



# Development Methodology to Share Vehicles Optimizing the Variability of the Mileage

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**Abstract.** A simulation is a tool used to visualize the behaviors of a system, which will later help make decisions regarding how to handle the variables involved in the system, as well as the specific changes that have to be made. This study shows a case of vehicle allocation for different people within a company, evaluating methodologies, vehicle rotation to reduce the variance of the mileage and eliminating penalties with rental agencies for exceeding the permitted mileage. The paper shows a literature review of allocation models and similar studies, and later displays a detailed description of the problem, the variables that was used, the composition of the simulation and the optimization model that were generated, the results of the simulation, and finally, the findings of the research.

**Keywords:** Simulation · Optimization · Assignment problem · Vehicle share · Mileage limit

## 1 Introduction

Assigning issues that occur in everyday situations, not knowing who is responsible for said issues, and ignoring a methodology where a decision was lightly taken and without an in-depth analysis may represent direct or indirect losses (missed opportunities), that later could have been converted into profits. Situations where contractors were assigned to projects, machine workers, and sales agent districts, among others, demand the making of a good decision, which is not always a simple one because of the various factors it must consider. Regarding vehicles, the focus of transportation planning has gradually shifted to infrastructural change, to improve the management of the existing one [1]. When the company has a transport fleet, the problem relies on knowing how to keep vehicles in certain mileages before the implied warranty expires. If the size of the fleet increases, data monitoring and collection become more operators that are problematic, especially if different are assigned the responsibility of driving the same vehicle [2].

This paper shows the development of a methodology to find the perfect moment to make a rotation of the vehicles, that was assigned by a company to specific regions and employers, was design using simulation and optimization techniques in order to optimize the efficiency in that time and at the same time reduce the variance of the mileage of all the vehicles and minimizing penalties for exceeding the mileage allowed by car.

## 2 Literature Review

The problem of allocation has become a focus of research papers in different scenarios. The idea is to act in the best way in every process where there are decisions to be made [3]. Provide a systematic review of selected publications that offer method-based solutions to the vehicle relocation issues in car-sharing networks. Part of the planning process, especially the process of managing your assets is related to creating the best possible configuration [4] and finding the best solution that comes close to reality [4]. In what regards the transportation issues, researches base their analysis on deciding who will lead an activity, proposing routes, points of entry and exit. In the history of research, [5] investigated the reasons behind traffic situation, government rules and optimal working hours in the rail system that allow the designing of a discrete simulation model to allocate equipment and its movements. The model allowed them to verify the impact of the changes that occur in the flow of trains, work rules and government regulations on the overall operational efficiency. The system helps evaluate changes to the current crew and allows them to test different allocation scenarios related to work schedules.

The platform used for the simulation was Trainsim; said the platform provides a replica of the allocation of the task force as a function of time and operational parameters, thus achieving a close prediction of the results of an assignment of the teamwork based on historical data. The information obtained can answer questions like “what if?” made in the simulation. Model inputs that determine system performance are variable. These inputs are:

- a) Traffic on trains.
- b) Regulations of the staff and costs associated.
- c) Allocation scenarios including team schedules.

During the simulation, Trainsim reproduces the process of assigning working trains to teams based on traffic conditions. As a result, the output of the simulation model allowed us to acknowledge the total costs needed to operate under the rules set for work teams in different schedules [3]. Another common scenario where you can apply the assignment problem is the project-related scenario. This occurs in situations where several projects and decisions that must be made, regarding who the leader of each of the situations will be. This is of vital importance in project management. According to research done by [7], this problem has been named “Expert Assignment Problem”. The authors formulated a mathematical model for this problem using genetic algorithms; however, there have been drawbacks in convergence rates when utilizing these algorithms.

For the former case, we propose to use optimization through the *ant colony algorithm*, which has greater abilities to solve such complex problems of discrete optimization and to solve the “Expert Assignment Problem” as well. In such problems, they had to consider three main criteria:

- a) Should we assign a senior academic leader for each project?
- b) The fewer the leaders, the better the draft allocation plan.
- c) The number of projects that should be checked by every leader needs to be moderate.

Given these criteria, the mathematical model for the problem was formulated using a heuristic ant colony optimization, applied to meet the needs of the model and to perform the allocation of project leaders. This procedure resulted in making the model more efficient and, unlike genetic algorithms, in improving the convergence speed by finding the best solutions [4].

