# When to provide express services for buses?

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# Regular service

# Express service

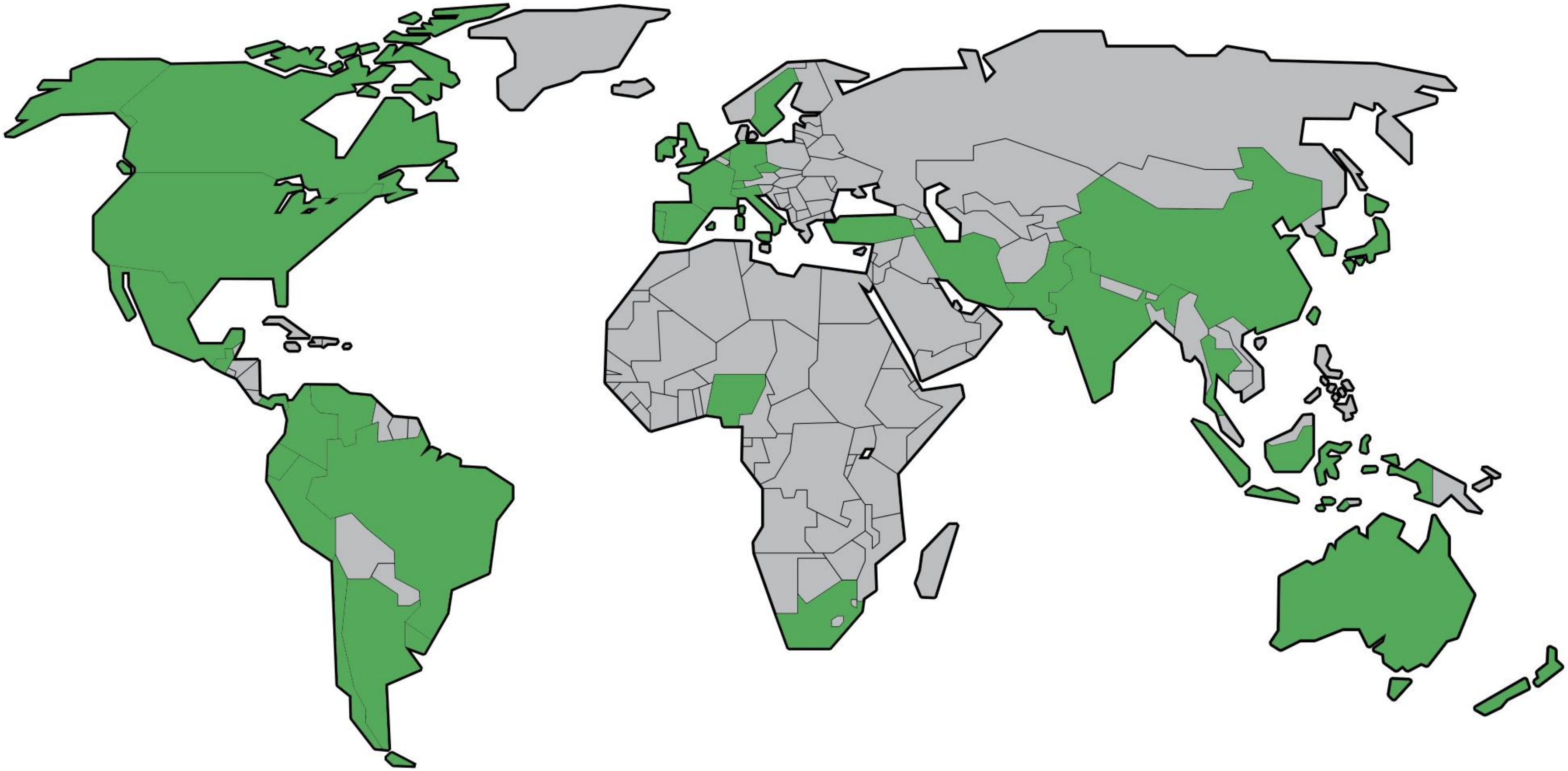
Travel times? :)

