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OPTIMAL DESIGN OF A LEASED VEHICLE FLEET WITH CONSIDERATION OF MAINTENANCE AND ENVIRONMENTAL CONSTRAINTS

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ABSTRACT: *In this paper, we are interested in designing a fleet of vehicles made of two types (fuel and electric), which will be leased to achieve a set of transportation missions during a maximum period of time. A mathematical model is developed in order to determine the number of vehicles of each type to be leased, the number of months of use of each vehicle and the preventive maintenance period for each one. The objective is to minimize the expected total cost including leasing, operation, preventive and corrective maintenance, and environmental impact. An illustrative example is provided and numerical results are presented and discussed.*

KEYWORDS: *Leasing, logistics, vehicle fleet, maintenance, environmental constraints.*

1 INTRODUCTION AND LITERATURE REVIEWS

This paper deals with the selection of the types and the number of vehicles to be leased by logistics departments to achieve transportation missions. This decision is not an easy one given the diversity of vehicles on the market, each one involving specific parameters such as the type (fuel, electric, or hybrid), reliability, costs related to leasing, operation, maintenance, and environmental impact. Due to significant changes in the environmental impacts legislation, the logistics service providers have to take these incremental changes into account. Consequently, it is important to think about the right choice of transportation means and take them into consideration when designing a logistics network, which provides a comprehensive visibility and control. Logistics costs are usually computed according to the type of means of transport as well as the quantity transported, the distance traveled, and the penalty costs caused by delays. (Benoist et al., 2010) deal with the vehicle routing problem combined with inventory management in order to minimize logistics costs. The authors demonstrated that their model could reduce costs by 20 % compared to what was done by experts in the field of logistics. (Mtalaa et al., 2010) proposed a mathematical model that minimizes the effects of carbon dioxide. They then proposed an alternative model that minimizes the overall economic costs of the supply chain i.e. the direct traditional logistics costs, in closed loop and the costs of reverse logistics.

These costs are considered in the paper as external transport costs. Similarly, (Sawadogo et al., 2010) focused on the integration of environmental and societal impacts in an intermodal transport network. The aim of their work is to determine the most efficient path to minimize transport costs, transport time and the various environmental and societal impacts. The criteria used for decision making are the following: economic cost, transport time, air pollution, energy consumption, noise pollution, damage due to transshipments and risk of accidents. They presented each criterion using a mathematical model. The specificity of this approach lies in allowing the link between the environmental impacts emanating from the means of transport and their estimated costs.

To address the problem of integrating maintenance into transport logistics, (Ben Mechlia et al., 2018) presented a motivational and bibliographic study on the selection of the best transportation means in order to ensure the supply of customers depending on the type of merchandises. Moreover, they presented works that deal the reliability and maintenance strategy for several types of transportation means, while pointing out that little work addressed the integration of maintenance and logistics. Further (Troudi et al., 2015) worked on the influence of road type and the weather conditions on vehicle failure rates. In fact, they sequentially established the optimal number of preventive maintenance actions to be performed on the vehicle as well as the optimal distance to be travelled. Furthermore, (Rezq et al., 2014)

considered one type of vehicle required to carry out a set of tours during a deterministic period. The different circuits to be carried out are characterized by the time required to complete a tour as well as their road types. Each tour generates a process of vehicle degradation, which reduces the profit generated by the tour, which can cause failures where the maintenance cost increases rapidly. They developed a mathematical model that minimizes the cost of transport between different elements of the logistics network, as well as the road cost, and the cost of maintenance actions.

