Big Data Analysis of Public Transportation Data

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Thesis - Rough Draft

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Author:

Aausuman Deep

Supervisor:

Dr. Alejandro Arbelaez

Second Reader:

Dr. Gregory Provan

**Abstract**

The data generated in the public transportation sector has an enormous potential to assist us in making key decisions to improve those services over which a vast majority of population depends for their travels and daily commutes. This can be achieved by properly cleaning, treating and processing the raw available data and extract relevant information through various analytical techniques.

In the following project, I have subjected a month of public bus network data of Dublin Ireland and performed a big data analysis over it to harness some important details that can help the concerned department in better understanding the service that they work with, how it is performing and whether there is any room for improvement. Since the data generated at each instant in this network is quite detailed, the level of data analysis that can be performed in this regard is also quite comprehensive. Therefore, usage of a proper big data technology was on the cards and this is why I have used Apache Spark on Hadoop as my main tool here.

The primary concerns related to public bus transportation networks is undoubtedly the delays with which they run on their respective lines throughout the day and the major factors which directly affect these delays, like congestions. An algorithm has been initially produced to identify the most affected lines by these delays, with stepwise delve into deeper and more detailed delay analysis. A prediction model has also been made on the expected arrival times of the buses in the future dates from the data that we have as our principal repository. Furthermore, another algorithm has also been formalized which is capable of handling real time data by the help of Spark streaming, to analyze data from second to second and give us valuable insights on to how the network is performing.

All this analysis has then been compiled by me in an attempt to give out a detailed explanation with minimal background knowledge required by the reader so that anyone reading this thesis document can understand the key insights I have presented in it and utilize this analysis for their own benefit.

**Keywords**

* Public Transportation Data
* Apache Spark
* Hadoop
* PySpark
* Spark Streaming
* Big Data Analysis

**Declaration**

I confirm that, except where indicated through the proper use of citations and references, this is my original work and that I have not submitted it for any other course or degree.

Signed: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Aausuman Deep

July 31, 2020

**Acknowledgement**

I would like to show the greatest appreciation to my supervisor Dr. Alejandro Arbelaez for guiding me through this project and for assisting me in the journey, considering we were miles apart in this current pandemic situation of Covid-19. His continued direction in progressing through this thesis, with the efficient scrutiny over my work with constructive feedback on a weekly basis over Microsoft Teams really helped me in completing this dissertation. This fulfilment won’t have been possible without him and for this I am deeply grateful.

I would like to thank Dr. Eric Wolsztynski and Dr. Micheal Cronin for aligning me with the industry level machine learning algorithms and data analysis techniques which form the backbone of any analysis project. I would also like to thank Dr. Gregory Provan who introduced me to Deep Learning mechanisms and how we can work with them by utilizing online computing platforms like Google Collaboration environment. This knowledge had assisted me in understanding the distributive nature of the technology I have used in this thesis. Finally, I would also like to mention Dr. Kieran Hurley, whose collective classes on Python and its various data specific capabilities laid the groundwork for me to choose PySpark as my technology in this thesis.

All the information that I gained and garnered here at UCC has cumulatively assisted me in performing the tasks I set out to do through the course of this dissertation and I appreciate everyone’s efforts for taking this venture with me.

**Dedication**

“Without effort, there are no rewards. And for the effort, we need support.”

I would like to dedicate this research thesis to my parents, without whose support and countless sacrifices, I would not have been able to achieve what I already have in life and whatever I achieve in the future.

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# Introduction

What ‘buzzwords’ have you heard while being associated in the information technology industry over the last few years? Every day when we open up our workstations and our phones and arrive at the feed where we obtain our daily dosage of information before getting ready for work, we come across a few repeated words which claim to be the next big thing in the technological industry. Artificial Intelligence, Internet of Things, Blockchain and Quantum computing are to name a few. Every couple of years one of these words creates a hype and seeds itself into the minds of each and every professional trying to make in the industry with an idea of their own. Now, I am not saying that they are over-hyped, but we have to admit, people have been working at them in one or the other way for years already and it seems just a fancy way of reigniting curiosity in us.

But, sometimes one of them comes along and sweeps us off our feet. “Big Data” was already huge by the time I associated myself with it, but to be honest it was worth the wait. I thought it was again one of those hyped up frameworks which will die down to normality eventually after people get bored off it, but it did not and that’s where its sheer potential was first revealed. If a technology, after flowing through each technical valley in the world, still managed to maintain its hype amongst those same people which discarded them like a used-up tissue, it was a real deal. And am I glad that I got into it.

The usage of predictive analytics dates back to the 1940s when governments began using early computers to carry them out. So, it’s easy to say that this is also a very fundamental area of technology, but the big data introduction in recent years has unlocked a whole new level of information processing that can be performed by us.

The need for processing the vast amounts of data being generated every minute in every industry is ever increasing. It is quite important to derive methods to reduce the production of redundant data in this data pool. Technologies are there at our disposal, but how we effectively use them is what makes an analytical algorithm into an analytical funnel. This extracted knowledge can then be used to perform further tasks for predictions and decision making.

As seen in the illustration above, the amount of big data generated increases every second, and we need to model out ways to identify relevant data out of it (this is called data cleaning – we will talk about this later) and after this subsequently we need to extract knowledge from that relevant data.

## What is Big Data?

Before we go any further in this thesis, let’s clarify what exactly is meant by Big Data. By its very definition, it comprises of a set of extremely large datasets that may be analyzed computationally to reveal patterns, trends and associations. It is formed by a combination of structured, semi structured or unstructured data.

When talking about Big Data, it’s 3Vs take the forefront in explaining its significance.

1. Volume – The huge volume of data in various environments.
2. Variety – The varied nature of the data types collected.
3. Velocity – The speed at which the data is generated, collected and processed.

These characteristics of Big data were introduced by Doug Laney on 6 February 2001, who at that time was an analyst at META Group. He highlighted a few facts in his article.

1. Within a year, organizations would increase their usage of a centralized data warehouse to align internal and external practices for a more standard driven approach.
2. In a couple of years, data quality and integration problems will be eradicated by data profiling technologies (for generating metadata).
3. In a span of 4-5 years, data, document and knowledge management will amalgamate through a single schema indexed strategy.

Considering all these practices have been brought to realism over the defined timelines and not only grown but exponentially evolved over the past couple decades, it is fair to say that this marked the birth of big data in a formal manner.

More recently, ‘Veracity’ has been added as the fourth V in this structure which signifies quality and value of data at hand.

