1-9-2015

Influential Vectors in Fuel Consumption by an Urban Bus Operator

João de Abreu e Silva
University of Lisbon, Portugal

Influential vectors in fuel consumption by an urban bus operator

João de Abreu e Silva

joao.abreu.silva@tecnico.ulisboa.pt

CESUR/DECivil - Instituto Superior Técnico, University of Lisbon, Portugal

FUEL CONSUMPTION IN BUS OPERATION

Introduction

- Transportation role in energy use and GHG emissions has been growing in the last decade, being responsible for 23% of all world energy consumption

- In the case of bus companies, fuel consumption represents a very large proportion of their budgets

- Optimizing resources, ranging from vehicles to drivers, is one of the main concerns of a bus operator in order to reduce fuel consumption

Literature review (I)

- Vehicle type, physical and operational characteristics of lines, driving behavior and company policies (training courses) are the main parameters to be explored in the study of fuel consumption patterns
- Many initiatives are taken on the vehicle side - improving the performance of powertrains and transmission systems
- Bus maintenance is also relevant. Major maintenances could result in significant fuel economies
- Training actions have proven to be effective to some extent, although their effect decreases with time

Literature review (II)

- More systemic approaches include all vectors of fuel efficiency in the same analysis. These parameters were organized into four categories:
  1. ***energy efficiency of the bus*** - vehicle weight and road grade
  2. ***driving cycle of the bus operation*** - speed, frequency of stops and idle time
  3. ***traffic environment*** - volume to capacity ratios as well as road surface conditions
  4. ***bus use*** - mainly a load factor

Literature review (III)

- Ang and Fwa (1989) found routes and vehicle types as the most significant influences on fuel efficiency, followed by average speed and loaded weight. Driver behavior and scheduled times also accounted for variations on fuel efficiency, although to a lesser extent

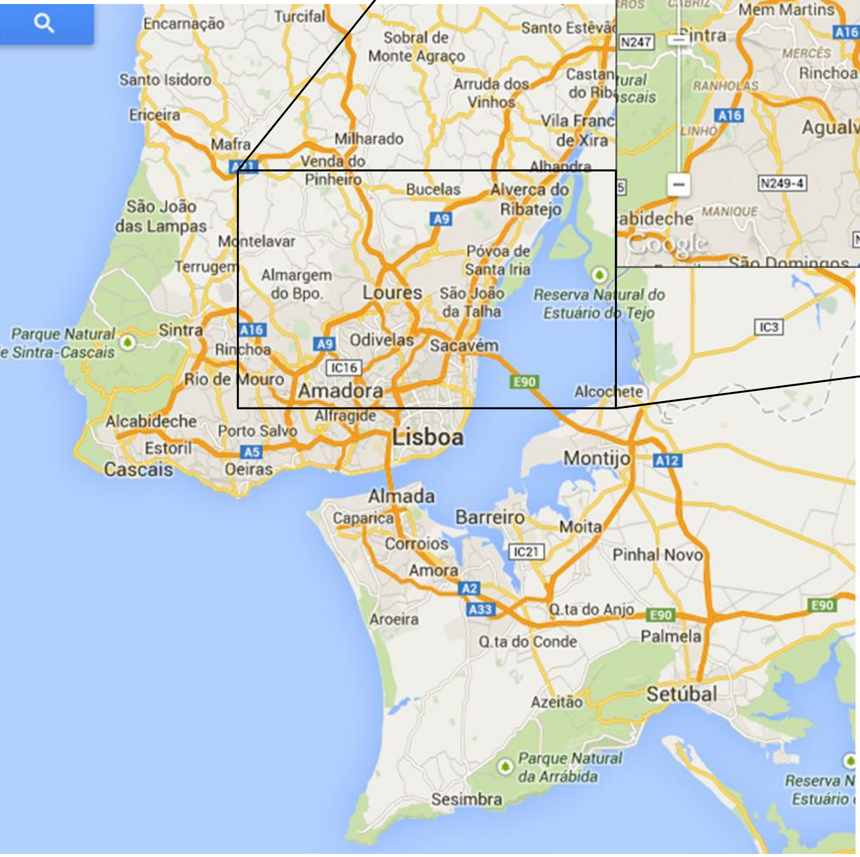
- Frey et al. (2007) found that speed, acceleration and road grade were able to largely explain the variability of fuel consumption

