Natural Evolution Tells us How to Best Make Goods Delivery: Use Vans

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ABSTRACT

Nowadays, city streets are populated not only by private vehicles but also by public transport, distribution of goods, and deliveries. Since each vehicle class has a maximum cargo capacity, we study in this article how authorities could improve the road traffic by changing the different vehicle proportions: sedans, minivans, full-size vans, trucks, and motorbikes, without losing the ability of moving cargo throughout the city. We have performed our study in a realistic scenario and defined a multi-objective optimization problem to be solved, so as to minimize these city metrics. Our results provide a scientific evidence that we can improve the delivery of goods in the city by reducing the number of heavy duty vehicles and fostering the use of full-size vans instead.

CCS CONCEPTS

•Theory of computation → Continuous optimization; Evolutionary algorithms; •Applied computing → Transportation;

KEYWORDS

Application; evolutionary algorithm; road traffic; city policy; real world; smart mobility

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1 INTRODUCTION

There is a noticeable increment in the number of trips that citizens have to take nowadays and their duration [7], especially because urban infrastructures are not scaling properly. Several traffic jams are consequence of private vehicles sharing streets with services for distribution of goods, deliveries, etc. Furthermore, the need of cargo space makes those services to use small trucks to perform their commercial activities [8], which represent an increment not only in the street space usage but also in the pollutant emissions.

Our proposal consists of studying different configurations of road traffic in a realistic scenario of Malaga, Spain, to better know how greenhouse gas emissions, travel times, and fuel consumption change. Common sense would suggest that reducing the number of Heavy Duty Vehicles (HDV) in the city's streets and incrementing the Light Duty Vehicles (LDV) should be the right thing to do. We wished to check if it is so, when the cargo capacity is a constraint to be kept, as well as potential traffic jams are taken into account.

2 PROBLEM DESCRIPTION

In this article we present a multi-objective strategy to reduce travel times, gas emissions, and fuel consumption in the city. We start from the real number of vehicles measured in the city as well as their proportions and routes. Then, we calculate new vehicle proportions by using NSGA-II, to obtain different policies to improve road traffic metrics, without losing the observed available cargo capacity.

Formally, let $\vec{v} = (v_s, v_{mv}, v_{fsv}, v_t, v_m)$ be a vector containing the number of vehicles in the actual city (sedans, minivans, full-size vans, trucks and motorbikes) obtained from the proportions sampled during one hour. We assumed that only the 20% of sedans ($v_{s\prime} = 0.2 \cdot v_s$) and motorbikes ($v_{m\prime} = 0.2 \cdot v_m$) are used for delivering goods so that $\vec{v}\prime = (v_{s\prime}, v_{mv}, v_{fsv}, v_t, v_{m\prime})$

According to the average cargo capacity of each vehicle type $\vec{t} = (t_{s\prime}, t_{mv}, t_{fsv}, t_t, t_{m\prime})$, and the number of cargo vehicles $\vec{v}\prime$, we can calculate the cargo capacity available in the real city during our study time as $T = \vec{v}\prime \cdot \vec{t}$.

Our objective is to obtain a Pareto set [1] of N vectors $\vec{v}\prime^{\star}_j = (v\prime^{\star}_{s_j}, v^{\star}_{mv_j}, v^{\star}_{fsv_j}, v^{\star}_{t_j}, v\prime^{\star}_{m_j})$, $1 \leq j \leq N$ which contains different optimal solutions, minimizing travel times, emissions, and fuel consumption in the city, subject to the restrictions shown in Equations 1, 2, and 3. Note that the set of vectors $\vec{v}\prime^{\star}_j$ represent the number of vehicles delivering goods, while $\vec{v}^{\star}_j$ includes also private trips, so that $\vec{v}^{\star}_j$ represents the total number of vehicles in the city. Thus, we have set $\tau = 0.8$, according to our cargo use estimation.

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$$T^{\star}_j = \sum_i \vec{t}_{i_j} \cdot \vec{v\prime}^{\star}_{i_j} \quad \geq \quad T, \quad \forall j \in N \tag{1}$$

$$v^{\star}_{s_j} \quad \geq \quad \tau \cdot v_s, \quad \forall j \in N \tag{2}$$

$$v^{\star}_{m_j} \quad \geq \quad \tau \cdot v_m, \quad \forall j \in N \tag{3}$$

3 SOLVING THE PROBLEM

In this work, we use a realistic scenario of Malaga [6] featuring different vehicle proportions to be optimized. We calculate the amount of cargo for each new configuration $T^{\star}$ (subject to Equation 1).