The above illustration clearly defines the major associations with Big data and what they signify.

## Big Data Technologies

There are various technologies associated with big data. They are various software utilities that are capable of analyzing, processing and extracting information from an extremely large complex dataset. From the initial step of collection, across multiple stages of cleaning, transformation and processing to the end of decision making through predictions, the tasks needed to be done are immensely complicated.

Top big data technologies are divided into 4 major categories –

1. Data Storage
2. Data Mining
3. Data Analytics
4. Data Visualization

### Data Storage

Hadoop – A framework developed by Apache Software Foundation to store and process datasets on a distributed environment i.e. a collection of systems breaking up chunks of tasks for faster processing.

MongoDB – In comparison to basic rigid schemas of a relational database system like SQL, MongoDB offers a larger flexibility making it capable of handling large datasets of varied datatypes.

### Data Mining

Elasticsearch – A search engine based on Lucene library.

Presto – It is an open source distributed SQL query engine capable of running interactive analytic queries on data sources.

### Data Analytics

Kafka – It is a distributed streaming platform with 3 major capabilities – publisher, subscriber and consumer.

Spark –Another hugely popular tech with in memory computing capabilities to deliver high speed and a generalised execution model to support various types of applications.

### Data Visualization

Tableau – A hugely popular data visualization tool used in business intelligence industry.

Plotly – Another tool used for creating graphs in an efficient manner.

## Tools and Technologies being used in this project

In this project, considering the dataset that I have at hand, which I will elaborate upon in the next section, I have decided to utilise Spark for our big data analysis procedure. The sheer amount of data available had already made sure that a proper and efficient big data tool needs to be relied upon, after that it was just the point of identifying the right one. Apache Spark has already been a proven technology for handling big datasets with ease and its distributed nature would have undoubtedly made the tasks at hand a lot easier.

The public availability of the dataset, and our usage of just a month’s data has prevented us from using a database system like MongoDB.

For the choice of programming language, Python and its integration in the Spark environment as ‘PySpark’, made going along with it the easiest decision.

## Familiarization with our dataset

The dataset that we are working on in this thesis is the government provided data of bus network of the public transportation sector of Dublin, the daily commute lifeline of the multi-million people residing in the capital city of Republic of Ireland.

It has been published by the Dublin City Council onto the data.gov.ie website, which is the centralised government repository for all generally available data for usage by subsequent parties in Ireland and internationally located. The license with which this data is available is ‘Creative Commons Attribution 4.0 International’ which allows the users of these datasets to

1. Freely share – copy and redistribute the material in any medium or format.
2. Freely adapt - remix, transform, and build upon the material for any purpose, even commercially.

We are under one important term by using this data. Attribution — We must give appropriate credit, provide a link to the license, and indicate if changes were made. We may do so in any reasonable manner, but not in any way that suggests the licensor endorses us or our use. And hereby I have done exactly that by providing an insight as to where I exactly obtained this dataset and have clearly defined usage requirements.

Now, moving on to the data structure. The dataset have been provided to us in csv format.

Each datapoint (row in the CSV file) has the following entries:

1. Timestamp
2. Line ID
3. Direction
4. Journey Pattern ID
5. Time Frame
6. Vehicle Journey ID
7. Operator
8. Congestion
9. Lon
10. Lat
11. Delay
12. Block ID
13. Vehicle ID
14. Stop ID
15. At Stop

Following is a table showing a sample of the dataset that we have at our hand.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Timestamp | LineID | Direction | JourneyPatternID | TimeFrame | VehicleJourneyID | Operator | Congestion | Lon | Lat | Delay | BlockID | VehicleID | StopID | AtStop |
| 1.357E+15 | 747 | 0 | 7470001 | 31/12/12 | 3493 | SL | 0 | -6.236852 | 53.425327 | -709 | 747006 | 40040 | 7411 | 0 |
| 1.357E+15 | 27 | 0 | null | 31/12/12 | 3883 | RD | 0 | -6.233417 | 53.342232 | 0 | 27017 | 33521 | 395 | 0 |
| 1.357E+15 | 40 | 0 | null | 31/12/12 | 2226 | HN | 0 | -6.27825 | 53.416683 | 0 | 40206 | 33142 | 6071 | 0 |
| 1.357E+15 | 7 | 0 | 71003 | 31/12/12 | 6106 | D1 | 0 | -6.231633 | 53.317768 | 0 | 7019 | 43004 | 3222 | 1 |
| 1.357E+15 | 747 | 0 | 7471001 | 31/12/12 | 3531 | SL | 0 | -6.254617 | 53.355484 | -454 | 747007 | 40039 | 1445 | 0 |
| 1.357E+15 | 56 | 0 | 056A1001 | 31/12/12 | 1830 | RD | 0 | -6.233183 | 53.342201 | 0 | 56001 | 33488 | 2379 | 0 |
| 1.357E+15 | 25 | 0 | 025A0001 | 31/12/12 | 2866 | CD | 0 | -6.296867 | 53.3475 | 0 | 25007 | 33604 | 4604 | 0 |
| 1.357E+15 | 747 | 0 | 7470001 | 31/12/12 | 3493 | SL | 0 | -6.238668 | 53.425789 | -687 | 747006 | 40040 | 7411 | 0 |
| 1.357E+15 | 27 | 0 | null | 31/12/12 | 3883 | RD | 0 | -6.2334 | 53.342232 | 0 | 27017 | 33521 | 395 | 0 |
| 1.357E+15 | 4 | 0 | null | 31/12/12 | 4243 | HN | 0 | -6.279 | 53.416683 | 0 | 4001 | 43043 | 7226 | 0 |

As can be seen in each of the above, all the columns denote some significance to the dataset at hand. Delay column will be one of the most important variable of interest to us because it is the one which will be predicted, due to its relation to the actual performance of a bus network, once the appropriate model has been trained.

For the grouping scenario for division of dataset, I will be starting at the Line ID, because logically it will be the one which ideally separates the performance of the buses within their own defined patterns.

Let’s take a deeper look at all the columns defined above.

