# OPTIMIZED MAINTENANCE POLICY FOR THE MEANS OF TRANSPORT IN ITS SUPPLY CHAIN UNDERGROUND ENVIRONEMENT CONSTRAINTS

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**ABSTRACT:**
*In this paper we present a maintenance policy that improves the fleet reliability and enhance its performance. The goal is to determine an optimal maintenance strategy in the context of the means of transportation. To deal with this problem, we apply a preventive maintenance strategy with a minimal repair. In this strategy, we consider that the crossed distance and the climatic conditions have an influence in the failure rate.*
*The transport missions are planned for the purpose of reducing maintenance and transport costs. Therefore, the routing distance will be minimized and will contribute to in the determination of the failure rate.*
*An analytical model was developed to determine an optimal vehicle routing distance as well as a minimum maintenance costs. In order to illustrate this model, a numerical example will be presented.*

**KEYWORDS:** *Maintenance Policy, supply chain, vehicle routing problem, integrated maintenance.*

## 1 INTRODUCTION

The economical 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 minimum costs. So, being a pioneer company in the market requires a managed supply chain with minimum dispenses. In this context, the notion of the supply chain will be highlighted.
Industrials manage their supply chain from the provision to the delivery. This management covers the coordination between supply and demand and organizes production, storage and distribution.
In this paper, we will highlight the means of transportation that companies dispose to deliver their products.
In fact, controlling the means of transport contribute to minimize dispenses and increase benefits. Industrials manage their fleet by planning the delivery schedule and the maintenance plan in order to reduce transport costs. Having a fleet well maintained guarantee a high level service and provide the respect of the delivery schedule. Therefore, they gain several customers.
Companies try, usually, to lower their vehicles routing' costs by minimizing distances, optimizing the routing planning and also by reducing maintenance costs independently. From here comes the convenience of introducing environment constraints and creation a link between transport plan and maintenance plan.
The reminder of this paper is as follow : presentation of the literature review related to maintenance in supply in chain in section 2; introduction of the problem in section 3;.in section 4 development of the analytical in section 5 description of the optimization phase of our study and finally the numerical example in section 6.

## 2 LITERATURE REVIEW

Many researchers devoted their studies to develop optimal maintenance strategy. The purpose is to reduce maintenance costs using the reliability of the system (Nakagawa, 1981; Murthy and Nguyen, 1981). We can take the example of maintenance age type and block type (Barlow and Hunter, 1960). After that, studies formulate a new integrated maintenance strategies which take into account the influence of production rates in the equipment failure rate under subcontracting and retraction, constraints (Hajej and *al.*, 2012).
In the same context, (Dellagi, 2006), presents an integrated maintenance in a subcontracting context. To face the subcontractor unavailability, Improved Maintenance Policy (IMP) was developed to find the appropriate delay of the preventive maintenance task to avoid lost order.

In fact, applying integrated maintenance in the supply chain improve the production quality and contribute to organize the workforce too. That's what (Gang and *al*., 2006) present. Their idea consists in using an evolutionary algorithm to optimize the preventive maintenance plan and the allocation of qualified workforces with a minimum dispense.
Instead of the production sector, maintenance policy may impact energy efficient of the means of transportation. That is what (Vujanovic and *al*, 2012) indicate in their article. Having an efficient maintenance policy contributes to decrease fleet' energy dispenses. By finding all the links between maintenance and environment of the means of transport, the researchers prove that the maintenance plan has the most important action on the energy efficient in the means of transportation.
(Friesz and Fernandez,1979), explored a dynamic maintenance plan consecrated to the means of transportation. They showed that "*the quality of the equipment is determined by the natural factors the rate of use and the maintenance investments"*. The aim is to find an optimal maintenance policy which respect all this circumstances. This study highlights the impact of the natural factor in the deterioration of the system.
(Schutz, 2009) covers the aspect of the influence of environmental constraints in the maintenance plan in naval sector. It consists on organizing the transport plan in order to establish a maintenance plan. This maintenance plan should match with all the missions.
To conclude, 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, (Eckhart and Rantalab, 2012; Iannone,2012) without taking in account the maintenance costs of the vehicle.

