PondiônsTracker: A framework based on GTFS-RT to identify delays and estimate arrivals dynamically in Public Transportation Network

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Introduction

Motivation

- Public Transportation Network
- Smart cities
- GTFS and GTFS-RT specifications

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Motivation

GTFS-RT Matching Identifiers Issue

To work with GTFS-RT, it is **required** to track vehicles in real-time. But, in some cases, it is not easy to match the identifier between a real-time record and the GTFS static data. In Rome in 2016, this issue was reported by Raghothama et al. (2016). We still face this issue in Belo Horizonte in 2023.

Objectives

Main Objective

- Proposing and validating PondiônsTracker

Specific Objectives

- Collecting data from the real-time API and combining with the GTFS
- Understanding if Belo Horizonte's delays are spatial and temporal dependent by analyzing delays among bus stops
- Comparing the arrival times defined at the GTFS with the arrival times generated by *PondiônsTracker*.

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Smart Cities

Definition

Nam and Pardo 2011 describe a smart city is a city whose "data infuses information into its physical infrastructure to improve conveniences, facilitate mobility, add efficiencies, conserve energy, improve the quality of air and water, identify problems, and fix them quickly, recover rapidly from disasters, and collect data to make better decisions, deploy resources effectively, and share data to enable collaboration across entities and domains".

Smart Cities

Urban Computing

Interdisciplinary toolkit that uses the data generated in urban spaces by multiple sources to tackle issues that a city could face.

- Transportation, health, and tourism
- Sensors, devices, vehicles, buildings, and humans

Human Mobility

Human mobility aims to study the movement of humans through time and space. And its impacts on the environment.

- **Why do people migrate?**

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General Transit Feed Specification (GTFS)

Definition

Defines a common format for public transportation schedules and associated geographic information

Main ideas

- Open Data
- Many Apps, SDKs, libraries, and tools

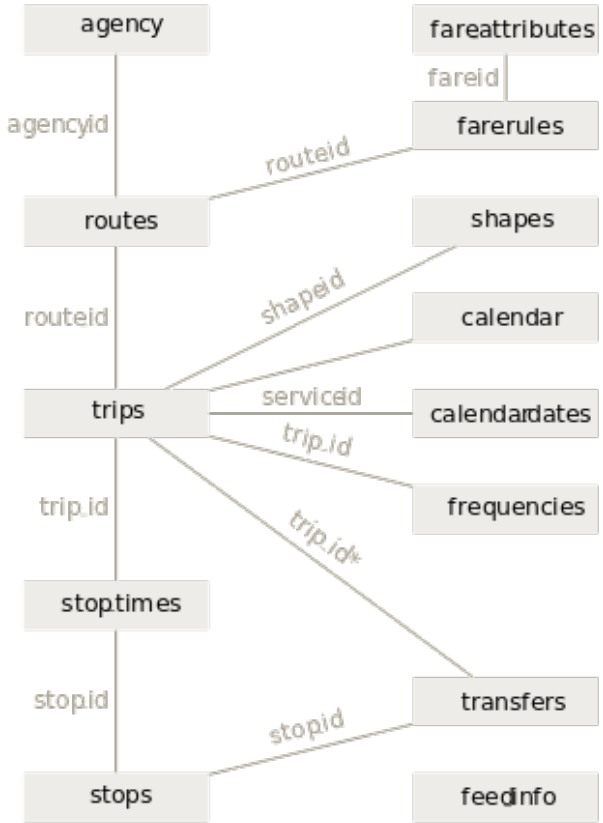

Figura: GTFS class diagram

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General Transit Feed Specification Real-Time (GTFS-RT)

GTFS-RT

GTFS-RT is the real-time extension to GTFS. GTFS-RT allows public transportation agencies to provide real-time updates about:

- Trips
- Services
- Vehicles

Complex Networks and Graphs

Definition

Bacciu et al., 2020 state that "a graph has a compositional nature, being a compound of atomic information pieces and a relational nature, as the links defining its structure denote relationships between the linked entities".

- $g = (V_g, E_g, X_g, A_g)$

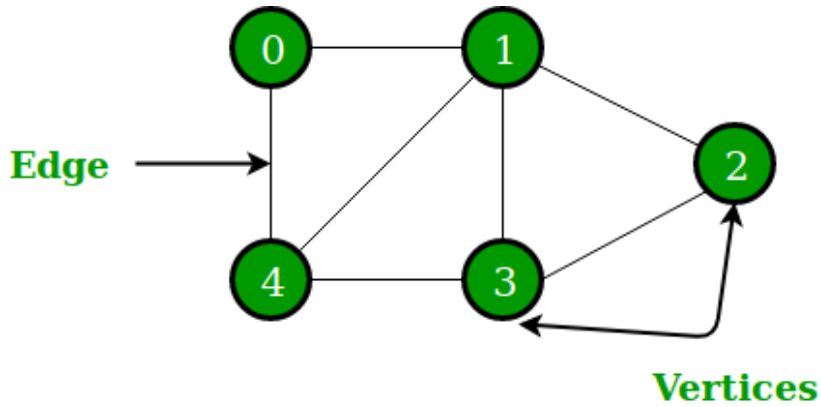

Figura: Example of an undirected graph

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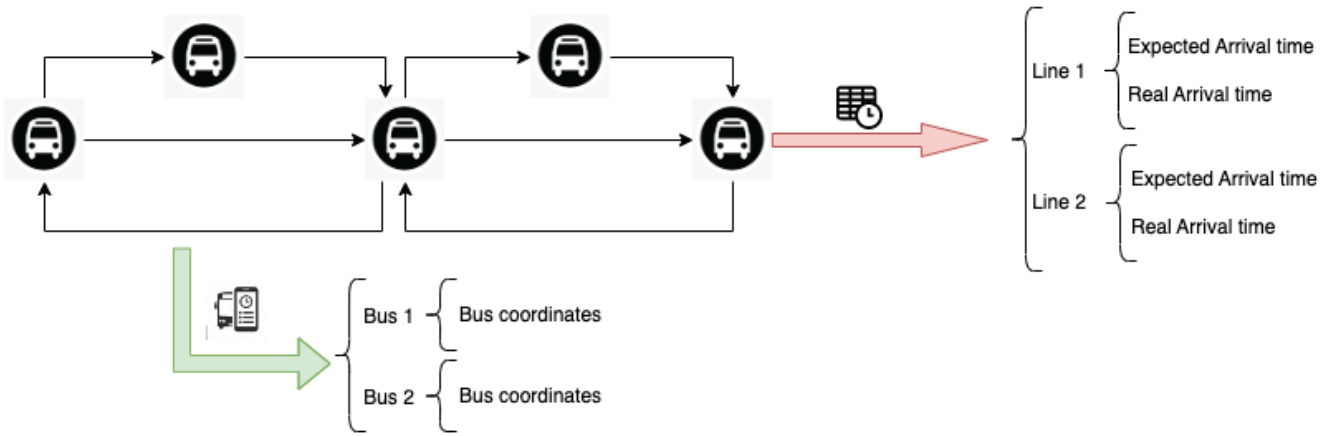
Public Transportation Network as a Complex Network

$$G^{l} = (V_g, E_g, X_g, A_g)$$



G^{l}: Graph G at a given time l

V_g: Bus stops

E_g: Routes connecting two bus stops

X_g: Additional information about bus stops (V_g)

A_g: Additional information about routes connecting two bus stops (E_g)

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PondiônsTracker

Overview

PondiônsTracker[a] is a framework to enrich GTFS data with real-time data. The name *PondiônsTracker* is a small gag from the sonority of the expression *bus stop* when pronounced in Portuguese with the accent from Minas Gerais.

