Reducing Dwell Time:

London Underground Central Line

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

Jake Kelley
Dong Hyun (Danny) Ko
Laurie Mazza
Samantha E. Robinson

Date: June 23, 2016
Sponsor: Eric Wright (Transport for London)
Advisors: V.J. Manzo and Jianyu Liang

Abstract

Inconsistent and excessive dwell times often cause delays to underground metro systems. The goal of this project was to recommend solutions to minimize dwell times in the Central Line of the London Underground. The team conducted employee interviews, station observation, train observation, CCTV observation, and passenger surveys to more thoroughly understand the issue. Our team identified four system constraints that could be altered to encourage more efficient passenger behavior in order to reduce dwell times.

Table of Contents

Click a topic to be directed to the start that section or chapter within this proposal.

Acknowledgements

We would like to thank everyone that helped us perform and complete our research. We want to thank the employees at the Central Line and Victoria Line Control Centers, staff at the stations we were able to observe, and the people at Transport for London that allowed us to have this opportunity. Specifically, we would like to thank our sponsor, Eric Wright, for his inspiration, enthusiasm, and unbounded support. Without his vast knowledge on the London Underground and his resources, we would not have been able to complete this project.

We would also like to thank:

Vincent J. Manzo and Jianyu Liang for advising our project

Sarah Crowne for her help during ID2050 as our professor

Neil Elrick for sharing information and secure locations like Victoria's SER

Jason DaPonte for providing inspiration and ideas from the innovations team

Gary Fitzgerald, John Yeoman, and all those at Woodlane for access and information

Liz Poulter for giving us access to the Transport Museum

Steve Walling and Chris Fowler for helping to arrange employee interviews

Lawrence Weller for providing Central Line information and access to the Control Room

Executive Summary

In an ideal underground rail system, every train would arrive and depart at its intended station without delay, but in reality, trains are behind schedule very frequently. In the London Underground in the past three years, passengers have experienced an average excess travel time of more than 4 minutes from their original scheduled journey (See Appendix G Figure 1; Transport for London, 2016g). Dwell time, the time from wheel stop to wheel start at a station, is one of the major factors that cause the train delays and diminishes the system's ability to operate on schedule (Karekla & Tyler, 2012). Dwell time depends on system constraints, such as the station layouts and mechanical aspects of the train system, as well as passenger behavior. Excessive dwell times cause delays to singular trains, which can spread delays to the entire underground system (Wright, 2015).

The goal of this project is to recommend solutions to the current issue of high dwell times in the Central Line of the London Underground, a section of Transport for London (TfL). In order to form these solutions, the team identified the common factors that affect dwell time in terms of both system constraints and passenger behavior. First, the team became familiar with the system and the dwell time factors through initial employee interviews, including discussions with Templar House and the control room staff of the Central and Victoria Lines. Next, the team conducted station observation on the ten key stations, which were chosen due to their high dwell times. Train observation completed the first objective of identifying common factors through noting passenger flow and dwell times from within the trains during the morning peak time.

To narrow these factors into the final two key factors, the team studied the frequency and impact of factors through CCTV observation, a passenger survey, and frontline employee interviews. CCTV observation provided critical data on the frequency of platform crowding, types of problem passengers, and door reopening causes. The passenger survey conducted during peak and nonpeak hours lead to data compared between the different types of passengers: commuters, tourists, shoppers, and casual riders. Finally, interviews with train operators confirmed other data and suggested the importance of platform attendants.

The first key factor is uneven platform crowding that is extremely frequent during the morning peak hours as passengers crowd by the entrances and do not spread evenly along the platforms. Obstructed alighting and boarding is the second key factor because of its direct correlation to increasing dwell times as the doors remain open or reopen. These two key factors are caused by a combination of problem passengers and system constraints of the platform layout, information display, TfL employees, and the rolling stock. Updating or altering these system constraints could appease the currently high dwell times in the Central Line.

The suggestions on station platform layouts include foldable benches to provide more space for platform passenger flow, altering ventilation to encourage motion along the platforms, and decreasing train visibility from passageways to discourage rushing passengers. The information display options are updating current signage to create more informed passengers, creating a new passenger information display to provide more useful information, and including information on the platform floor such as way out arrows. One of the types of TfL employees directly related to dwell times, the Central Line train operators, commonly suggested to increase the presence of platform attendants that currently decrease dwell times during peak hours. Finally, rolling stock could be improved through more strategic handle placement to discourage passengers from blocking alighters, directional train doors to promote passenger flow through the trains, and an entirely new rolling stock with interconnected cars to cause less uneven train/platform crowding.

As this project concentrates on the non-technical factors associated with high dwell times, further research on these suggestions should be conducted. Further study should be completed on station-based passenger flow, communication between TfL employees, and increasing information for tourists in an interactive display. Studies on particularly complicated interchange stations like Bank/Monument would be beneficial as the passenger flow within these stations could be improved. Similarly, further research into the effects of updating technical aspects, such as the signalling system, may prove helpful for the Central Line in the future.

Table of Authorship

Chapter	Section	Primary Authors	Primary Editors
	Introduction & Summary	Laurie, Sam	All
Background	Chapter Introduction	Danny	Sam
Background	1.1 Rail Transportation Overview	Danny	Laurie
Background	1.2 Common Obstacles	Danny	Laurie
Background	2.1 Dwell Time Definition	Jake	Sam
Background	2.2 Dwell Time Factors	Jake	Danny
Background	2.3 Dwell Time Importance	Jake	Sam
Background	3.1 New York MTA	Danny	Sam
Background	3.2 Tokyo Metropolitan Area	Sam	Danny
Background	3.3 Hong Kong Mass Transit Railway	Sam	Jake
Background	4.1 London Population	Laurie	Sam
Background	4.2 London Underground	Laurie	Danny
Background	4.3 Central Line	Laurie	Jake
Background	4.4 LU Dwell Time Current Minimization	Laurie	Danny
Methods	Chapter Introduction	Laurie	Jake
Methods	1.1 Employee Interview	Jake	Sam
Methods	1.2 Direct Observation	Danny	Jake, Sam
Methods	1.3 Passenger Survey	Jake, Sam	Laurie
Methods	1.4 Propose Solutions	Laurie	Danny
Methods	2.1 Ethical Considerations	Danny, Sam	Jake
Methods	2.2 Alternative Plans	Sam	Jake
Analysis	Chapter Introduction	Laurie	Danny
Analysis	1.1 Behind The Scenes Employees	Jake	Danny

Analysis	1.2 Frontline Employees	Jake	Laurie
Analysis	2.1 Station Observation	Danny	Laurie
Analysis	2.2 Train Observation	Sam	Danny
Analysis	2.3 CCTV Observation	Jake	Danny
Analysis	3.1 Overall Results	Laurie	Jake
Analysis	3.2 Types of Passengers	Laurie	Jake
Conclusion	Chapter Introduction	Laurie	Sam
Conclusion	1.1 Passenger Behavior	Sam	Jake
Conclusion	1.2 System Constraints	Sam	Laurie
Conclusion	2.1 Uneven Platform Crowding	Danny	Sam
Conclusion	2.2 Boarding & Alighting Issues	Jake	Danny
Conclusion	3.1 Station Platforms	Danny	Sam
Conclusion	3.2 Information Display	Laurie	Jake
Conclusion	3.3 Rolling Stock	Jake	Laurie
Conclusion	3.4 Platform Attendants	Jake	Sam
Conclusion	4.1 Further Solutions Research	Sam	Laurie
Conclusion	4.2 Future IQPs with Transport for London	Sam	Danny

Introduction

Effective public transportation systems are an essential part of modern society, especially in urban communities. Less than a third of the world's population was urban in 1950, and it is predicted to grow to two thirds by 2050. Currently, 54% of the world's population is urban, with 73% of Europeans living in urban areas (United Nations, 2014). Public transportation systems must be fast, safe, clean, affordable, and easy to use since public transportation is crucial to the lives of many, especially the impoverished, elderly, and disabled. Of all public transportation, underground railways are one of the best methods because they are the main competitor to cars in terms of speed and convenience (Eagling & Ryley, 2015).

In an ideal underground rail system, every train would arrive and depart at its intended station without delay, but in reality, trains are behind schedule very frequently. For example, in the London Underground in the past three years, passengers have experienced an average excess travel time of more than 4 minutes from their original scheduled journey (Appendix G Figure 1; Transport for London, 2016g). Dwell time, time from wheel stop to wheel start at a station, is one of the major aspects of train delays, because high dwell times diminish the system's ability to operate on schedule (Karekla & Tyler, 2012). Dwell time depends on system constraints, such as station layouts, as well as human behavior in passenger flow. Increased dwell times cause delays to singular trains, which can spread delays to the entire system (Wright, 2015).

Every underground system in the world is concerned with dwell times and have methods to minimize them. In New York's 100-year-old metro system, the Metropolitan Transportation Authority implements big budget Capital Programs and utilize platform controllers to improve the system (Metropolitan Transportation Authority, 2010). The Tokyo Metropolitan Area has electronically operated platform screen doors, an additional barrier between passengers and the tracks. The doors are intended to increase safety and have been implemented in nearly half of Tokyo stations (Briginshaw, 2015). The underground in Hong Kong claims to possess a 99% punctuality rate for their system. Some of this claim can be attributed to their state of the art mechanical systems, including artificial intelligence (Wong, 2015). These systems each have a distinct approach to reducing delays and dwell times, which can be implemented within other systems like the London Underground (LU).

As urbanization and global population continue to increase, overcrowdedness will cause more delays and inconsistent dwell times. The current population of the city of London is over 8 million and is predicted to be around 10 million by 2030 (Office for National Statistics, 2014). London also accommodates over 18 million overnight visitors annually (MasterCard, 2016). With a large population and high amount of visitors, the London Underground is an important urban transportation system within Transport for London (TfL), which carries over one billion passengers annually (Transportation for London, 2016b). Out of the eleven lines in the London Underground, the Central Line is one of the oldest lines and has not been upgraded in decades.

The Central Line operates from Epping Station to West Ruislip Station and is the longest line consisting of 78 kilometers of track (TfL, 2016d). During March 2016, the Central Line had an average excess journey time of 4.22 minutes and the highest moving annual average of signal and point related delays lasting over two minutes. As a result the Central Line has the highest moving annual average of total lost customer hours among all LU lines (TfL, 2016g). The Central Line has recorded many delays since 2010 with 158 reported delays due to overcrowding (Bentley & Ehrenberg, 2015). Because of the severity of delays in the Central Line, understanding the factors that influence those delays is necessary to reduce them.