## 3 PROBLEM STATEMENT

### 3.1 MOTIVATION

According to the previous works, the minimization of the transport dispenses are treated in two steps. The first step is the optimization of vehicle routing: distances and cost minimization.
The second step is the improvement of maintenance policies. So, the maintenance of the means of transportation is developed separately from the problem of the vehicle routing.
But the integrated maintenance proves that it is an efficient method to reduce maintenance costs, for example in aeronautic or reducing energy' dispenses in the context urban transportation. In addition, it improves the service quality too.
However, in this paper we propose to join the notion of the maintenance and the routing planning together for a common optimization and using environmental factors like the crossed distance and the climatic constraint.

### 3.2 PROBLEM DESCRIPTION

We consider one factory, *i* retailer and *j* clients associated to each retailer. We have one delivery-truck which charged to do the distribution products.

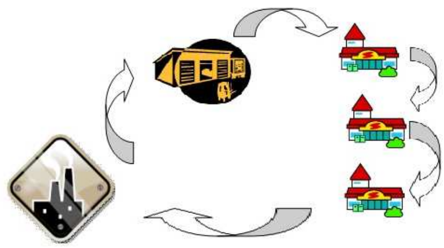


Figure 1: Routing cycle

We suppose the following hypotheses for our routing cycle:

- the truck capacity is limited,
- all clients are satisfied and delivered on time,
- the truck is charged from the first client to the last one and it discharges products client by client.
- empty returns from the last client to the factory

The ultimate aim of this study is to determine an optimal maintenance strategy taking an optimized routing vehicle, crossed distance factor and climatic constraint in account. So, we will resolve sequentially this problem in two step.
The first step presents routing vehicle optimization by the minimizing of the total transport cost.
In order to determine an optimal transport cycle from the factory to the last client, we define a set of variable linked to problem:
$i$: retailer
$j$: client
nr : number of retailer
$r$: routing's number
$nc_i$: number of client associated to retailer $i$
$C_i$: transport cost from the factory to retailer $i$
$X_i$: transported quantity from the factory to retailer $i$
$C_{ij}$: transport cost from retailer $i$ to client $j$
$X_{ij}$: quantity from the retailer $i$ to client $j$
$U_i$: transfer cost between the factory to retailer $i$
$d_i$: distance between factory and retailer $i$
$U_{ij}$: transfer cost between retailer $i$ client $j$
$d_{ij}$ : distance between client j associated to retailer $i$ and factory
$U_{j(j+1)}$ : transfer cost between two successive clients
$d_{ij(j+1)}$ : distance between two successive clients
$U_{nci}$: transfer cost between the last client and the factory
$d_{nci}$: distance between the last client associated to retailer $i$ and factory.
$\delta_r$: the distance of the routing $r$
Mc: corrective maintenance cost
Mp: preventive maintenance cost
$\phi$c: Average number of failures over the vehicle routing
$\lambda(t)$ : the nominal failure rate

The transport objective function is as follow:

$$Ct = \mathrm{Min}[\, [\sum_{i=1}^{nr}(C_i\, X_i + U_i\, d_i + U_{nci}\ d_{nci\, i} + U_{i1}\, d_{i1} + \sum_{j=1}^{nci} C_{ij}\, X_{ij} + \sum_{j=2}^{nci-1}(U_{j(j+1)}\, d_{j(j+1)} + \sum_{k=j}^{nci} C_{ik}\, X_{ik}))]/ \sum_{i=1}^{nr} d_i + d_{nci} + d_{i1} + \sum_{j=1}^{nci-1} d_{j(j+1)}]$$

This function regroups all the transport costs for all the routings. The objective is to obtain the minimal distance that the truck will cross.

Once the transport problem is optimized, the second step consists in optimizing the maintenance strategy.

The maintenance policy adopted is well known in literature as preventive maintenance strategy with minimal repair. The preventive maintenance adopted is assumed to be perfect, the unit is then considered as good as new. However, when a failure occurs between two successive preventive maintenance actions, a minimal repair action will take place to maintain the system during the current period. As consequence, the failure rate is undisturbed. In this policy, we assume that the repair and replacement times are negligible.

The maintenance optimization consists in determining the number of preventive maintenance actions to do over the transport 's plan. The originality of our study is to take the influence of the type of crossed distance and the climatic condition on the degradation degree of the means of transportation into account, consequently, on the average number of failure $\phi c$ and the total maintenance costs Cm.

