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Ex-ante Evaluation of Optimal Mixed Transit Fleet Management Plans

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Abstract

Transit operators are gradually incorporating hybrid and electric vehicles in existing conventional-drive and natural gas fleets, in an effort to improve carbon-footprint of transit services. The objective of this study is to provide an ex-ante evaluation of bus fleet management plans in cases of fleets with mixed propulsion technologies. An integer programming model is exploited, seeking to minimize the total cost of purchasing, operating and selling buses, under various fiscal and operational constraints. A realistic data set from various sources is collected and a thorough scenario analysis is performed to assess the various trade-offs between different propulsion technologies. Results show that the largest reduction in the fleet management cost stems from favorable conditions for the purchase of more fuel-efficient types of buses, such as electric and natural gas buses.

Background

- Compressed NG bus purchases accounting for 20%–25% of U.S. transit bus sales.
- Hybrid and electric vehicles are gradually incorporated in existing diesel and natural gas fleets.
- Electric vehicle demonstration projects are underway in several cities both in the US and Europe.
- The associated **fleet replacement problem** arising for operators must aim to **reconcile conflicting goals** in an efficient manner:
  - Financial investment of transit operator.
  - Public image of transit operator
  - Level of service provided to passengers.
- Maintenance and operating costs increase with vehicle age.
- Purchase, maintenance and operating **costs vary across different technologies.**
- Lack of studies on **planning for mixed fuel-type fleets for transit agencies.**
- One relevant study considering diesel and hybrid buses (Feng and Figliozzi, 2014).
  - incorporation of **natural gas and electric propulsion vehicles in transit fleets** still missing .

Objectives

- Determination of **optimal fleet management plan for a transit operator**
- Consideration of **different fuel types**:
  - Diesel
  - Compressed Natural Gas
  - Hybrid-Electric
  - Electric
- Thorough data collection:
  - Transit agencies
  - Literature
  - Online databases
- Application for transit operator in a large urban area:
  - Solution by Integer Programming
  - Scenario analysis to estimate effect of economic parameters
- Assist transit operators in management decisions during transition from conventional to alternative fuel fleets

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Model

X_{ijk}: the number of type-k buses of age i in operation at year j

Y_{ijk}: the number of type-k buses of age i sold at year j

P_{jk}: the number of type k buses purchased at year j

$$\min \sum_{j=0}^{T-1}\sum_{k=1}^{K} v_k \cdot P_{jk} \cdot (1+dr)^{-j} - \sum_{i=1}^{A_i}\sum_{j=0}^{T-1}\sum_{k=1}^{K} s_{ik} \cdot Y_{ijk} \cdot (1+dr)^{-j} + \sum_{i=1}^{A_i-1}\sum_{j=0}^{T-1}\sum_{k=1}^{K} (o_{ijk} + m_{ik} + ec \cdot e_{ik}) \cdot u_{ik} \cdot (1+dr)^{-j} \cdot X_{ijk}$$

purchasing — salvage revenue — operation, maintenance, emissions' cost

Subject to:

$$\sum_{k=1}^{A_i-1} v_k \cdot P_{jk} \le b_j \quad \forall\, j \in \{0,1,\ldots,T-1\}$$ Budget constraint

$$\sum_{i=0}^{A_i-1}\sum_{k=1}^{K} u_{ik} \cdot X_{ijk} \ge d_j \quad \forall\, j \in \{0,1,\ldots,T\}$$ Distance constraint

$$F_{max} \ge \sum_{i=0}^{A_i-1}\sum_{k=1}^{K} X_{ijk} \ge F_{min} \quad \forall\, j \in \{0,1,\ldots,T\}$$ Fleet size limits

$$P_{jk} = X_{0jk} \quad \forall\, j \in \{1,2,\ldots,T\}$$ New vehicles must be used right away

$$P_{0k} + h_{0k} = X_{00k} \quad \forall\, k \in K$$

$$X_{i0k} + Y_{i0k} = h_{ik} \quad \forall\, k \in K,\ \forall\, i \in \{1,2,..A_k\}$$ conservation of vehicles

$$X_{(i-1)(j-1)k} = Y_{ijk} + X_{ijk} \quad \forall\, k \in K,\ i \in \{1,..A_k\}, j \in \{1,..T\}$$ A vehicle must be used or sold the following year

$$X_{A_k jk} = 0 \quad \forall\, j \in \{1,2,\ldots,T\} \forall\, k \in K$$ Maximum age constraint

$$Y_{0jk} = 0 \quad \forall\, j \in \{0,1,\ldots,T\} \forall\, k \in K$$ A new vehicle (of age 0) cannot be sold

$$P_{jk}, X_{ijk}, Y_{ijk} \quad \in I = \{0,1,2\ldots.\}$$ Form of decision variables

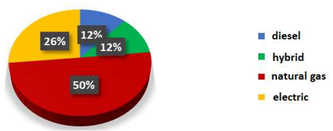
Data Collection

- Data collection based on existing studies, agency reports and online databases.
- Average figures computed for each parameter.