[a] Available at `https://github.com/Pongelupe/PondionsTracker/`

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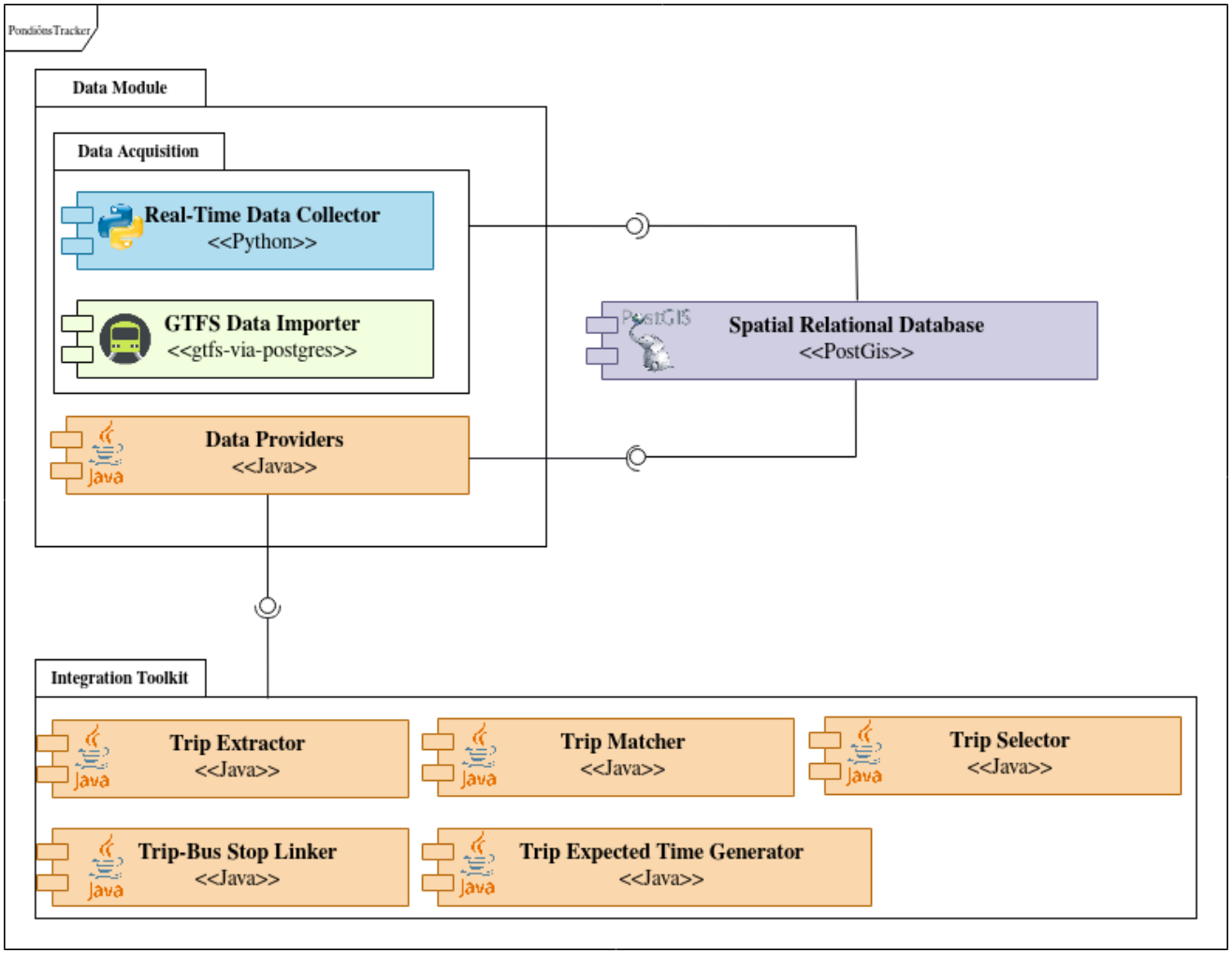
PondiônsTracker's Architecture



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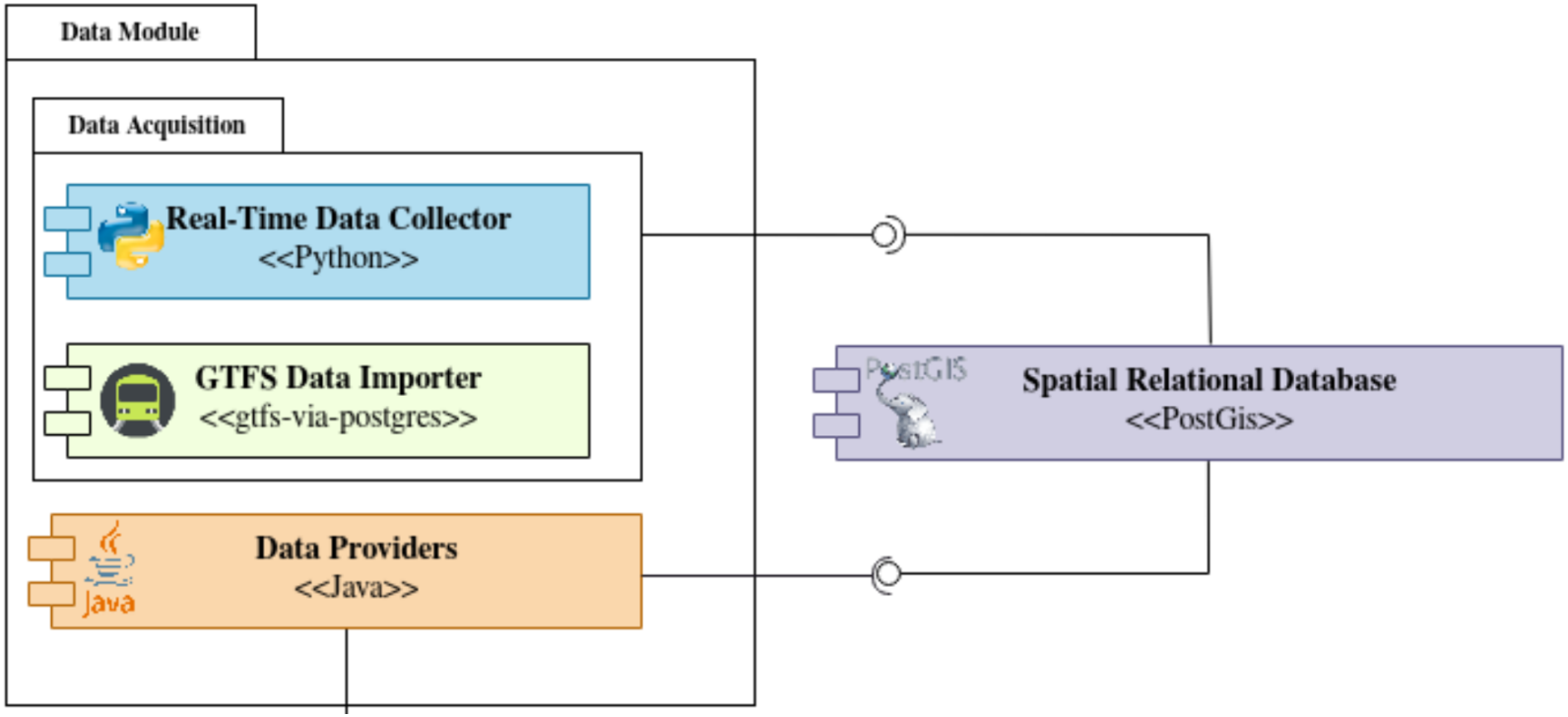
Data Module Overview



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Data Providers

```
1  <dependency>
2    <groupId>br.pondionstracker</groupId>
3    <artifactId>data-module</artifactId>
4    <version>1.0.0</version>
5  </dependency>
```