Waiting times? :(

Transfers? :(

Operation costs? :)

# Around the world



39 countries

168 cities

324 corridors

source: brtdata.org

# Express services in the literature

Case-study oriented:

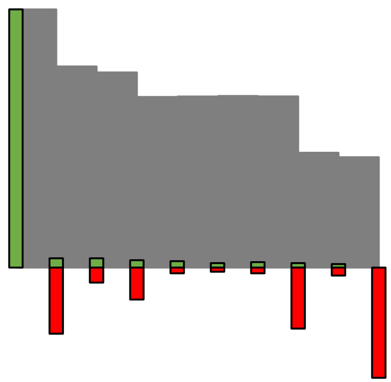
Ercolano (1984), Silverman (1998), Tétreault and El-Geneidy (2010), El-Geneidy and Surprenant-Legault (2010), Scortia (2010).

Design models:

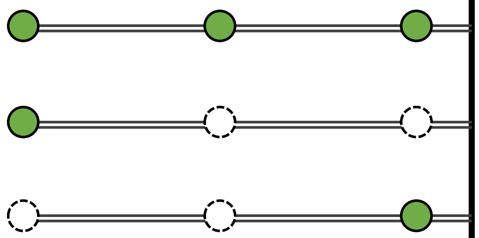
Jordan and Turnquist (1979), Furth (1986), Leiva et al. (2010), Larrain et al. (2010, 2015), Sun et al. (2008), Chen et al. (2012), Chiraphadhanakul y Barnhart (2013).

# When to provide express services?

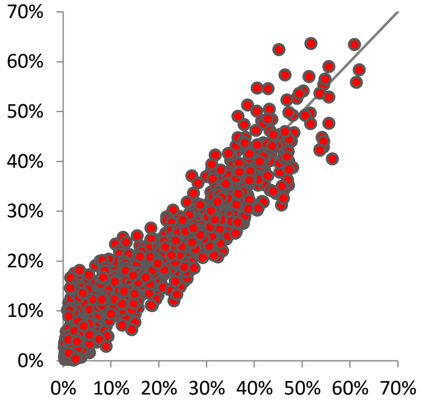
Our experiment in three steps:



Corridor Generation



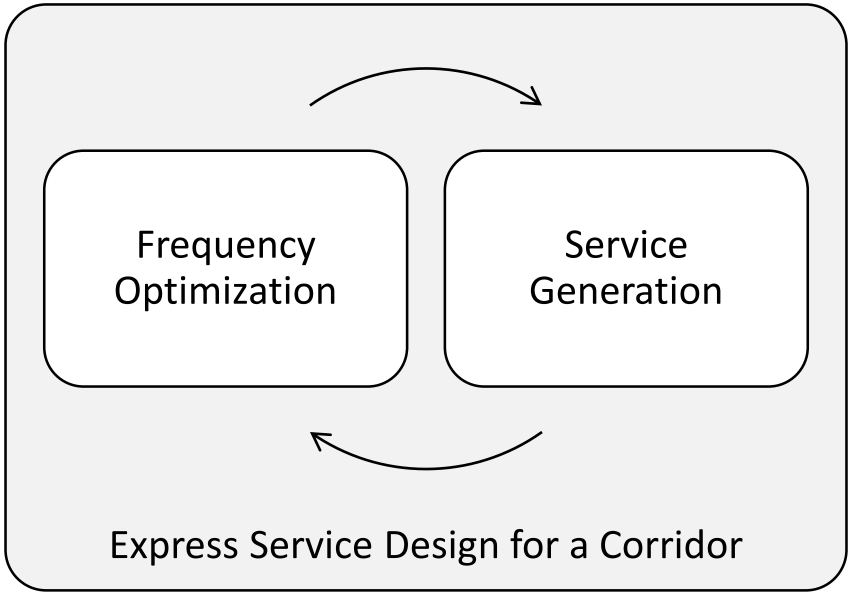
Service Optimization




Regression Model

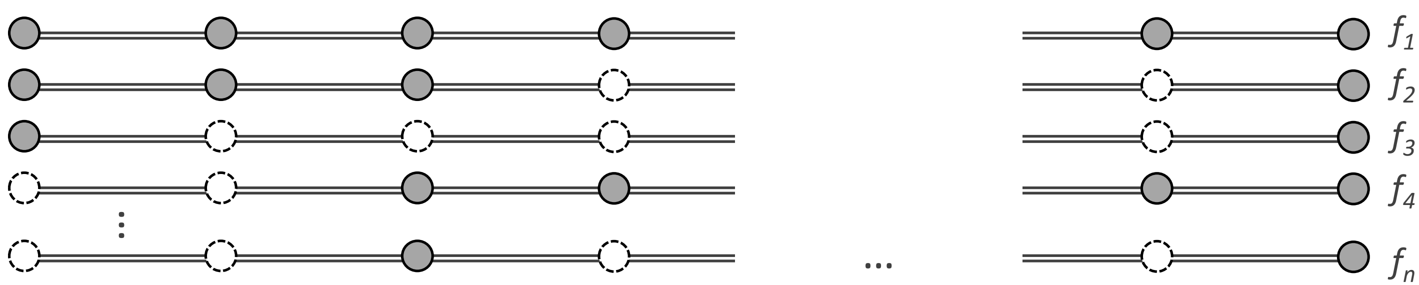
1. Algorithm for the design of express services.
2. Conceptualization of the experiment.
3. Generation of scenarios.
4. Calibration of the regression model.
5. Analysis of the results and conclusions.

# Design algorithm



# Design algorithm

Frequency optimization:




$$\min_{f_l, f_l^s, V_s^w} \left[ \sum_{l \in \mathcal{L}} c_l f_l + \theta_{WT} \sum_{w \in \mathcal{W}} T_w \frac{\lambda}{\sum_{l \in \mathcal{L}} g_l^w} + \theta_{TT} \sum_{w \in \mathcal{W}} T_w \frac{\sum_{l \in \mathcal{L}} t_l^w g_l^w}{\sum_{l \in \mathcal{L}} g_l^w} \right]$$

operation costs + waiting costs + traveling costs

s.t.: non-negativity, frequency continuity.

The model determines which services will operate ($f_l > 0$).

# Design algorithm

Frequency optimization:

- The model minimizes social costs and assigns passengers to their optimal routes.
- Bus capacity is considered indirectly, using a heuristic to correct the capacity deficits from an initial solution.
- Transfers are not considered in the modelation in this experiment.

# Design algorithm

## Service generation:

| Name | Capacity constraints | Short or zonal | Existing services | Description |
|---|---|---|---|---|
| $GEN_1$ | No | No | No | Generation of initial services: Using a greedy heuristic, chooses an all-stop service and sequentially eliminate some of them on a local optimality criterion, thus generating an initial list of express services. |
| $GEN_2$ | No | Yes | No | Generation of short services: Builds a list of short turn services. |
| $GEN_3$ | No | Yes | No | Generation of zonal services: Builds a list of zonal services that visit a complete set of stops in the initial and final segments or zones of a route while skipping a large number of consecutive stops constituting the middle zone. |
| $GEN_4$ | No | No | Yes | Generation of additional services: Builds a series of new express services for a corridor from a given solution. The services are created by adding stops to an initial base service. |
| $GENc_1$ | Yes | Yes | No | Short service considering capacity: Builds a solution that satisfies the capacity constraint using a short service and an all-top service in the critical direction of the corridor. |
| $GENc_2$ | Yes | Yes | No | Zonal service considering capacity: Builds a solution that satisfies the capacity constraint using a zonal service and a regular service in the critical direction of the corridor. |
| $GENc_3$ | Yes | Yes | No | Zonal service considering capacity: Builds a solution that satisfies the capacity constraint using a zonal service, a short service and an all-top service in the critical direction of the corridor. |

# Conceptualization

Which effects do we need to capture in our scenarios?