Regarding the choice of vehicles by type, (Turki and Rezg, 2016) studied a manufacturing system with transport activities in urban area. The authors considered two cases for the transportation of the products from the warehouse to the customer. In the first case, the transport is performed by an electric vehicle and in the second case by a fuel vehicle. They presented a model that allows the manufacturer to decide to use fuel or electric vehicle based on transportation, maintenance costs and the cost of carbon penalty. Two simulation algorithms based on discrete events are used for each type of vehicle to compare total costs and then provide a decision. Furthermore, (Prud'homme and Koning, 2015) performed a comparative study between an electric and a fuel vehicle taking into account the negative environmental impacts generated by the vehicles. They have a model to estimate the costs of an electric vehicle, compared to a similar fuel vehicle, as well as the CO₂ emission. These magnitudes are a function of a dozen parameters, such as purchase cost, electrical efficiency, the cost of the battery, the price of electricity, CO₂ content of electricity (for the electric vehicle), the purchase cost, the efficiency and price of fuel, the costs of local pollution, CO₂ emission (for the fuel vehicle), as well as the lifetime of the vehicle and the mileage travelled. The methodology adopted is a comparative study between an electric vehicle and a fuel vehicle providing approximately the same level of service during the same period. It does so from three important points of view: costs to the consumer, socio-economic costs and CO₂ emissions.

Management of vehicles leasing has attracted the attention of several researchers. For example, (Balcik et al., 2015) proved in their study how the UN High Commissioner for Refugees (UNHCR) has successfully improved its vehicle fleet management through the introduction of an Internal Leasing Program (ILP). The authors compared the fleet performance indicators before and after implementation of the (ILP). They indicated that the introduction of the (ILP) has positively impacted the fleet management by reducing procurement costs, fleet size and the average age of the fleet. Thanks to the use of the (ILP), a decrease of the fleet size by 11% has been realized between April 2013 and October 2015.

Dealing electric vehicles leasing, (Miao et al., 2018) proposed a comprehensive pricing for a Chinese electric vehicle lease company in order to optimize the annual operations profit for vehicle lease service based on mileage-based pricing (MBP). The profit introduced by

authors integrated the revenue and the maintenance costs. In order to reach this objective, the authors developed a differential pricing strategy. In addition, an enumerative algorithm is proposed in order to determine the optimal pricing and examine the influence of some parameters on the optimal profit. The authors proved through the use of the differential pricing strategies, a significant increased profit (between 2.3% and 69.8%).

Looking at the literature related to fleet vehicles sizing or comparison between several types of vehicles in logistic problems, the simultaneous consideration of a vehicle fleet size while considering maintenance and environmental impacts in the context of leasing, has not been studied in depth to highlight the strong interaction between these aspects.

The specificity of our study consists in designing a fleet of vehicles made of two types (fuel and electric), which will be leased to achieve a set of transportation missions during a maximum period of time. This is done taking into account the environmental impact, the maintenance of the vehicles and their availability.

The paper is organized as follows. The description of the problem is presented in section 2. In section 3 we provide the mathematical model with the working assumptions and the used notation. In section 4 we propose a numerical example, an analytical result is presented in the same section to understand and ensure the performance of the model developed and solved with MATLAB software. Finally, the last section concludes the paper and gives some perspectives to our work.

2 PROBLEM DESCRIPTION

Generally, deliveries have to be made to customers scattered over a very large area (different cities on a continent) and the vehicles must therefore be available for distribution.

In such situations, breakdowns are likely to occur at any time on the way between two recipients and repairs can last more or less time causing sometimes important delays and consequently significant penalties. Today, the impacts of transportation mean on the environment are well known and include global warming, deterioration of the ozone layer, dispersion of organic and inorganic toxic substances, and the landscapes degradation. In fact, the gaseous emissions are responsible for respiratory diseases, environmental damage and visibility problems, such as the fog. Therefore, to protect the environment, all companies must find solutions to control gas emissions as well as those of other toxic products. In addition, the logistics sector has experienced a significant growth. This growth has been marked by a negative impact on the environment, which has led governments to establish laws and requirements such as the (Kyoto protocol, 1998) and the (ISO 14001, 2015). This standard sets an efficient framework for the company to move towards an environmentally efficient system.