Figura: *DataModule*'s maven dependency

Integration Module

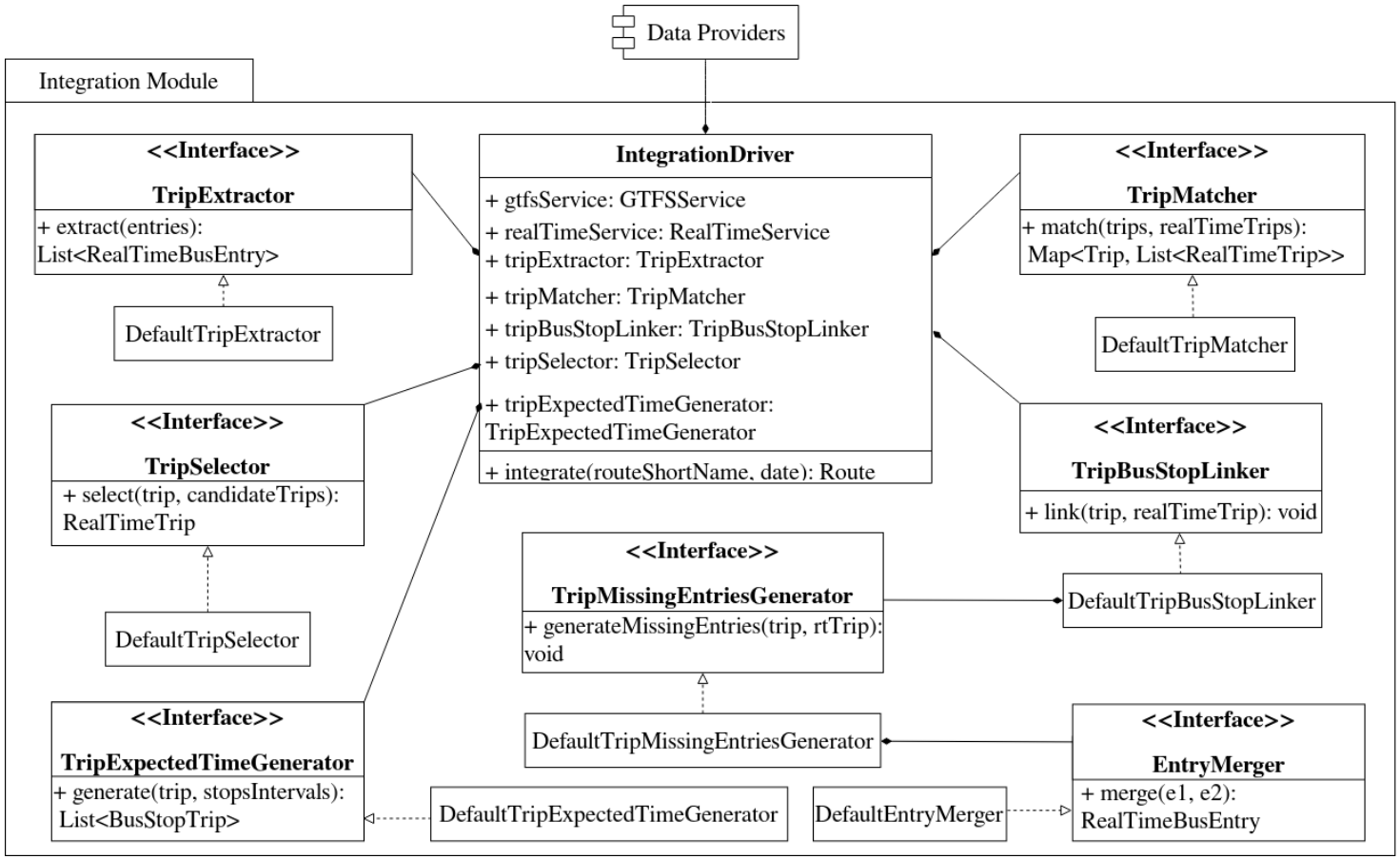

Figura: Integration Module Class Diagram

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Integration Driver

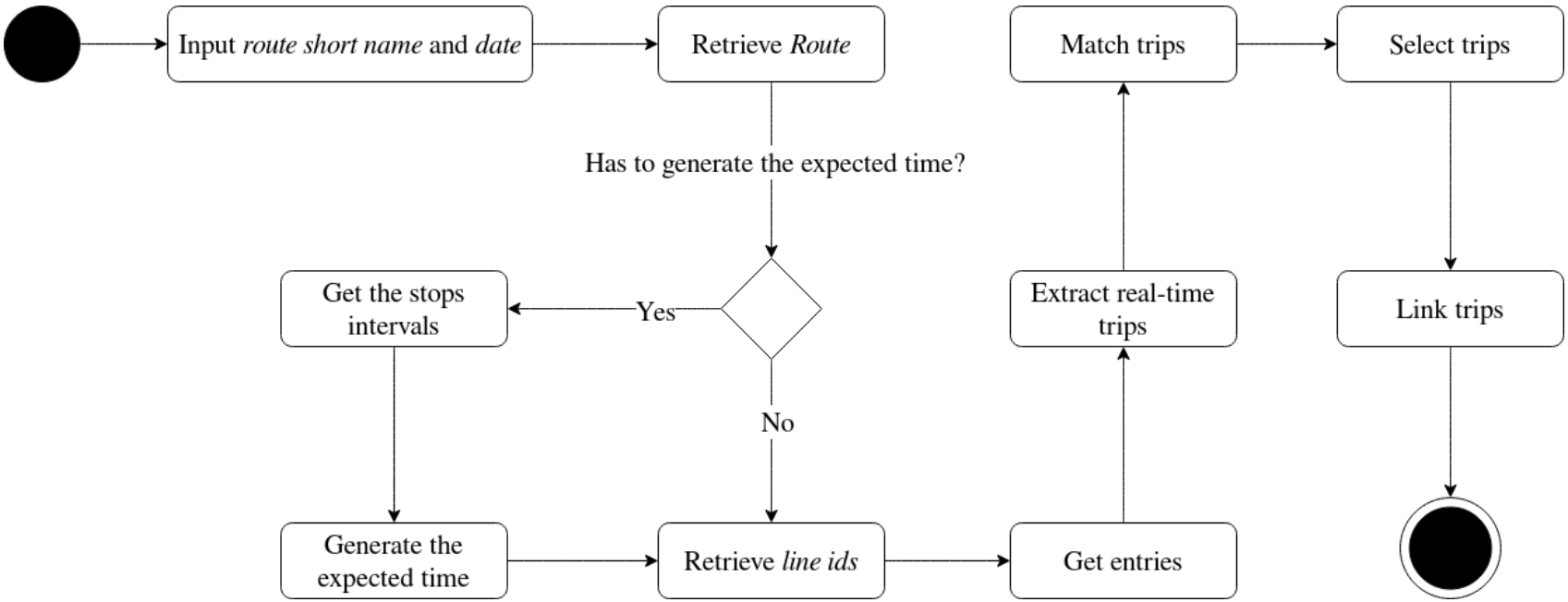

Figura: Integration Driver Activity Diagram

Integration Driver - 1st Step

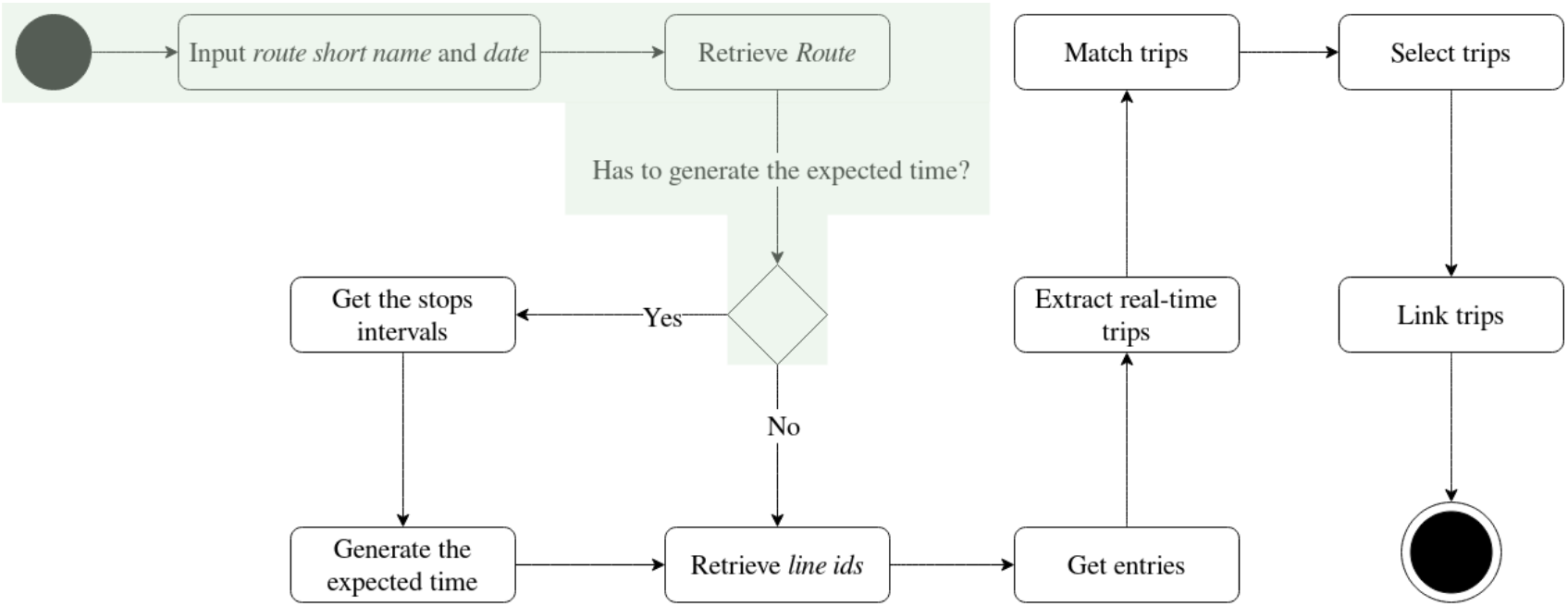

Figura: Integration Driver Activity Diagram

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Has to generate the expected time?

`arrival_time`	Time	Conditionally required	Arrival time at a specific stop for a specific trip on a route. If there are not separate times for arrival and departure at a stop, enter the same value for `arrival_time` and `departure_time`. For times occurring after midnight on the service day, enter the time as a value greater than 24:00:00 in HH:MM:SS local time for the day