* Timestamp – It denotes the exact timestamp at which that particular row was collected.
* LineID – It denotes the numerical ID of the Line to which that particular row belongs to.
* Direction – It informs us of the direction that particular bus is running in. It is denoted by a 0 if the bus is going from the source station towards the destination station or 1 if the bus is going in the opposite direction towards the source.
* JourneyPatternID – It is a division within the LineID. Various kinds of patterns are predefined within a LineID and JourneyPatternID is there to present that exact information.
* Timeframe – Denotes the timeframe within which that particular row of data falls into. (The start date of the production timetable - in Dublin the production timetable starts at 6am and ends at 3am).
* VehicleJourneyID – It denotes a given run within a journey pattern.
* Operator – This denotes the Bus Operator initials (not to be confused with the driver)
* Congestion – This denotes that whether at that exact timestamp, the bus is experiencing any congestion on the route it is currently running on. It is 0 if no, otherwise 1 if yes.
* Lon – Longitude value in WGS84 format. WGS stands for World Geodetic System and it is a standard used in cartography and satellite navigation including GPS. WGS84 is an earth centered, earth-fixed terrestrial reference system falling under WGS.
* Lat – Latitude value in WGS84 format
* Delay – This signifies the delay with which the bus is currently running. It is negative if the bus is running ahead of schedule.
* BlockID – This denotes a section ID of the journey pattern.
* VehicleID – As the name suggests, it denotes the ID of the vehicle within this particular row of data.
* StopID – As the name suggests, it denotes the ID of the stop that the bus is closest to (usually the next stop, or the current stop it is standing on), with respect to the current row of data.
* AtStop – It denotes the status value whether a bus is at the stop it is showing in the previous column i.e. StopID, or not. It is 0 if no, otherwise 1 if yes.

The dataset available to us, is present in this similarly structured set of 31 csv files, all containing data of each individual day in the month of January 2013. Due to the large volume of data combined in these files, this dataset at our hand can be defined as big data. Approximately 44 million records are present in these files combined.

We are going to apply a few big data technologies, which have been discussed before to this dataset in order to fulfil our objectives. All of this will comprise of our methodology. However it is always a beneficial method to delve deep into previous works that have been done in the same field to get an idea on how the industry demands information pertaining to such problems.

I went through a few such research papers, which are all related to analysis of data in the public transportation sector. The information presented in them ranges from a simple analytical project to some deep layered architectural approaches. I will be reviewing those works in the next chapter. Let’s have a look.

# Literature Review

When we talk about the public transportation sector, the data generation points are numerous and they provide us with amazing opportunities of capturing some really interesting sets of data. If we think about this topic from a real world perspective, the rising population has led the people seeking some mode of transportation to move about. Granted, in current times of COVID-19, this is something we really can’t stress upon, but when life does go back to normality, this will always be a pressing matter. In this technological age that we live in, we will undoubtedly set up some sort of a pipeline where data is collected from these modes of transportations for various reasons, be it for analytical purposes or just surveillance. Everything from the person using the transportation to the functioning attributes of it will be extracted.

## Introduction to the problem statement

Everyone out there can’t afford a vehicle of their own. A majority of inhabitants of residential demographics depend on the public transportations that have been provided by their city councils and facilitated to them as there rights. These modes range from land, aquatic and airborne and some time or the other we do need them.

Also, along with the affordability being one factor, the rising congestion problems due to increasing vehicle numbers on the roads is one such another problem. Managing this issue has a very successful tried and tested technique of focusing on proper development of public transportation which have the capacity of carrying more people with the similar on-street footprint. By ensuring there operating frequency and efficiency meets the demand of the urban population around them, we can somewhat curb this problem.

And not to mention, the rising problem of global warming and climate change is directly affected by the emissions made by the vehicles. The higher the number, the bigger the problem gets. Although, there have been numerous modifications to existing transportation technologies to reduce these emissions, a decrease in vehicle number will be of much greater help. That’s where public transportation can also chime in by carrying more amount of people with minimal regulated vehicles.

In the following data, we focus on the number of registered vehicles per 1000 people residing in different parts of the world. This data will be indicative for us to map out the rising number of vehicles in a country and how public transportation can be useful in reducing these numbers.

|  |  |
| --- | --- |
| **Country** | **Number of vehicle per 1000 population** |
| San Marino | 1263 |
| Monaco | 899 |
| New Zealand | 860 |
| United States | 838 |
| Iceland | 824 |
| Liechtenstein | 773 |
| Malta | 766 |
| Finland | 752 |
| Australia | 730 |
| Brunei | 721 |
| Switzerland | 716 |
| Canada | 685 |
| Guam | 677 |
| Luxembourg | 670 |
| Italy | 655 |

These above 15 nations rank the highest number of registered vehicles with respect to their total populations. These high numbers can definitely be reduced by introduction of higher focus on the public transportation.

As cited by researchers, in recent years there has been an immense advancement in the field on intelligent transportation systems. Due to this, the public transportation authorities across the world have developed efficient data acquisition techniques and workflows. The sweeping in of the big data era has not only helped this situation but introduced the analyst teams with amazing opportunities to mitigate forthcoming problems even before there arrival.

The availability of multiple sourced data in different forms, with cell phone data, GPS data, surveillance data, Wi-Fi data to name a few, these acquisition techniques had to be refined in an iterative manner to become efficient over time. However, the collection of these datasets was not an easy task, because traditionally, surveys has always been the go to methods for data collection at a large scale. The operation and planning of the public transportation systems depends a whole lot on these factors of demand and supply, and surveys were not able to effectively work in collection of the detailed spatial and temporal data we need.

That’s why the usage of smart transportation systems has had such an impact as it has had.

* The Geo-positioning data monitored via our consent through our phones and satellites
* Urban transportation smart cards for riders
* Occasional surveys
* Road sensors
* Radio frequency identification readers
* Social media feeds
* Cameras
* Microphones

These methods produce massive amounts of data without hindering the convenience of the system users. They agree to it once, and then the data is automatically collected according to the needs of the analytical companies who work continuously to acquire the relevant data that can assist them in their protocols. This data collected has a standard set of characteristics which are essential for big data processing. These include

* Continuous nature instead of discrete
* Wide coverage rather than a clustered set of survey data
* Contain comprehensive information
* Update dynamically

Since it was obvious to the world that prioritizing public transport was necessary, the reliability of them was the next concern. Resource allocation, network planning and frequency setting are parameters that substantially depend on the short term passenger demand. But why stop there? As we already have intelligent transportation systems in place which pour in streams of information by the second, dynamic decision making was possible for forecasting delays and subsequent scheduling of buses and tweaking there frequencies. Accuracy in these predictions will not only reduce the operation cost but also increase the service quality as a whole.

## Description of the publications

Following are a few related publications to the topic of Big Data processing and its impact on the public transportation sector.