This study focuses on the case of a logistics company that wants to lease a commercial vehicle fleet in order to satisfy a well-defined mission. More precisely, the present study was particularly motivated by the determination of the optimal number of two types of vehicles to lease (fuel and electric), in order to satisfy customers and meet delivery schedules. This objective will be reached by minimizing the expected total cost integrating leasing, operation, environmental impact, and maintenance costs.

3 THE MATHEMATICAL MODEL

3.1 Notation

The following notations are used in the mathematical formulation of the model:

- ✓ T_{Max} : Period during which the mission has to be performed (months)
- ✓ N : Number of vehicle types, with i is considered the type of vehicle $i \in \{1, \dots, N\}$
- ✓ K : The minimum total number of kilometers to be traveled by all types of vehicles (kms)
- ✓ C_{Li} : The leasing cost of a vehicle of type i (cost fixed by the lessor) (m.u/month)
- ✓ C_{Oi} : Operating cost of a vehicle of type i (m.u)
- ✓ C_{Mi} : Expected total maintenance cost for a vehicle of type i (m.u)
- ✓ C_{Ei} : Expected cost of environmental impact for a vehicle of type i (m.u)
- ✓ C_{Mci} : Cost of corrective maintenance action for vehicles of type i (m.u)
- ✓ μ_{ci} : The average duration of a corrective maintenance action for a vehicle of type i (months)
- ✓ C_{MPi} : Expected cost of preventive maintenance (PM) for a vehicle of type i (m.u)
- ✓ μ_{pi} : The average duration of a preventive maintenance for a vehicle of type i (months)
- ✓ v_i : The average usage rate associated with a vehicle of type i (kms/month)
- ✓ T_i : The possession duration of each leased vehicle of type i (months)
- ✓ T_{min} : The minimum period for leasing vehicles of type i (months)
- ✓ $\emptyset(Y_i, m_i)$: The average number of breakdowns (minimal repairs) over a period of use of a vehicle of type i for a given PM period μ_{pi}
- ✓ $\lambda_i(\cdot)$: The failure rate function of a vehicle of type i
- ✓ $\lfloor \cdot \rfloor$: Rounds to the nearest inferior integer
- ✓ $\lceil \cdot \rceil$: Rounds to the nearest superior integer

The decision variables are defined as follows:

- ✓ X_i : Number of vehicles to lease of type i , $i \in \{1, \dots, N\}$, with $X_i \in \mathbb{N}$
- ✓ Y_i : Number of months of use of each leased vehicle of type i , $i \in \{1, \dots, N\}$, with $Y_i \in \mathbb{N}$
- ✓ m_i : Preventive maintenance period to be adopted for a vehicle of type i (months) with $m_i \in \mathbb{N}^*$

3.2 Working assumptions

The following assumptions are considered:

- ✓ Two types of vehicles are considered (fuel and electric vehicles).
- ✓ Each type of vehicle will travel a $(Y_i \cdot v_i)$ number of kilometers.
- ✓ The renter of vehicles will ensure the maintenance of each vehicle.
- ✓ The leasing cost of vehicles depends on the type, agency and duration.
- ✓ The renter is in charge of renewing the batteries

3.3 The objective function and constraints

Our objective consists in minimizing an objective function of cost including the leasing, the operating, the maintenance, and the environmental impact costs according to variable decisions; which are the number of vehicles to lease by type i (X_i), the number of months of use for one leased vehicle of type i (Y_i) and the periodicity of a preventive maintenance action associated to the leased vehicle (m_i) in order to ensure K kilometers during a specified period (T_{max}) with a fixed mean usage rate (v_i) for each type. We start by developing analytically the objective function which will be optimized in order to determine the optimal decision variables. We also presented the constraints which will be respected.