on which the trip schedule begins. Scheduled stops where the vehicle strictly adheres to the specified arrival and departure times are timepoints. If this stop is not a timepoint, it is recommended to provide an estimated or interpolated time. If this is not available, `arrival_time` can be left empty. Further, indicate that interpolated times are provided with `timepoint=0`. If interpolated times are indicated with `timepoint=0`, then time points must be indicated with `timepoint=1`. Provide arrival times for all stops that are time points. An arrival time must be specified for the first and the last stop in a trip.

Figura: *arrival_time* definition from *stop_times.txt*

Integration Driver - 2nd Step*

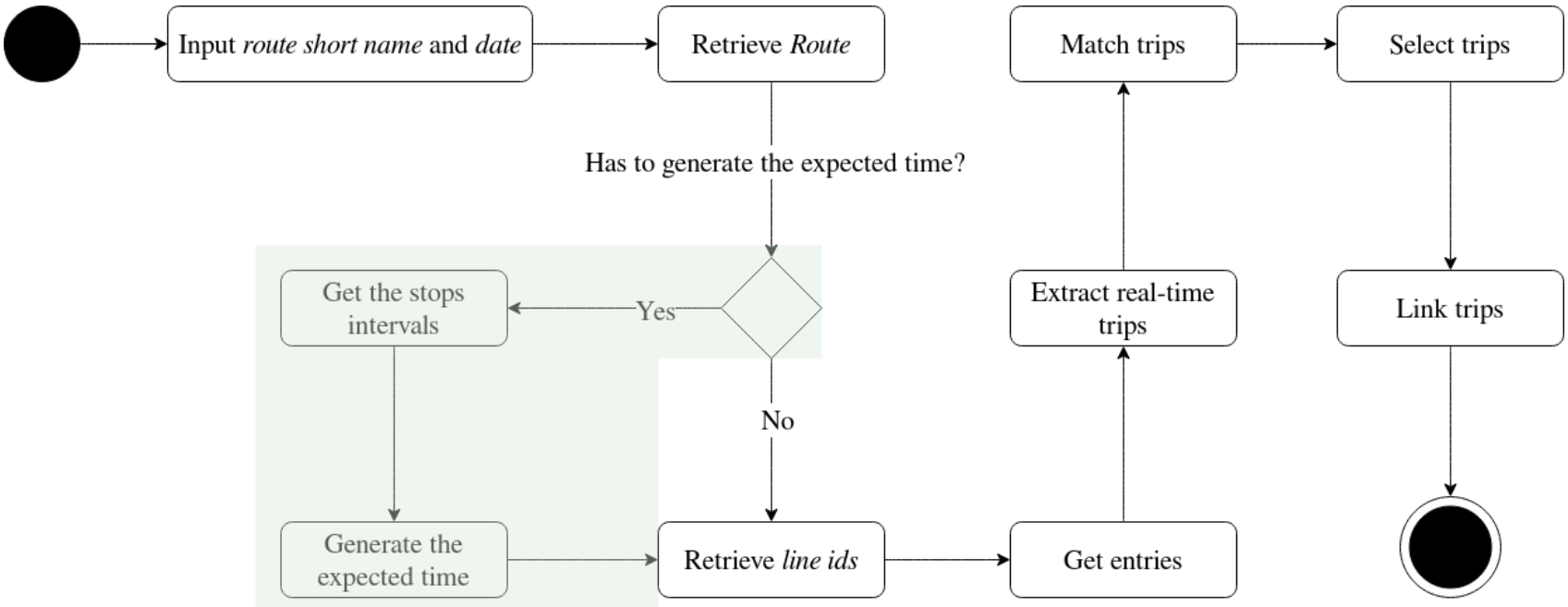

Figura: Integration Driver Activity Diagram

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Integration Driver - 3rd Step