### An Architecture for Big Data Processing on Intelligent Transportation Systems

In this publication at the Universidade Nova de Lisboa, Portugal, the researchers have aimed at proposing an ETL architecture for intelligent transportation systems for addressing an application scenario of dynamic toll charging on the highways.

The have utilised big data technologies to store and process large datasets from various sources provided by different highway operators. According to this research, the bigger challenge after collection of data is the processing of huge volumes of unstructured data for subsequent analytics. The data available is such cases is also full of inconsistencies due to missing data and un aligned data. The traditional approaches towards data analysis do not work efficiently on them, and this is the reason why they have utilized an ETL approach. There proposed architecture has three major capabilities.

1. Account for the available data quality.
2. Ability to mould itself according to already existing data standards under the Intelligent Transport System domain.
3. Furnish a robust and scalable storage system.

Elaborating a bit more on their architecture, Apache Spark lies at the soul of this. SparkSQL works simultaneously along with it for the processing needs and MongoDB has been used for data storage requirements. These technologies allow the parallel in-memory processing of data.

To successfully implement the structure defined by them for their workflows, CRISP-DM methodology has been followed by them in the project. It stands for Cross Industry Standard Process for Data Mining and is a highly regarded framework in data analysis. It consists of six basic steps –

1. Business understanding – Success criteria, objectives. From this perspective, the data was generated by interviews with several highway operators.
2. Data Understanding - Data collection, quality check and developing introductory insight into data.
3. Data Preparation – Cleaning and transformation of data to more closely suit our needs.
4. Modelling – Application of appropriate modelling technique after comparative selection.
5. Evaluation – Evaluation of obtained model in the previous step and decision making on how to interpret the results for collective benefit.
6. Deployment – Charting out use cases of the obtained knowledge and results.

Moving on to the actual model developed by the team, the primary objective set was to encourage drivers to use national highways by dynamically affecting toll prices of national roads during peak hours. This was done to restore a balance on the streets and manage financial ratios in infrastructure management in the long run, simultaneously increasing the quality of life for all inhabitants by preventing them to project themselves through the same roads causing congestion and pollution.

There were several factors in play while developing this toll pricing model.

1. Real time conditions of road networks
2. Quality of service
3. Road safety
4. Environmental data
5. Cost maintenance
6. Toll revenues
7. Congestion
8. Traffic events
9. Weather conditions

All these data values were collected and subjected through the Spark engine. MongoDB was used for storing and managing the data. The direct integration of this NoSQL database system with Spark and its scalability made it the obvious choice. After the pre-processing step of data by cleaning it, classification into two categories was done – tolling data and vehicle counting data, with both different in the essential meaning they supplied to our model.

Tolling data described the actual number of vehicles that were tolled within a 5-minute interval at a specific area of the highway in question. Vehicle Counting data described the total number of vehicles counted within a 5 minute interval at a specific area of the highway in question.

Since the data had already been subjected to transformation prior to being processed through the model, the trained model obtained was appropriate for future DATEX-II transformed data as well (DATEX-II was the data transformation standard used while data cleaning step).

The results obtained using the classic approaches took approximately double the time than that it took by using the Spark approach. The conclusion was driven that usage of big data technologies had improved efficiency and computational timelines. Since the data used now was of historical nature, plans were laid out to use it in the future on much larger datasets.

### Effective Bus Arrival Time Prediction based on Spark Streaming platform

This research touched upon the discussion we had before in our problem statement of the reliability of public transportation systems. In order for the operations to be smooth a lot of analysis has to be invested into perfecting it.

This publication at Inner Mongolia University proposed a particle filtering algorithm to formulate a bus arrival time prediction model. Going a further step in achieving higher optimization in the incepted model, the prediction error of using particle filter was reduced by accounting in latest bus speeds for collaborative data analysis. Apache Spark Streaming technique was used in the development phase, because achieving real time analysis was only possible by setting up a real time data stream and processing it on the go.

It was identified that the simultaneous processing of both real time and historical data was necessary in this project. Also, each 15 second ejected record was not required to be put through computation, and small batch processing of the real time stream was selected as a better approach.

The successful execution of particle filter algorithm is dependent on acquiring relatively recent data continuously and then correcting and updating the prediction results defined in the previous iteration with the real time computation on the recently acquired dataset. Since there is a pre-existing issue with particle filter algorithms on weight degradation in the iterative process, in order to avoid this problem of particle becoming less effective in representing the probability distribution of variable over time, they used a resampling method to curb this. Sequential Importance Sampling was selected for this step.

The two main problems in particle filter algorithms usage for a bus time prediction model, which are discussed in short in previous paragraphs, are –

1. Prediction error
2. Acquisition of records

The first problem has been mitigated by introducing average speed of the latest previous bus in the same road segment, and the second by construction of optimized observations.

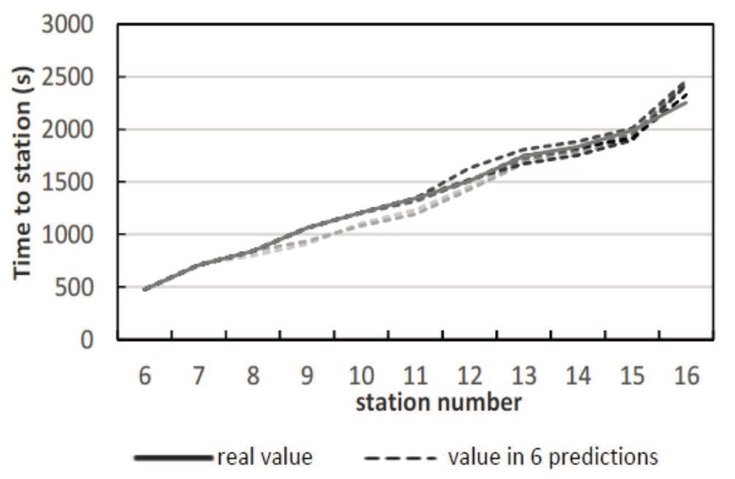
The core algorithm adopted in the model was as follows –

1. Initialise the basic parameters
2. Categorizing all pre-processed GPS records
3. Gathering all bus data which are not at terminals, i.e. in transit
4. Initialising the particle swarm and taking the sequence number of key road segments as 0 to obtain the data of latest two buses.
5. Computing number of key road sections where that particular bus trip is located at that particular timestamp.
6. Classifying the data for each bus trip according to the number of key road segments.
7. Computing the historical average speed of each bus trip on that key road segment.
8. Calculating the particle group expectation
9. Calculating the weight of each particle based on the weight calculation formula and putting it through a normalisation funnel.
10. Calculate degree of degradation and deciding whether to resample or not
11. Performing the resampling if necessary
12. Showing the final prediction result