The expected total costs are as follows:

$$\min \sum_{i=1}^N X_i \cdot (C_{Li} \cdot T_i + C_{Oi} + C_{Mi} + C_{Ei}) \quad (1)$$

3.3.1 Detailed constraints

The constraints of the objective function are defined as follows:

$$\sum_{i=1}^N X_i \cdot Y_i \cdot v_i \geq K \quad (2)$$

$$T_i \leq T_{max} \quad \forall i = 1, \dots, N \quad (3)$$

$$T_i \geq T_{min} \quad \forall i = 1, \dots, N \quad (4)$$

$$Y_i \leq \lceil \lambda_i \rceil \cdot \min \left(T_{max}, \frac{K}{v_i} \right) \quad \forall i = 1, \dots, N \quad (5)$$

We recall that the objective function (1) minimizes the sum of leasing, operating, maintenance and environmental impact costs; whereas, constraint (2) ensures that the number of kilometers traveled by the all vehicles must be greater than or equal to the minimum total number of kilometers (K) to be traveled by all types of vehicles. Constraint (3) ensures that the possession duration of each vehicle of type i (T_i) is shorter than or equal to the period during which the missions have to be performed (T_{max}). Constraint (4) denotes that the possession duration of leased vehicles of type i (T_i) must

be greater than or equal to the minimum period for leasing vehicles of type i (T_{min}). This constraint ensures the long-term lease of vehicles as well as a minimum leasing cost. Constraint (5) ensures that the number of months of use for one leased vehicle of type i (Y_i), will be 0 if no vehicle of this type is leased.

3.3.2 The leasing cost

The leasing cost represents an important parameter in our work. It is obtained by the product of the unit leasing cost (proposed by the lessor) and the possession duration of each leased vehicle of type i (C_{Li}, T_i). In fact, (T_i) includes the number of months of use of each leased vehicle of type i (Y_i) and the average duration of all corrective and preventive maintenance actions performed on the vehicles. It is expressed as follows:

$$T_i = \left[Y_i \cdot \phi(Y_i, m_i) \cdot \mu_{ci} + \left\lfloor \frac{Y_i}{m_i} \right\rfloor \cdot \mu_{pi} \right] \quad (6)$$

Moreover, we consider in our study two types of vehicles to lease (fuel ($i = 1$) and electric vehicle ($i = 2$)). Therefore, the leasing cost is different between the two types.

We consider that the leasing cost of vehicles depends on the type of the vehicle, the leasing agency and the lease duration. It is negotiable. Based on data from rental agencies, we propose in Table 2 the leasing costs of vehicle for each type i . Indeed, these costs are proposals for a long leasing duration and they do not include the operating, maintenance and environmental impact.

3.3.3 The expected maintenance cost

We adopt a strategy of an imperfect periodic preventive maintenance with minimal repair at failures; known in the literature (Gertsbakh 2000) and used by (Gouiaa-mtibaa et al., 2018). More precisely a PM action is performed for vehicles of type i after each m_i kilometers. The model assumes that, after each PM action, the failure rate is decreased to a certain extent and the failure rate function is then increased by a certain coefficient that can be determined empirically. Minimal repairs take place whenever failures are detected between PM actions to restore the system into the operating state without changing its failure rate function.

In our work, the number of PM actions is the ratio of the number of months of use of each leased vehicle of type i (Y_i) and the periodicity of a PM action associated to the leased vehicle of type i ; $\left\lfloor \frac{Y_i}{m_i} \right\rfloor$.

Adapting the model proposed by (Gertsbakh 2000) to our study, the average number of breakdowns (minimal repairs) $\phi(Y_i, m_i)$ is expressed in the following way:

$$\phi(Y_i, m_i) = \sum_{j=1}^{\left\lfloor \frac{Y_i}{m_i} \right\rfloor} \int_0^{m_i} e^{(j-1)\alpha} \cdot \lambda_i(x) dx + \int_0^{Y_i - \left\lfloor \frac{Y_i}{m_i} \right\rfloor m_i} e^{\frac{Y_i}{m_i} \cdot \alpha} \cdot \lambda_i(x) dx \quad (7)$$

It is easy to see in equation (7), that PM actions induce a reduction in the failure rate. However, the average number of breakdowns is increased, between PM actions, by a “degradation” factor (e^α) where α represents a positive parameter to be determined empirically.

