Reliability of medium-frequency bus services: some empirical evidences

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Summary

✓ Introduction

✓ Irregularity analyses: experimental evidences
  ➢ Data collected
  ➢ Data analysis: dispatching irregularity decomposition
  ➢ Dispatching irregularity vs travel time

✓ Main findings and the road ahead
Introduction

Sustainable city development requires high quality public transport → reliable transit services

Relevant determinant for moving people to transit

Punctuality

Low-frequency services

Regularity

High-frequency services
Introduction

Service punctuality

Service operations

Transit users

Service reliability

Business model

Punctuality

often measured at origin terminal and/or in some stops (s) along the route, through measurement of the difference between actual departure times ($DT_{act}$) with the scheduled ones ($DT_{sch}$)

$$Dif_s = \left| DT_{s}^{act} - DT_{s}^{sch} \right|$$
Introduction

Main indicators used for punctuality

The maximum allowed difference $\Delta$ and the percentage of delayed runs $\alpha$ are fixed, and the $Dif$ can be greater than $\Delta$ only in a percentage of cases less than $\alpha$. Therefore, referring to a given stop $s$ (origin terminal or intermediate stop), follows:

$$Dif_s = \left| DT_s^{act} - DT_s^{sch} \right| \leq \Delta_s$$

where

$$\frac{n_s^{over}}{n_s^T} < \alpha_s$$

$n_s^{over}$ is the number of times in which buses depart from stop $s$ with a $Dif$ greater than $\Delta$ and $n_s^T$ is number of the times in which buses depart from stop $s$.

The choice of $\Delta$ and $\alpha$ has a great impact on level of service and efficiency, as they impact on user’s waiting times and on the necessary number of buses (and of crew).
Introduction

Service punctuality

Literature on service reliability mainly focused on high-frequency service systems (Cats, 2014), and further investigation on punctuality in medium/low-frequency service system needs.

Therefore, in the city of Rome a study was addressed to investigate bus service punctuality for medium/low-frequency services.

Here the first results are presented of the analysis of the dispatching irregularity.
Dispatching irregularity analyses: experimental evidences

Data collected

The analysis was performed using automatic vehicle location (AVL) data (dispatching times) of a bus line in the urban area of Rome.

<table>
<thead>
<tr>
<th></th>
<th>Average travel time (to city centre) [minutes]</th>
<th>Average travel time (from city centre) [minutes]</th>
<th>Travel length [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39.5</td>
<td>41.7</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Peak-hour headway [minutes]</th>
<th>Off-peak-hour headway [minutes]</th>
<th>Observation period (T) [weeks]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>30</td>
<td>8</td>
</tr>
</tbody>
</table>
Dispatching irregularity analyses: experimental evidences

Data collected

30-minutes fluctuations of dispatching time of analyzed bus line (working days)

A significant variance according to the time of the day can be pointed out to or from city center.

The variance is higher in the morning peak hours.
## Dispatching irregularity data

<table>
<thead>
<tr>
<th></th>
<th>from city centre</th>
<th>to city centre</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mean</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>213</td>
<td>211</td>
</tr>
<tr>
<td><strong>median</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td><strong>standard deviation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>240</td>
<td>180</td>
</tr>
<tr>
<td><strong>variation coefficient (vc)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>1.127</td>
<td>0.853</td>
</tr>
</tbody>
</table>

Higher dispersion from city center due to similar characteristics of travel time on the opposite way (to city center, *as will be seen later*)
Dispatching irregularity analysis

State of the Art

Bus service punctuality can be analyzed through several methods:

➢ **state-based methods** (Markovian estimation models and Kalman filters),

➢ **time series models** (including decomposition-based and exponential smoothing-based methods and ARIMA models),

➢ **machine learning and regression models** (including, for example, artificial neural networks).

(e.g. Rajbhandari 2005; Swardo et al., 2010; Chen et al. 2012; ....)
Dispatching irregularity analysis

Does a systematic nature in time exist?