Another scenario where the assignment problem is the focus of the investigation is in a logistics park. An example is the Lianyungang Port Logistics Park, where the forecast traffic volume and traffic assignment are the focus of research by [9]. To forecast the volume, we implemented a TVNC method (for its acronym in English that stands for “Non-repeated Traffic Volume Method”). To assign traffic, we considered theoretical foundation-related models in equilibrium and disequilibrium models. In this research, a model was handled in balance for its effectiveness; the said model is known as System Optimum Assignment Model. Experimental study results made the logistics park more effective, which is reflected in significant social and economic benefits [9]. In a research conducted by [10], they developed a transport model frequently used to solve problems of physical distribution and location, which applies to typical situations, such as resource allocation, scheduling of vehicles, specialized cooperation and redistribution of the plant. However, the transport model had three disadvantages:

- a) The ways to balance production - market and transportation costs are presented separately, which is a drawback for worktables.
- b) Figures and tables are listed separately. This represents a problem for the calculation of different values.
- c) Minimize the generation of Hamilton Circles.

These authors present some methods to overcome these drawbacks and a case study of the transport model applying the proposed methods [10].

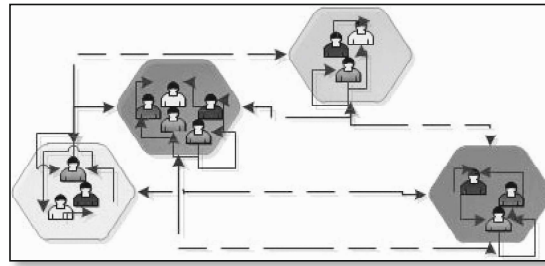
Problems that have involved railways were researched by [10], who used a method that is the basis of the DAI (Distributed Artificial Intelligence), which is used for mapping the flow of passengers on railways and evaluating its performance through simulation. Passenger flow assignment is a key resource in the location, design, and scheduling of service vehicles, in this case, trains. In this study, the model of linear planning is considered for this method and is found distorted, due to the behavior of the passengers. This model seems to work in theory but not in practice. Therefore, the authors present the following method: The allocation of passenger flow, based on competition, cooperation and allocation of passenger flow through the decision making with multi-agents [7].

Airports are also environments where the allocation problem can happen in various ways. One is applied to the gate, which allows assigning an entry for arrivals and departures of flights to ensure that they are under the established schedules. In research conducted by [11], the approach was to allocate those gates, which are key to ensuring the efficiency of airports, with high rotation flights. This problem of assigning gates can be represented as a complex optimization problem. The study proposes a model of robust allocation to minimize the variability of productive time. According to the intrinsic characteristics of the formulated objective function, the authors implemented a search algorithm called TABU (Tabu Search Algorithm) and a meta-heuristic to solve the problem of gate assigning [8]. Furthermore, car-sharing services and analysis have become much more relevant in these times due to their environmental contribution and sustainable way of transportation [12]. Analyzed and classified 137 papers, covering the last fifteen years of research and deriving an insight of all the mainstream in this topic.

### 3 Problem Description

As has been mentioned by many authors, the projection of a good mobility system will be contemplating the key drivers like lower costs and lower environmental costs [11]. In this specific case, a company dedicated to providing services gives its employees a car to move to different places, depending on their role in the company; Technical, commercial, and managerial areas, among many others. After a period has passed, the distance traveled by the vehicles always varied greatly according to the position and the region where the employee was located. The company, who rents the vehicles, often had to pay large fines because some of the rented vehicles ran more mileage than what was agreed to, while others did not reach half of this value. The main propose is to rotate vehicles that use a higher amount of mileage with those that run below the established limit to obtain less of used average by vehicle. The distance traveled by each employee does not vary, the work area where they mobilize is the same, and however, depending on the velocity the time behaves like a random variable. Many companies that handle this type of rental systems incur in extra costs because users exceed the allowed mileage limit, and that results in renting a second vehicle for the person or extending the contract, while others stay within the mileage allowed in the stipulated time.

The problem lies in finding the ideal point in time for rotations, giving all the possible permutations that can be done, taking both the proximity of vehicles and the traveled mileage into consideration. In Fig. 1, a problem statement is observed for groups of cities; internal rotation, including a maximum and estimated rotations that the vehicle may have per period. Focusing on the company, in this case, helps maximize the utilization of vehicles and tries to reduce the use of GAP vehicles, decreasing unnecessary costs caused by penalties for exceeding the mileage, and delivering a continuous performance in the fleet car. This model contemplates that decide on the best option from a financial performance viewpoint, there may be overriding practical limitations, which dictate the ultimate choices made [12].



