Land Logistics

Jakub Krol

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This chapter describes the methodology of estimating travel time, energy consumption and emitted emissions for land logistics. Our definition of land logistics encompasses diesel vans, electric vans and bikes.

1 Travel Time Estimation

Travel time estimation is performed based on the results from Google Map (GM) queries, which uses historical values for a particular time of day. The GM prediction is highly granular providing different travel time if departure time is changed even by a single second. In order to reduce the number of queries, the GM travel time is only obtained for every hour between 9am-5pm, and linearly interpolated otherwise. In the current application, the logistic services are only expected to operate on weekdays therefore the output of a representative day (Wednesday) is duplicated for other days of the week.

The GM query allows for specification of travel mode. Two values of relevance for this analysis are “driving” and “bicycling”. The “driving” option is used for diesel and electric vans, where the output denoted as “duration in traffic” that considers historical traffic condition is used for further analysis. The “bicycling” is used for bicycles where the output denoted as “duration” is used since GM assumes that cycling is not affected by traffic conditions.

2 Energy consumption estimation

In the current version, the estimation of energy consumption is performed for diesel and electric van, and it is assumed that there is no energy expenditure associated with bicycles.

The energy consumption of the van travelling between origin and destination has to be estimated based on limited information such distance between origin and destination, historical travel times (and consequently probable mean speed) and live traffic information. A factor that contributes a lot to the energy consumption is an amount of repeated acceleration and deceleration of the vehicle, which is not known ahead of time. Nonetheless, mean speed can provide certain degree of information about the speed fluctuations. For example, the high mean speed implies driving on the highways where the amount of fluctuations is low, whilst mean speeds corresponding to urban environments imply large amount of fluctuations.

In order to estimate the energy consumption of diesel and electric vans, a technique introduced in [?] is used. First the energy consumption of the van is calculated first using physics-based model assuming a constant speed. Subsequently, this quantity is corrected using the statistical model obtained from historical data. The same approach is used for diesel and electric vans but using different physics-models and form of statistical corrections.

The physics-based models chosen for this analysis are Comprehensive Modal Emission Model (CMEM) [1] for diesel vans and Comprehensive Power-based EV Energy consumption Model (CPEM) for electric vans. The fuel rate, f_t, in CMEM can be decomposed into mass-dependent and mass-independent terms which are given as:

$$f_t = \underbrace{\frac{\zeta}{\kappa} \frac{v_t(g \sin\alpha_t + gC_r \cos\alpha_t + a_t)}{1000\epsilon\bar{\omega}} M}_{\text{mass-dependent}} + \underbrace{\frac{\zeta}{\kappa}\left(\frac{0.5 C_D \rho A v_t^3}{1000\epsilon\bar{\omega}} + kN_eV\right)}_{\text{mass-independent}}, \tag{1}$$

where the time-varying quantities are denoted using subscript t and constitute of vehicle's speed v_t, its acceleration a_t and road angle α_t. The mass M consists of a mass of empty vehicle and a mass of its payload. For the constant parameters, the values assumed in [2] are followed: the coefficient of aerodynamic drag $C_d = 0.7$, the air density $\rho = 1.2041$, the frontal area of the vehicle $A = 4$, the gravitational constant $g = 9.81$ and the rolling resistance $C_r = 0.01$. Engine parameters have the following interpretation: $\zeta = 1$ denotes fuel-to-air mass, $k = 0.2$ is the engine friction factor, $N_e = 40$ is the engine speed, $V = 5$ is the engine displacement, $\bar{\omega} = 0.9$ is the efficiency parameter for diesel engines, $\epsilon = 0.4$ is the vehicle drive train efficiency, κ is heating value of a diesel fuel give by

$$\kappa = \frac{1}{43.2}\left(1 + b_1(N_e - N_0)^2\right), \tag{2}$$

$(N_e - N_0)$ represents deviation of normal engine speed from stationary engine speed $N_0 = 23.2379$, and $b_1 = 0.0001$ is a constant.