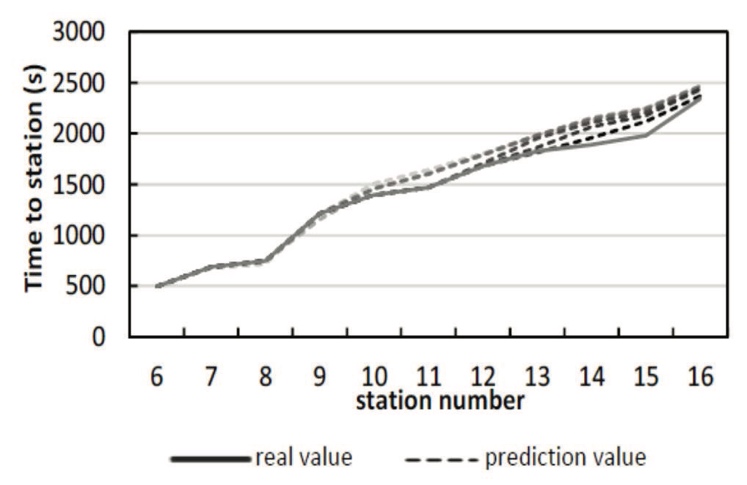
After the formulation of the final algorithm, the prediction model was designed. Since streaming in the form of batch processing had already been decided upon before, the streaming window was only set for particular amount of time. HDFS was used because of the efficiency and reliability of distributed architecture in such a case.

It was identified that as the number of particles go up, the distribution of the characterisation gets better. After setting the particle number to 2000, the prediction simulation was ran. This prediction process actually predicted the travel time in the next key road segment according to the driving condition of the previous key segment of the bus, on the constraint that the driving speed of the bus in these two sequence segments remains unchanged.

The results of this experiment were categorised for each bus into two periods – peak hours and non-peak hours. During the non-peak hours, the maximum absolute error is 78.16 seconds. During the peak hours the maximum absolute error is 270 seconds.



The above image is for the non-peak periods. The following is for peak hours.



In conclusion, the utilization of Spark platform, facilitated these researchers to effectively create a fruitful algorithm for arrival time prediction and played a key role in reducing the computational complexity considerably.

### Short Term Bus Passenger Demand Prediction

This research article is based on Time Series Model and Interactive Multiple Model Approach and was published at Shanghai Jiao Tong University. It focuses on short term passenger demand forecasting through the help of time series analysis. This will in turn assist in improving the dynamic bus scheduling techniques and their management. Also, accurately predicting the demand will also help in increasing operation efficiency and overall reliability amongst the passengers.

The objectives of this research were as tabulated below

1. Analyse characteristics of historical data with prime focus on stationarity, periodicity and volatility on differing time scales. After this, formulation of three time scales has to be done, one in a week, one in a day and last in 15 minutes which were constructed based on different characteristics.
2. Design separate prediction models which illustrate the characteristics of data to effectively predict weekly, daily and 15 minutes time series.
3. Dynamically amalgamate the prediction models estimations for further usage of outputting the hybrid predictions by applying IMM algorithm (Interactive Multiple Model) and evaluate it’s performance.

Time Series modelling on the data available to predict the bus passenger demand has been done in a hybrid manner. Both the data available in historical repositories and the real time extracted streams have been utilised in this modelling framework.

A four step process was followed in development of these time series

1. Based on the characteristics of historical data, three time series were made
2. After correlation analysis, each time series was further skimmed down to each having a separate weekly, daily and 15 min interval time series.
3. Adjust the time dependent transition probability matrix based on performance values of models based on historical data.
4. Combine the models’ predictions using IMM algorithm.

The data collected for a couple of months comprised primarily of the passenger boarding data. Since this was acquired through the smart card usage of the passengers, Intelligent Transport System standard apply to this research. Following is the demand graph for the month of August.

The x axis has the indexed number of the day and the y axis gives us an indication of the demand in trips per 15 minute intervals.

A screenshot of a cell phone

Description automatically generated

This historical data was then subjected through various analytical techniques to map out a set of descriptive statistics. To further analyse this historical data’s characteristics, three time series were constructed for the weekly, daily and 15 minutes intervals to illustrate upon the stationarity, periodicity and volatility of real time passenger demand.

Those time series are as illustrated below

A close up of a piece of paper

Description automatically generated

Above is the Weekly time series with the ARMA model (Auto-regressive moving average) implementation for constructing a stationary time series. Similarly, see below for the other time series developed in this research.

A screenshot of a cell phone

Description automatically generated

Above is the SARIMA (Seasonal Auto-Regressive Integrated Moving Average) model fitting for the daily time series of first week of August.

Below is the comparison of the autoregressive conditional heteroskedasticity models for August 1st vs August 3rd.

A close up of a map

Description automatically generated

After these time series were developed, next came the implementation of the IMM algorithm and its validation. Its basic idea was to match the varying snapshots of data and with different models and zero in on usage of a specific model with minimal error.

The process followed while implementing this is as mentioned as follows

1. Calculate the mixed state and covariance at time t based on transition probability matrix.
2. Update the estimations for each model using Kalman filter algorithm and calculate the prediction residual and covariance with the input of real time passenger demand.
3. Update the probability for each model based on likelihood function of each model using prediction residual and covariance before.
4. Calculate the final estimation at time t by combining the updated estimations at time t.

To conclude, the real time prediction modelling facilitated by the usage of Time Series has been of prime importance in this research and has the helped in increasing the operational efficiency and reliability of the bus network. This performance evaluation has optimised real time decision making capabilities of the network administrators and furnished them a way to achieve high functioning dynamic scheduling for better usage throughout the city.

## Summary of main points

From the above literature review, we can set aside a few points that might be considered as the foundational steps in moving forward with deeper dives in works in this field. The related work mentioned above, in addition to the work I read online, has been my driving force to move ahead in this dissertation.

If we think about the points I have extracted the most knowledge out off in this literature review, they can be as listed below.