Our purpose is to minimize the objective function of maintenance costs per unit of distance expressed as follow:

$$Cm = \mathrm{MIN}[\frac{[Mc\, \phi c + Mp\, (Nmp - 1)]}{\sum_{i=1}^{nr} d_i + d_{nci} + d_{i1} + \sum_{j=1}^{nci-1} d_{j(j+1)}}]$$

## 4 ANALYTICAL MODEL

This section presents the mathematic model of our maintenance strategy which is based on an optimum routing . The method of optimized journey will be presented in the next paragraph.

The following model covers the maintenance strategy. We remind that in our study we take into account two factors, the crossed distance (x) and the climatic condition (y)on the degradation degree of the means of transportation. Formally, we traduce these constraints by an effect on the failure rate.

The variables $x_r$and $y_r$ have 3 different levels that present the influence level of the constraint.

The factors appear in the failure rate through a risk function $G(x_r, y_r)$, (Cox, 1972) :

$$G(x_r, y_r) = e^{b_1 * x_r + b_2 * y_r}$$

But to determine $b_1$ and $b_2$ which present the weighting coefficients related to the distance and the climatic constraint, we should resolve the partial derivate of the partial likelihood L* (Lyonnet,2000):

$$L^* = \sum_{y=1}^{m} b_1 x +_i b_2 y_i - \ln\ (\sum_{j \in n(t)} e^{b_1 x_j + b_2 y_j})$$

$$\frac{\partial L^*}{\partial x} = 0\ ;\ \frac{\partial L^*}{\partial y} = 0$$

After the determination of the risk function for each journey r. The function of the failure rate $\lambda_r$ is :

$$\lambda_r\, (t, r) = G(x_r, y_r) * \lambda(t)$$

It means that in every journey *r* the failure rate has a different value of $x_r$ and $y_r$.

The characteristic of a periodic maintenance strategy,(Schutz,2009), is the constant crossed distance that we calculated to define after how many kilometers we will have the preventive maintenance task to realize. So the expression of this distance is :

$$\Delta = \frac{\sum_{r=1}^{nr} \delta_r}{Nmp}$$

The expression of the average number of failures is the summation of the average number of failures for each interval n:

$$\phi c = \sum_{n=1}^{Nmp} \sum_{r=s(n)}^{f(n)} \int_{\tau_{r-1}}^{\tau_{r-1}+\sigma_r} \lambda_r\, (t) dt \text{ (Schutz,2009)}$$

Before the determination of $\phi c$, we identify the routing that start and finish s(n) and f(n) in each interval n:

$$s(n) = \begin{cases} 1 \text{ if } n = 1 \\ \text{solution of } r \quad \sum_{y=1}^{r} \delta_y \geq (n-1) * \Delta \\ \text{else} \\ \sum_{y=1}^{r-1} \delta_y < (n-1) * \Delta \end{cases}$$

$$f(n) = \begin{cases} \dim(nr) \text{ if } n = Nmp \\ \text{solution of } r \quad \sum_{y=1}^{r} \delta_y \geq n * \Delta \\ \text{else} \\ \sum_{y=1}^{r-1} \delta_y < n * \Delta \end{cases}$$

After that we resolve the following system to find the crossed distance $\sigma_{rn}$ for each routing in each interval n :

$$\sigma_{rn} = \begin{cases} \delta_r\ ;\ \text{if } s(n) \neq r \neq f(n) \\ \sum_{n=1}^{s(n)} \delta_r - (n-1) * \Delta\ ;\ \text{if } s(n) = r \neq f(n) \\ n * \Delta - \sum_{l=1}^{f(n)-1} \delta_l\ ;\ \text{if } s(n) \neq r = f(n) \\ \Delta\ ;\ \text{if } s(n) = r = f(n) \end{cases}$$