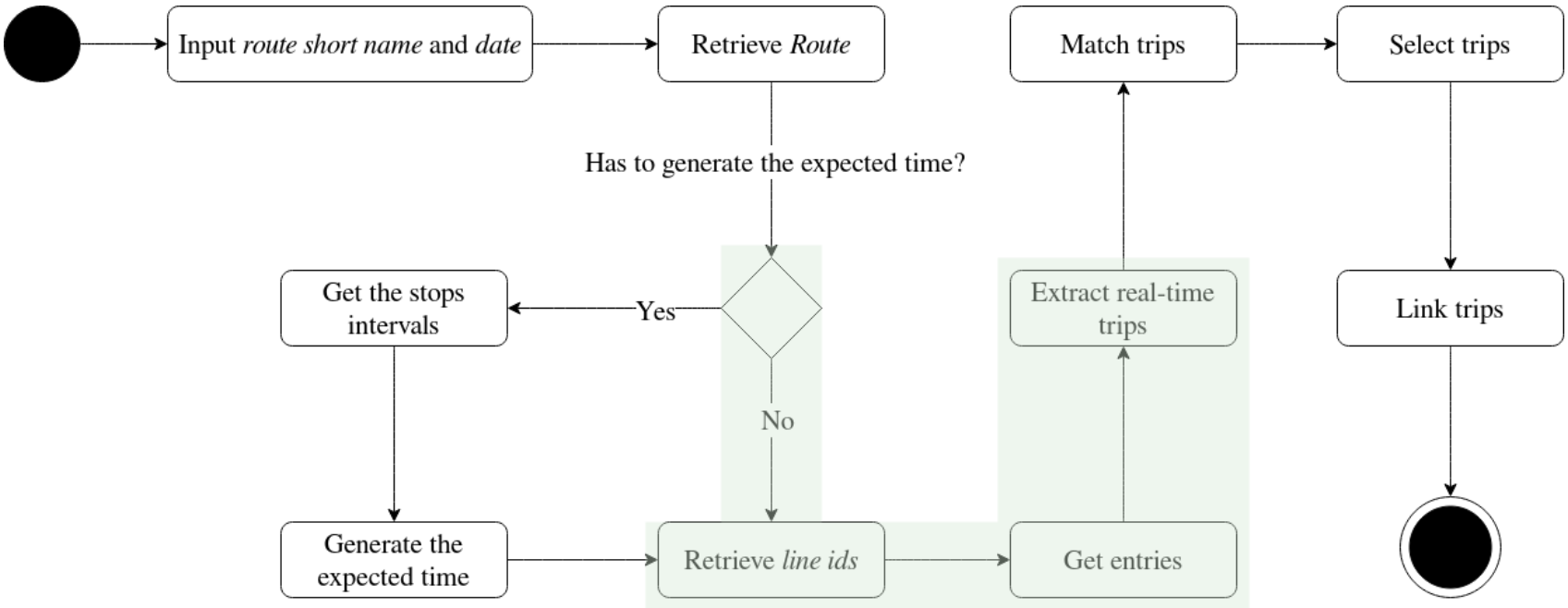

Figura: Integration Driver Activity Diagram

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Integration Driver - 4th Step

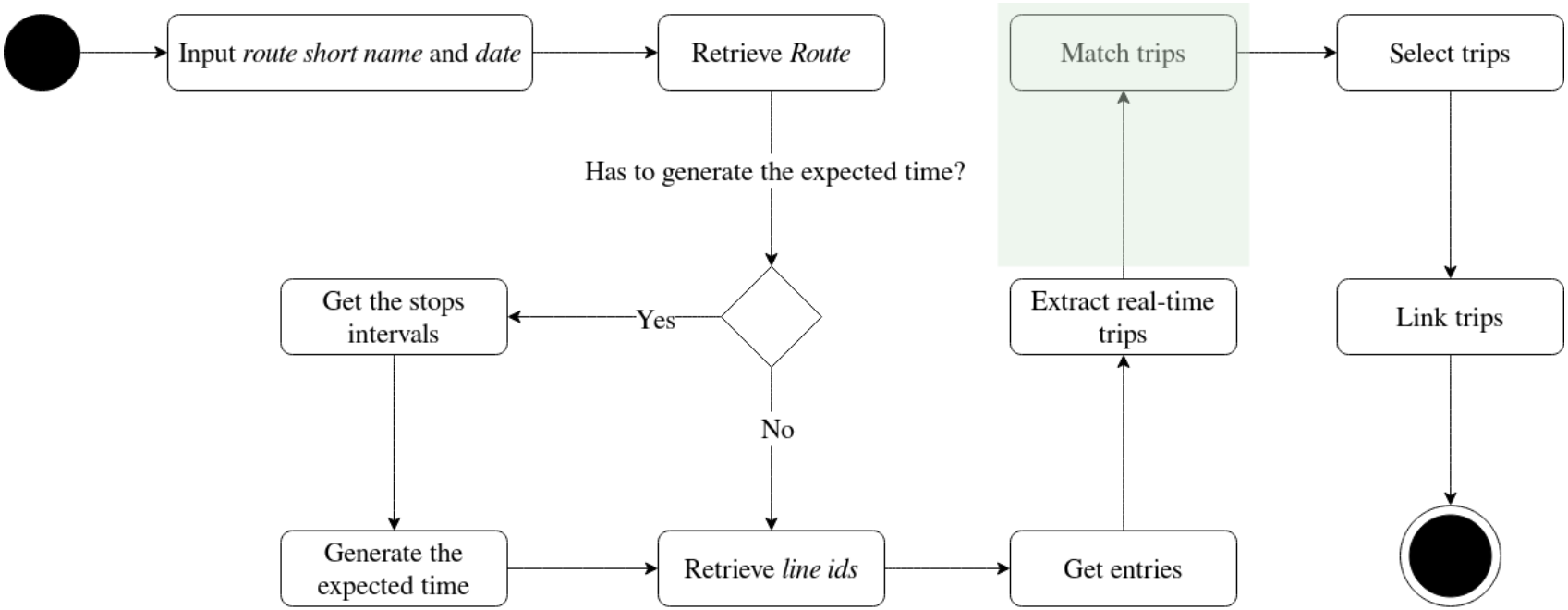

Figura: Integration Driver Activity Diagram

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Integration Driver - 5th Step

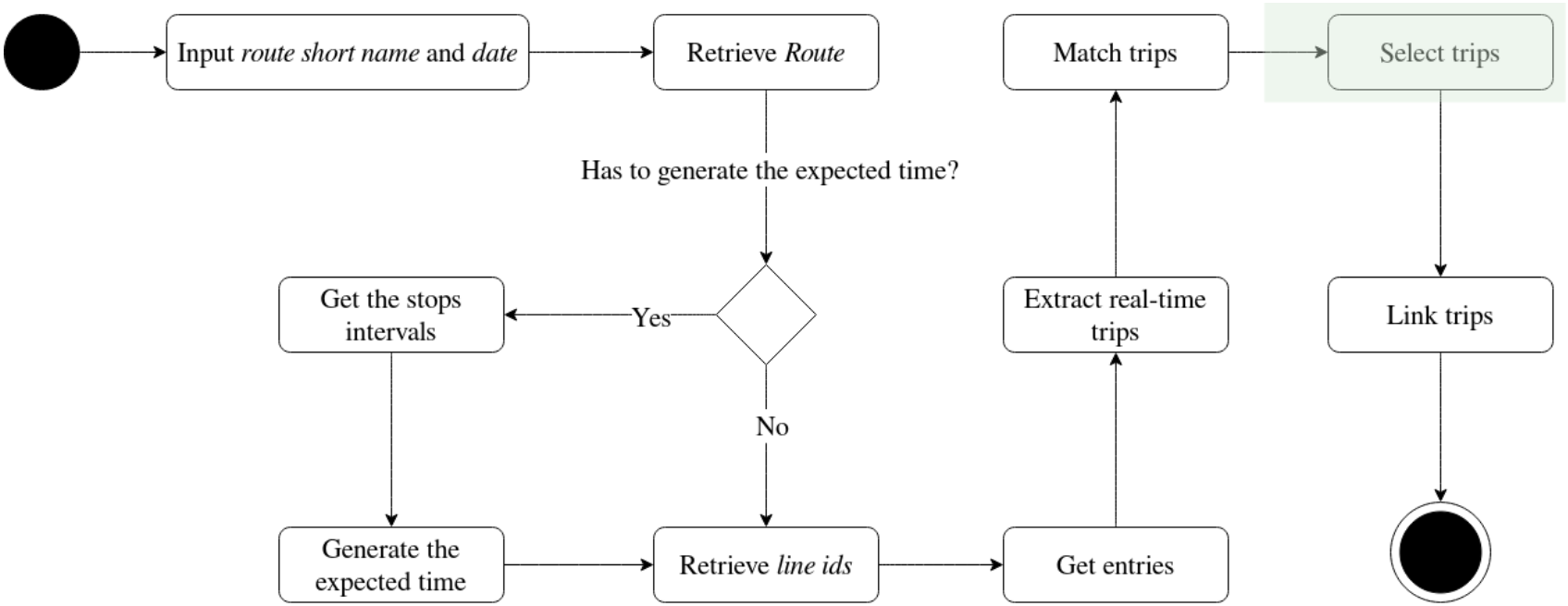

Figura: Integration Driver Activity Diagram

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Integration Driver - 6th Step

