Optimal Green Fleet Composition Using Machine Learning

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Summary:

This research focused on formulating an optimal fleet replacement policy that considers on costs as well as sustainability in terms of CO_2 emissions. We used machine learning algorithms to analyze vehicles' performance and examined their CO_2 emissions for varying route and load conditions. We used these insights to build an optimization model. By running different scenarios on our test case fleet, we observed 700,000 $KgCO_2$ drop in emissions for approximately 37000 USD of the increase in overall fleet costs. This increase was marginal compared to the cost benefits realized by optimal fleet replacement policy over the baseline scenario.

Before coming to MIT, Vrushali worked in the Supply Chain Center of Excellence in Accenture for 12 years. She implemented supply chain planning solutions (SAP APO and Kinaxis RR) for Accenture's clients across industry sectors and geographies. She holds a BEng from University of Pune.

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KEY INSIGHTS

1. We propose a framework for companies to manage their fleets in cost efficient and sustainable ways.
2. Our two-pronged approach includes a fleet replacement optimization model and identification of vehicle characteristics that play important role in CO_2 emissions.
3. Brand and age play an important role in the CO_2 emissions performance of the vehicles

INTRODUCTION

"From shifting weather patterns that threaten food production, to rising sea levels that increase the risk of catastrophic flooding, the impacts of climate change are global in scope and unprecedented in scale. Without drastic action today, adapting to these impacts in the future will be more difficult and costlier." UN IPCC Fifth Climate Report, 2014. The latest UN climate report mentions that reducing environmental impact is no longer a choice. Greenhouse gas emissions (GHGs) are the main drivers of climate change. CO_2 contributes the largest portion to the greenhouse effect and transport sector is one of the two principal contributors of global CO_2 emissions and GHG emissions from this sector may double by 2050. As a result, companies are looking into sustainable as well as cost-efficient delivery fleets.

To achieve a cost-efficient and sustainable delivery, companies need to develop effective fleet replacement policies. A fleet replacement problem becomes more complex when it must factor in diverse operating conditions of delivery vehicles. This diversity comes from different road conditions in which vehicles must operate and the types of load they have to carry.

In both research and industry environments, the focus of vehicle replacement policies has been centered on operating and capital expenditures. While fuel consumption is a key factor in these replacement policies, it is usually looked at through the prism of costs only, neglecting the resulting CO_2 emissions. These replacement policies often focus on life-cycle analysis of each vehicle in isolation and lack the holistic approach of considering the overall fleet. In our research, we studied CO_2 emissions in the fleet replacement problem.

METHODOLOGY

We used two-pronged approach in this research. In the first part, we analyzed the relationship between vehicle characteristics and average CO_2 emissions of each vehicle. We performed this analysis for all vehicles in each route cluster-load bin combination. By analyzing vehicles within the same route cluster and load bin, we isolated the effects of vehicle characteristics while assessing CO_2 emissions. We considered following vehicle characteristics in this analysis: Brand, engine type, age, mileage, maintenance costs in last year.