Our project aims to provide possible solutions to the current problem of high dwell times in the Central Line by identifying factors, determining the key factors, and suggesting possible solutions to minimize dwell time. The project concentrates on ten key stations within the Central Line in the London Underground. Initial employee interviews, station observation, and train observation were conducted in order to familiarize the team with the Central Line and to identify the factors related to the high dwell times. Next, the key factors were determined by studying which of the factors have the most impact, in terms of both frequency and severity, concerning increased dwell times in the Central Line. In order to determine which are the key factors, data was collected through CCTV observation, a passenger survey, and additional employee interviews. Finally, the team formed possible solutions to the issues associated with the key factors that affect dwell time and delivered suggestions on minimizing dwell time to TfL.

Background

The background chapter of this report explores history and vocabulary surrounding the concepts included in this study. This chapter contains a brief section on rail transportation history, followed by the definition, causes, and importance of dwell time. The next section describes New York City, Tokyo, and Hong Kong underground systems and their approaches to reducing dwell time. The last section provides an overview on London, the London Underground (LU), the Central Line, and their recent implementations to reduce dwell time.

1. Rail Transportation

1.1 Rail Transportation Overview

The earliest trace of rails dates back over 2000 years and were created by the Greek and Roman empires. Men and animals pulled the vehicles, such as chariots and wagons, along the grooves cut into the stone road to guide the vehicles (Tzanakakis, 2013). Using primitive wooden rails, early wagonways were developed in Germany in fifteenth century. The carts were used to transport ore tubs in and out of mines to improve transportation. In the seventeenth and eighteenth century, the railways were laid down for the purposes of public transportation for the first time. Wooden railways were laid down along the streets, and horses pulling iron cast cars were able to transport twice as many people at faster speeds (Tzanakakis, 2013).

During the Industrial Revolution, the invention of steam engines led to the first functional steam locomotive in 1794. As construction of efficient steam locomotives continued, George Stephenson manufactured Locomotion No. 1, the first steam-powered locomotive that was used for public transportation in 1825 (Tzanakakis, 2013). The use of steam locomotives spread throughout industrialized countries, and it became one of the dominant ways of transportation. With rapidly growing usage of steam trains, pioneers initiated the construction of steam locomotive railway network known as the underground; it was first built in London in 1863 (TfL, 2016b).

In 1888, streetcars were powered by electricity for the first time. Since then, electric power became a practical and popular source of power for railway transportation (Tzanakakis, 2013). The transition from steam locomotives to electric trains allowed for rapid transit service which was a significant step in the growth of large scale electrical systems (Duffy, 2003). All of the streetcars were electrified, and big cities including New York, London, and Paris implemented electrical power in their underground railway systems to enable the transportation of significant amounts of people with great efficiency (Tzanakakis, 2013).

1.2 Common Obstacles

Underground railways are one of the dominant modes of urban transportation for commuters and tourists. Of all public transportation, underground railways are considered the best alternative to cars in terms of speed and convenience (Eagling & Ryley, 2015). In the United Kingdom, for example, even though ownership and usage of cars over the past 50 years have increased significantly accounting for 86% of all journeys made, people seem to prefer using the subway more than cars whenever available (Eagling & Ryley, 2015). One research found that 77% of the people living and working near underground stations were more likely to use the rail compared to the 47% of the people who lived far away from underground station entrances (Passenger Focus, 2009).

Despite its convenience, passengers experience countless train delays due to many factors, which are grouped into system constraints and passenger behavior. System constraints include technical and signaling aspects, as well as station layouts. Common technical and signaling issues include problems such as buckled or broken rails due to extreme heat, train malfunction due to random mechanical failures, points failures when the switch that operates the junction of two rails malfunctions, and signaling failure due to circuit or power source malfunction (Network Rail, n.d.). In addition to technical aspects, the system is also constrained by the layout of the station, including passenger capacity, entrance/exit placement, handicap accessibility, and passenger flow.

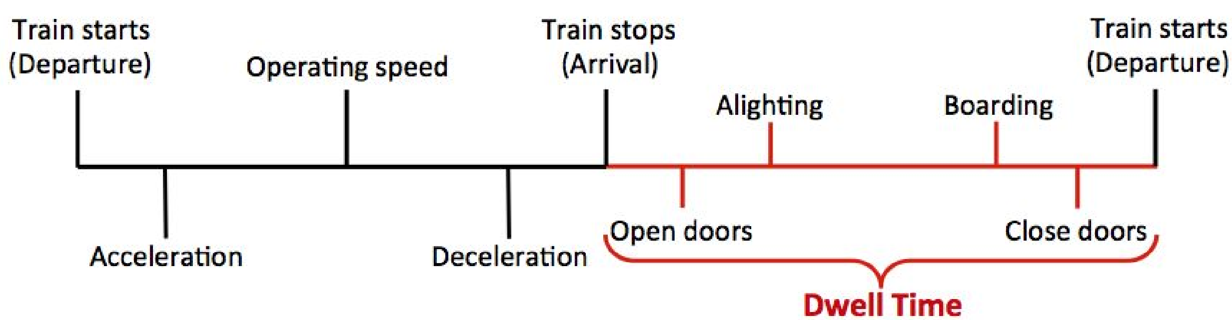
With regards to passenger behavior, overcrowding in trains or stations is generally caused by an excessive amount of train passengers exceeding the train system capacity. The most delays and instances of overcrowding occur during peak hours, because peak hours have the largest number of passengers as they are during the time periods before and after typical work days when commuters are the majority of passengers. Especially during instances of overcrowding, dwell time is one of the major factors that govern the train delays and its ability to operate on schedule, and excessive dwell time at a station will cause severe train delays.

2. Dwell Time

2.1 Dwell Time Definition

Dwell time is defined as the time spent in the same position, area, or stage of a process (Oxford Dictionaries, 2016). In terms of rail transportation, dwell time is the duration from wheel stop to wheel start when a train arrives at and departs from a station platform (Karekla & Tyler, 2012). Dwell time can be divided into five processes: door-unblocking, opening doors, passenger alighting/boarding, closing doors, and train dispatching (Buchmueller, Weidmann & Nash, 2008). Figure 2 provides a timeline between a train departing from one station and another, where dwell time is the most varying segment.

Figure 2: Train Journey Timeline



(Adapted from: Coxon, Burns, Bono & Napper, 2011)

2.2 Dwell Time Factors

Dwell time depends on two types of factors: system constraints, such as station design, as well as passenger behavior. Other factors, like climate, public sporting events, and holidays are impossible to control and will not be explored in this report. In order to address dwell time, it is necessary to identify the manageable factors that increase it. Increased dwell times can cause minor to major delays to singular trains and the entire system itself (Wright, 2015).

As a train arrives at the platform, the first issues of increased dwell time begin with door unblocking, which is based on human action of the train operator activating the door opening process in order to continue to the next process (Martinez, Vitriano, Fernandez & Cucala, 2007). The door opening and door closing processes are determined by the door width and control system (Buchmueller et al., 2008). Research suggests that a door width of at least 1.4 meters is needed to enable two simultaneous passenger flows; however, the width should not exceed 1.6 meters, because it would be more efficient to have an additional door (Barron, 2015).

The most significant variables of dwell time occur during alighting and boarding, the time it takes for passengers to board and disembark from the train car. Alighting and boarding is mainly affected by passenger flow, which is restricted with larger numbers of passengers in a station. Extended dwell times suggest a struggle in passenger alighting and boarding at any of the stages outlined in Appendix G Figure 3. Passenger flow is constrained by the physical design of the station, such as entrance/exit placement, number of escalators, and platform size, that affect dwell time since the passengers can concentrate in choke points, making access to the train difficult (Martinez et al., 2007). On average, metro trains spend 25% of their time stopped at stations and of that stationary time, 40% typically consists of passenger movement (Barron, 2015). As the number of passengers increase, the increase in dwell time at one station will affect not only the train at the next station but also following trains. When a delayed train arrives, the number of passengers waiting at the station increases. As a consequence, trains spend more time at stations in order to enable the larger number of passengers to board and alight, which leads to increased dwell times (Karekla & Tyler, 2012). One study identifies the main train passenger behavior issues as boarders entering before alighters can exit, passengers holding or blocking doors, passengers crowding doors, and passengers bunching on platforms, leading to uneven loading (Barron, 2015). These issues prevent the operator from moving to the door closing process and therefore increases dwell time. Although passenger numbers and behavior increase dwell times, system constraints may be the key issue. The design of the train car also contributes to dwell time. If a car is too small, it will have a lower passenger capacity and may restrict passenger movement. Ideally, stations and cars should be designed to enable maximum passenger flow.

After alighting and boarding, the train dispatching process occurs: the time between the last train door closing and the train departing the station. The dispatching process, much like the unblocking period, is determined by the actions of the operator. The driver will typically not depart from the station until they judge that it is safe to do so or until any operational conflicts, such as delays have been resolved (Buchmueller et al., 2008). Dwell time concludes once the train begins to accelerate on its journey to the next station.

2.3 Dwell Time Importance

The importance of analyzing dwell times has increased as transportation authorities seek to improve the continuity and efficiency of their railways (Buchmueller et al., 2008). The purpose of a mass transit system is to move as many people as possible in a fast, safe, and inexpensive manner (Wright, 2015). Achieving this efficiency is difficult since there are several conflicting requirements, including dwell time. Extended or inconsistent dwell times lead to longer trips, delays, and irregular headways. While these problems are more common where passenger volumes and train frequencies are higher, passenger time can also be wasted during less crowded times if dwell times are not well-managed. If dwell time is left unchecked, there is a reduction in total capacity and customer satisfaction (Barron, 2015). These consequences of inefficient dwell time have a significant negative effect on the service quality of a metro.