How will we measure the benefits of express services?

# Conceptualization

Previous literature has pointed out some relevant factors when designing express services:

1. Demand characteristics.
   Trip volume, trip lenght, trip concentration.

2. Operation conditions.
   Dwell time, vehicle capacity, corridor length.

3. Relative weights of cost components.
   Operator costs, value of travel time, value of waiting time.

# Conceptualization

For measuring the benefits of the express services on each scenario, we propose the **corrected percentage savings** ($CPS$) as a performance indicator.

$$CPS = \frac{CTC^{*} - CTC_{AS}}{CTC_{AS}}$$

This indicator compares the **corrected total cost** ($CTC$) of the express services solution and the optimized single all-stop service solution for the scenario.

The corrected total cost subtracts the minimum travel time costs from the total cost.

# Scenarios

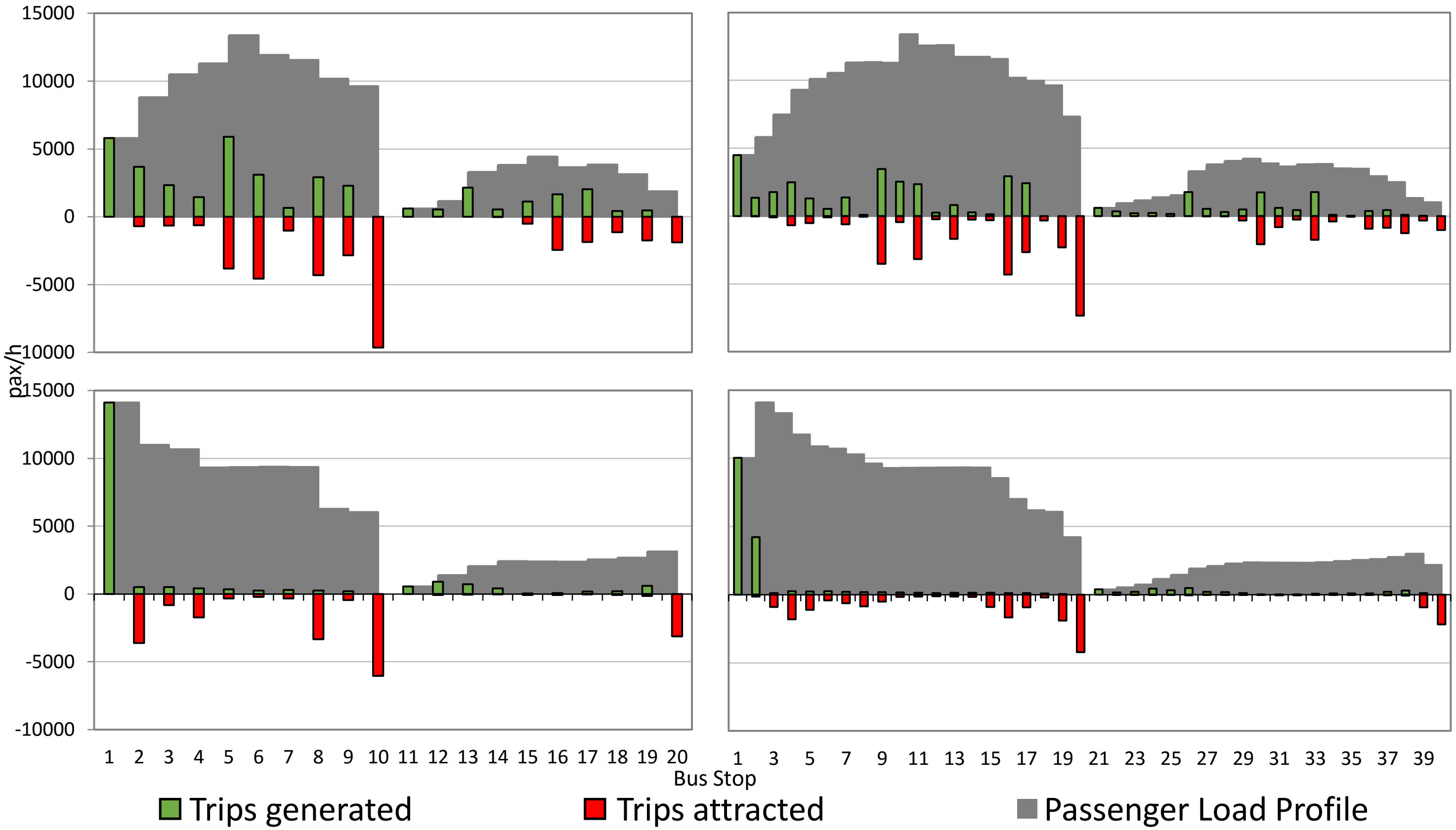
A scenario corresponds to a corridor, defined by its topological characteristics, demand matrix, operation conditions, and user preferences.