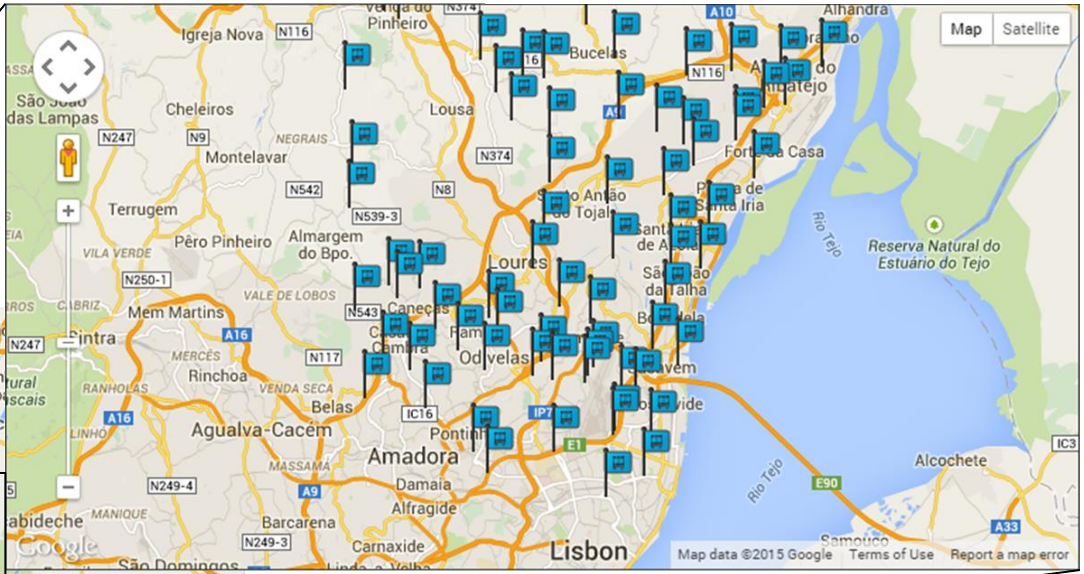
- Delgado et al. (2011) found that average speed, average positive acceleration, and average distance between stops, as being the most adequate parameters to predict fuel consumption

THE CASE STUDY

Lisbon and its Metropolitan Area

- Lisbon is the Capital of Portugal and its biggest city (550 thousand inhabitants)
- The metropolitan area (LMA):
  - 2.8 million inhabitants (26% of the country)
  - 18 municipalities
  - The country's economic powerhouse (37% GDP)





- RL operates in the northeast part of the LMA
- Serves 400 000 people
- 200 000 pass/day
- 94 lines – 4 500 km/day
- 375 buses

- Average age of the vehicles is 14,8 years old, all powered with diesel
- Since 2004, the GISFrot fleet management program was implemented in Rodoviária de Lisboa
- GISFrot aims to optimize fuel consumption in the company, by comparing the performance of drivers based on a rate of driving events occurrence
- These results are used to support an eco-driving training program, resulting in an overall reduction of 2.5% of global fuel consumption