**Fig. 1.** Possible vehicle rotations.

## 4 Model Description

Considering all the variables that have an impact on decision making, the required data for the development of the model was collected and analyzed. Based on the employee's position and geographical location, the traveled mileage was analyzed as the main variable. According to this situation, the development of a dynamic model that combines simulation and optimization is necessary, where the best options will be found to optimize the time and distance traveled by car and therefore, we will be able to correct the rotation of the vehicles according to the proportion of distance traveled.

To estimate the parameters of the model was recognized that each employee could change the vehicle that they have a disposal that they can be managed as an entity at the simulation model. Was assign certain characteristics (attributes) to each of the employees or entities like position, location in the country and/or region where they are, and the random variable associated with the distance. This last parameter is considered, due to the stochastic nature of the collected data. For the calculation of the type of distribution and the values of the associated statistical parameters, according to the employee and the region, a test of goodness of fit and independence was used.

In the model this different sets and variables were considered:

### Sets:

- $i$ : a set of short periods to analyze
- $j$ : a set of vehicles available
- $x$ : a set of employers

### Variables:

- $D_{ij}$ : represents the cumulative distance traveled by vehicle  $j$  in time  $i$
- $Vkm(i)$ : variance of the total traveled by all vehicles in time  $i$

### Parameters

- $M(x)$ : represents the distance traveled by the employer in a period

To simulate the process, the methodology applied in Fig. 2 was developed. First, each vehicle  $j$  is assigned an employee  $x$  by default and the  $D_{ij}$  measurements are assigned the value of  $M(x)$ , when the time is over, the mileage attributes of each

vehicle are updated, considering that car temporally ownership is an important determinant of car usage, general travel behavior, and energy consumption [13].

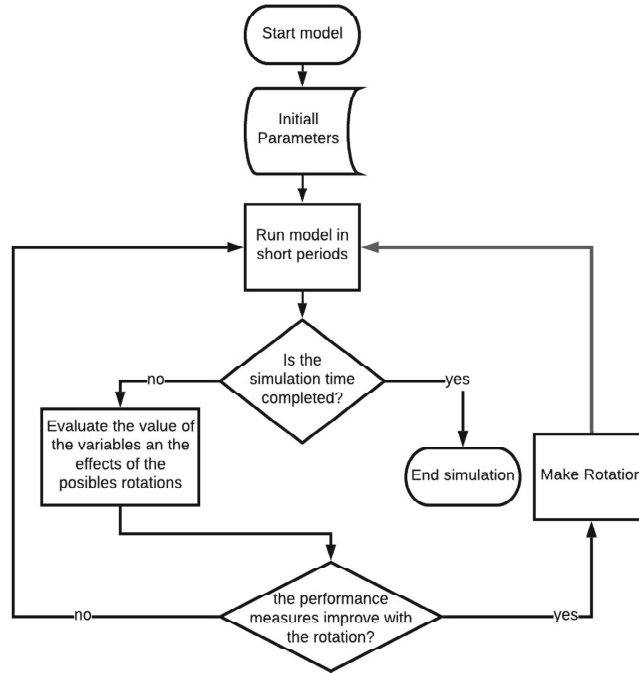


Fig. 2. Model description

To perform the exchange at  $D_{ij}$ , the vehicles are sorted from “low to high” according to their current mileage. The situation is evaluated if a change is necessary. To do this, we take into consideration the generated exchange zones and exchange pairs, which are those who are geographically closer to each other and at the same time can compensate the traveled mileage (Fig. 4). This is done to reduce the average mileage of vehicles (Fig. 3).

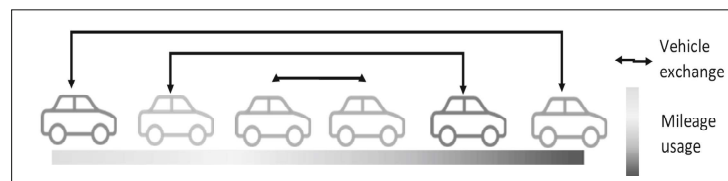


Fig. 3. Vehicle rotation logic

When the evaluation of changes is made, the model analyzes the variable ( $Vkm(i)$ ) as an objective function to measure the difference between the vehicle's trajectory and the total average trajectory or the variance of the distance of all vehicles.

$$Vkm(i) = \frac{\sum_j (D_{ij} - \bar{D}_{ij})}{j} \quad (1)$$

The main idea is to minimize this difference to reduce the variance. In such a case that a vehicle is changed with another that is very far away from the location where it is supposed to be working, a mileage corresponding penalty incurred as a consequence of the switching process from the current area to the one assigned on time  $D_{i+1,j}$ . Once the changes are made, the entity goes to the step to have delays and this procedure repeats while the total time to be analyzed is completed.