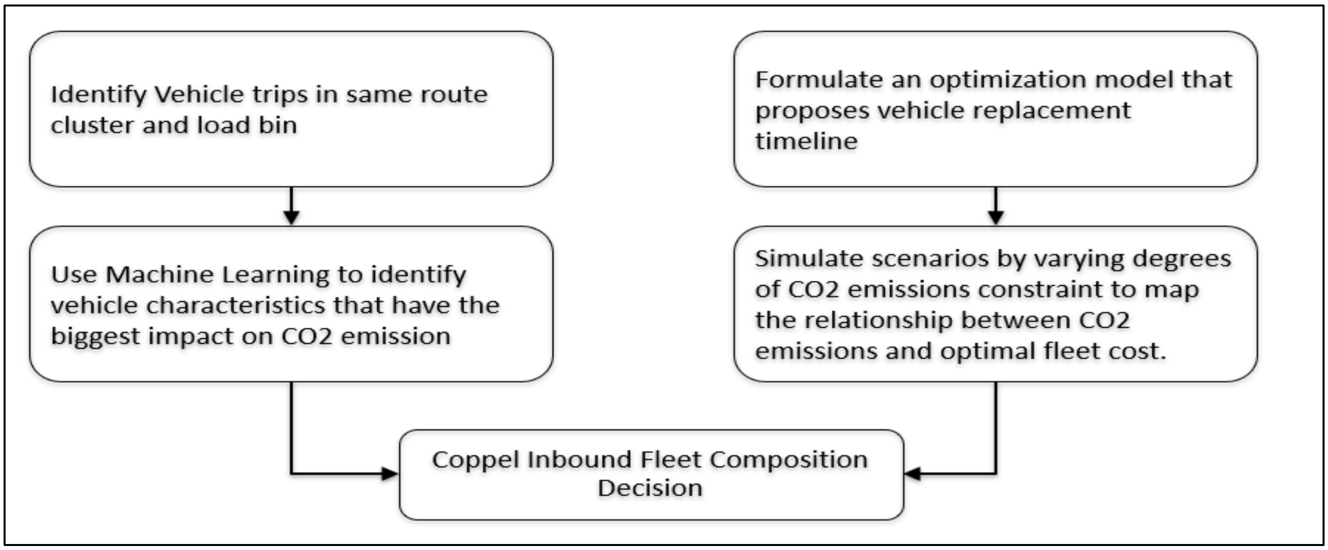

Figure 1: Methodology Overview

Using supervised machine learning technique on the historical data, we developed a vehicle classification algorithm. As CART is a greedy algorithm, first few splits in the tree are considered as the most important characteristics that influence the outcome variable (CO_2 emissions).

In the second part of the research, we developed an optimization model to minimize the costs of the overall fleet. This model proposed the number of vehicles to be replaced every year. It used the purchase price for new vehicles, depreciation rates, resale value, and operating costs (fuel consumption and maintenance costs) and was constrained by demand for total number of vehicles in the fleet, upper and lower limit on a number of vehicles that can be replaced every year. Though fuel consumption costs (which is a proxy for CO_2 emissions) was part of the above model, the model objective was not to explicitly minimize CO_2 emissions but to reduce overall fleet cost. We incorporated the additional constraint of 'maximum total fleet CO_2 emissions' in this model that forced the model to consider CO_2 emissions as a key focus area rather than just as one of many costs.

We ran multiple simulations of this model by varying 'maximum total fleet CO_2 emissions' and observed its effect on total cost as well as on the number of vehicles to be replaced every year. We plotted the relationship between total cost and total CO2 emissions.

RESULTS

We analyzed the vehicles trips in different data subsets with same route cluster and load bin. We ran a classification tree algorithm with CO_2 emissions as a target label. As seen in figure 2 below, the first split of the tree is on the "age" feature, this implied that this is the most informative characteristic influencing CO_2 emissions. We analyzed multiple data subsets in exactly same way. In some datasets,

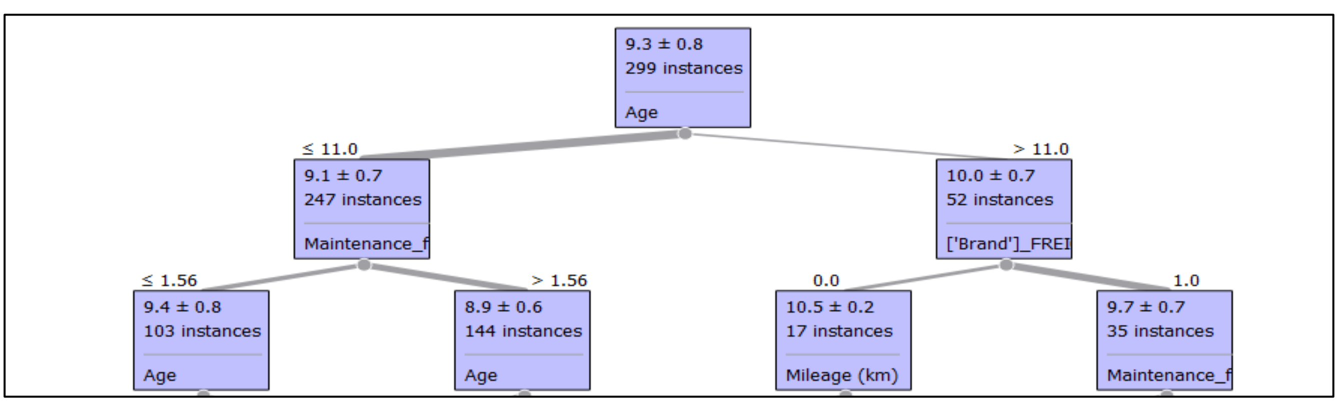

Figure 2: Characteristics impacting CO_2 emissions

brand came out as the most informative characteristics. But in these datasets, brand and age were highly correlated. Hence, we concluded that age and brand are the most informative characteristics influencing CO_2 emissions of vehicle irrespective of route it operates on and load it carries.