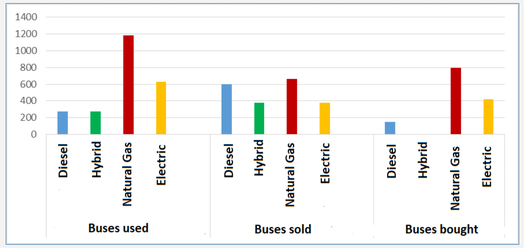
	Bus type				General
Average parameter values	**Diesel**	**Hybrid**	**CNG**	**EV**	
k	1	2	3	4	
Energy cost €/km (o_{ijk})	0,80	0,63	0,51	0,24	
Maintenance cost €/km. (m_{ik})	0,35	0,29	0,30	0,29	
Motor efficiency €/lt (f_{ik}, k≠4)	1,6	2,1	1,6	-	
Electric Motor efficiency €/kwh (f_{i4})	-	-	-	0,82	
CO_2 emissions kg/km (e_{ik})	2,290	1,722	1,732	0,124	
Fuel cost €/lt (f_{c0}, c≠3)	1,30	1,30	0,51	-	
Electricity cost €/kwh (f_{c0})	-	-	-	0,20	
Average annual km traveled (t_k)	55,000	50,000	55,000	50,000	
Purchase cost (€) (v_k)	236,841	394,004	333,954	538,500	
Minimum fleet size (F_{min})					1,000
Maximum fleet size (F_{max})					2,000
Minimum annual km (d_j)					70 mil.
Max age for all types (A_k)					15
Depreciation rate (d_r)					1.5%
Annual budget (b_j)					100 mil.
Initial number of vehicles of age i	40	25	30	15	
Initial number of vehicles	600	375	450	225	1,650

Results

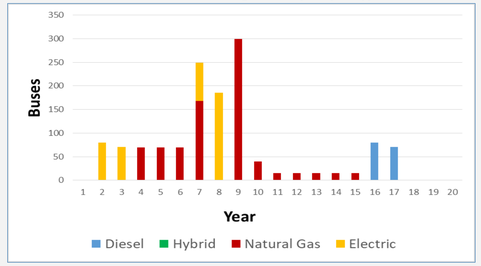
Usage Share for each bus type



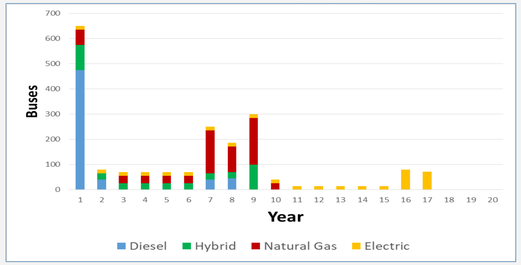
Total number of vehicles used, sold and bought per type



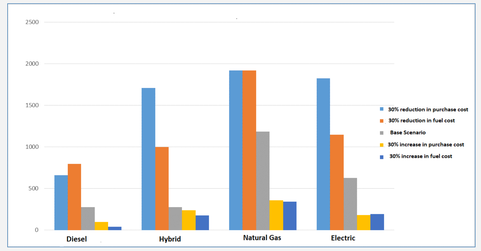
Number of vehicles bought each year per type



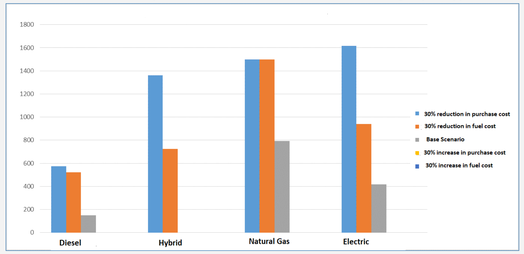
Number of vehicles sold each year per type



Total number of vehicles used per cost scenario

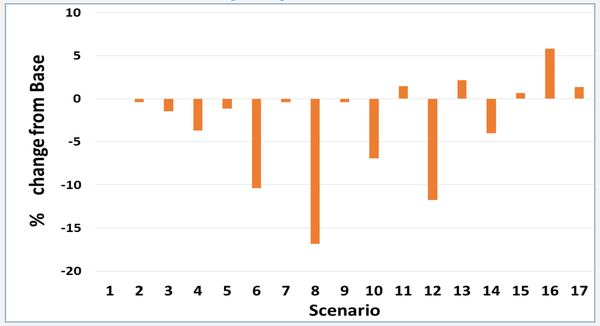


Effect of purchase and fuel cost on vehicles bought per type



Scenario
1. Basic Scenario
2. Low Diesel bus cost (-30%)
3. High Diesel bus cost (+30%)
4. Low Hybrid bus cost (-30%)
5. High Hybrid bus cost (+30%)
6. Low NG bus cost (-30%)
7. High NG bus cost (+30%)
8. Low Electric bus cost (-30%)
9. High Electric bus cost (+30%)
10. Low diesel price (-30%)
11. High diesel price (+30%)
12. Low NG price (-30%)
13. High NG price (+30%)
14. Low electricity price (-30%)
15. High electricity price (+30%)
16. Emissions' tax (100€/ CO2 –ton)
17. 40 mil. Budget (-60%)

Percentage change in total cost from Basic Scenario



Conclusions

- Hybrid and electric vehicles are advantageous in terms of operation and maintenance costs
- High purchase costs for hybrid and electric buses limit vehicle purchases
- A 30% increase in fuel price prohibits new bus purchases regardless of vehicle type
- An emissions' tax would bring about a drastic reduction in conventional and NG vehicles, as well as in average fleet age
- Lower prices of non-diesel vehicles and energy sources produce favorable solutions in terms of cost