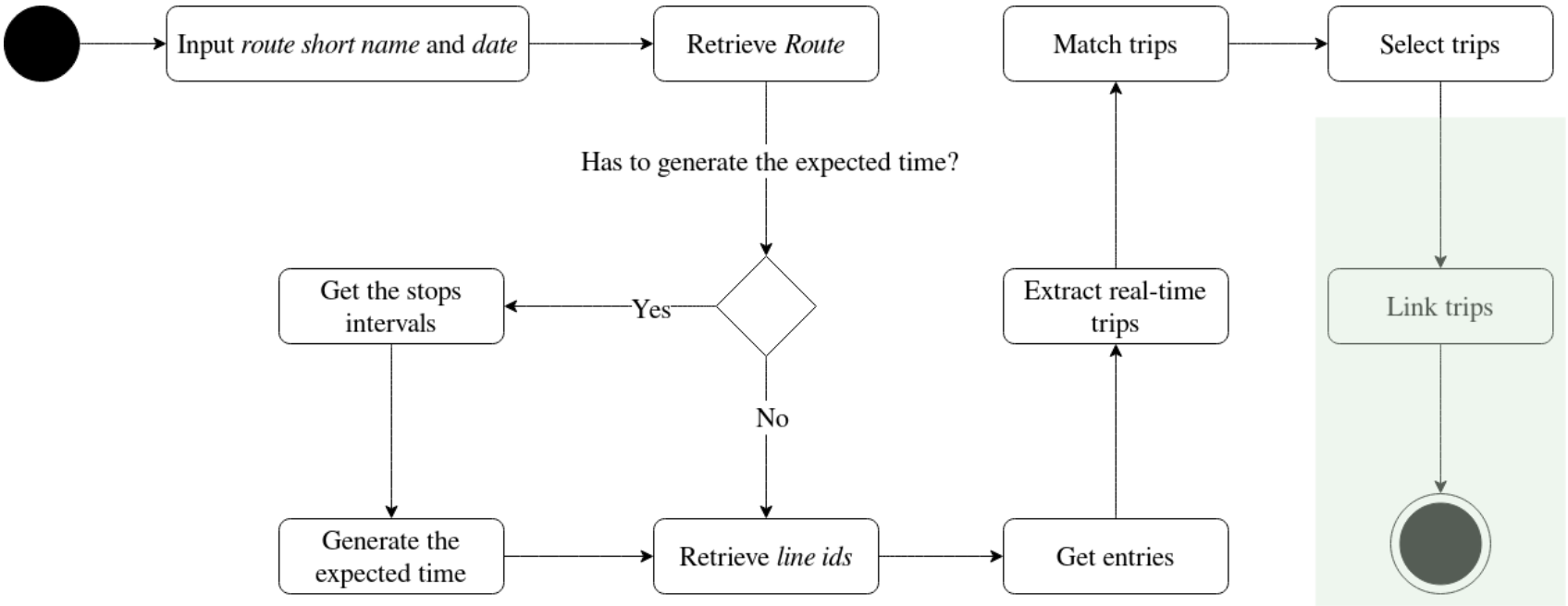

Figura: Integration Driver Activity Diagram

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Integration Module

```
1  <dependency>
2    <groupId>br.pondionstracker</groupId>
3    <artifactId>integration-module</artifactId>
4    <version>1.0.0</version>
5  </dependency>
```

Figura: *IntegrationModule*'s maven dependency

PondiônsTracker-BH

Overview

PondiônsTracker-BH[a] is our *PondiônsTracker*'s specialization to deal with Belo Horizonte's Network. So, we have implemented our own *Real-Time Data collector*, and we have overwritten a method from the *RealTimeService* from the *DataProviders*.

[a] Available at `https://github.com/Pongelupe/PondionsTracker-BH`

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Belo Horizonte's RealTimeService

BHRealTimeService - getIdsLineByRouteId

This happens due to a **one-to-many** relationship between the GTFS and the real-time data.

- *BHTrans* $\rightarrow$ *GTFS*
- *Transfacil* $\rightarrow$ *Traffic API*

Workload Overview

Workload

- Data collected for 11 days straight in August 2023
- 30 Gigabytes

Date	Day-of-Week	Entries
29-07-23	Saturday	22,319,765
30-07-23	Sunday	22,635,117
31-07-23	Monday	22,583,380
01-08-23	Tuesday	22,432,739
02-08-23	Wednesday	21,970,073
03-08-23	Thursday	22,050,579
04-08-23	Friday	22,402,865
05-08-23	Saturday	22,642,955
06-08-23	Sunday	22,786,254
07-08-23	Monday	22,109,606
08-08-23	Tuesday	22,405,222
Total	-	**246,338,555**

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Schedule Analysis

Schedule-Filled Percentage

Schedule-Filled Percentage = **Matched Trips** / **Scheduled Trips**

- **Total**: 156,628 / 205,884 = 76.08%
- **Weekdays**: 118,559 / 159,418 = 74.37%
- **Saturdays**: 22,796 / 28,200 = 80.84%
- **Sundays**: 15,273 / 18,266 = 83.61%

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Schedule Analysis - Schedule Deviations

Schedule Deviations

Regarding the real-time API, there are collected trips which were not defined at Belo Horizonte's GTFS.

82 - Estação São Gabriel / Savassi Via Hospitais

On Sundays, the GTFS does not schedule any trip for route 82, but the API provided entries regarding this route twice during the period observed.

Delay Analysis

Delay Notation

- **Delay**: $\geqslant$ 1 minute after
- **Ahead-of-Schedule**: $\geqslant$ 1 minute before
- **On time**: $\leqslant$ 59 seconds after OR $\leqslant$ 59 seconds before

	Weekday	Saturday	Sunday
Total trips matched	118,559	22,796	15,273
Trips entirely out of schedule	60,244	10,899	7,148
Trips with departure or arrival on time	39,403	8,731	5,988
Trips with departure and arrival on time	324	95	56
Trips entirely on time	1	2	1

Figura: Delays detailed in whole Public Transportation Network scale

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Delay Analysis

331 - Estação Barreiro/Conjunto Antonio Teixeira Dias Via Upa

Has 32 bus stops, representing a length of almost 9 kilometers.

1. Jul. 29 15:30:00 - 15:56:27 $\longrightarrow$ Jul. 29 15:30:03 - 15:57:03
2. Jul. 30 08:20:00 - 08:46:27 $\longrightarrow$ Jul. 30 08:20:31 - 08:46:15
3. Aug. 04 05:40:00 - 06:06:27 $\longrightarrow$ Aug. 04 05:40:30 - 06:06:00
4. Aug. 05 17:10:00 - 17:36:27 $\longrightarrow$ Aug. 05 17:10:45 - 17:36:49

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Delay Analysis

Distribution of each status over the network

- **Delay**: 89.8%
- **Ahead-of-Schedule**: 6.9%
- **On time**: 3.3%

Attention!

The predominance of *DELAYED* in the Public Transportation Network **does not imply** that the network is not working nor completely stopped!