We ran the optimization model with a relaxed CO_2 constraint over a period of 3 years, the model proposed to sell 213 vehicles from fleet of 402. Refer to the table 1 for sample of results:

Table 1: Model results with relaxed CO2 constraint

	YEAR 1	**YEAR 2**	**YEAR 3**
Vehicle 386	SELL	KEEP	KEEP
Vehicle 387	KEEP	SELL	KEEP
Vehicle 388	SELL	KEEP	KEEP

We changed the overall CO_2 emissions constraint. The tighter the emission the higher the costs, but an initial drop of 3.5% in CO_2 emissions was gained by 0.04% increase in overall fleet costs for the test case fleet. Even though optimal cost increased with tighter CO_2 constraints, the increase was not significant and overall fleet cost was still significantly lower than it would have been in absence of any fleet replacement policy.

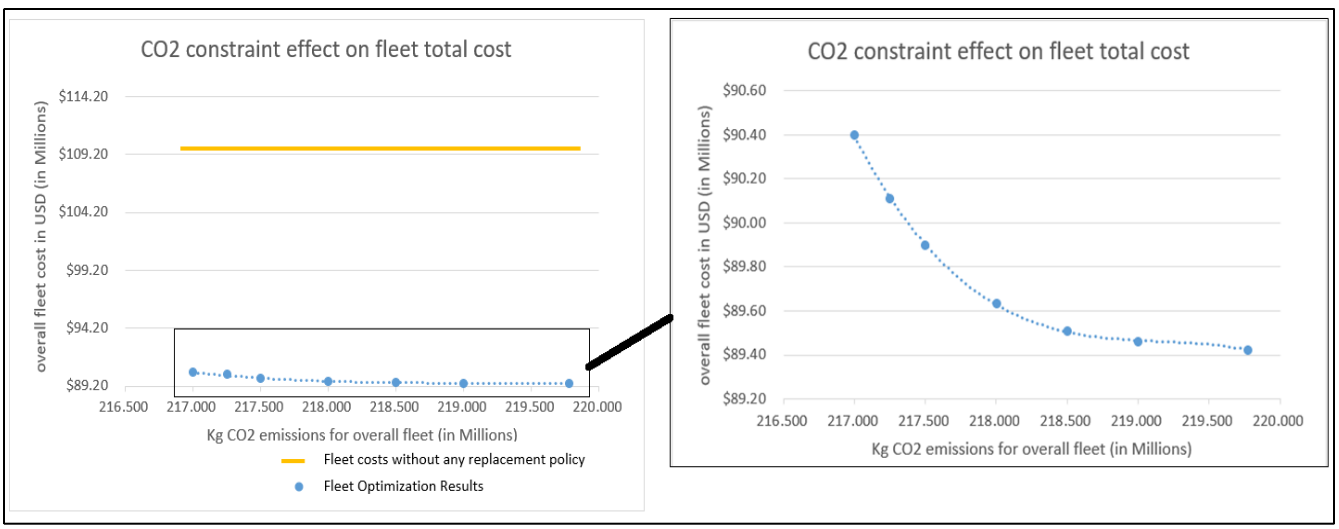

Figure 3: Overall fleet costs vs CO2 emissions

CONCLUSION

Transportation, in particular freight transportation, is undoubtedly one the principal contributors of global CO_2 emissions. Increase in environmental awareness, consumers' preference for green organizations, new CO_2 emissions related laws and regulations, all of these now force the companies to have environmentally-responsible fleet operations. Hence, companies are now focusing on having optimal green fleet composition.

Our capstone partner is one of the largest retailers in Mexico and one of their main goals is to reduce CO_2 emissions for their fleet of 1200 last-mile delivery trucks and 590 inbound trailers. To address Coppel's concerns, we analyzed their data to determine what vehicle characteristics influence CO_2 emissions the most. We found that age and brand are the most important characteristics influencing CO_2 emissions performance of vehicles. When Coppel buys new vehicles, they can select the brands that have proven high performance in terms of CO2 emissions.

We developed a fleet replacement model that proposes a vehicle replacement timeline for optimal overall fleet costs and is constrained by the desired CO_2 emission level. We ran this model for varying degrees of CO_2 emissions constraint and observed that reducing CO_2 emissions means an increase in the overall fleet costs (as expected) but this increase can be quantified for the given fleet and was not significant for Coppel fleet. For a fleet of 402 vehicles, an initial gain of 700,000 $KgCO_2$ drop in emissions was observed for approximately 37000 USD of the cost increase. Optimal overall fleet cost in all scenarios was significantly lower that costs Coppel would incur in absence of fleet replacement policy.

Coppel's transport managers can use the fleet replacement model every year for the strategic composition of their fleet considering vehicle demands. The fleet replacement model has a number of budget-based levers that allow managers the flexibility to incorporate changing budget constraints and financial priorities of the company year-on-year.

As more and more countries impose CO_2 emissions regulations and policies (like emissions tax and credits), our mathematical and fact-backed fleet replacement approach will help companies to align their fleet operations with their strategic sustainability agenda.