3. Differing Approaches

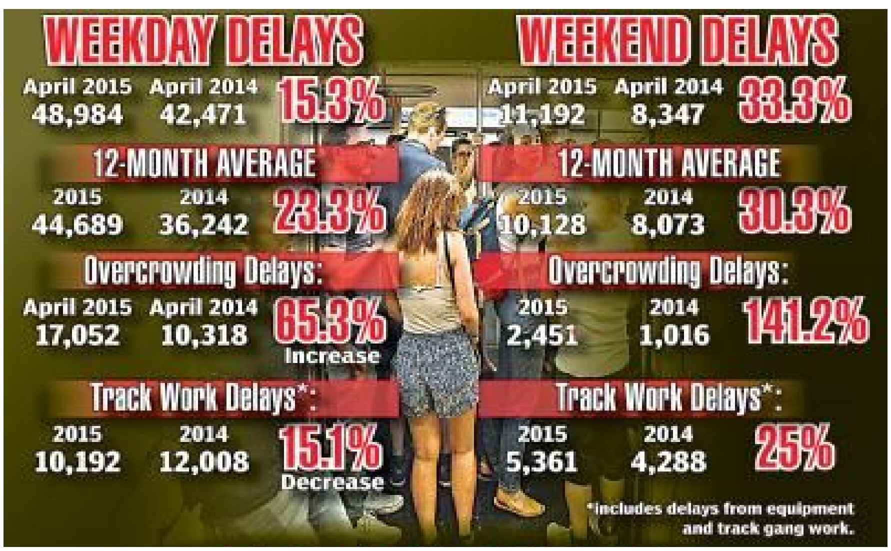
3.1 New York Metropolitan Transportation Authority

The New York City subway system, established and operated by the Metropolitan Transportation Authority (MTA), is one of the largest in the world. The network consists of over 270 underground stations and 24 different lines serving passengers all over the city (MTA, n.d.a). In 2014, the subway had approximately 5.6 million average ridership during the weekdays and 5.9 million during the weekends (MTA, n.d.b). Annual ridership reached about 1.75 billion, which places this system as the 7th busiest subway system in the world (MTA, n.d.c).

To improve its 100-year-old metro system, the MTA implements Capital Programs continuously; this investment has been a critical factor of New York's revitalization and growth for the past 30 years. In 2010, the MTA approved the 2010 - 2014 Capital Program Plan, a 26.3 billion dollar budget program (MTA, 2010). The goal of the program was to provide better and efficient transportation services to customers and improve current infrastructures. The program funded the purchase of 403 new subway cars and initiated the design of cars with improved efficiency for future Capital Programs (MTA, 2013). It also implemented new signal and communication technology, known as Communication Based Train Control, which allows the trains to run nearly every two minutes and to serve about 2,500 more passengers during rush hours (MTA, 2010).

The 2010-2014 Capital Program was expected to decrease the frequency of train accidents and delays caused by mechanical design issues and technical failures; however, recent data suggests otherwise. From October 2013 to October 2014, about a quarter of all trains arrived at the end of the line at least five minutes behind schedule.

Figure 4: Increase in delay frequency between 2014 and 2015



(Lewis, Sommerfeldt, & Rivoli, 2015)

During that time, the MTA reported an average of 41,547 train delays per month, which is a 51% increase from the average over the previous year (Donohue, 2015). From April 2014 to April 2015, the average number of delays per month on weekdays and weekends increased by 23.3% and 30.3% respectively while delays caused by overcrowding on weekdays and weekends increased by 65.3% and 141.2% respectively (Lewis et al., 2015).

As a follow up to the 2010-2014 Capital Program, the MTA launched a 29 billion dollar 2015-2019 Capital Program. The program will spend about 14 billion dollars towards New York subways. The program funds purchase of new subway cars which will provide more reliable service and passenger capacity, repair and reconfigure train stations throughout the network, and continue the expansion of CBTC signaling technology, which will increase the capacity of crowded trains (MTA, 2015). The MTA hopes that implementation of the 2015-2019 Capital Program will decrease dwell time and lessen the number of delays.

Along with the new Capital Program, which will decrease dwell time caused by mechanical and technological limitations, the MTA recently implemented a couple of different ways to sustain fast and smooth passenger flow in and out of the train. The MTA replaced the announcements broadcasted inside the train and on the platform with newer versions. The new announcements are updated more quickly than with the older version ([Mr railfan], 2012; [Mr railfan], 2015). The faster announcements decrease the door opening and closing time, which decreases dwell time while delivering necessary information to the passengers inside and outside the train (Blau, 2015). Also, the MTA recently hired Platform Controllers to reduce dwell times. Platform Controllers are equipped with safety equipment, a microphone, and a flashlight, and are located on platforms near the train doors. Their main job is to motivate and help the passengers alight and board the train as quick as possible while ensuring customer safety, assisting train crews with technical issues, and providing general information to passengers ([mtainfo]. 2015).

3.2 Tokyo Metropolitan Area

With 2.9 billion journeys per year, the Tokyo subway system serves the largest amount of passengers in the world (Coxin, 2011). The Tokyo Metropolitan Area (TMA) must provide public transit for not only its own citizens but also for 13 million foreign passengers annually.

During the year of the 2020 Olympics in Tokyo, the TMA is expected to carry more than 20 million foreign passengers (Briginshaw, 2015). The rapidly increasing demand for public transport is expected to cause excessive overcrowding within the city's underground, even though the Tokyo is world famous for its fast and efficient train system (Falzon, 2013).

Multiple lines in the TMA possess both express trains and local trains; however, the express trains are consistently more congested and have increased delays (Yamamura, 2014). The railway network planned to reduce train congestion through a high frequency train operation that involves different companies to share sections of lines. However, this high frequency operation actually increased train delay because of additional overcrowding of trains and congestion at stations (Hibino, 2010). Large concentrations of passengers at train doors will significantly increase the dwell time, thus increasing train delays (Hibino, 2010). In order to decrease train delays and increase efficiency, TMA constantly implements upgrades.

In the past few years, the TMA has made upgrades to its rail system revolving around three pillars: increasing safety, expanding lines, and exploring possibilities. Because of Japan's geographical position, rail safety includes earthquake protection and flood barriers (Briginshaw, 2015). Another safety-centered upgrade is electronically-operated platform-screen doors that have been implemented in nearly half of the TMA stations. The doors are a barrier between passengers and the tracks and only open once the train has come to a complete stop and opened its doors. The platform-screen doors have increased dwell time by a few seconds but have also eliminated the use of human train guards (Briginshaw, 2015). This is a unique instance when dwell time is purposefully increased in a system because of the platform-screen doors. The benefits of these doors include an improvement in the organization of passengers on the platform and an increase in safety, which may decrease delays.

The TMA employees are proactive towards reducing delays in the system as a whole. In order to reduce the frequency of delays in the Tozai Line, four of the five improvements made between 2008 and 2010 involved the goal of reducing dwell times, as seen below in Figure 5 (Yamamura et al., 2014). As one of the leaders in technological advancement, Tokyo also maintains a highly technical and constantly improves system in their city's main form of transportation, the Tokyo Metropolitan Area.

Figure 5: Delay reduction methods in Tozai Line

Topic	Factor	Content	Date implemented
Station Facilities	Alteration of Stop Line at Monzennakacho Station	Alleviation of congestion **Shortening of dwell time**	September 2008
Station Operation	Throughgoing operation by Extra Station Staff at high SI value stations	**Shortening of dwell time**	October 2008
Signal Facilities	Installation of Approach Code Signal at high AI value legs between stations	Shortening of running time Prevention of secondary delay	November 2008
Train Schedule	Modification of Train Time table	**Optimization of dwell time**	March 2009
Car Facilities	Intensive of Trains with wider door car	**Shortening of dwell time**	May 2010

(Adapted from: Yamamura et al., 2014)

3.3 Hong Kong Mass Transit Railway

The Mass Transit Railway (MTR) system is the most popular mode of public transportation in Hong Kong with 1.6 billion passengers yearly. The Hong Kong MTR has 218 kilometers of line and more than five million passengers daily (Wong, 2015). The MTR has employed some innovative methods in reducing dwell time on highly congested lines. To minimize overcrowding, the MTR added an extra charge during peak hours and a standard price for non-peak hours (Lam, 1998). This pricing method dissuades non-commuters from using the train during peak hours, thereby reducing the number of passengers (Wong, 2015). Although unconventional, the MTR does not have a timetable because trains arrive every few minutes and even sooner during peak hours. Delays and excess journey time are easily avoidable because it is simple for visitors to buy a ticket through automated machines and board the next train (Falzon, 2013).

Today, the corporation operating the Hong Kong MTR claims to possess a 99% punctuality rate for their system (Wong, 2015). Some of this claim can be attributed to their state of the art mechanical systems, including artificial intelligence. In the central control room, there is a black incident box that indicates any problem with tracks or delays in any section of the entire system. The control room workers strive to solve every incident in under two minutes. According to MTR reports, most delays are caused by last minute passengers rushing onto the train and passengers accidentally activating emergency alarms (Wong, 2015). Even in one of the most advanced technological underground systems, dwell time, as indicated by passengers boarding trains last minute, is one of the most common factors for train delays.

4. London

4.1 London Population

Currently the population of London is over 8 million and is predicted to be around 10 million by 2030 (Office for National Statistics, 2014). The population has been increasing over the past two decades and is projected to grow by around five percent per decade over the next thirty years (Greater London Authority Intelligence, 2015). In this growing population, there are currently proportionally fewer residents over the age of 50, especially within the population of Inner London, the main central area of the city. Inner London has a higher percentage of younger adults as 25% of people living there are ages 25 to 34. This along with London having a higher proportion of children ages 0 to 4 compared to the rest of England shows a prevalence of young adults starting families (London's Poverty Profile, 2015).

Public transport is important for the population of London, especially because 41% of trips in London are made using public transportation (LSE Cities, 2016). Each person in Great Britain takes an average of 921 trips, according to the results of the 2014 National Travel Survey. Out of these 921 trips, about 19% are for shopping while 16% are for commuting (Department of Transport, 2015). The cost of commuting affects the lives of many London residents as 2.25 million people are currently living in poverty. Residents earning more than £600 per month lose 20 minutes of pay per day for commuting costs while those earning less than £200 lose 1 hour 56 minutes of pay. This causes 36% of commuters to not use the quickest or best route available because it is more expensive (London’s Councils, 2015).

