{b_j z_j}\right)\right] \quad (12)$$

In our study, the function risk is expressed as follows:

$$g(Z)_{q_v} = e^{(z_1 b_1)} \quad (13)$$

Besides the z1 should have three levels depending on the distance dqv, which dqv is the distance from the tour index q.

$$Z_1 = \begin{cases} 1 & if \quad d_{q_v} \in]a,b] \\ 2 & if \quad d_{q_v} \in]b,c] \\ 3 & if \quad d_{q_v} \in]c,d[\end{cases} \quad (14)$$

- ✓ Functional age

It is understood that the function of the failure rate varies depending on the distance travelled (type of path), the reliability of transport means must be continuous over time.
When a tour is over and another begins, this change involves a change in the failure function, this change reproduced on the reliability function. Thereby to ensure the continuity of reliability, we will call the concept of functional age whose objective is to ensure continuity. To determine that age, it is necessary to know the reliability of the transport means to end of the previous tour and the type of path for the risk function of the next tour.

In addition, to ensure the continuity, the functional age τ_q associated of the tour q+1 must satisfy the following relationship:

$$\left[\mathbf{R}\left(\mathbf{t}_{\mathbf{q}_v}\right)\right]^{g(\mathbf{Z}_{\mathbf{q}_v})} = \left[\mathbf{R}\left(\boldsymbol{\tau}_{\mathbf{q}_v}\right)\right]^{g(\mathbf{Z}_{\mathbf{q+1}_v})} \quad (15)$$

with

$$\boldsymbol{\tau}_{\mathbf{q}_v} = \begin{cases} 0 \quad if \quad \mathbf{q}_v = 0 \\ \mathbf{R}^{-1}\left[\left(\mathbf{R}(\mathbf{t}_{\mathbf{q}_v})\right]^{\mathbf{g}(\mathbf{Z}_{\mathbf{q}_v}) / \mathbf{g}(\mathbf{Z}_{\mathbf{y}_{\mathbf{q+1}_v}})}\right. \end{cases} \quad (16)$$

with

$$\mathbf{t}_{\mathbf{q}_v} = \boldsymbol{\tau}_{\mathbf{q-1}_v} + \boldsymbol{\delta}_{\mathbf{q}_v} \quad (17)$$

t_{qv} : age of transport mean v at the end of tour q.
Denoted that Δ the constant duration of preventive maintenance intervals, this duration is determined by the cumulative duration of tours and the number of intervals N.

$$\Delta = \frac{\sum_{\mathbf{q}=1}^{\mathbf{y}} \boldsymbol{\delta}_{\mathbf{q}_v}}{\mathbf{N}_v} \quad (18)$$

5 Optimization

5.1 Shortest path

The shortest path problem is to determine the shortest path under and the lowest possible cost between two vertices. Mathematically the shortest path is a straight line, excluding that in practice it is not always possible to translate this result in specific cases. When you want to move from one city A to another city B is trying to follow the least expensive roads with a short distance, the problem in this case is how to find the shortest path between two cities. In graph theory, this problem can be modelled by applying fast algorithms for finding the shortest path and in our case study applied the algorithm is the Dijkstra (Edsger, 1959).

The variables used by the Dijkstra algorithm are:
S: the set of vertices for which we already know their shortest distance to the source.
A: The set of vertices, which are to visit.
L (Xk , y) : the distance of an arc from vertex Xk to vertex y.
i: index of the starting vertex.
n: the n vertices to visit
G: the set of vertices processed by the algorithm.
Data: S, A, L, $i \in S$
Result: Π, G

1) G:={i}; Π (i)=0 ; k:=1; X1:=i;
2) $\forall$ X$\in$S\ {i} do Π (X) :=∞ end do
3) while k<n et Π (Xk) <∞ do
4) $\forall$ y$\in$A(Xk) as y$\notin$G do
5) Π (y)=min [Π (y), Π (Xk) +L (Xk , y)]
6) the end
7) Extract a vertex X $\notin$ G as Π (X)=min [Π (y) ;$\forall$y$\in$G] ;
8) K=k+1 ;Xk :=X ; G := G $\cup${Xk}
9) end

5.2 Maintenance optimization

For this policy, the decision variable is the optimal number of preventive maintenance intervals N*. Mathematically, it is difficult to determine the optimal solution due to the complexity of the maintenance cost equation. Normally, to search the optimal solution is to solve the following equation:

$$\frac{\partial \Gamma(Y,N)}{\partial N} = 0 \qquad (22)$$

From (Schutz et al. 2009), they have shown that exist an optimal number of preventive maintenance, and to obtain this optimal number, they performed a numerical procedure.