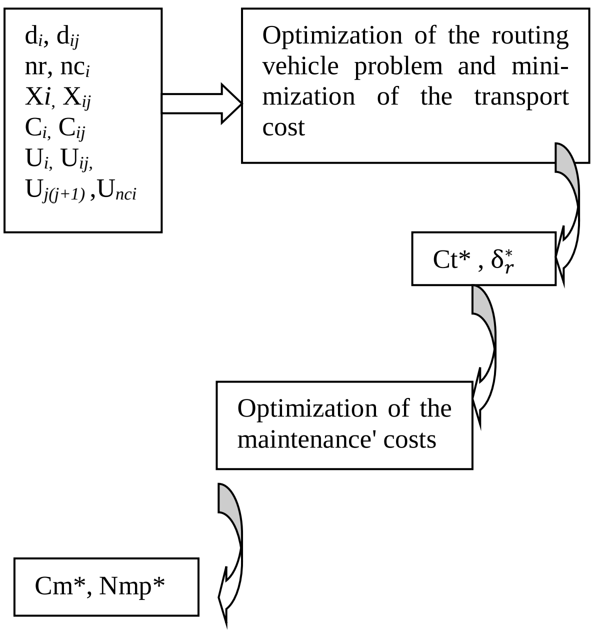
We noted that the average number of the failure rate changes in every journey *r*. However, the reliability must be continuous.
For this reason, we establish a functional age $\tau_{rn}$ in order to insure this continuity:

$$\tau_{rn} = \begin{cases} 0; \text{ if } r = s(n) \\ R^{-1}[R(tr)]^{\frac{G(x_r,y_r)}{G(x_{r+1},y_{r+1})}} \text{ with } tr = \tau_{r-1n} + \sigma_{rn} \end{cases}$$

Using the this model allow us to start the optimization step in the next section.

## 5 OPTIMIZATION

According to the objective functions, the optimization phase will be in tow steps: the first one consists in optimizing the transport routing minimizing the transport costs. The second step consists in determining the optimal number of preventive maintenance actions to do over the transport routing minimizing the total maintenance cost by time unit.
The aim of the routing optimization is to define the economical delivery order from the factory to all clients for each retailer *i*. In this optimization we take into account the charge that the trucks transport all over the routing.
The optimization method is presented in the following diagram:




## 6 NUMERICAL EXAMPLE

A numerical example is presented in this section in order to illustrate the effectiveness of the analytical model developed in the previous section. The rest of numerical data is summarized in the following table:

| Reliability data | |
|---|---|
| Degradation law | Weibull distribution shape parameter , *β=2* scale parameters, *η=600* |
| Corrective maintenance cost | *Mc=2000* mu |
| Preventive maintenance cost | *Mp=500* mu |
| **Cost data** | |
| transport cost from the factory to retailer *i* | $C_i$ = 4mu |
| transport cost from retailer *i* to client *j* | $C_{ij}$= 4 mu |
| transfer cost between the factory to retailer *i* | $U_i$= 3 mu |
| transfer cost between retailer *i* client *j* | $U_{ij}$= 4 mu |
| transfer cost between two successive clients | $U_{j(j+1)}$ = 4 mu |
| transfer cost between the last client and the factory | $U_{nci}$= 7 mu |
| **Routing problem data** | |
| Number of routing | Nr =10 |

Table 1: Example's data

For the determination of $b_1$ and $b_2$, the weighting coefficients related to the distance and the climatic constraint, we use the different distance constraint level in function of the distance in kilometer and also the climatic constraint level in function of the temperature:

| | ]0,1000] Km | ]1000,2000] Km | ]2000,30000] Km |
|---|---|---|---|
| x | 1 | 2 | 3 |

Table2: Distance constraint levels

| | ]-5°,30°] | [-5,15]; ]30,45] | ]-30°,-15]; ]45,50] |
|---|---|---|---|
| y | 1 | 2 | 3 |

Table 3 : Climatic constraint levels

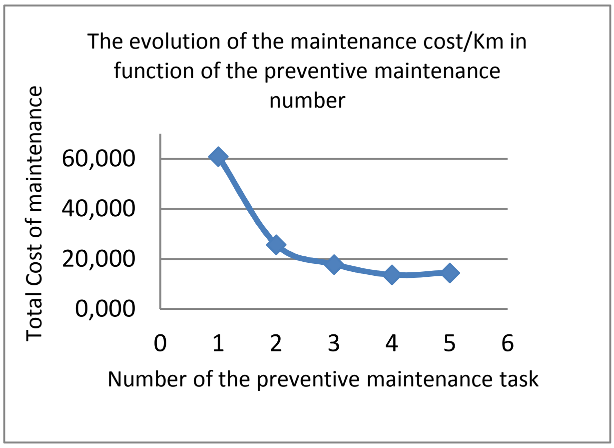
The results of the first step of the optimization program are:

| *i* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\delta_r^*$ | 998 | 1216 | 1184 | 1196 | 696 | 1394 | 1147 | 870 | 1277 | 993 |