We generated 972 scenarios covering different combinations of attributes.

| Parameter | Number of options | Possible values |
|---|---|---|
| **Base matrix** | 4 | 1, 2, 3 or 4 |
| **In-vehicle travel time ($\theta_{TT}$)** | 1 | 15 $/min |
| **Wait time ($\theta_{WT}$)** | 3 | 15, 30 or 45 $/min |
| **Operating cost - distance ($c_L$)** | 3 | 250, 500 or 750 $/bus-Km |
| **Operating cost - time ($c_T$)** | 1* | $10c_L$ $/bus-min |
| **Demand volume ($\beta$)** | 3 | 0.5, 1.0, 2.0 |
| **Dwell time ($\tau$)** | 3 | 0.5, 1.0, 1.5 min |
| **Vehicle capacity ($b$)** | 3 | 80, 120, 160 pax/bus |

# Scenarios

The four base matrices are inspired in real data from Santiago.



# Scenarios

The four base matrices are inspired in real data from Santiago.

| Matrix | No. of stops | Corridor | Total trips (pax/hr) | Std dev (pax/hr) | Av. no. of trips(pax/hr) | Coeff. of var. | Av. trip length (in stops) | Critical load (pax/hr) |
|---|---|---|---|---|---|---|---|---|
| **1** | 10 | Grecia | 37,728 | 507.0 | 419.2 | 1.2 | 3.2 | 13,392 |
| **2** | 10 | Pajaritos | 20,546 | 673.7 | 228.3 | 3.0 | 5.1 | 14,119 |
| **3** | 20 | Grecia | 38,744 | 205.9 | 102.0 | 2.0 | 6.3 | 13,400 |
| **4** | 20 | Pajaritos | 20,453 | 176.0 | 53.8 | 3.3 | 10.6 | 14,101 |

# Regression model

After optimizing the 972 scenarios using our design model, the following regression model was calibrated to predict the express services benefits:

$$CPS = \alpha_0 + \alpha_1 PTTS + \alpha_2 CV + \alpha_3 OI + \alpha_4 c_L + \alpha_5 \tau$$

| Parameter | Variable | Description | Formula | $\alpha_i$ value ($t$ statistic) |
|---|---|---|---|---|
| $\boldsymbol{\alpha_0}$ | - | Constant | | -1,41E-01 (-18,67) |
| $\boldsymbol{\alpha_1}$ | $PTTS$ | Potential Travel Time Savings | $PTTS = \theta_{TT}\tau\overline{S}kT$ | 2,58E-08 (27,15) |
| $\boldsymbol{\alpha_2}$ | $CV$ | Coefficient of Variation | $CV = \frac{\sigma_w}{\overline{\overline{T_w}}}$ | 8,41E-02 (38,39) |
| $\boldsymbol{\alpha_3}$ | $CI$ | Overcrowding Indicator | $OI = \frac{f^*}{f_{AS}^*} = \frac{P/b}{\sqrt{\frac{\theta_{WT}\lambda T}{c_{AS}}}}$ | 3,24E-02 (19,24) |
| $\boldsymbol{\alpha_4}$ | $c_L$ | Operation Cost per unit of Length | $c_L$ | -9,35E-06 (-24,48) |
| $\boldsymbol{\alpha_5}$ | $\tau$ | Dwell Time | $\tau$ | 1,21E-01 (25,56) |
| $\boldsymbol{R^2}$ | - | | | 86.90% |