1. Data availability and variety of sources where we will accumulate it from is the first thing we need to concern ourselves with when working with a big data project. Sometimes the sheer numbers of sources make the process harder to keep a uniform nature in the incoming data and we need to formulate a plan on how to act in such a scenario.
2. Pre-processing techniques that are present in the industry have a set of standards that need to be followed in order to achieve proper data cleaning and transformations.
3. Sometimes the same source of data, may provide an irregular or alienated structure of incoming records and we need to be prepared for such a scenario with dynamic updates to our pre-processing techniques.
4. Public transportation sector is a gold mine when it comes to available streams of real time data. In order to prevent an anticlimactic situation at the point of maximum output, we need to select an appropriate model for our analysis algorithm development.
5. Big Data techniques need to subjected upon harmonized data to the platform we have decided to use and have a hybrid setting in their mind for maximum information gathering. A stream of real time data going through Kafka engine will readily be sometimes of reduced usage without the Spark engine working on historical data first.
6. When big data is in the question, the approach of using a traditional relational database may sometimes have to be pondered upon. A lot of works in this field have employed the capabilities of NoSQL database systems like MongoDB or PostgreSQL for their data storage needs.
7. Mining for data has various industry standard methodologies which are quite popular amongst miners in the data analytics industry. CRISP-DM is an example of this.

These few keynotes from the years of related works by noted scholars and professionals in this field has led us to inherit techniques which are proven to work in our cases and we move ahead with a strong foundation. Identifying out problem statement at the very beginning was essential and then walking through these publications has provided us with essential knowledge that will go a long distance in helping us achieve our benchmarked subobjectives.

## Contributions of these publications to Big Data in Public Transportation sector

The publications brushed through by me, along with the other sources cited by them, have done a whole lot of groundwork and made significant contributions to the Big Data domain as a whole. In the recent years, since the Big Data terminology has compounded within the Information Technology sector, the research works have helped pave the paths of aspirants like us.

Considering the Public Transportation sector specifically, the contributions have been marvellous. The advancement in methods to acquire data and moving those techniques from traditional survey based sheets of paper handed out to the travellers, which more often than not, they threw away because they simply didn’t have the time, to the automated collection of data using smart card in this era of Intelligent Transportation Systems is a boon.

The implementation of these big data techniques onto the vast transport datasets, and their appropriate usage in the publications above, is an example of how the public transportation sector is moving in the right direction, and with more relevant researches on the way, painstakingly trying to make all these tasks even simpler, we can only imagine the future ahead.

# Methodology

Considering the standard processes followed in the industry to conduct successful data analysis projects like CRISP-DM (Cross Industry Standard Process of Data Mining) and TDSP (Team Data Science Project), the lack of manpower behind this project drilling down to just an individual has led me to adopt a simpler workflow to meet the needs of the project.

A phased out roadmap of steps with set objectives is the simplest approach for any project, not just in the data analysis field. The methodology followed for this project strongly resembles the 11 independent benchmarks that are set out in any data analysis project. Even though this is a big data scenario, the key established routes for progressing in the analysis remain same to their core.

Let’s have a look by the following visualisation illustrating these methods.

1. **Collaborate your needs** – Under the supervision of Dr Alejandro Arbelaez we initially discussed the need to do this project.
   1. How analysing the public bus data for Dublin could be of assistance to the authorities?
   2. Why big data was going to play a part in this?
   3. How Apache Spark would serve our purpose?
2. **Establish Questions** – The foundation of any project are the questions we are pursuing to answer through the work put into it. The primary ones set out by me were to
   1. Work with the Delay data and congestion data and analyse them and see was there an effect of one over the other.
   2. Also, which bus lines are struggling the most i.e. which have the maximum delay over time.
3. **Harvest Data** – Harvesting or identifying the main source of data was not an issue in this project, because I had a clear cut idea from the start that importing the January month’s data of 2013 from the government website of Irish datasets was the primary source. This was an ‘opendata’ website, and has the following link.

<http://opendata.dublincity.ie/TrafficOpenData/sir010113-310113.zip>

1. **Set KPIs** – Next I drew a clearer picture of the Key Performance Indicators of the project. The raw data collected by me was definitely of use, but we still have to filter out which features are going to be of more importance than compared to the others. For instance, in this dataset the KPIs are the
   1. Delay
   2. Congestion
   3. AtStop

These three columns clearly mark the situation that particular bus was in at that timestamp.

1. **Omit Useless Data** – Data cleaning is an essential part of a data analysis lifecycle. There are records which have incomplete information or mismanaged values and they need to be omitted to have a clearer picture of the analysis being performed by us. In this dataset, there are a lot of records which have one or the feature with an empty value. Instead of imputing those values, I have decided to remove those records because imputing them becomes tricky, as the features missing like Timestamp would be useless by imputing as we cannot perform that task on the basis of any aggregate measure.
2. **Conduct statistical Analysis** – I conducted some preliminary statistical analysis to identify the amount of data we were going to process and some key aspects of the various features in the data. This sole part of the process was performed using R language, as I performed this on just the first day of data i.e. January 1st, 2013 to get an idea of the dataset in general.
3. **Build a data management roadmap** – Since the data in consideration is of the static form, its upload to a cloud repository is the easiest way to manage it. I am using Databricks as my platform for processing of big data. It is an Azure service provided by Microsoft Corporation.
4. **Integrate technology** – Databricks has native support for PySpark which is a subsidiary tool of Apache Spark Technology. I have utilised it for the entirety of the project, with minor levels of the algorithms replicated onto my local machine first, which is running a Spark engine with just my system cores as the essence of its distributed architecture.
5. **Answer Questions** – After performing all my analysis by using the constructive algorithm techniques, I was able to answer the questions that we had initially constructed.
6. **Visualise Data** – The result obtained after any analysis project are effectively projected onto the viewers by the help of graphs and charts. This is why the visualisation techniques used are of prime importance.
7. **Create a narrative** - In the end of the process lifecycle, I am writing this dissertation document to summarise and cumulate all the findings and results obtained from the methods and analysis done throughout. This document is an attempt to completely project all my research and analysis and provide that to the reader in such a way that they can replicate all this from scratch.

# Detailed Process

The methodology has been explained in the previous pages and now we move on to the granular level in detail residing within the project lifecycle.

## Environment Setup

The first order of business attended to in the environment setup phase was to download the dataset from the website. It comprised of 31 separate csv files, one for each day of January 2013. The file size for this entire download was a zipped 1.01 GB and expanded to over 4 GB once unpacked.

The next thing to do was to setup a local installation of PySpark on my machine, because I wanted to make sure to run the jobs with a minor set of data before moving onto the cloud services and run it over the entire dataset. This was to be certain of the algorithm I was attempting on the data.