GISFrot and drivers' performance

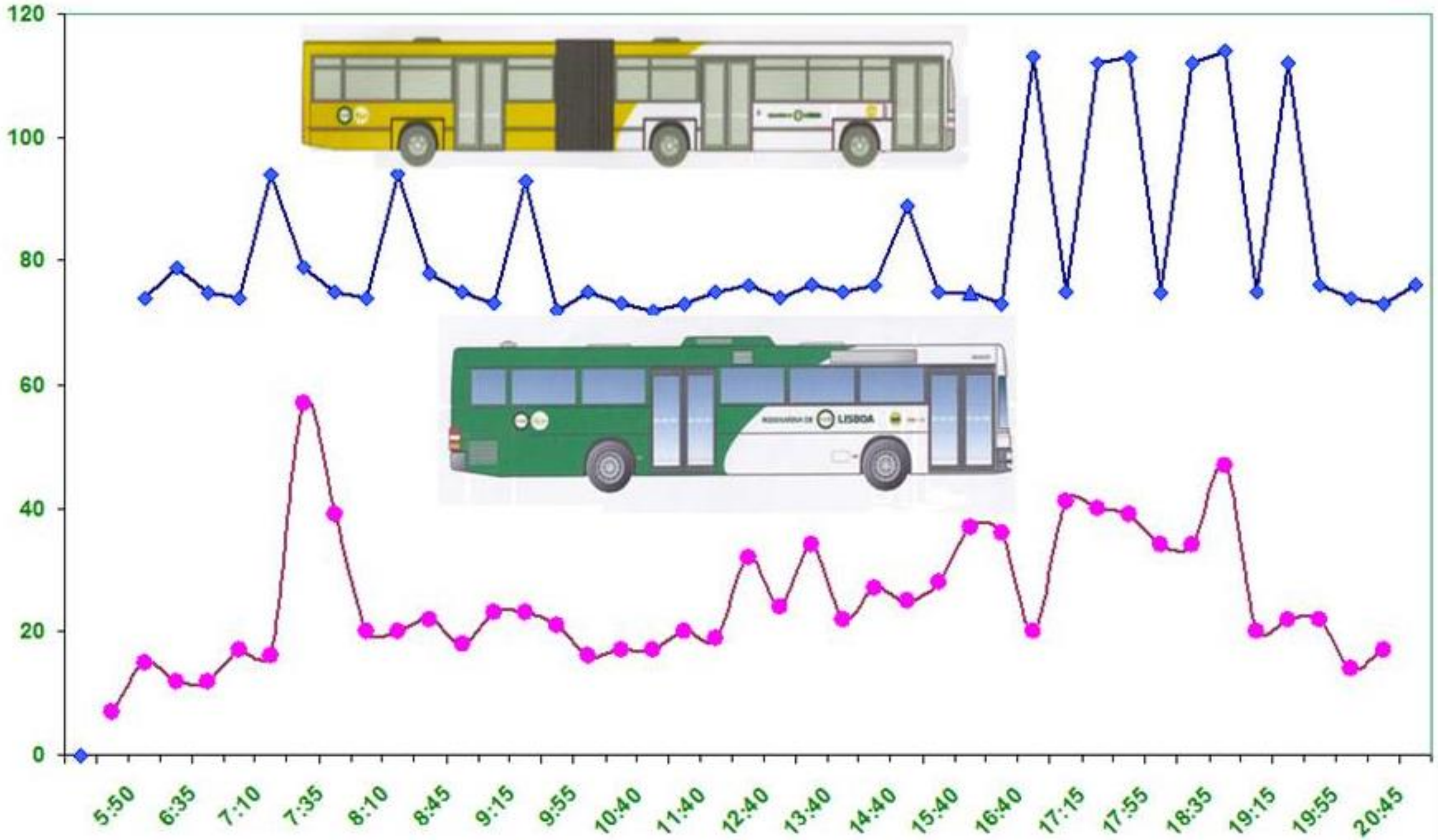
Source: Rodoviária de Lisboa, 2014

GISFrot results

Incidência % de Comportamentos Desviantes					
Conforto e Segurança	Arranque Brusco	Travagem Brusca	Velocidade Excessiva	Rotação Excessiva	Ralenti Excessivo
Julho 10 / Dezembro 10	0,38%	0,40%	1,92%	0,31%	2,07%
Julho 13 / Dezembro 13	0,21%	0,29%	1,73%	0,14%	0,61%

Source: Rodoviária de Lisboa, 2014

Fleet management



Source: Rodoviária de Lisboa, 2014

Results of the measures adopted by RL

Indicador	2004	2014	14 / 04
Gasóleo (litros10^3)	9.068	7.606	- 16 %
KM (10^3)	19.598	17.254	- 12 %
Lt. / 100 Km	46,27	44,09	- 5 %

Indicador	2004	2014	14 / 04
GEP (10^6)	7.911	6.636	- 16 %
PKT (10^3)	440.500	289.406	- 34 %
GEP / PKT	17,96	22,93	+ 28 %

Source: Rodoviária de Lisboa, 2014

Data Collection

- The data was collected with an on-board data logger for a significant set of routes, over two periods:
  - ➢ October and November 2009, and March 2010 (model estimation)
  - ➢ May and September 2010 (model validation)
- Caveats
  - ➢ The daily fuel consumption registry (based on checking the amount of fuel required to completely fill the vehicle's tank), could produce errors. Unrealistic values were deleted from the dataset
  - ➢ Grade intervals were created regardless of route directions
  - ➢ Vehicle sample was limited to those equipped with on-board data loggers
  - ➢ There was no data available about transported passengers