Delay Analysis

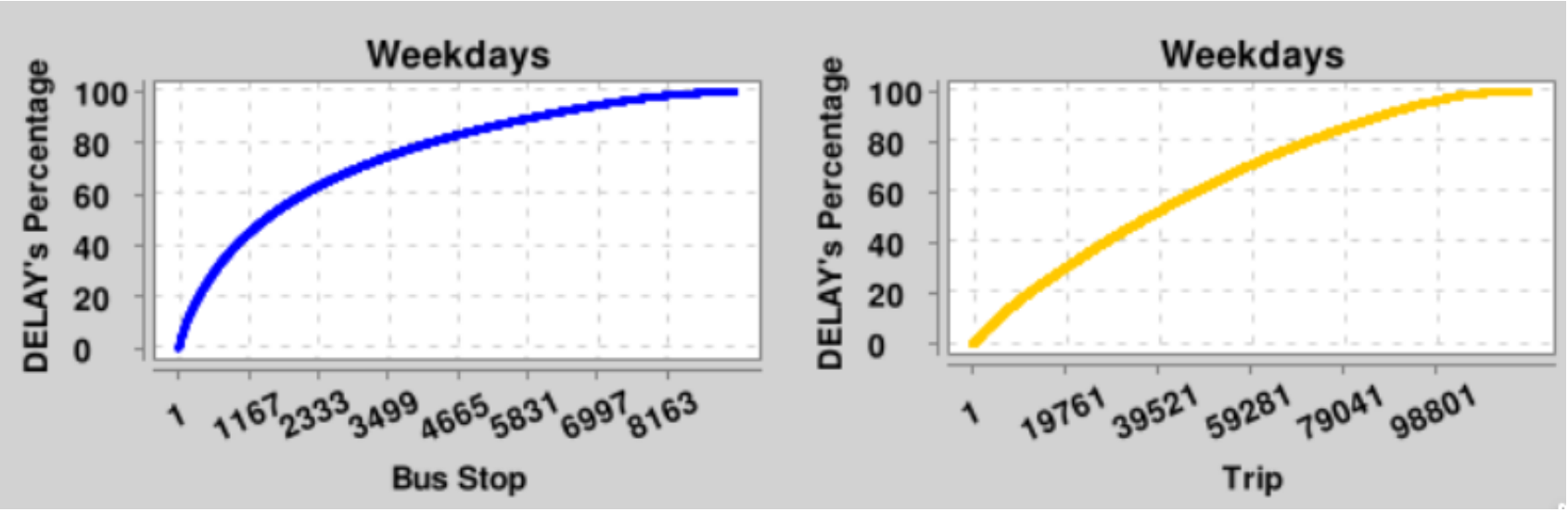

Figura: *DELAY*s Distribution: Bus Stop and Trip

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Delay Analysis

Figura: 300 Most Delayed Stops

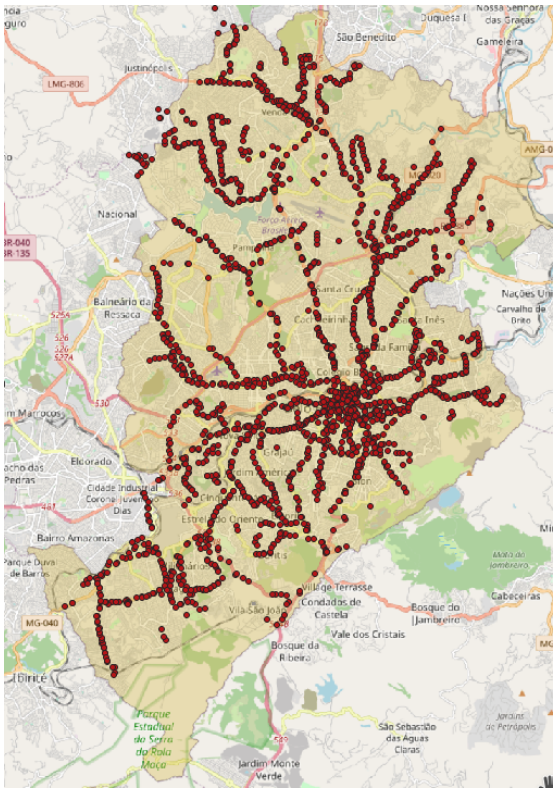

Figura: Fragment of the 50 Most Delayed Stops

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Delay Analysis

Three Most Delayed Stops for Weekdays

1. #14793268 - *Avenida Dom Pedro II 1520* with 7,309 delays
2. #14791617 - *Avenida Amazonas 7309* with 7,009 delays
3. #14790997 - *Avenida Dom Pedro II 1980* with 6,692 delays

Constants

1. *Global Ahead Average*: 13.42 minutes
2. *Global Delay Average*: 20.49 minutes

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Delay Analysis

Stops #14793268 and #14790997

The stops #14793268 and #14790997 are the first and third most delayed in the Public Transportation Network, respectively. Also, these stops are **462** meters from each other on the same avenue, *Avenida Pedro II*, and share **2,590** common trips, so they are spatially related.

Local Out-Of-Schedule Average

- #14793268: 19.29 minutes
- #14790997: 19.68 minutes

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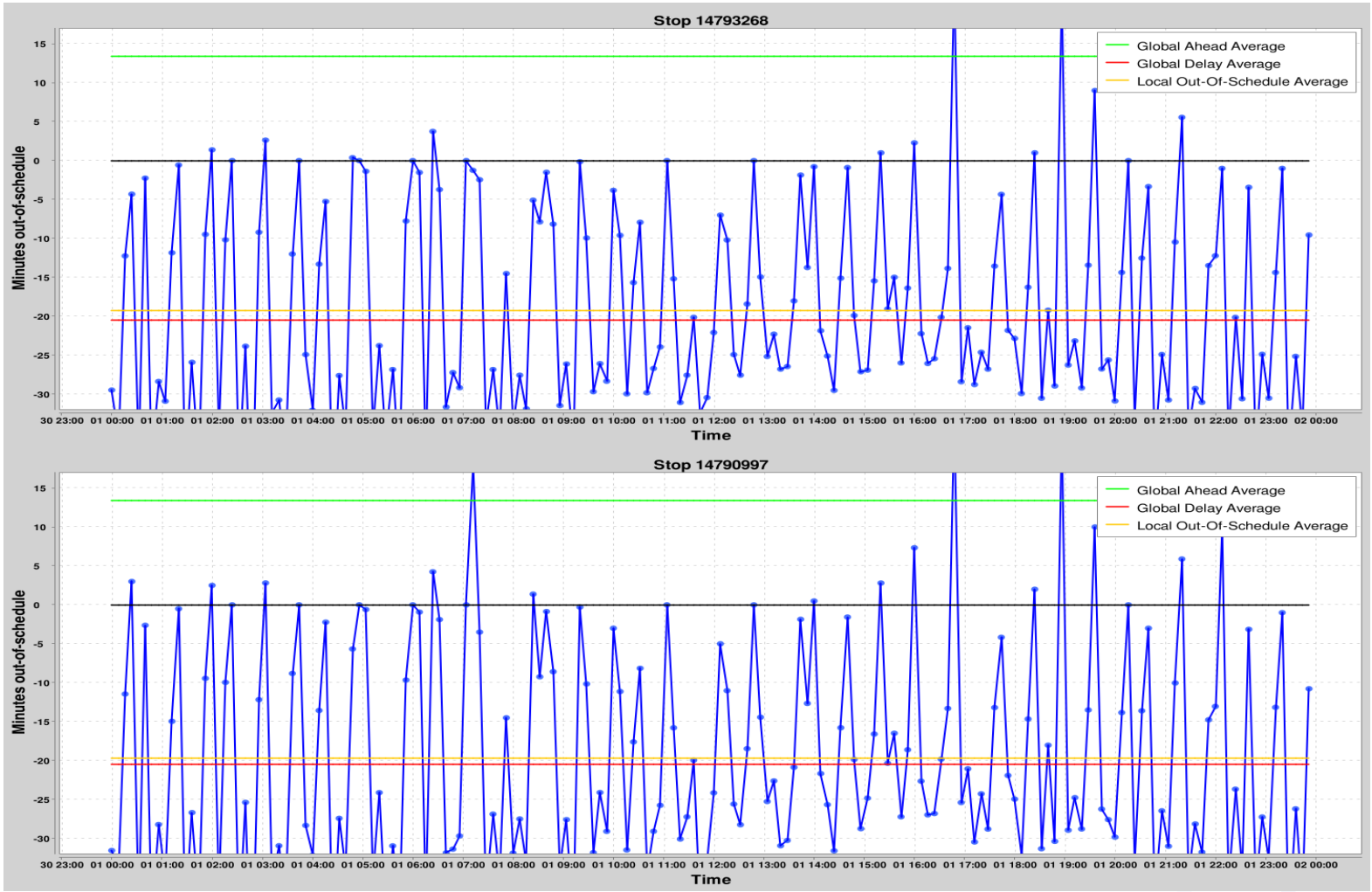
Delay Analysis