Table4: Routing distances

The optimal transport cost Ct* is 20.93 um/Km.
After the calculation partial like-hood L*, we find the value of $b_1$ and $b_2$ for $x_r$ and $y_r$ :

$b_1$=0.0763
$b_2$=0.0234
To determine the "local" Cm*, we should find the optimal number of the preventive maintenance .The following graphic shows the evolution of the maintenance cost/Km.
For the maintenance cost we obtain:
Cm*= 13,667
Nmp*= 4




## 7 CONCLUSION

In this paper, we present an integrated maintenance in the supply chain. We established sequentially the optimal routing distance as well as the optimal number of preventive maintenance action to do over the transport routing. The optimal maintenance strategy ensures a minimal cost of maintenance and transport. The key of our study consists in taking two significant factors into account: the type of crossed distance and the climatic condition during the transport routing.
The influence of those factors is presented analytically in the failure rate expression. So, using these constraints, we obtained an economical maintenance plan for the means of transportation adapted for the routing plan.
Finally, a numerical example is presented in order to prove the analytical study developed.

## REFERENCES

Barlow, R., and L. Hunter, 1960. Optimum preventive maintenance policies. *Operations Research, 8,* p. 90-100.

BENNOUR, M., C. BLOCH, ZERHOUNI, N.,2001. Modélisation intégrée des activités de maintenance et de production. *3ème conférence Francophone de modélisation et simulation: "Conception, Analyse et Gestion des systèmes industriels" (MOSIM'01)*,Troyes, France.

Cox, D.R, 1972. Regression Model and life-Tables. *Journal of the Royal Statistical Society*,34(2),p.187-220.

Dellagi, S., 2006. *Développement de stratégies de maintenance dans un contexte de sous-traitance partielle de production* . Doctoral Thesis, Metz University, France.

Eckhardt,j., j. Rantalab, 2012. The role of intelligent logistics centers in a multimodal and cost-effective transport system. *Procedia - Social and Behavioral Sciences, Transport Research Arena– Europe 2012* 48 p.612 – 621.

Friesz, T. L., and J. E. Fernandez, 1979. A model of optimal transport maintenance with demand responsiveness. *Transportation Research Part B: Methodological*, *13*(4),p. 317-339.

Gang, Q., W. G., Greenwood., Donglin, L., H. Sharon.,2006. Searching for multiobjective preventive maintenance schedules: Combining preferences with evolutionary algorithms. *European Journal of Operational Research, 177*, p.1969–1984.

Hajej, Z., S, Dellagi , and Rezg, N.,2012. Joint optimization of maintenance and production policies with subcontracting and product returns. *Journal of Intelligent Manufacturing*, p. 1-14.

Iannone,F.,2012. The private and social cost efficiency of port hinterland container distribution through a regional logistics system. *Transportation Research Part A, Volume 46(9)*,p.1424–1448.
Lyonnet, P. ,2000. *La maintenance: mathématiques et méthodes*. Edition Tec et Doc , Paris.

Murthy D. N. P. and D. G. NGUYEN,1981**.** Optimal age-policy with imperfect preventive maintenance. *IEEE Transactions on Reliability*, vol. 30, no 1, p. 80-81.

Nakagawa, T., 1981. A summary of periodic replacement with minimal repair at failure. *Journal of the Operations Research Society of Japan* 24, p. 213–227.

Rezg, N., S. Dellagi, and Chelbi, A., 2008. Joint optimal inventory control and preventive maintenance policy. *International Journal of Production Research*, *46*(19),p. 5349-5365.

Schutz, J.,2009. *Contribution à l'optimisation des plans d'exploitation et de maintenance, selon une approche basée sur le pronostic: Application au domaine naval*. Doctoral Thesis, Lorraine University, France.

Vujanovic´, D., V. Momcilovic', Bojovic, N., V.Papic, 2012. Evaluation of vehicle fleet maintenance management indicators by application of DEMATEL and ANP. *Expert Systems with Applications* 39 p.10552-10563