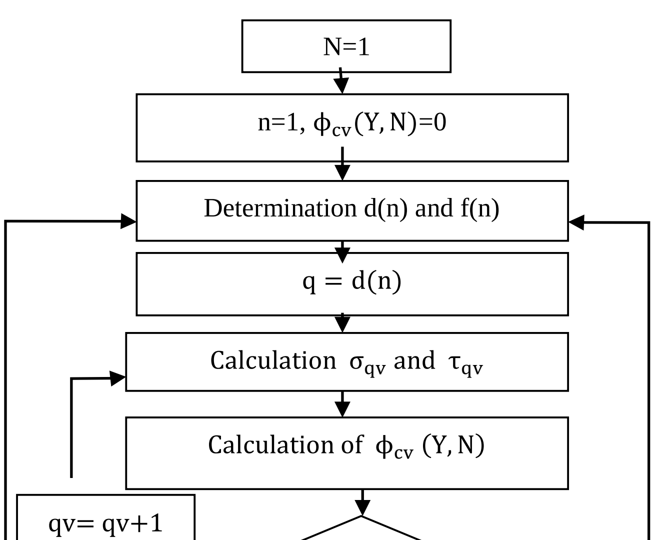

Figure 2. Numerical procedure to obtain the optimal number of preventive maintenance actions

6 NUMERICAL EXEMPLE

In this section, we will present an illustrative case in order to apply the analytical study presented in the previous sections. Our example composed by 3 distribution centers and 3 manufactories. The following table presents the solution for the logistics model together optimal quantities:

Table1. Delivery quantity from manufactory k to distribution j

Similarly, we will determine the quantities requested by clients, the following table shows the quantities delivered by each distribution center:

	Distribution Center			
Manufactories	C1	C2	C3	Manufactories capacities
M1	67	80	80	400
M2	67	80	80	560
M3	66	80	80	560
Demands of the distribution centers	200	240	240	

Table2. Delivery quantity from distribution center j to customer i

	Customers			
Distribution centers	Cl1	Cl2	Cl3	Capacities Of d.c
C1	33	0	40	300
C2	33	120	40	350
C3	34	0	40	350
Customers' demands	100	120	120	

After completing the first stage, the second objective is to determine the paths that will eventually be covered by the chosen transportation means to perform the all of these delivery roads. For information in our case we used a single means of transport that will accomplish all tours.
Recall that to determine the levels of influence factor, we have:

$$Z_i = \begin{cases} 1 & d_{q_v} \in]a,b] \\ 2 & d_{q_v} \in]b,c] \\ 3 & d_{q_v} \in]c,d] \end{cases}$$

With a=0; b=950; c=1500; d=30000
The table below indicated the factor with coding the levels of influence factor

Table 3. Coding and model values for types of path

Factor	Traveled distance dqv		
Coding Zi	1	2	3
Distance	]0,950]	]950,1500]	]1500,30000]
Types of road	Short (S)	Medium (M)	Long (L)

The following table presents the distance and these path types together that the duration for each road:

Table 4. Distance and type of road and duration of each round

Road (qv)	1	2	3	4	5	6	7	8	9
Duration δqv	44	72	93	94	95	123	124	140	152
Distance en km	565	950	1265	1267	1282	1690	1698	1926	2092
Type of road	S	S	M	M	M	L	L	L	L

In order to determine the coefficient of influence factor, we computed the partial derived of equation (12). The numerical solution of this equation (11) gives the following value:
Coefficient associated of traveled distance: 0,077
According to the equation (10), the expression of risk function has become:

$$g(z_i) = e^{0.077 \times z_i}$$

Point of view reliability, we suppose that the failure time of delivery means has a degradation law characterized by a Weibull distribution. The Weibull scale and shape parameters are respectively β=600 and γ=2. The corrective and preventive maintenance cost are respectively Mcv =500 mu, Mpv=350 mu.
The above figure illustrates the minimum total maintenance cost for different values of the number, N, of PM actions to be performed.

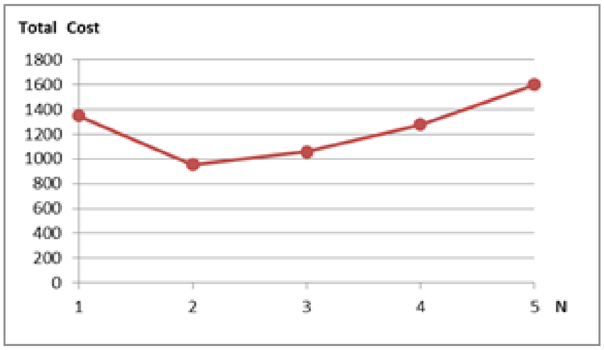

Figure 3. Minimal total cost according to *N*

Fig. 4 shows the curve of the total cost of maintenance according to N (Number of preventive maintenance actions). We conclude that the optimal number of preventive maintenance actions that minimizes the total cost of maintenance is N*=2. Hence, the cumulated distance after which we will make the intervention for preventive maintenance equal to 6637km through the transported means.

7 Conclusion

In this study, we consider an integrated maintenance strategy optimization characterized by an optimal number of preventive maintenance actions applied on transport means in its supply chain. The maintenance strategy in this optimization problem takes into account the infrastructure constraint related to the crossed distance between the various elements building the logistics network. An objective function is developed in order to minimize the total cost integrating transport, road and maintenance and to ensure the availability and reliability of transport vehicle during the implementation of a tour to avoid any costs related to the no customer satisfaction.

For future research, we will consider a more complex system with new environmental constraints (climatic constraint and the crossed distance). We will consider the influence of these factors on the maintenance strategy. Also, concerning the maintenance strategy, we will consider new hypotheses: the corrective and preventive times are not negligible. We can consider also the type of product transported which can impact the optimal integrated maintenance-supply chain policy established.

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