Then, the NSGA-II algorithm calculates the optimal proportions of vehicles evaluating its individuals by using the SUMO traffic simulator [3]. This evaluation comprises a realistic city model made of open data published by the local city council, plus data measured *in situ*, and the city map obtained from OpenStreetMap [2].

We have encoded each solution as a real number vector $\vec{x} = (x_s, x_{mv}, x_{fsv}, x_t, x_m)$ in which each component is the proportion of sedans, minivans, full-size vans, trucks, and motorcycles intended to transport goods. Before evaluating a solution we transform the proportion of vehicles $\vec{x}$ into more detailed proportions $\vec{x}^{\star}$ according to their different characteristics of fuel and gas emissions.

First, we calculate the amount of cargo vehicles N_c that we need to supply the tonnage demand T (constraint). Second, we compute the total amount of vehicles $N^{\star} = N_p + N_c$, with N_p the total of vehicles intended for private use (constraint). Third, we get the correction factor ϕ in the number of vehicles $\phi = N^{\star}/N$, with N the total amount of vehicles in the base solution. Fourth, we correct each proportion $y \in \vec{x}$ for the new total of vehicles: $x' = y \cdot N_c/N^{\star}$, returning a new vector $\vec{x}'$. Fifth, we calculate the new proportion of private use vehicles (sedans and motorcycles) and add them to the solution. And finally, we calculate the extended solution $\vec{x}^{\star} = \{x' \cdot fuel \cdot emission | \forall x' \in \vec{x}', \forall fuel, emission\}$. We use the hydrocarbons (HC) emitted to measure pollutants.

Additionally to the extended solution $\vec{x}^{\star}$, an increment factor ϕ is used to increase (or decrease) the total number of vehicles N, in order to supply the cargo demand. Note that the realistic scenario to be optimized has a factor $\phi = 1.00$. Also, we have set a threshold $\theta = 0.8$ to allow up to 20% of vehicles in the queue when the analysis time ends.

We show in Equation 4 the fitness function used in the optimization process and in Equation 5 the penalization term.

$$\mathrm{f}(\vec{x}) \quad = \quad \left(k + \frac{1}{n}\right) \cdot \sum_{i=1}^{n} (travel\ time(x_i), HC(x_i), fuel(x_i)), \tag{4}$$

$$k \quad = \quad \begin{cases} 0 & \text{if } \frac{n}{N} \geq \theta, \\ \frac{100}{n} \cdot \left(\frac{n}{N} - \theta\right) & \text{otherwise.} \end{cases} \tag{5}$$

4 RESULTS

We executed 30 independent runs of our experiments to test our proposal. The most used cargo vehicles in the whole experimentation were vans. Their speed and cargo capacity are an ideal choice for delivery goods throughout the city. HDV and motorcycles were not good options, as the former are too slow and pollutant and the latter have too little cargo capacity. Sedans had a greater presence than the last two, but much lower than vans.

Even if these results are common sense, it was an automatic model and a solver which arrived at that conclusion: we now have scientific support for mobility policies in the city.

After optimizing the case study, travel time has improved by 10%, fuel and emissions were considerably lower than the measured in Malaga. In 74% of the solutions the number of vehicles was less than the number initially measured in the city.

We compared our solution with other two strategies [4, 5] used in actual cities based on limiting the speed of the vehicles to 30 and 70 km/h. Our proposal achieved better fitness (30% improvement on average) than the other strategies. These results show that employing intelligent techniques can help city managers to discover new ways of reducing traffic jams and air pollution.

The fastest travel times are obtained when there are 1,734 full-size vans. Less emissions occur when using 3,193 minivans for delivering cargo instead of trucks and full-size vans. Finally, a more balanced distribution of both van types would save more fuel.

5 CONCLUSIONS

In this study we have obtained results that show that the number of trucks should by kept at a minimum inside the city. However, due to the limited capacity of the city's streets, the number of LDV vehicles cannot be considerably increased, as this makes traffic jams very likely to occur. The multi-objective algorithm was capable of identifying this restriction and obtaining solutions where using minivans and full-size vans for delivering goods is advisable.

Our results do not mean that companies have to sell all their trucks. Instead, HDVs should be used as freight transport by highways and then use vans for local delivery. All this information would be extremely useful for city managers and these results would serve as goals for the creation of municipal strategies to promote the well-being of drivers, workers and other citizens.

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