Variables

- *NTraining* – Average number of eco-driving training sessions per driver
- *ComSpeed* – Average commercial speed
- *VehicMini* – Percentage of routes made with mini vehicles
- *VehicMidi* – Percentage of routes made with midi vehicles
- *VehicStand* – Percentage of routes made with standard vehicles
- *VehicArtic* – Percentage of routes made with articulated vehicles
- $(5\%\_slope)^2$ – Square of the percentage of routes with more than 5% slope
- *AvrLength* – Average length of routes
- *log(ComSpeed)* – Logarithm of average commercial speed
- *log(MaxDistStops)* – Logarithm of maximum distance between stops
- *log(DriversAge)* – Logarithm of average age of drivers
- *log(VehicMass)* – Logarithm of vehicle mass
- ***Ev1040* – Percentage of loading air with excessive rotation, among all events registered (coded as event 1040)**
- ***Ev1007* – Percentage of abrupt longitudinal decelerations, among all events registered (coded as event 1007)**
- ***Ev1067* – Percentage of engine rotation above maximum value, among all events registered (coded as event 1067)**

Model Goodness of fit and validation

Model	# obs	R	R^2	Adjusted R^2	Standard error
Lines model	87	0,986	0,972	0,970	0,01554
Drivers_model	488	0,958	0,917	0,916	0,01750
Vehicles_model	105	0,977	0,954	0,952	0,02393

Model	R^2 model estimation	R^2 model validation
Lines model	0,970	0,953
Drivers model	0,916	0,846
Vehicles model	0,952	0,902

Lines Model Results

Model	***Variables (units)***	***Effects (standardized)***
Lines	*VehicArtic (%)*	++
	VehicMidi (%)	--
	VehicMini (%)	----
	ComSpeed (km/h)	---
	5%_slope (%)	++
	MaxDistStops (m)	+
	Ntraining (#)	--
	Ev1040(%)	+

++++ > 0,75

+++ between 0, 25 and 0,75

++ between 0, 10 and 0,25

+ < 0,10

Lines model elasticities

Model	*Variables (units)*	*Mean*	*Elasticity formula*	*Elasticity at the mean values of x*
Lines	*VehicArtic (%)*	*4,170*	βx	*0,008*
	VehicMidi (%)	*5,121*	βx	*-0,005*
	VehicMini (%)	*7,640*	βx	*-0,031*
	ComSpeed (km/h)	*20,943*	βx	*-0,105*
	5%_slope (%)	*28,478*	$2\beta x$	*0,001*
	MaxDistStops (m)	*1916,030*	β	*0,019*
	Ntraining (#)	*3,581*	βx	*-0,043*
	Ev1040(%)	*0,026*	βx	*0,001*

Drivers Model Results

Model	*Variables (units)*	*Effects (standardized)*
Drivers	*VehicStand (%)*	---
	VehicMidi (%)	---
	VehicMini (%)	----
	5%_slope (%)	+++
	ComSpeed (Km/h)	--
	AvrLength (km)	--
	Ev1007 (%)	+

++++ > 0,75

+++ between 0, 25 and 0,75

++ between 0, 10 and 0,25

+ < 0,10

Drivers model elasticities

Model	*Variables (units)*	*Mean*	*Elasticity formula*	*Elasticity at the mean values of x*
Drivers	*VehicStand (%)*	*85,117*	βx	*-0,170*
	VehicMidi (%)	*2,719*	βx	*-0,005*
	VehicMini (%)	*3,990*	βx	*-0,020*
	5%_slope (%)	*26,161*	$2\beta x$	*0,105*
	ComSpeed (Km/h)	*21,633*	β	*-0,145*
	AvrLength (km)	*12,218*	βx	*-0,024*
	Ev1007 (%)	*2,007*	βx	*0,006*

Vehicles Model Results

Model	*Variables (units)*	*Effects (standardized)*
Vehicles	*VehicMass (ton.)*	++++
	ComSpeed (km/h)	--
	AvrLength (Km/h)	--
	Ev1067 (%)	++
	DriversAge (Years)	+