## 5 Model Results

To validate the methodology, a 24-month history of data from a local company was worked, in which data analysis was carried out to determine the behavior of the data for each of the employees  $x$  and to know through goodness-of-fit tests how was the probability function for the mileage traveled in a short time  $I$ . Once the data was processed, a simulation model was designed using the Arena 10.0 software to emulate the current and proposed situation. With this model, three scenarios were evaluated; in the first scenario, we recreated a model that represented the current situation to validate and compare the results obtained by the program with the real data analyzed. A second scenario was created with the proposed improvements with the new methodology without including the rotations of vehicles between cities and the tired model was design including an exchange between different cities.

Models 2 and 3 were created by adding an optimization model to determine the number of suitable changes to minimize the variation of the accumulated distances and handle asymmetry between them, all this under the following structure;

$$\begin{aligned} &\text{Minimize Max}[Vkm(1), Vkm(2), \dots, Vkm(i)] \\ &\text{Subject to : } 1 \leq i \leq 12 \end{aligned}$$

The model input information, as well as the final results, were validated through data analysis through sample sizes, their length and ideal run numbers, and hypothesis tests. With the first scenario, it was possible to validate the simulation model and with scanners 2 and 3, the best results were analyzed. Once the different scenarios were run, an improvement of more than 20% was obtained in the leveling of the used vehicles was evident, which has a positive direct and impact on the company's achievements, since by improving the use of these resources, the penalization imposed by exceeding the mileage of the vehicles are considerably reduced.

In Fig. 4, we can see some previous penalized for exceeding the mileage admitted in each one of the three cities analyzed, with the implementation of the new proven

methodology through the simulation model, all these penalties disappear, since by minimizing the variance of the time traveled, the vehicles are used more in relation to the average mileage.

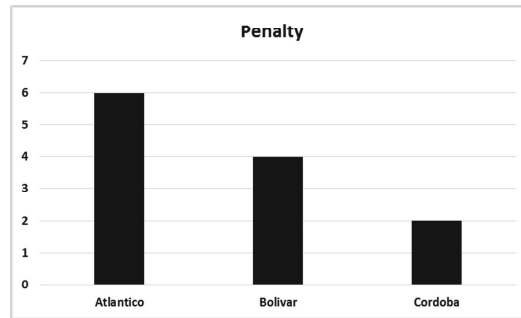


Fig. 4. Number of previous penalties by location

With respect to vehicle mileage, we can see that plans to share vehicles among employees reduce the variation in the average mileage used throughout the system. Figure 5 shows the result comparing the variations between the three cities analyzed. The line in bold shows the results under normal conditions and with the dotted line the results are shown applying the methodology. With the results obtained, the total amplitude of the mileage traveled by the vehicles by zone (the difference between the vehicles that had more use with the one that was used less) was reduced by 28% compared to the range that they currently drive, also, vehicles with less use increase their use by 55%, while those with more use reduce their activity by 44%, which balances their mileage. Also, in this case, analyzed in particular and due to the large distances between the cities, there were no differences between the results obtained between scenarios 2 and 3.

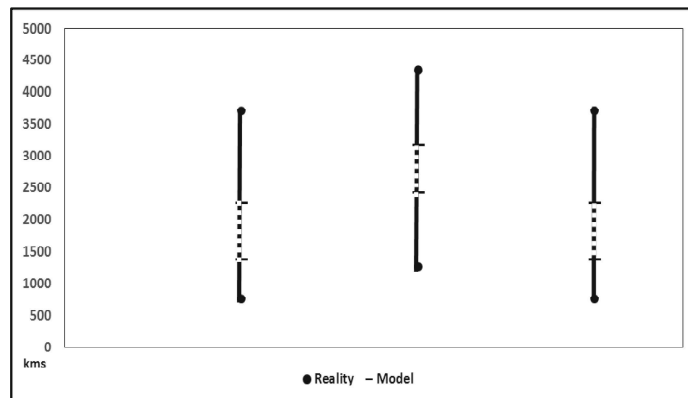


Fig. 5. Min and max distance drove before and after the optimization

## 6 Conclusions

To determine the best plan of action, a problem should be, in many cases, analyzed as a complete system, this approach allows comparisons between different cases. The lack of communication between those responsible for the process allowed these possibilities for improvement to go unnoticed.