The analogous expression for the power of electric van is derived from mechanical power, P_m, which is similarly decomposed into mass-dependent and mass-independent terms

$$P_m = \underbrace{v_t(g \sin\alpha_t + gC_r \cos\alpha_t + a_t)M}_{\text{mass-dependent}} + \underbrace{\frac{1}{2}C_D \rho A v_t^3}_{\text{mass-independent}}, \tag{3}$$

The primary difference from diesel van is that the electric van can be either in traction or regenerative breaking mode. In the first case, the energy flows from the motor to the wheels and vice versa in the latter case.

In the traction mode, power at the electric motor, P_e, is greater than P_m and depends on the drivetrain efficiency μ_d and electric motor efficiency μ_e such that

$$P_e = \frac{1}{\mu_d \mu_e} P_m, \tag{4}$$

whilst in regenerative breaking mode, it is defined as:

$$P_e = \frac{\mu_{rb}}{\mu_d \mu_e} P_m, \tag{5}$$

where μ_{rb} is the efficiency of the regenerative breaking. It is noted that in (5), the value of P_e will be negative signifying that the state of charge of the battery is increasing. The formulation in [3] is used to model the regenerative breaking efficiency as an exponential function of vehicle's acceleration. For large values of deceleration, the value of μ_{rb} approaches one, and it decreases to zero for smaller values (e.g. for deceleration smaller than 0.5m/s^2 the regenerative breaking efficiency is smaller than 0.9).

In order to construct a statistical correction to energy consumption corresponding to a trip, let F denote total fuel consumption over the trip with duration T which is expressed as:

$$F = \int_0^T f_t \, dt. \tag{6}$$

Similarly, the total energy consumption of electric van, E, is calculated by integrating motor power P_e over T. It is noted that analogously to (1) and (3), F and E can be decomposed into mass-dependent and mass-independent terms, e.g. $F = F_{m-dep} + F_{m-indep}$, where subscripts 'm-dep' and 'm-indep' refer to mass-dependent and mass-independent terms respectively.

We employ the following formulation of statistical model

$$F^* = c_{m-dep}(\bar{v})\bar{F}_{m-dep} + c_{m-indep}(\bar{v})\bar{F}_{m-indep} \tag{7}$$

where $\bar{\cdot}$ signifies that corresponding quantity was evaluated using constant mean speed $\bar{v}$ at every timestep. It should be noted that both $c_{m-dep}(\bar{v})$ and $c_{m-indep}(\bar{v})$ are not constant but are functions of $\bar{v}$. Similar expressions are derived for electric vans where corrections are applied to mass-dependent and mass-independent terms of E.

The appropriate form of $c(\bar{v})$ is selected based on Gaussian Process Regression (GPR) [4]. In order to construct appropriate form of coefficients in (7), the CMEM and CPEM are applied to historical driving cycles on instantaneous basis and then compared to the application of CMEM where $v_t = \bar{v}$. The number of driving cycles used for the analysis is $N = 14,984$, and they encompass a variety of traffic states, ranging from highway driving to urban driving. The data was collated by National Renewable Energy Laboratory and contain measurements from different regions in United States and can be downloaded from [5].

The statistical model was evaluated using data collected with a van driving between different surgeries in Solent Region in South Western part of United Kingdom. The visited locations imitate real-life logistics problem, where the medical samples are delivered to Southampton General Hospital for analysis. The proposed models are compared to applications which use constant mean speed without statistical correction which are often used to solve green vehicle routing problems. We refer to those models as CPEM-CONST and CMEM-CONST. Additionally the diesel van model is compared against COPERT model; an average speed model that is widely used in most European Union countries to compile national emission inventories.