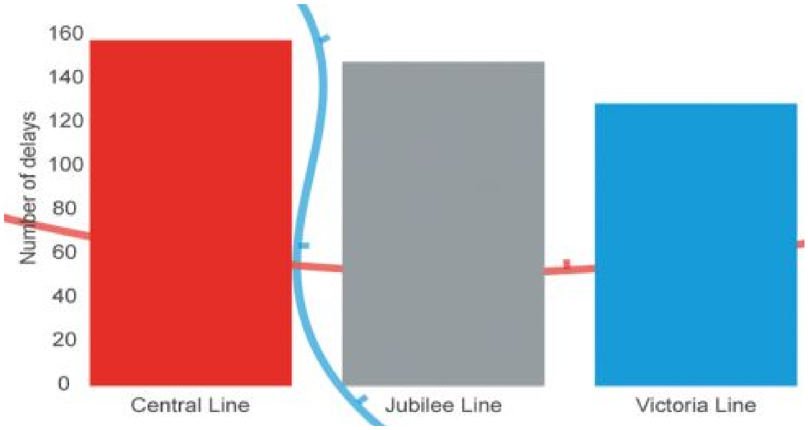
4.2 London Underground

The London Underground (LU) is the rail system located underneath the capital of the United Kingdom. In addition to its large population, London also accommodates over 18 million overnight visitors annually (MasterCard, 2016). With a large population and high amount of visitors, the LU is important for transporting large amounts of people around the city, as it carries over one billion passengers annually (TfL, 2016b). Since it opened in 1863 as the world's first underground railway, the LU has grown to consist of 11 different lines traveling on 402 kilometers of rails that service 270 stations across London (TfL, 2016d). In order to transport passengers between these stations, over 76 million kilometers of rail is traveled annually at an average of 33 kilometers per hour (TfL, 2016b). Each of the lines on the LU run at different paces in order to keep up with the varying demand for public transportation across London.

4.3 Central Line

The Central Line is represented by the red line on the map of the London Underground (See Appendix G Figure 6). It opened in 1900 as the Central London Railway as a cross-London route and has grown into the longest line in the LU with 78 kilometers of track connecting 49 stations (TfL, 2016d). The route travels east-west from Epping Station to West Ruislip Station and has a one way travel time over an hour and 20 minutes (TfL, 2016e). The Central Line runs through four of the ten busiest stations including Oxford Circus Station, the busiest LU station with 100 million passengers in 2014 (Gelbart, 2015). At its peak, the Central Line has 34 trains per hour carrying over 250 million passengers per year (Wright, 2015). During its last major modernization completed in 1995, the Central Line implemented automatic operation and entirely new trains (TfL, 2013). Each of these trains has the ability to carry 892 passengers with eight cars totaling to 133 meters in length. Compared to the current rolling stock on other lines, the Central Line 1992 rolling stock is one of the most compact trains in the LU (TfL, 2007). In addition to compact trains, Central Line platforms tend to be more narrow than platforms that have been upgraded in the past few decades. The combination of limited train and platform capacity with busy stations contribute to the consistent overcrowding of the Central Line. As seen below in Figure 7, it has recorded the highest number of LU delays since 2010 with 158 reported delays due to overcrowding (Bentley & Ehrenberg, 2015).

Figure 7: Tube delays due to overcrowding since 2010



(Source: Bentley & Ehrenberg, 2015)

During early March 2016, the Central Line had an excess journey time of 4.22 minutes and the highest moving annual average of signal and point related delays lasting over two minutes out of all the lines in the underground. This contributes to the Central Line having the highest moving annual average of total lost customer hours (TfL, 2016g). Due to the number of delays within the Central Line, increased dwell time is a major factor influencing passenger journey times.

4.4 Current Dwell Time Minimization

Rail performance across the UK is flat-lining, not being as good as it was in the previous five years (The Golden Whistles, 2016). While the LU network excess journey time was at its lowest in seventeen years at 3.64 minutes, it is still significant as it causes inconsistencies in predicted times (TfL, 2016g). In 2012, the dwell time during peak hours averaged to 34.7 seconds while the dwell time during non-peak hours averaged to 27.4 seconds (Karekla & Tyler, 2012). This inconsistency in dwell time as well as other factors have prompted TfL to make improvements and create plans for further improvements in the future.

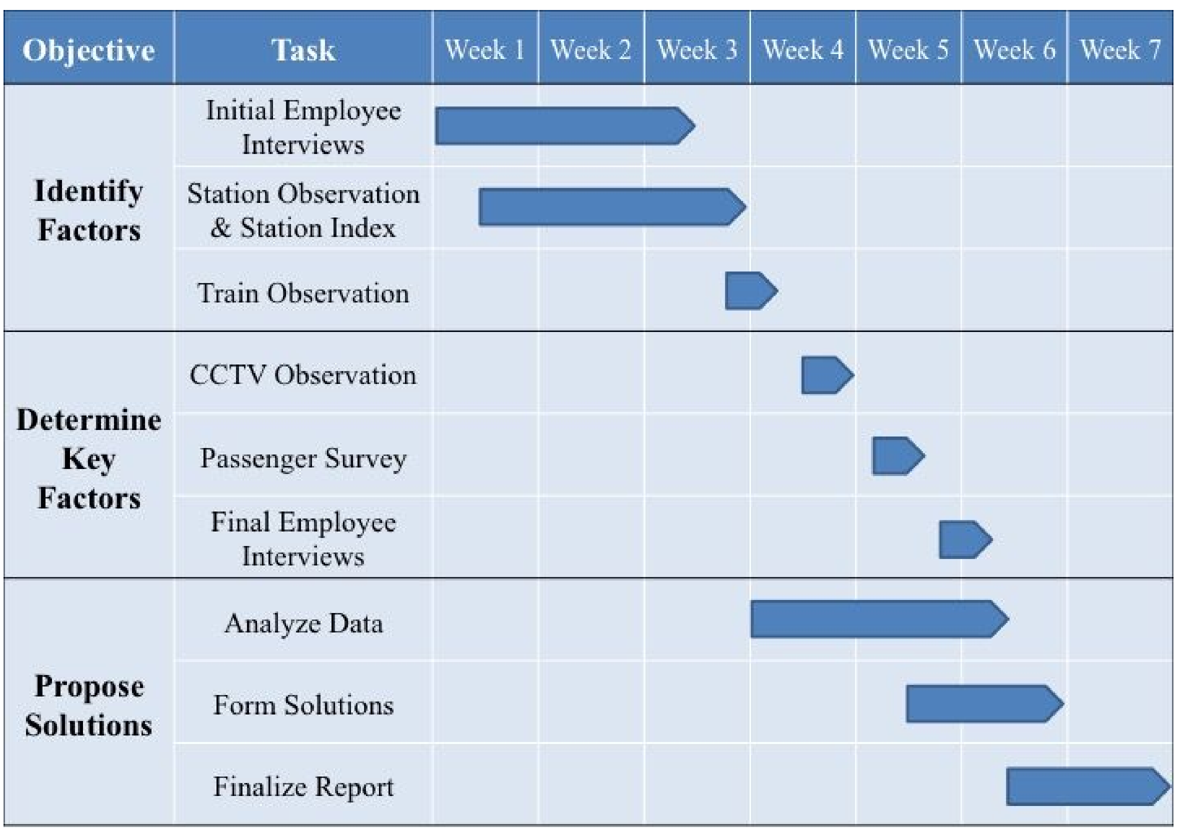
Transport for London aims to not only maintain the current system but also to improve the system based on increasing passenger demand. The Victoria Line was upgraded in 2012 to have a new signaling system and a new fleet of trains which increased the amount of trains per hour during peak times from 28 to 34 trains (TfL, 2014 June 30). Currently, the LU is working on the modernization of the Circle, District, Hammersmith & City and Metropolitan lines. The changes planned for these lines include new trains, tracks and signaling system in order to increase passenger capacity, improve speed and reduce delays (TfL, 2016c). In addition to modernization, the LU also focuses on increasing safety and decreasing delays due to accidents. Along the Jubilee Line, platform gates have been installed at new stations to prevent passengers from falling onto the tracks which causes major delays.

There are currently two major plans in place that focus on improving the LU over the next few decades. The first plan, the Tube Improvement Plan, has been running for the past decade refurbishing stations, upgrading lines, and installing step free access (TfL, 2016d). Another plan is Fit for the Future which is an improvement plan that started in 2014 with the goal of preparing TfL for the increase in population in the coming decades. This plan focuses on four priorities: safety and reliability, increased maximum capacity, network growth, and customer service (TfL, 2014). The plan is scheduled to be completed in 2024, and these improvements will add customer hours, increase trains per hour, increase speed, and add more capacity across the entire network (TfL, 2014).

Methods

Three objectives were devised and met in order to complete the overarching project goal of minimizing the dwell time issue in the Central Line. First, factors that can affect dwell time were identified. Building on background research, initial observations and informal employee interviews allowed for the identification of factors that influence dwell time in the Central Line. Second, the key factors were determined by studying which of the factors have the most impact, in terms of both frequency and severity, concerning increased dwell times in the Central Line. In order to determine which are the key factors, data was collected through CCTV observation, a passenger survey, and additional employee interviews. Thirdly, the team formed possible solutions to the identified key factors that affect dwell time and delivered suggestions on minimizing dwell time to Transport for London employees. A project timeline is provided below to illustrate when each task was completed.

Figure 8: Project Timeline



1. Data Collection Methods

1.1 Employee Interview

We conducted informal interviews with 20 TfL employees to identify professional opinions about dwell time causes and to gather a deeper understanding of the LU itself. The interviews focused on determining dwell time factors, current procedures implemented to minimize dwell time, and suggested solutions to minimize dwell time (See Appendix A for interview draft questions). We interviewed both "behind the scenes" office-type employees and "frontline" station-type employees. In order to improve our understanding of both the Central Line itself and common dwell time factors, we began by interviewing the behind the scenes employees.

Behind the scenes employees include engineers and officials who work with the Central Line, London Underground, and dwell time in general. The behind the scenes employees that we interviewed were from the Templar House and the Central Line Control Room. The Templar House is one of the LU main offices and houses several engineers and other staff with valuable knowledge on everything related to the LU. This knowledge includes current improvement plans, technology updates, information on stations, etc. The Central Line Control Room is the command center for the entire Central Line, lead by differing line managers. These employees were able to provide insight on possible solutions and information of a technical nature as they face issues with delays and increased dwell times nearly every day. These employees were able to provide insight on possible solutions and information of a technical nature.

After having compiled a list of dwell time factors, we interviewed frontline employees to assist us in focusing in on the key factors. Frontline employees include the train operators and station managers. This secondary round of interviews was in a more formal setting with the team members writing notes. They gave us a more detailed view into the problems of the Central Line, particularly human behavior as they see and deal with passenger problems everyday. By interviewing these two different types of employees, we gained a greater perspective of the problems that the Central Line faces with regards to dwell time.