The results show that an option that could go unnoticed can sometimes increase the productivity of a sector. In this particular case, it was possible to achieve measurable improvements of more than 20% in the use of vehicles and penalty reductions which has a significant impact on the company's finances and helps improve the environment. Because of this investigation, we can highlight the importance of linking simulation and optimization methods to evaluate, validate and improve the decision-making process.

Additionally, in the work was possible to develop a model that can predict the consequences of a specific decision, allowing companies to see that changes are not always necessary if the decision-making processes work well. Our research has some limitations, as we were not able to measure the financial and environmental advantages of the changes in the proposed method, the reason why we recommend that further analysis should be undertaken in those areas.

## References

1. Sundaram, S., Koutsopoulos, H.N., Ben-Akiva, M., Antoniou, C., Balakrishna, R.: Simulation-based dynamic traffic assignment for short-term planning applications. *Simul. Model. Pract. Theory* **19**(1), 450–462 (2011)
2. Lawrence, K.R., Tunke, J.A.: Analysis and profiling of vehicle fleet data. United States Patent 6505106 (1999)
3. Illgen, S., Höck, M.: Literature review of the vehicle relocation problem in one-way car sharing networks. *Transp. Res. Part B: Methodol.* **193**(204), 120 (2019)
4. Herazo-Padilla, N., Montoya-Torres, J., Muñoz-V, A., Nieto Isaza, S., Ramírez Polo, L.: Coupling ant colony optimization and discrete-event simulation to solve a stochastic location-routing problem. In *Proceedings of the 2013 Winter Simulation Conference: Simulation: Making Decisions in a Complex World*, pp. 3352–3362, 2013
5. Ramírez Polo, L., Mendoza, F., Jimenez, M.: Simulation model to find the slack time for schedule of the transit operations in off-peak time on the main terminal of massive transport system. *Espacios* **38**(13), 1 (2017)
6. Guttkuhn, R., Dawson, T., Trutschel, U., Walker, J., Moroz, M.: Simulation planning and rostering: a discrete event simulation for the crew assignment process in north american freight railroads. In: *Proceedings of the 35th Conference on Winter Simulation: Driving Innovation* (2003)
7. Guttkuhn, R., Dawson, T., Trutschel, U., Walker, J., Moroz, M.: A discrete event simulation for the crew assignment process in North American freight railroads. In: *Winter Simulation Conference, Washington, D.C* (2013)
8. Li, N., Zhao, Z., Gu, J., Liu, B.: Ant colony optimization algorithm for expert assignment problem. In: *Proceedings of the Seventh International Conference on Machine Learning and Cybernetics, Kuming* (2008)

9. Xie, H., Ji, S., Shen, J., Han, X.: Research on traffic volume forecast and assignment of logistics park. In: 2008 IEEE, Vancouver, WA (2008)
10. Donghua, W., Xue, L.: A study on transportation problem model. In: International Conference on Management and Service Science, Wuhan (2009)
11. Jiang, X., Bao, Y.: A DAI-based method for rail traffic passenger flow assignment and simulation. In: International Conference on Artificial Intelligence and Computational Intelligence (2010)
12. Zheng, P., Hu, C., Zhang, C.: Airport gate assignments model and algorithm. In: International Conference on Artificial Intelligence and Computational Intelligence, Sanya, China (2010)
13. Ferrero, F., Perboli, G., Rosano, M., Vesco, A.: Car-sharing services: an annotated review. *Sustain. Cities Soc.* **37**, 501–518 (2018)
14. Hamilton, A., Waterson, B., Cherrett, T., Robinson, A., Snell, I.: The evolution of urban traffic control: changing policy and technology. *Transp. Plann. Technol.* **36**(1), 24–43 (2013)
15. Wright, S.: Designing flexible transport services: guidelines for choosing the vehicle type. *Transp. Plann. Technol.* **36**(1), 76–92 (2013)
16. Tanishita, M.: Life events, car transaction, and usage by car type: longitudinal data from Japan. *J. Traffic Transp. Eng.* **6**, 88–96 (2018)