➢ If yes, time series based models could be a powerful tool to analyse repetitiveness in time
Dispatching irregularity analyses: experimental evidences

Data analysis

\[ Y_t = f(T_t, S_t, E_t) = T_t + S_t + E_t \]

✓ \( Y_t \) observed value at time \( t \) (actual \( vS \) scheduled departure time)
✓ \( S_t \) seasonal component at time \( t \)
✓ \( T_t \) containing both trend and cycle at time \( t \)
✓ \( E_t \) remainder component at time \( t \)
Dispatching irregularity analyses: experimental evidences

Decomposition

STL decomposition with weekly period (February – March 2015)

to city center
Dispatching irregularity analyses: experimental evidences

*Decomposition – to city center*

STL decomposition with weekly period (February – March 2015)

**Trend component**

trends/cycles are **quite flattened** with a small difference between maximum and minimum values: *less than 30 seconds both to and from city center.*
Dispatching irregularity analyses: experimental evidences

Decomposition

STL decomposition with weekly period (February – March 2015)

The effects of daily seasonality emerge for all days with higher values from city center on Tuesday and Wednesday (probably due to late arrival times of buses).

to city center

from city center
Dispatching irregularity

✓ Comparing the seasonality of both time series, different temporal patterns to and from the city center emerge:

Higher values for runs departing from center
Dispatching irregularity

Departure from city center – seasonal component

• five time periods emerge:

✓ before 8am (starting service): irregular dispatching (late starting service)
✓ 8am to 10am (morning peak hours): high value of dispatching irregularity
✓ 10am to 4pm (off peak hours): not significant irregularity
✓ 4pm to 7 pm (evening peak hours): similarly on the morning but more limited
✓ after 7pm (closing service): closing operations
Dispatching irregularity

Departure to city center - seasonal component

Different pattern — low fluctuations quite around zero
Dispatching irregularity

Departure to city center - seasonal component

Different pattern – quite homogeneous with fluctuations

Does this difference depend on travel times to city center (i.e. late arrivals of buses)?
Dispatching irregularity and Travel time dispersion

Is irregularity related to travel time dispersion patterns?

The previous results were hence compared with the results of similar analyses on bus terminal-to-terminal travel time series (Comi et al., 2017).

Main findings for terminal-to-terminal travel time decomposition: *the contribution of trend/cycle to stochasticity is low, while a daily seasonality effect emerges in both direction (i.e. from and to the city center).*
## Bus travel time data

<table>
<thead>
<tr>
<th></th>
<th>from city centre</th>
<th>to city centre</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mean</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>2357</td>
<td>2421</td>
</tr>
<tr>
<td><strong>median</strong></td>
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<td></td>
</tr>
<tr>
<td>daily</td>
<td>2364</td>
<td>2420</td>
</tr>
<tr>
<td><strong>standard deviation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>446</td>
<td>554</td>
</tr>
<tr>
<td><strong>variation coefficient (vc)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>0.189</td>
<td>0.196</td>
</tr>
</tbody>
</table>

High dispersion of travel time to city center influence dispatching irregularity from city center *(as seen earlier)*
Irregularity *and* travel time

*Departure from city center*
Irregularity *and* travel time

*Departure from city center*

Peak in travel time causes peak in dispatching irregularity

from city center

the runs tend to depart with a **higher discordance** of scheduled time, during morning peak-hour due to **longer travel time of runs travelling to the center**.
Irregularity and travel time

Departure to city center
Going to the city center, lower values of irregularity were revealed according to lower congestion of vehicles coming from city center in the morning (i.e. 8 – 10 am).

A strong dependence on travel time emerges:
- Due to low mean and standard deviation of travel time of buses from center the dispatching is more regular.
Dispatching irregularity and travel time

Main findings

✓ the increasing of irregularity has a pattern similar to travel time, which is strictly related to traffic flow pattern;

✓ during the hours of over-congestion, small variations of flows cause high variations of travel time and hence fluctuations, more than increasing of delay of buses which share the lanes. Therefore, it determines an increase of variance of arrival delays at stops and at terminal;

✓ late bus arrivals causes the increasing of dispatching irregularity in the opposite direction of routes.
Conclusions

First indications towards suitable strategies and measures

✓ Attention should be paid to **systematic** on-time failures. The return of service to schedule could be done by

- changing run times or
- adding layover times or
- adding more buses to have lower the $\alpha$ percentage (e.g. maximum allowed shared of delayed runs).
The road ahead

✓ Generalization of such results through the analyses of other lines

✓ Analyses of non-systematic components

✓ Definition of indications for sustainable strategies and measures pointing out operations costs and travellers’ disutility