# Analysis

Coefficient of variation:

| Parameter | Variable | Description | Formula | $\alpha_i$ value ($t$ statistic) |
|---|---|---|---|---|
| $\boldsymbol{\alpha_1}$ | $PTTS$ | Potential Travel Time Savings | $PTTS = \theta_{TT}\tau\overline{Sk}T$ | 2,58E-08 (27,15) |

The benefits from using express services will increase with $PTTS$, which in turn increases with:

- Value of travel time.
- The number of stops per trip. This variable is also correlated with the average trip length and the stop density.
- The total number of trips.
- Dwell time. This factor influences the regression in its own right, and does so in the same direction in both cases. The greater the dwell time, the greater is the incentive to use express services.

| Parameter | Variable | Description | Formula | $\alpha_i$ value ($t$ statistic) |
|---|---|---|---|---|
| $\boldsymbol{\alpha_5}$ | $\tau$ | Dwell Time | $\tau$ | 1,21E-01 (25,56) |

# Analysis

Potential travel time savings:

| Parameter | Variable | Description | Formula | $\alpha_i$ value ($t$ statistic) |
|---|---|---|---|---|
| $\boldsymbol{\alpha_2}$ | $CV$ | Coefficient of Variation | $CV = \frac{\sigma_w}{\overline{T_w}}$ | 8,41E-02 (38,39) |

The benefits from using express services will increase with the coefficient of variation, which can be understood as an indicator of trip concentration.

# Analysis

Overcrowding factor:

| Parameter | Variable | Description | Formula | $\alpha_i$ value ($t$ statistic) |
|---|---|---|---|---|
| $\boldsymbol{\alpha_3}$ | $CI$ | Overcrowding Indicator | $OI = \frac{f^*}{f^*_{AS}} = \frac{P/b}{\sqrt{\frac{\theta_{WT}\lambda T}{c_{AS}}}}$ | 3,24E-02 (19,24) |

Express services are more beneficial when $OI$ is higher. Assuming that the critical load is proportional to the total number of trips (i.e. $P = kT$), we can conclude that express services work better when:

- The critical arc load relative to total trips is higher.
- Vehicle capacity is lower.
- Wait time value is lower.
- Increasing number of total trips. This effect agrees the one found in $PTTS$.
- Operation costs are higher… maybe.

# Analysis

Operation costs:

| Parameter | Variable | Description | Formula | $\alpha_i$ value ($t$ statistic) |
|---|---|---|---|---|
| $\boldsymbol{\alpha_4}$ | $c_L$ | Operation Cost per unit of Length | $c_L$ | -9,35E-06 (-24,48) |

This effect contradicts the one found in the $OI$. We can analyze the combined effect:

$$\frac{\delta CPS}{\delta c_{AS}} = \alpha_3 \frac{P}{2b\sqrt{c_{AS}\theta_{WT}\lambda T}} + \alpha_4$$

Since $\alpha_4 < 0$, we can't decide in general what's the effect of operation costs.

# Conclusions

So…

When should we provide express services?

Express services become more attractive in presence of:

- Increasing dwell time,
- Increasing number of stops per trip or average trip length,
- Increasing number of trips on the system,
- Increasing travel time,
- Increasing concentration of trips on a limited number of origin-destination pairs,
- Increasing critical arc load as a proportion of the load for all trips,
- Decreasing vehicle capacity,
- Decreasing value of wait time.

# Conclusions

Next steps:

- Extend the analysis to scenarios taking values of corridors around the world, to obtain a universal model.
- Include transfers in the design model, in order to measure the impact of transfer costs in the potential benefit of express services.

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