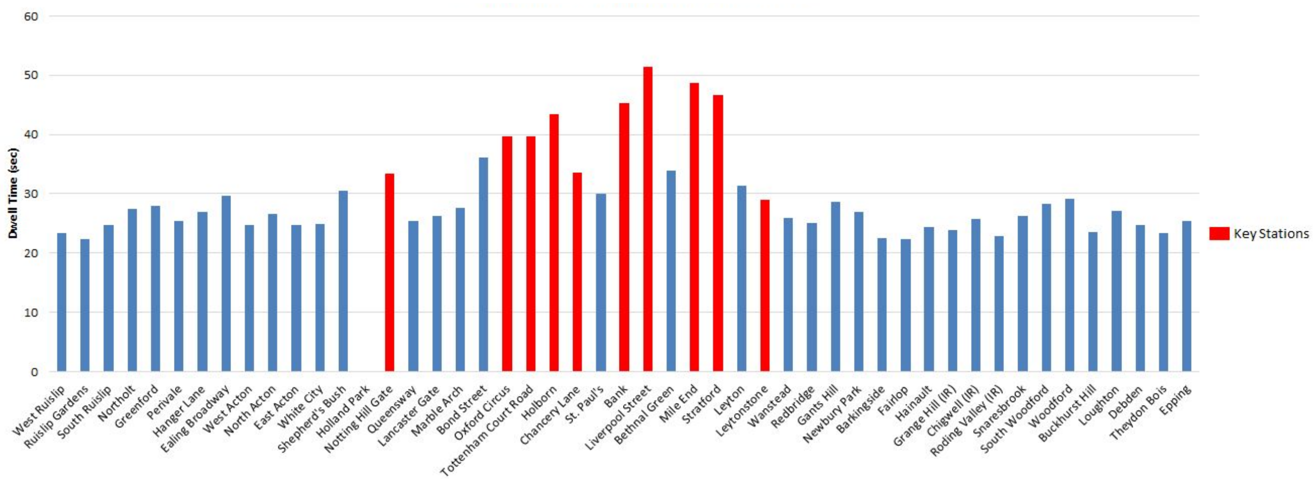
1.2 Direct Observation

Direct observation was our main qualitative source of information to identify factors that disrupt passenger flow and increase dwell time. We used three different types of observation: station observation, train observation, and CCTV observation. Throughout direct observation, we used two qualitative methods to measure the amount of passengers on the trains and the platforms.

Train Crowdedness Level (TCL) is a qualitative measurement of the amount of passengers in the train cars (See Appendix G Figure 9). A TCL of 0 is a completely empty train. A TCL of 1 consists of some passengers filling seats. A TCL of 2 is when all seats are taken or could be taken with the amount of passengers in the train. A TCL of 3 occurs when all seats are taken and some passengers are standing with easy passenger motion. A TCL of 4 is when all seats are taken and most standing area is taken with medium passenger motion. A TCL of 5 consists of an overcrowded train with all seats and standing space taken with difficult passenger motion.

Platform Crowdedness Level (PCL) is a similar measurement of the amount of passengers but is recorded on each section of a station platform (See Appendix G Figure 10). The platforms are divided into four sections based off of the CCTV camera views that generally correlate with one carriage, which is two train cars. The PCL is measured for each section directly before the train doors open. A PCL of 0 is a completely empty platform section. A PCL of 1 consists of scarce (5 or less) passengers on the platform section. A PCL of 2 has few (10 or less) passengers on the platform section. A PCL of 3 occurs with some (15 or less) passengers on the platform section with easy passenger motion. A PCL of 4 consists of many (20 or less) passengers on the platform section with medium passenger motion. A PCL of 5 possesses excess (over 20) passengers on the platform section with difficult passenger motion.

Figure 11: Central Line Average Dwell Times on 3 Feb. 2015



(Adapted from: Harries, 2015)

As indicated above in Figure 11, ten key stations were selected because of significantly high dwell times. The ten key stations, organized from West to East geographically, are Notting Hill Gate, Oxford Circus, Tottenham Court Road, Holborn, Chancery Lane, Bank, Liverpool Street, Mile End, Stratford, and Leytonstone. Although observing each of the Central Line's 49 stations would be ideal, the time constraint on the project made this impossible. Only two of these key stations, Chancery Lane and Leytonstone, do not have interchanges with other lines. Chancery Lane was included because it possesses the highest dwell time for a non-interchange station. We also included Leytonstone for its uniqueness as an external station with three platforms, crew release, and a nearby depot.

The goal of station observation was to document information on each of the key stations in order to identify common factors (See Appendix B). The recorded information includes the station name, time of observation, station layout, platform layout, information display, passenger notes, train crowdedness levels, average dwell times, and nearby areas. Station and platform layout information was supplemented by diagrams gathered from the Heartbeat Database in Templar House. The average dwell times are based on the five recorded dwell times for each Central Line platform, both Westbound and Eastbound. While this average dwell time may not be precise due to a small sampling size and timing errors, the recorded times provide a more quantitative approach to the increased dwell time issue. The nearby areas section was added in order to identify the types of passengers that may make up the majority of the passengers at that particular station. For example, if one key station has a popular shopping area nearby, then the passengers are more often shoppers and casual riders. Station observation is designed to broaden the list of the factors that do increase dwell times.

For train observation, the team was divided into two groups in order to observe the entire Central Line in a short time frame. One group used the service from West Ruislip to Holborn and the other from Epping to Holborn during morning peak time, which is between 07:00 and 09:00. At each station, the team noted the dwell time, train crowdedness level, and passenger behavior. Train observation allowed for closer encounters with passenger flow in boarding and alighting, as well as flow through the car itself. Passenger flow and TCL are both necessary to identify passenger behavior factors that increase dwell time.

Once the key factors that increase dwell time were identified, we performed broader observation using closed circuit televisions (CCTVs) installed on the platforms to determine and record the frequency of key factors occurring during morning peak times. We used the CCTVs at the Central Line Control Room with access from our sponsor and other TfL staff. We observed all 10 key stations during morning peak time, each for 30 minutes, and recorded the type and frequency of factors that occurred. The data was collected in a chart including time of observation, platform crowdedness level, dwell times, frequency of large items, reasons for door reopening, number of problem passengers, and amount of alighters. Large luggage is defined as any carriable items larger than an average backpack, including suitcases, duffle bags, and packages. Problem passengers are the passengers that may cause increased dwell times, such as running to board the train, obstructing flow, staring at maps for direction, or traveling in groups of two or more. We organized obtained data into bar graphs and used a checklist for visual representation and analysis.

1.3 Passenger Survey

In order to gather data directly from passengers, a verbal survey was conducted in two Central Line stations: Holborn and Chancery Lane. Both of these Zone 1 stations have relatively high dwell times and Holborn contains an interchange with the Piccadilly Line while Chancery

Lane only services the Central Line. An ideal survey would be conducted over multiple weeks in many locations and times to more completely solidify the results, but the time constraint on the project only allowed for a few days to administer the survey to a hundred passengers.

The survey questions were designed to extract information about the effects of passenger demographics on dwell time as well as customer satisfaction with aspects related to dwell time (See Appendix E for a complete list of questions). For example, if many respondents are dissatisfied with signage at stations, then it would suggest that many passengers have difficulty with gaining the necessary knowledge for their journey. Uninformed and inexperienced passengers could be a major factor in increasing dwell time because of bunching by maps or in entrances. This type of result would lead to suggesting various methods to increase or alter information display in Central Line stations.

We believe that surveying both daily commuters and occasional users of the rail system would give us the most accurate representation of data from typical Central Line passengers. Since different types of passengers use the trains at different times, it was important to distribute sampling throughout the day. Therefore, we selected two time periods: an afternoon non-peak time and an evening peak time interval. At these centrally located stations, the afternoon non-peak time focused on casual passengers, such as tourists and shoppers, and the evening peak time concentrated on commuters. The optimal time ranges to conduct the survey include the afternoon non-peak at 11:00-13:00 and evening peak at 17:00-20:00 (Campoli, Johnstone & Szafarowicz, 1999).

The survey was conducted on both Westbound and Eastbound Central Line platforms in the stations. Each team member was responsible for verbally surveying the passengers and recording their answers through the offline version of the Qualtrics survey. Although we had considered distributing paper copies of surveys, the verbal to digital method is more effective as it was quicker for passengers, safe for team members, more clear for analysis, cost efficient, and reduces litter/waste. Because passengers are more likely to respond to a short survey than a long one, we created a survey that is ten questions long, which was typically able to be completed in less than two minutes.

As mentioned above, the survey data was collected through an offline version of a survey through Qualtrics, a web-based survey software tool. We used Qualtrics from our mobile devices to record the responses of each participant and uploaded the data once back online. We organized the recorded data by using Qualtrics' analysis features. Based on the demographic data gathered from the survey, we partitioned the responses into subgroups, such as commuters and non-commuters.

1.4 Solution Proposal

Probable solutions to the previously identified key factors needed to be formed in order to complete the project goal of forming options for minimizing dwell times in the Central Line. To form probable solutions, the results from each of the methods were analyzed to determine areas where changes could be made to improve a combination of system constraints and human behavior problems. CCTV observation and the passenger survey were studied in depth through various graphs because of their more quantitative nature.

Data analysis improved our understanding of the causes of passenger flow issues and other human behaviors. Completing data analysis enabled us to form practical and effective solutions to reducing the Central Line dwell times. Once we compiled probable solutions to the combination of system constraints and human behaviors, we conferred with our sponsor and his colleagues for their professional opinions on the efficiency of the proposed solutions. After adjusting the solutions from their advice, we then published our findings and solutions through this final report and the final presentation to our sponsor, our advisors, and the public.

2. Other Considerations

2.1 Ethical Considerations

As with any research with human subjects, ethical issues may arise while we conduct the research. Throughout this project, we interacted both formally and informally with the employees and passengers of the Central Line. In the employee interview, an ethical issue of possibly placing the interviewee at risk of damage to the subjects' employability or reputation because we may disclose the employee's identity or responses. We only used information provided from interviewees who agreed to allow us to use the information; we did not ask questions that could cause responses that could possibly damage employability or reputation.