Comparison Between Generated and Real Data

Overview

The previous analysis was only possible because Belo Horizonte's GTFS defines the expected time for all bus stops on every trip. The *Trip Expected Time Generator* generates the expected times when missing, so, we executed this component with Belo Horizonte's data and compared the expected times generated with those defined at the GTFS.

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Comparison Between Generated and Real Data

Trip entirely out of schedule

- GTFS: 78,291
- Generated: 75,073
- **Diff**: 3,218 (**4.29%**)

Trip entirely on time

- GTFS: 4
- Generated: 0
- **Diff**: 4 (**100%**)

Trips with departure **or** arrival on time

- GTFS: 54,122
- Generated: 54,271
- **Diff**: 149 (**0.27%**)

Trips with departure **and** arrival on time

- GTFS: 475
- Generated: 596
- **Diff**: 121 (**25.47%**)

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Comparison Between Generated and Real Data

		GTFS	Generated
Weekday	*ON_TIME*	3.3%	3.2%
	AHEAD_OF_SCHEDULE	6.9%	17.8%
	DELAYED	89.8%	79.0%
Saturday	*ON_TIME*	3.9%	3.5%
	AHEAD_OF_SCHEDULE	6.5%	18.4%
	DELAYED	89.6%	78.1%
Sunday	*ON_TIME*	4.4%	3.9%
	AHEAD_OF_SCHEDULE	5.4%	18.5%
	DELAYED	90.2%	77.6%

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Comparison Between Generated and Real Data

Global Averages

- *Global Ahead Average*
  - GTFS: 13.42 minutes
  - Generated: 38.57 minutes
  - **Diff**: 25.15 minutes
- *Global Delay Average*
  - GTFS: 20.49 minutes
  - Generated: 24.75 minutes
  - **Diff**: 4.26 minutes

Local Out-Of-Schedule Average

- #14793268
  - GTFS: 19.29 minutes
  - Generated: 15.54 minutes
  - **Diff**: 3.75 minutes
- #14790997
  - GTFS: 19.68 minutes
  - Generated: 14.68 minutes
  - **Diff**: 5 minutes

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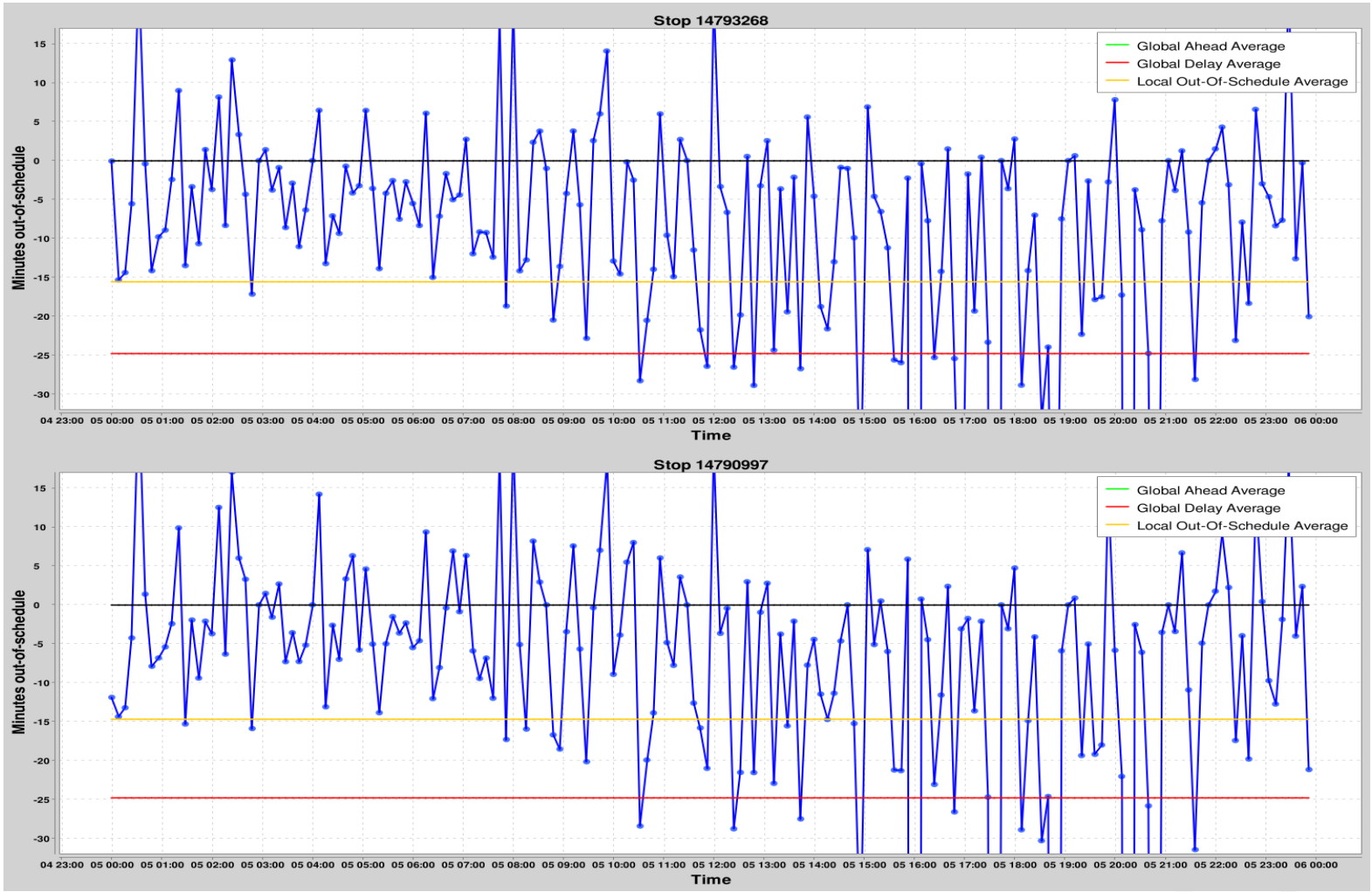
Comparison Between Generated and Real Data



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Limitations

Limitations

The *Real-Time Data Collector* is the most fragile component due to the third-party real-time traffic API interface.

- Size and quality of the data
- Scheduled routes with no entries reported
  1. *720 - Circular Saúde MG20* missed 175 trips
  2. *912 - Conjunto Taquaril/Praça Che Guevara* missed 210 trips

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Conclusion

Concluding Remarks

- Comparison between the expected schedule with the actual schedule
- Delays in Belo Horizonte follow a *log-normal* distribution
- Analysis using data generated with the *Trip Expected Time Generator*
- *PondiônsTracker* as a viable option when GTFS-RT is unavailable

Conclusion

Future Work

- Futher explore Belo Horizonte Public Transportation Network using deep learning for graphs approaches
- Reproduce Belo Horizonte's results with other cities
- Explore the delays analysis combining temporal and spatial dimensions

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Conclusion

Thanks!!