The installation of PySpark on my MacBook was easily done by following the steps mentioned in the following webpage and I would like to give specific acknowledgment to the author of this page for this derived assistance I received from it.

<https://kevinvecmanis.io/python/pyspark/install/2019/05/31/Installing-Apache-Spark.html>

After following the process in the above page, I tested whether I had been successful in doing that or not. To test this I opened a terminal window, entered ‘pyspark’ command and pressed the ‘return’ button (these will be replaced by a command prompt window and ‘Enter’ button on a Windows machine).

A screenshot of a cell phone

Description automatically generated

The above screenshot confirms that Spark is up and running on the machine. Now we move on to the next steps.

Please note that in the image above it says that ‘Python 2.7’ is not recommended to perform any tasks as it has been depreciated, and I have an explicit installation of Python3 on the machine for the fulfilment of this project’s tasks.

The next step was to procure a proper cloud environment to process the big data that we had at our hands. There were multiple options like GCP’s (Google Cloud Platform) service ‘Dataproc’, AWS’s (Amazon Web Services) ‘Elastic MapReduce’ also known as EMR. But in the end I, along with the guidance of my supervisor, decided to move ahead with a similar offering of the Microsoft’s cloud platform called ‘Databricks’. Databricks is an industry leading data engineering tool that is used for the processing and transformations of massive quantities of data and their exploration through various machine learning models. It has been recently added to the Azure environment post-acquirement of it by Microsoft.

Since this is a ‘pay as you go’ service, I only used the Community edition of it to avoid paying hefty fees for its features. This only provided access to a reduced performing distributed architecture of Hadoop and limited storage, but considering the tasks at hand it served all the purposes.

The main architecture provided by a Hadoop framework is a cluster of machines over which we run our Spark jobs. One machine is called the driver node and the rest are called the worker nodes. The driver node, as the name suggests, is responsible for initiating the job and carrying out the distribution of the data into chunks and providing them to various worker nodes to effectively and efficiently process them. Higher the distribution in the architecture, better is the efficiency in data processing. The community edition account of Databricks only provides access to a network of one driver node and no other worker nodes i.e. that driver node itself is responsible for the processing of the data. Naturally it is not a powerful architecture as one with multiple worker nodes, but considering the static nature and small size of the data at hand, it worked well enough for me.

The cluster created was having the following configuration:

1. 1 driver node, 0 worker nodes
2. 15.3 GB of memory
3. Spark 3.0.0 version
4. Support for Python3
5. Availability zone of US West

I uploaded all the data files to the repository on the Databricks called the ‘FileStore’ within the Databricks File System (DBFS). It is a straightforward repository, however there are a few quirks associated with it.

1. To remove a folder or file from FileStore use the following command in Databricks notebook.

dbutils.fs.rm("/FileStore/<\_\_\_\_>",True)  
  
2. To download a file from Databricks FileStore open the following URL in browser.

https://community.cloud.databricks.com/files/<folder>/<file>?o=8736540974339418

The long number in the URL above is the unique token associated with my account. It will be different for each account and will have to be pulled out separately by each user.

There is native support for Python notebooks in the web UI of Databricks, and I have utilised that for the project.

## Data Preliminary Analysis

An initial exploration of the data was done. Since the total amount of records for the entire month of dataset are in excess of 44 million, a preliminary analysis needs to be done to get an estimated idea of the data we are dealing with.

The records collected are collected from all bus operators at regular intervals and the number of records are different on different days of the week.

As seen by the illustration above, the number of records by the authorities sees a fall in the weekend i.e. Saturday and Sunday, which suggests a decline in service during these days. The chart starts from a Tuesday because 1st January 2013 was a Tuesday.

This aggregation of data was performed by using the RDD datatype which is a native to Spark framework. RDD stands for a Resilient Distributed Dataset and is at the core of the distributed architecture of Apache Spark, with the key concept being division of dataset onto different nodes and then simultaneous execution of those subsets as part of one job.

The next step was to identify the number of records which consisted of missing data. This is an essential part of any data analysis project as cleaning of the data becomes necessary in preserving the accuracy of any model we train onto the training dataset.

Out of the 44 million, around 5 million records were identified to be consisting of some missing data in one or more features. Since imputation was not useful considering the nature of the features, it was decided to remove those records altogether from the dataset to get a clearer picture through analysis.

Certain more metric were calculated while doing preliminary analysis. They are as listed follows –

1. 8 bus operators were present in this Dublin bus network during that time period.
2. 59 bus lines were present in this network.

The pseudo code for this above algorithm is as follows –

Importing SparkConf, SparkContext and SQLContext from pyspark library

Importing countDistinct from pyspark.sql library

function preprocessing(record){

Separate each record string using ‘,’ operator and return as separate fields

end

}

Initializing an empty rdd variable

For file in file\_list:

Read each file as an rdd as a variable

Union this variable to the empty rdd variable

Remap the total records rdd through the preprocessing function

Converting rdd to a dataframe with predefined schema

Using countDistinct method to get different levels of Operators and LineIDs from this dataframe

The data cleaning function talked about previously was also utilised in the same code snippet. The pseudo code explanation for the same is as below

Function cleaning(dataframe){

Extract a list of columns in the dataframe

Create a filter expression to check for null values

Run the dataframe through this filter criteria

Drop duplicates from the filtered dataframe

Return the cleaned dataframe

end

}

This concluded the preliminary analysis performed upon the dataset. I also explored the dataset to ensure that the understanding which was mentioned on the website related to the description of the data, checked out by confirming those points on the 1st day of data in RStudio, such as no wrong values were present in any of the columns other than the ones which were supposed to be present in them.

Next, I started working with the more detailed and complex algorithms for the analysis of the data.

## Stop Locations

This algorithm consisted of mapping out the location of each StopID and mapping that onto an actual map of Dublin. This would verify that the data was accurate and the subsequent analysis that we perform on the dataset would be completely true with respect to the features furnished by it.

A couple of assumptions were made before constructing this method. Number one, only the first day data would be required for this analytical algorithm, because all the stops would be covered by one or the other bus in a single day within the entire city. And second, since the latitude and longitude values given in records are at a very granular level, the mapping at the end of it may be deviating a little bit because of inaccuracies in procuring a map of the exact same scale.

The algorithm was divided into two sections, firstly to gather the approximately accurate values of the latitude and longitude of each stop of each line and then secondly plotting those coordinates. After setting up the three Spark global level variables – a Spark Configuration variable, a Spark Context variable and a SQL Context variable, the actual processing of data begins.