Since they were asked to complete the passenger survey, some Central Line passengers may have felt that their privacy was being invaded. The survey aimed to collect data on all factors that affect dwell time, which include confused passengers. We minimized the risk by informing all passengers that the survey is entirely optional, confidential, and anonymous and by obtaining approval to conduct this research from the Worcester Polytechnic Institute Institutional Review Board.

2.2 Alternative Plans

Throughout the project, methods were flexible and prone to changes depending on factors such as response rate and issues with survey or interview questions. Direct observation through the CCTV recordings contains the least variation from outside sources when compared to the employee interview or passenger survey. In the case of failure to access CCTV recordings, we planned to collect additional direct observations while physically on the trains and platforms during peak hours.

The passenger survey could have been problematic because of our questions or because of the respondents. If the problem with the data was due to an issue with the methods themselves, such as a commonly misinterpreted survey question, then we planned to either take out that problem question or replace it and to re-administer the survey to a new sample of passengers in order to collect more reliable data. If the passenger survey response rate was much lower than anticipated because of a lack of anonymity, bad timing, or anything of that nature, then an online survey was the most reasonable alternative. An online survey could collect the most similar data to the original survey, so it would make an appropriate substitute if necessary. The target population would remain the same and the sampling strategy would still be non-probabilistic sampling. The collected online survey data would be analyzed in the same fashion as the original survey. Because we have already set up the Qualtrics survey, we only needed to make minor changes to distribute the digital Qualtrics survey through a London Underground website or emailing list. If neither of those were available, we planned to distribute physical papers with QR codes and the website link in the stations of the Central Line.

Data Analysis

This section displays the analysis process for the methods mentioned in the previous chapter. The employee interviews section includes the general types of information gathered from behind the scenes and frontline employees. Next, the three different types of direct observation provide a complete analysis of factors that affect dwell time as they provide different views of passenger behaviors, system constraints, and how they interact. The passenger survey includes the analysis of the passenger survey with overall results and data based on passenger type. This section provides information on the prevalence and influence of factors that influence dwell times in order to provide solutions in the conclusion chapter.

1. Employee Interviews

1.1 Behind the Scenes Employees

Behind the scenes employee interviews provided professional opinions on the factors of dwell time, as well as more general information on certain aspects of the Central Line and the Underground. Their opinions helped us to determine factors that could potentially affect dwell time and provided information that we incorporated to enhance our background information.

Our first interviewee was our sponsor, Eric Wright, a signaling engineer that has worked with TfL for over 10 years. Eric was able to provide us with a plethora of general knowledge regarding railways that comes from a lifetime of experience. The information helped us to bolster our background and gain a better understanding of the complex systems in the LU. Eric also supplied us with access to the Heartbeat database through his account at Templar House. The Heartbeat database contains statistical information about the entire LU. We used Heartbeat to acquire data on the negative effects of dwell time such as lost customer hours and excess platform wait time. He also gave us access to station layout blueprints.

Another behind the scenes employee that we interviewed was a member of TfL's innovations team, Jason DaPonte. Jason shared his findings from the innovation team's crowding indicators project. This project was related to minimizing dwell time because of its focus on passenger behavior. By viewing the innovation team's project, we were able to confirm the validity of our methods. The project also inspired us to use the TCL and PCL metrics to quantitatively measure the crowding patterns of trains and platforms.

Other interviewees, such as Lawrence Weller, Steve Walling, and Neil Elrick, were immensely helpful in giving us important connections around TfL. These connections were used to gain access to secure areas like the Central Line Control Room, Victoria Line Control Room, and Signalling Equipment Rooms.

1.2 Frontline Employees

Frontline employee interviews provided a unique perspective on the factors of dwell time. Their experiences gave us great insight into how passenger behavior affects dwell time. Out of the five drivers that we interviewed, all agreed that platform crowding by entrances, rushing passengers, and holding doors were major issues in the boarding and alighting process. Four of the drivers agreed that tourists and other generally inexperienced passengers caused problems by being too hesitant. They explained that it can be difficult to judge what some people on the platform are doing and that many tourists will take a while to figure out if the train is actually going where they want to go. This forces the driver to wait and gives more time for the tourist to get their bearings and make a decision, usually resulting in a last second boarding. The drivers also agreed that most passengers are oblivious to announcements and signs. They explained that many passengers wear headphones, cannot hear, or just do not listen to announcements and miss out on critical information. Every driver agreed that more platform attendants would be a good solution to reduce dwell time.

Station managers were also in concurrence with the drivers that platform crowding is a major issue. Station managers explained that they sometimes close some of the ticket barriers to reduce the amount of passengers coming into the station to reduce crowding, although this only happens during peak time.

2. Direct Observation

2.1 Station Observation

All the data gathered from station observations are organized into Appendix B for complete station observation data of all ten key station. Due to the age of the Central Line, the platforms are older and small in comparison to other newly built platforms. The widths of all ten platforms observed during station observation vary between three to seven people wide when facing towards the tracks.

Announcements at each key stations were frequent and concise, but the amount of detail provided were not consistent across all stations. The announcements at Tottenham Court Road Station informs the passengers about when the next train will be arriving whereas the announcements at Oxford Circus Station informs the passengers about simple and general information of the service quality of all LU lines.

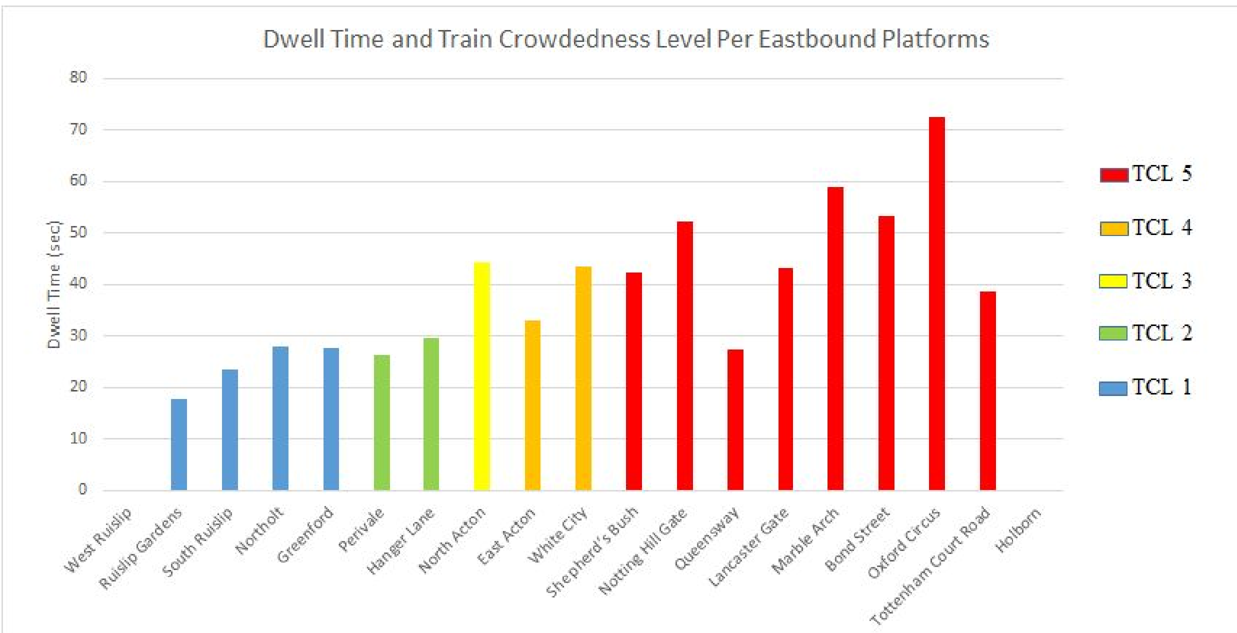
Each station has signs and maps to help passengers, even first time passengers, easily navigate the Central Line. The information displays and maps are placed directly in the passenger's view as they enter the platform at some stations. For example, at Stratford Station, the dot matrix informing the passengers when the next train will be arriving is right above the end of the staircase that leads to the platform. At many other stations including Mile End and Chancery Lane, the simple map of the Central Line is right in front of the entrance. Such sign placements encourages passengers looking for certain signage or information to halt in front of the entrance to the platform without realizing that they are doing so and cause obstruction to passengers entering and attempting to move down the platform.

2.2 Train Observation

The group that rode the train east into Holborn during peak hours was delayed on the journey to West Ruislip. The train was stopped in White City because of a track failure issue between North Acton and East Acton. The train was completely stopped at White City for 20 minutes then proceeded with manual driving, a low speed, and frequent stops. Announcements about the delay were relayed by the train operator and were clear with all available information. After arriving in North Acton Station, the track failure was completely fixed, and for the remainder of the journey, both to West Ruislip and back into Holborn, had typical journey times.

As you can see in Figure 12 below, the recorded dwell times mostly correlated with the Train Crowdedness Levels from West Ruislip to Holborn. Each platform with a TCL of 1 or 2 had a dwell time under 30 seconds, but platforms with a TCL of 5 had an average dwell time of 43.9 seconds. Dwell time was also notably influenced by the number of alighters and boarders, last minute boarders, and doors reopening.