Here, we quote only the key results which are errors in average power constumption over a trip for electric vans and average fuel rate over trip for diesel vans, defined respectively as E/T and F/T. The error values corresponding to experimetal data from Solent region are showed in Table 2. For diesel vans, our method outperforms both COPERT and CMEM-CONST reaching the error value of 14.6%, significantly smaller then the one corresponding to COPERT (51.8%). The error corresponding to an electric van is larger than for diesel van, we are nonetheless able to make significant improvement relative to CPEM-CONST.

Diesel Van			
	COPERT	CMEM-CONST	CMEM-2STAT
Average fuel rate error [ml/s]	0.679 (51.8%)	0.392 (27.9%)	0.200 (14.6%)
Electric Van			
	COPERT	CPEM-CONST	CPEM-2STAT
Power error [kW]	N/A	2.555 (67.76%)	1.267 (39.2%)

3 Emission estimation

In the following analysis the following emissions are estimated CO_2, CO_2e, NOx and PM. The estimation is performed for diesel and electric van, and it is assumed that there are no emissions associated with bicycles.

The CO_2 and CO_2e are obtained using estimated energy consumption as it is assumed that there is a constant amount of emissions associated with every liter of burned diesel fuel and every kWh used by electric van. The CO2 and CO2e emissions are split into WTT (Well-to-Tank), TTW (Tank-to-Wheel) and WTW (Well-to-Wheel) emissions. The coefficients used in the analysis come from [6] and are presented in Table 3.

	WTT CO_2e	WTT CO_2	TTW CO_2e	TTW CO_2	WTW CO_2e	WTW CO_2
Diesel Van [kg/l]	0.610	0.601	2.56	2.52	3.17	3.12
eVan [kg/kWh]	0.0462	0.0457	0.193	0.191	0.239	0.237

The NOx and PM emissions are estimated using functional form given by:

$$EF = \frac{c_0 + c_1\bar{v} + c_2\bar{v}^2 + c_3\bar{v}^3 + c_4\bar{v}^4 + c_5\bar{v}^5 + c_6\bar{v}^6}{\bar{v}} \tag{8}$$

for mean speed $\bar{v}$ where EF gives emissions in g/km. The multiplicative factors c_i are given for different emission and van types, and were obtained from [7] and [8] (the corresponding values are given in Table 3). It assumed that PM and NOx emissions are only emitted for diesel vans.

	c_0	c_1	c_2	c_3	c_4	c_5	c_6
PM	0.0188	2.51e-3	-5.48e-5	6.63e-7	-3.46e-9	2.43e-11	-6.88e-14
NO_x	1.98	0.461	-5.09e-3	1.37e-4	-2.03e-6	1.39e-8	-7.64e-12

References

[1] Matthew Barth, Theodore Younglove, and George Scora. Development of a heavy-duty diesel modal emissions and fuel consumption model. Technical report, University of California at Berkeley, 2005.

[2] Anna Franceschetti, Dorothée Honhon, Tom Van Woensel, Tolga Bektaş, and Gilbert Laporte. The time-dependent pollution-routing problem. *Transportation Research Part B: Methodological*, 56:265–293, 2013.

[3] Chiara Fiori, Kyoungho Ahn, and Hesham A Rakha. Power-based electric vehicle energy consumption model: Model development and validation. *Applied Energy*, 168:257–268, 2016.

[4] Christopher KI Williams and Carl Edward Rasmussen. *Gaussian processes for machine learning*, volume 2 (3). MIT press Cambridge, MA, 2006.

[5] National Renewable Energy Laboratory. https://www.nrel.gov/transportation/secure-transportation-data/tsdc-drive-cycle-data.html. Accessed: 2022-01-11.

[6] BEIS. UK Government GHG Conversion Factors for Company Reporting, 2023.

[7] DfT. TAG Data Book January 2023 v1.20.2, 2023.

[8] Ricardo Energy and Environment. Production of Updated Emission Curves for Use in the NTM and WebTAG, 2019.