The steps followed in the algorithm are as follows –

1. Importing the day 1 csv in the form of an rdd.
2. Pre-processing the rdd with the ‘cleaning’ function mentioned in the previous section of preliminary analysis. This will omit the incomplete records in the dataset.
3. Converting the rdd into a data frame with a defined schema. The conversion of rdd into a data frame is done using the ‘toDF’ function over the rdd variable. This accepts one parameter of schema which is essentially a list of all the column names in the dataset.
4. Creating an empty data frame with a set schema of the relevant data we will be extracting out of this algorithm. I created a schema using the StructType and StructField methods imported from the pyspark.sql.types library.
5. Next, converting the data frame just created into a key-value pair rdd, with LineID feature as the key.
6. Use groupByKey() transformation function to group the rdd by lineIDs and use collect() method to store the results as a list.
7. Iterate over that list and walk through the records line by line.
8. For each line, convert that subset of data into another key value pair rdd with StopID as keys.
9. Further use groupByKey() transformation to group that rdd by StopID and use collect() method as before to store the result as a list.
10. For each stop, convert that subset of data into an rdd. Subsequently convert that rdd into a data frame with a schema.
11. Register that data frame as temporary table by using the function dataframe.registerTempTable(“name\_for\_the\_table”).
12. Utilise Spark SQL and select the LineID, StopID, Latitude and Longitude values from that temporary table where the AtStop value is 1. Limiting the result to one to avoid repeated records of same Latitude and Longitude values.
13. Since a Spark SQL query returns a data frame type record set, unionising the result to the empty data frame created at the beginning.
14. Exporting that final data frame as a csv file for better and universal readability.

This entire process gives us quite an accurate picture of the coordinates of the various stops present around the bus network in Dublin city.

The resultant csv looks a bit as follows.

|  |  |  |  |
| --- | --- | --- | --- |
| 747 | 7456 | -6.260201 | 53.344318 |
| 747 | 3665 | -6.243983 | 53.428101 |
| 747 | 7401 | -6.240617 | 53.426517 |
| 747 | 3669 | -6.235045 | 53.428631 |
| 747 | 7399 | -6.22705 | 53.348381 |
| 747 | 2002 | -6.269407 | 53.343739 |
| 747 | 2507 | -6.227079 | 53.34819 |
| 747 | 2499 | -6.247149 | 53.348 |
| 747 | 1172 | -6.255172 | 53.351791 |
| 747 | 4319 | -6.292567 | 53.346931 |
| 747 | 7398 | -6.23983 | 53.347549 |
| 747 | 7400 | -6.239022 | 53.426693 |
| 747 | 271 | -6.259133 | 53.346367 |
| 747 | 4724 | -6.260755 | 53.350513 |
| 747 | 7404 | -6.223813 | 53.354996 |
| 747 | 4508 | -6.259915 | 53.352165 |
| 747 | 7453 | -6.265867 | 53.346268 |
| 747 | 7397 | -6.243228 | 53.347748 |
| 747 | 1359 | -6.261344 | 53.344357 |
| 747 | 5140 | -6.245507 | 53.35112 |
| 747 | 7410 | -6.225725 | 53.412155 |
| 747 | 7216 | -6.242425 | 53.347706 |
| 747 | 1935 | -6.268323 | 53.343948 |
| 747 | 1445 | -6.278273 | 53.345734 |
| 747 | 620 | -6.251458 | 53.351196 |
| 747 | 7468 | -6.260298 | 53.352089 |
| 747 | 7402 | -6.254838 | 53.35133 |
| 747 | 4717 | -6.252593 | 53.349796 |

This table above is a collection of all the stops present in the LineID 747. The third and fourth column are Longitude and Latitude respectively, with the second column being the StopID. This result type similarly details out the values for the remaining lines as well.

The next order of business was to plot these coordinates onto an actual map of Dublin to check for accuracy of results. By downloading an open text map from a website, we move ahead with the process for this, and the steps followed are as listed below.

1. Importing the csv file previously exported by the SQLContext’s read.csv command as a data frame.
2. Typecasting the Latitude and longitude values in this data frame from string type to double type.
3. Extracting min and max values for both latitude and longitude to establish a boundary box on the map.
4. Using matplotlib library to create a plot of the coordinates on the map.

image = plt.imread(**'/Users/aausuman/Documents/Thesis/Dublin-map.png'**)

fig, ax = plt.subplots(figsize=(8, 7))

ax.scatter(stops\_coordinates\_df.select(**"Lon"**).rdd.flatMap(lambda x: x).collect(),\  
 stops\_coordinates\_df.select(**"Lat"**).rdd.flatMap(lambda x: x).collect(),zorder=1, alpha=0.2, c=**'b'**, s=10)

ax.set\_title(**'Plotting Bus Stops on Dublin Bus Transport System'**)

ax.set\_xlim(boundary\_box[0], boundary\_box[1])

ax.set\_ylim(boundary\_box[2], boundary\_box[3])

ax.imshow(image, zorder=0, extent=boundary\_box, aspect=**'equal'**)

plt.show()

1. The above code snippet describes the various parameters set for the plot.

After export the plot and comparing it to real world data, the data generation authorities can be certain that the data is verified. A small part of the map consisting of the 747 LineID’s StopIDs is below

A close up of a map

Description automatically generated

The small greyed out points at the lower end of the diagram above are the plotted coordinates which closely resemble the stops present on the actual 747 LineID. This plot is obtained as soon as the plt.show() method is executed.

This procedure, although not exactly an analysis algorithm and more of an explanatory method, gave a small insight into the data and how it can be utilised to replicate the real life scenario. The credibility of the dataset has also been established and we move on to the next analytical algorithms.

## Busy Lines and Congestion

This analytical algorithm in our project lifecycle gives us an idea of what lines present in the bus network experience the most number of stops to make in a day and which of these buses face congestion on the roads and at what times. This bit of information will be useful in identifying which lines require constant monitoring and maintenance by the authorities so as to make the experience for the passengers a smoother one. Also having an idea of a generalised pattern of congestions faced, be it because of rush hours or other reasons, the vehicle can be prepared for alternative routes during these times.

The Busy lines identification algorithm is depicted by the following steps –

1. Importing and cleaning our data set using the previously discussed pre-processing and cleaning methods.
2. Creating an empty data frame with a user defined schema. The schema has four columns – ‘LineID’ of integer type, ‘Number of Times at Stops’ of integer type, ‘Date’ of string type, ‘Day’ of string type.