Figure 12: Dwell Times and TCL all stations on Eastbound Central Line

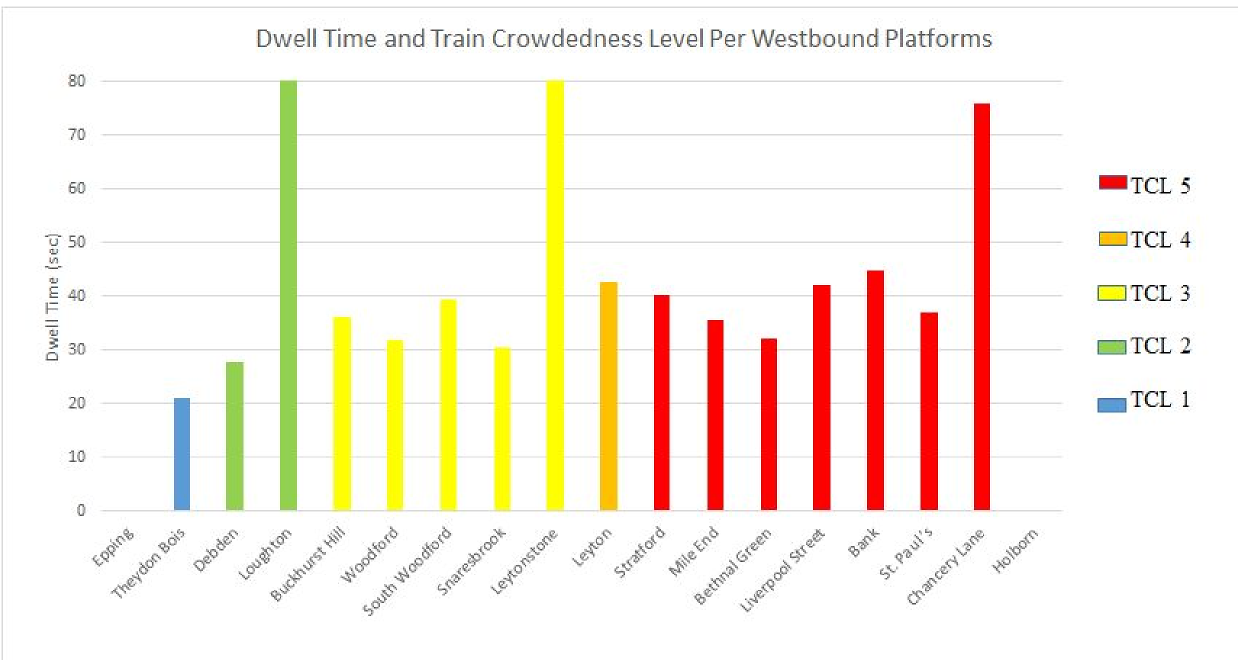


The main outlier is Queensway, which had a TCL of 5 and a dwell time of 27.43 seconds. With no alighters and only 5 boarders, the dwell time at Queensway is significantly lower than the dwell time at Oxford Circus. Oxford Circus had a dwell time of 72.64 seconds because of 15 boarders, 15 alighters, and baggage causing doors to reopen. The recorded information for Eastbound platforms relates to a typical AM peak journey (See Appendix C1).

The second group went to Epping and rode the train west into Holborn. On the journey to Holborn, the train was delayed by multiple issues which resulted in the train continuously stopping for short periods of time (2-3 mins). The announcements indicated that the delays were caused by a signal failure and a passenger tripping the emergency alarm. Due to delays, boarding and alighting was not consistent at each station as passengers boarded the train that departed the platform prior to our train's arrival.

As seen below in Figure 13, Loughton and Leytonstone are outliers with dwell times over 80 seconds because of delays due to signal failures. Compared to the unaffected Eastbound journey, the Westbound platforms with a TCL of 5 had an average dwell time of 48.65 seconds, over 5 seconds higher. The Westbound journey was consistent with an AM peak journey with notable delays (See Appendix C2).

Figure 13: Dwell Times and TCL all stations on Westbound Central Line



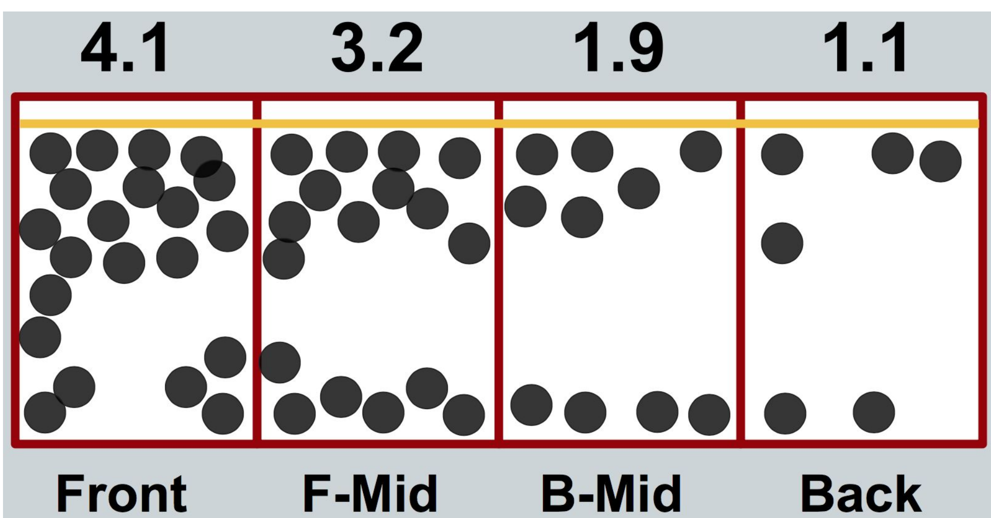
Throughout the journey in either direction, the types of passengers and their behavior remained fairly constant. As expected during the morning peak time between 7:30 and 9:00, the majority of passengers were commuters. There were a few instances of children going to school and more casually dressed riders. In terms of activity, passengers were mostly on phones, reading or chatting on phone or with other passengers. As the train became more crowded with commuters, more people were occupied with their phones or their thoughts instead of chatting or reading. The passengers all appeared to be calm, patient, bored, and familiar with the journey, similar to being on autopilot.

The ratio of female to male passengers fluctuated and did not display any large difference in behavior. While most females carried a medium to large purse, most males also possessed medium to large bags. The only minor difference in behavior was that women typically held their purses under their arms while standing but men tend to place large bags on the ground by their feet.

2.3 CCTV Observation

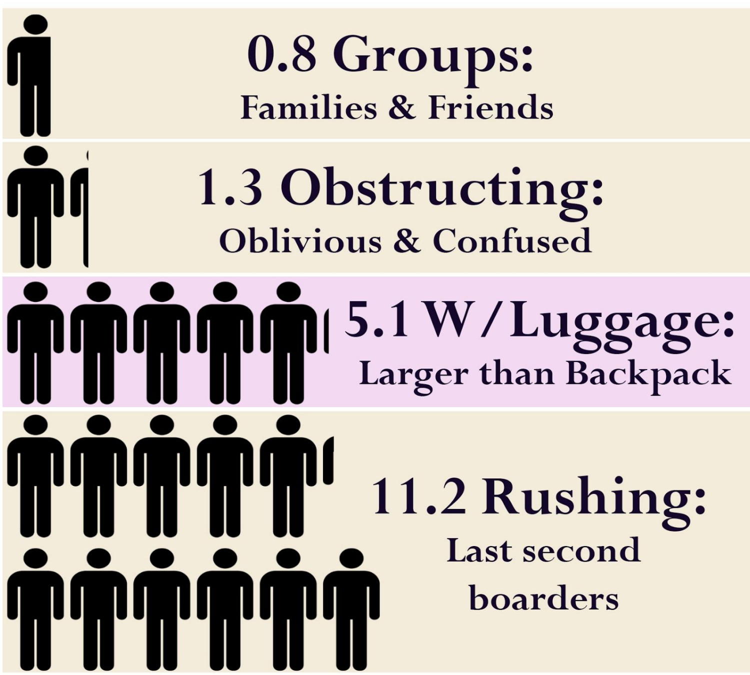
Ten key stations were observed during morning peak time from the Central Line Control Center. The dwell time and Platform Crowdedness Level (PCL) of all four sections (Front, Front-middle, Back-middle, Back) of the platform were recorded for the whole duration of CCTV Observation (See Appendix D). Through our observations, we found that the section of the platform that contained an entrance was the most crowded section. This pattern was followed by 19 out of the 20 platforms that we observed; the outlier being Leytonstone eastbound. Below is an example of the average PCL for the Oxford Circus westbound platform from 7:45 to 8:10 (See Figure 14). The entrance and exit on this platform was in the front section.

Figure 14: Average Platform Crowdedness Levels for Oxford Circus



Along with dwell time and platform crowdedness level, we also recorded door reopening and causes. Our data shows that over two thirds of door blockages are intentional (See Appendix G Figure 15). Intentional causes include last minute rushers and purposefully holding the door. Accidental causes include people's belongings such as backpacks, luggages, or hair getting caught between the doors accidentally. Of the intentional obstructions, we found that rushing passengers was the most common (See Figure 16). The second most common reason was holding the door for luggage. While there were both passengers who were in groups and oblivious, they were far less prevalent.

Figure 16: Frequency of Problem Passengers per 10 Trains



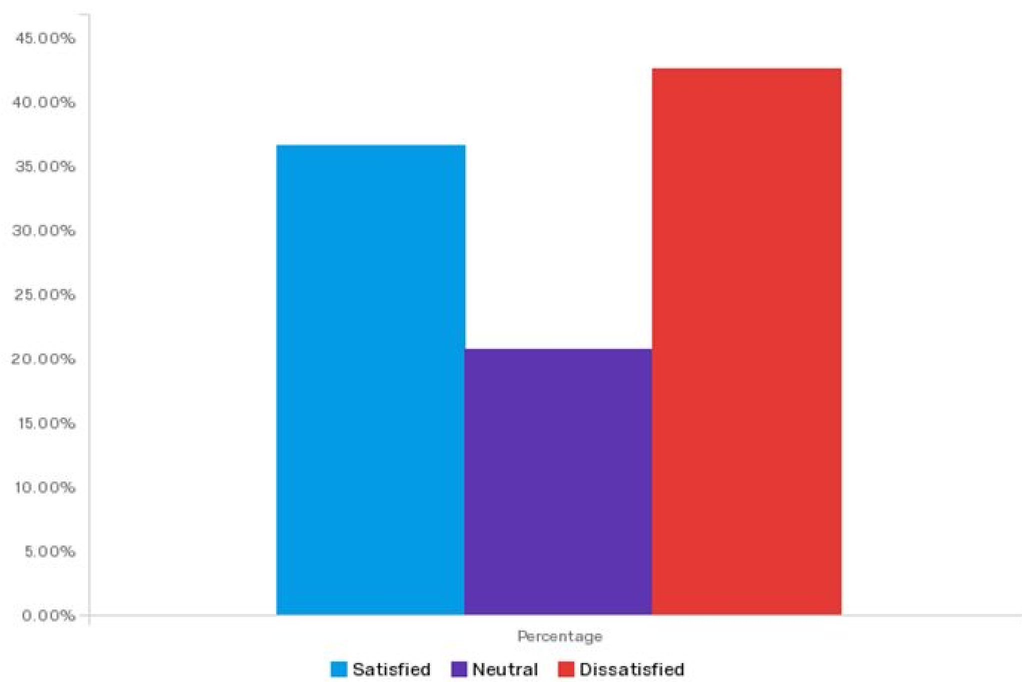
3. Passenger Survey

3.1 Overall Results

Collecting data on passengers and how they behave was done through a passenger survey. The data from this survey was collected in Qualtrics and can be further explored through a generated report in Appendix F. This survey was conducted at different times at two different stations to ensure a good variety of passengers were sampled. A total of 105 passengers were surveyed during peak and off peak times at Chancery Lane Station and off peak times at Holborn Station. Surveys were not conducted during the peak time at Holborn due to the difficulty of conducting surveys during the peak time at Chancery Lane which is not as busy of a station. Conducting surveys during the peak time was difficult as not many people were willing to take a minute out of their commute to stop and talk. During the non-peak time, passengers were a bit more willing to take the survey.