The total maintenance cost is expressed in the following way:

$$C_{Mi} = C_{Mci} \cdot \phi(Y_i, m_i) + C_{Mpi} \cdot \left\lfloor \frac{Y_i}{m_i} \right\rfloor \quad (8)$$

3.3.4 The expected operating cost

The operating cost is obtained according to the use of leased vehicles of type i during their operation duration. We refer to the literature in order to formulate the operating cost for each type:

Fuel type. The fuel vehicle is characterized by its fuel efficiency, which is the number of kilometers driven per unit of fuel consumed (km/liter). Efficiency and productivity are generally defined as an (output/input) ratio and increases in productivity or efficiency are considered desirable. This is in conflict with the European standards of measuring the performance of a fuel vehicle in liter/100 km or in kWh/100 km for electric vehicle (but not with the US standards of measuring it in miles/gallon). Based on the formulation developed by (Prud'homme and Koning, 2012), the efficiency is therefore considered as the inverse of the definition commonly used in Europe. The following equation (9) presents the operating cost for fuel vehicle ($i = 1$):

$$C_{O1} = C_{u_diesel} \cdot \left(\frac{Y_1 \cdot v_1}{eff_1} \right) \quad (9)$$

With :

- ✓ C_{u_diesel} : Unit cost of fuel (m.u/liter)
- ✓ Y_1 : Number of months of use of each leased fuel vehicle (months)
- ✓ v_1 : the usage rate associated to the leased fuel vehicle (kms/months)
- ✓ eff_1 : Fuel efficiency (km/liter)

Electric type. The operating of an electric vehicle is characterized by the electric consumption (the recharge cost and the battery autonomy).

Usually, the driver of this vehicle must lease a battery or buy a new battery just at the end of its service life. Thus, the lessor of this vehicle type supports of the battery leasing or purchase. The user pays only the leasing cost. Therefore, we have developed the operating cost of electric vehicle.

The following equation (10) presents the operating cost for electric vehicle ($i = 2$):

$$C_{O2} = C_{ch} \cdot \left[\frac{Y_2 \cdot v_2}{\theta} \right] + c_{unit} \cdot \left[\frac{Y_2 \cdot v_2}{\theta \cdot Nb_{MaxCh}} \right] \quad (10)$$

With:

- ✓ C_{ch} : The unit cost of a battery recharging (m.u)
- ✓ Y_2 : Number of months of use for one leased electric vehicle (months)
- ✓ v_2 : The usage rate associated to the leased electric vehicle (kms/month)
- ✓ θ : The battery autonomy (kms)
- ✓ c_{unit} : The unit cost of a battery for an electric vehicle (m.u)
- ✓ Nb_{MaxCh} : The maximum number of recharging

3.3.5 The expected environmental impact cost

We consider the emission of CO₂ is an important factor in the proper use of vehicles and the respect of environment, therefore a mathematical model on the cost of CO₂ emission is considered in our objective function as essential negative environmental impact. Based on the work of (Prud'homme and Koning, 2012), we propose the following equation that represents the cost of impact environmental calculated from the quantity of CO₂ emitted by the vehicle of type i multiplied by its unit cost. In fact, the unit cost of CO₂ is not the same in the world but can change between countries. Therefore, we used in our work the unit cost defined in the work of (Ba et al., 2016).

The impact environmental costs are given by:

$$C_{Ei} = CU_{CO2} \cdot Y_i \cdot v_i \cdot g_i \cdot \left(\frac{1}{eff_i} \right) \quad (11)$$

With:

- ✓ CU_{CO2} : The unit cost of CO₂ (m.u/kg)
- ✓ Y_i : Number of months of use for one leased vehicle of type i
- ✓ v_i : The usage rate associated to the vehicle of type i (kms/month)
- ✓ g_i : CO₂ emission in (kg/liter) for fuel vehicle ($i = 1$) and in (kg/kWh) for electric vehicle ($i = 2$)
- ✓ eff_i : The energetic efficiency (number of kilometers traveled per liter for fuel type (km/liter) or per kilowatt-hour for electric type (km/kWh))

4 NUMERICAL EXAMPLE

We conducted many computational experiments using the numerical resolution with MATLAB software (Version 2019a). We present in this section an illustrative example and show the obtained results.