++++ > 0,75

+++ between 0, 25 and 0,75

++ between 0, 10 and 0,25

+ < 0,10

Vehicles model elasticities

Model	***Variables (units)***	***Mean***	***Elasticity formula***	***Elasticity at the mean values of x***
Vehicles	*VehicMass (ton.)*	*15,852*	β	*0,776*
	ComSpeed (km/h)	*21,606*	βx	*-0,130*
	AvrLength (Km/h)	*12,890*	βx	*-0,039*
	Ev1067 (%)	*0,324*	βx	*0,006*
	DriversAge (Years)	*42,648*	β	*0,195*

Conclusions (I)

- Vehicle type is the most influential variable in all three models, confirming the importance of fleet renewal and management
- Commercial speed is also an important factor in all three models, with higher speeds meaning lower fuel consumption
- Number of drivers passing monitored training was detected in the routes' model as having a positive influence on fuel consumption. This result confirms the success of training measures on the energy efficiency of bus operator companies
- Driver age has also an impact on fuel consumption. Older drivers seem to be more adverse to change their behavior
- Driving events such as abrupt deceleration and excessive rotation have a negative impact on fuel consumption

Conclusions (II)

- To continue improving the energy efficiency, some actions should be considered such as:
  - Improvement of the data collection process (including passengers data)
  - Cost/benefit ratio evaluation of various energy conservation measures
  - Definition of similar models for each operation area of Rodoviária de Lisboa, since each one presents different traffic and topographical conditions
  - Definition of objectives regarding driver monitoring and formative training
  - A periodic validation of the developed models, followed by their readjustment, if necessary

Thank you for your attention

Questions?

This presentation is based on:

de Abreu e Silva, João, Moura, Filipe, Garcia, Bernardo and Vargas, Rodrigo, Influential vectors in fuel consumption by an urban bus operator: bus route, driver behavior or vehicle type?, submitted for *Transportation Research Part D*, under the process of reviewing and resubmitting

Rodoviária de Lisboa is acknowledge for all of their support in this study

Annex 1 - Lines Model Results

Models	Variables	Unstandardised coefficients		Standardised coefficients	Sig.*	Colinearity Statistics	
		B	Standard error	β		Tol.**	VIF
Lines	*Constant*	1.741	0.024		0.000		
	VehicArtic	0.002	0.000	0.238	0.000	0.911	1.098
	VehicMidi	-0.001	0.000	-0.167	0.000	0.933	1.071
	VehicMini	-0.004	0.000	-0.888	0.000	0.798	1.253
	ComSpeed	-0.005	0.001	-0.263	0.000	0.311	3.220
	$(5\%\_slope)^2$	1.17E-02	0.000	0.104	0.000	0.45	2.224
	log(MaxDistStops)	0.019	0.008	0.070	0.026	0.368	2.719
	Ntraining	-0.012	0.003	-0.117	0.000	0.458	2.183
	Ev1040	0.048	0.021	0.049	0.024	0.795	1.257

Annex 2 - Drivers Model Results

Models	*Variables*	*Unstandardised coefficients*		*Standardised coefficients*	*Sig.**	*Colinearity Statistics*	
		B	*Standard error*	*β*		*Tol.***	*VIF*
Drivers	*Constant*	1,965	0.024		0.000		
	VehicStand	-0.002	0.000	-0.561	0.000	0.624	1.604
	VehicMidi	-0.002	0.000	-0.325	0.000	0.735	1.360
	VehicMini	-0.005	0.000	-0.845	0.000	0.736	1.359
	$(5\%\_slope)^2$	0.002	0.000	0.310	0.000	0.373	2.685
	log(ComSpeed)	-0.145	0.020	-0.161	0.000	0.36	2.779
	AvrLength	-0.002	0.000	-0.132	0.000	0.237	4.219
	Ev1007	0.003	0.001	0.077	0.000	0.943	1.060

Annex 3 - Vehicles Model Results

Models	*Variables*	*Unstandardised coefficients*		*Standardised coefficients*	*Sig.**	*Colinearity Statistics*	
		B	*Standard error*	*β*		*Tol.***	*VIF*
Vehicles	*Constant*	-1.737	0.141		0.000		
	log(VehicMass)	0.776	0.020	0.912	0.000	0.805	1.242
	ComSpeed	-0.006	0.001	-0.195	0.000	0.273	3.666
	AvrLength	-0.003	0.001	-0.140	0.001	0.261	3.831
	Ev1067	0.017	0.004	0.108	0.000	0.931	1.075
	log(DriversAge)	0.195	0.077	0.056	0.013	0.927	1.079