4.1 Experiments input

For our numerical example, we used the values given in the following Tables 1 and 2.

Parameters	Numerical input data
K (kms)	10 000 000
T_{max} (months)	60
T_{min} (months)	24
CU_{CO2} (m.u/kg)	0.05
α	1.05

Table 1: Numerical input data

	Fuel vehicle (i=1)	Electric vehicle (i=2)
C_{li} (m.u/month)	250	260
C_{Mci} (m.u)	250	300
C_{Mpi} (m.u)	60	80
v_i (kms/month)	16 800	16 800
eff_i (kms/liter)	20	5
C_{u_diesel} (m.u/liter)	1.5	-
g_1 (kg/liter)	2.6	-
g_2 (kg/kWh)	0.09	-
C_{ch} (m.u)	12.50	-
c_{unit} (m.u)	-	6000
Nb_{MaxCh}	-	2000
θ (kms)	-	160

Table 2: Numerical input data for fuel and electric vehicle

Table 2 shows the input parameters used by type of vehicle (fuel and electric). In our study, we suppose to realize at least K kilometers with a same usage rate associated with each vehicle of type i (v_i) during 60 months (T_{max}). During this period, the missions have to be performed while obviously taking into account the environmental impact for which the nuisance caused by 1 kg of CO₂ emitted into the air is estimated to 0.05 m.u/kg by (Ba et al., 2016).

Point of view reliability, we assume that the type of vehicle has an increased failure rate following Weibull distribution with (shape parameter = 2) and (scale parameter = 25) for fuel vehicle and (scale parameter = 30) for electric vehicle. The durations of maintenance actions follow an exponential distribution with an average of 1 day for repairs (μ_{ci}) and a mean of 0.5 day for PM (μ_{pi}), regardless of vehicle type.

Regarding the energetic efficiency and the CO₂ emissions, we use the same parameters used by (Prud'homme and Koning, 2012).

4.2 Obtained results

Based on data from Tables 1 and 2, the numerical resolution of our problem provided the results shown in Table 3.

We recall that the decision variables (X_i), (Y_i) and (m_i) represent respectively the total number of vehicles of type i to lease, the number of months of use of each leased vehicle, the PM-period to be adopted for a vehicle of type i .

	Fuel vehicle ($i=1$)	Electric vehicle ($i=2$)
X_i	6	5
Y_i	52	57
m_i	14	15

Table 3: The obtained results

The obtained results show that it is recommended to lease 6 fuel vehicles and 5 electric vehicles. The fuel vehicles will be used for 52 months, each one of them is expected to travel a total distance of ($Y_1 \cdot v_1$) (873 600 kms) and be submitted to PM every 14 months. The electric vehicles will be used 57 months, each one of them is expected to travel a total distance of ($Y_2 \cdot v_2$) (957 600 kms) with a PM period of 15 months.

5 CONCLUSIONS AND PROSPECTS

In this paper, we considered optimizing the typology and size of a vehicle fleet to be leased for a given maximum period of time taking into account maintenance and environmental constraints. Two types of leased vehicles (fuel and electric) were considered. The decision variables are the number of vehicles to lease, the number of months of use of each vehicle and the periodicity of preventive maintenance actions to be performed on each vehicle. The derived solution must satisfy the fact that at least K kilometers must be travelled during a specified period (T_{max}) with an average usage rate (vi).

A mathematical cost minimization model has been developed. Furthermore, the problem is then solved using MATLAB language. A numerical experimentation has been performed and the obtained results have been analysed.

The average usage rate of every type of vehicles has been considered as constant and predefined. As an extension of this work, it is worth to consider it as an additional decision variable. In fact, the combination between the number of vehicles and the average usage rate for every type of vehicle impacts maintenance cost and environmental costs.

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