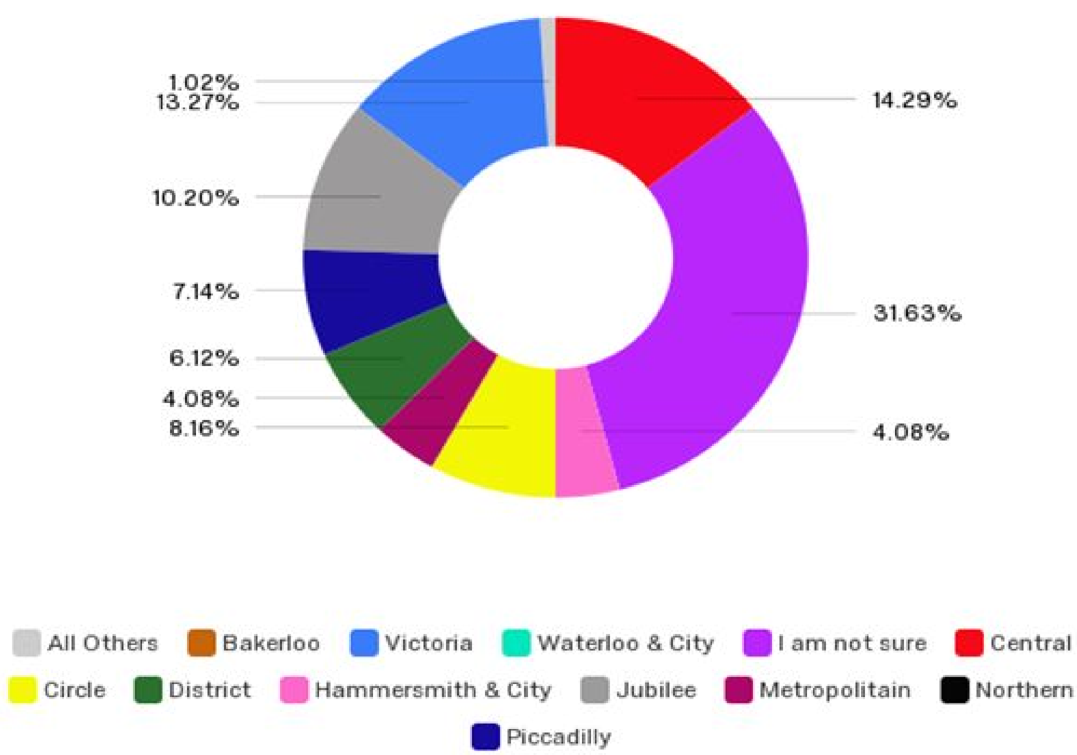
While conducting surveys, the team was mistaken for members of LU staff and asked various questions. This happened often at Holborn as passengers would ask how to get to various stations and how to get to the Piccadilly Line even though the members of the team were standing underneath the signs guiding passengers to that line. Despite needing to ask for directions 77.23% of passengers said they were satisfied with the provision of information. Along with the provision of information, passengers were also generally satisfied with platform layouts as 66.67% said they were satisfied.

Figure 17: Passenger Satisfaction with Train Passenger Capacity



Comfort is a priority for passengers as 71.15% said that they would wait for a later train if it was going to be emptier and the majority were either neutral or dissatisfied with the Central Line train size and passenger capacity, as seen above in Figure 17. This need for comfort is also seen in passengers' reasoning for why the line they chose is their favorite as they noted that there are always seats available, the trains are bigger, and it goes to where they live. While most of the passengers did not pick a favorite line as 31.63% said they were not sure, 14.29% picked the Central Line as their favorite line. Passengers who picked the Central Line as their favorite gave reasons such as convenience as it went to where they wanted to go or they lived on the line, and the efficiency of the service. Over half of the passengers said that a line other than the Central Line is their favorite for a few different reasons such as the efficiency, how crowded it is, and the type of train car the line runs. Many passengers chose a sub-surface line because of the S-stock trains that run on those lines. Passengers favored the S-stock because of its open cars, larger capacity, and more available seating.

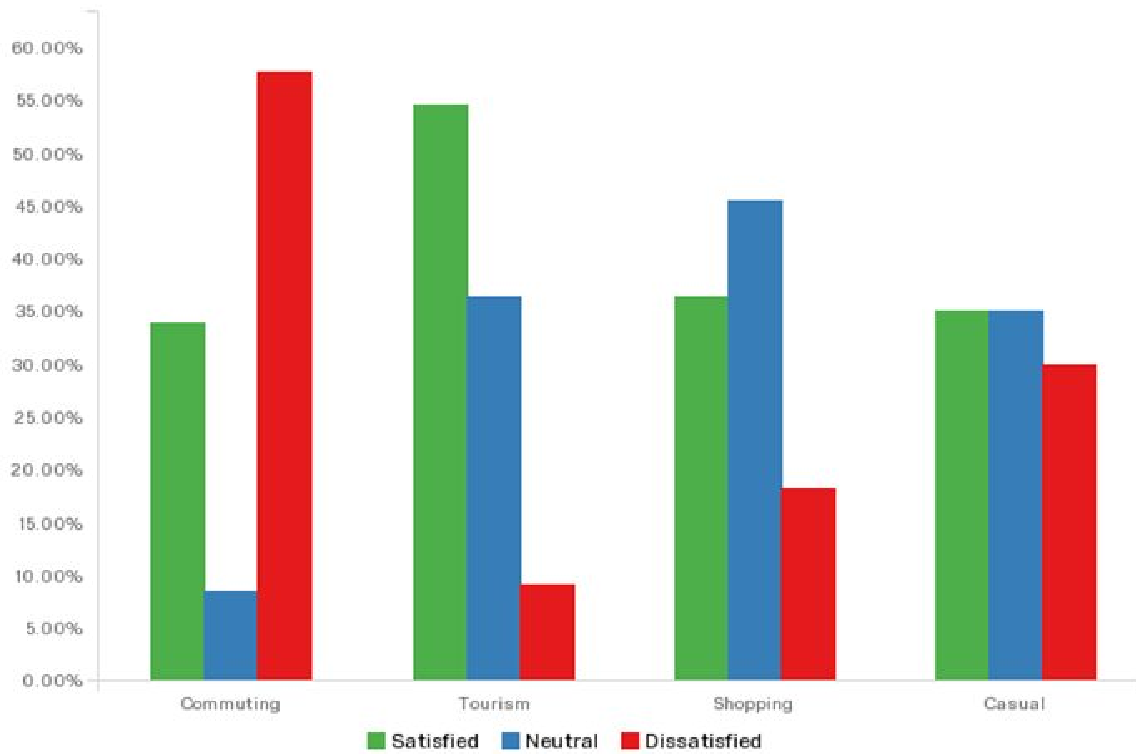
Figure 18: Favorite London Underground Line Among Passengers



3.2 Types of Passengers

Based on the results of the first question, passengers were sorted into two categories, commuters and non-commuters. The majority of passengers were commuting and only agreed to take the survey after they were told it would be done before the next train arrived. Despite the rush they were in to get to where they were going, 74% said they would be willing to wait for the next train if they knew it would be less crowded. Commuters have issues with how crowded the line get and the lack of space as the majority of commuters were dissatisfied with the passenger capacity of the train cars. Out of the commuters that had a favorite LU line, most said the Victoria line was their favorite because it is convenient and less crowded.

Figure 19: Passenger Satisfaction of Train Passenger Capacity For Each Type



Between the different types of passengers, commuters were the most dissatisfied with the train car capacity, as they experience the overcrowded trains during peak hours more often (See Figure 19). Tourists had a different view from the overall opinion of the passengers as 54.55% of tourists said they were satisfied with the train size and passenger capacity.

The category of non-commuters consisted of three kinds of passengers: tourists, shoppers, and casual travelers. Non-commuters are generally not in a rush as 56% said they would not run onto a train last minute and 67% said they would be willing to wait for the next train if they knew it would be less crowded. Of those that had a preference, non-commuters mostly chose the Central Line as their favorite LU line because of its convenience. When looking at the different types of non-commuters, shoppers showed a preference for the Central Line as 36.36% chose it as their favorite LU line, mainly because it travels to shopping areas.

Conclusion

This section includes a conclusion on each of the three objectives as well as recommendations for further solution research and future IQPs with Transport for London. Objective one is summarized in the common factors section, which concludes what the team observed as common causes to excessive dwell time. Both passenger behaviors that influence dwell times and system constraints that have the possibility of decreasing dwell times are indicated. Next, objective two is concluded by determining two key factors of uneven platform crowding and boarding/alighting issues. Finally, the third objective of the project concludes with solutions to minimizing dwell times by suggesting different options on the system constraints that may help alleviate the key factors. These solutions are broken down into station platforms, provision of information, rolling stock, and employees.

1. Common Factors

1.1 Passenger Behavior

Both passenger flow and individual passengers caused noticeable influence on dwell time. Passenger flow includes the motion between the street, station entrance, ticket gate, escalators/stairs, passageways, platform entrance, platform, train doors, and train cars. This project ultimately concentrates on the passenger flows more directly relatable to dwell time which are from platform entrances to the train cars. The passenger behaviors that affect dwell time are caused by individuals, particularly problem passengers. Passenger behavior issues tend to be more noticeable to the average observer because one can see the current problem without seeing the underlying issues, which is a combination of passenger behavior and system constraints.

Passenger flow is clearly restricted during peak times with severe platform crowding, but reducing the number of passengers during peak hours is difficult without lowering the revenue for TfL. The aspect to be further explored is the organization of the crowds and the passenger flow. The passenger flow issues in alighting and boarding include platform crowding, train crowding, doors reopening, boarders not allowing alighters to exit first, and last minute boarders. Even during the off-peak times in station observation, alighting and boarding issues were prevalent as there were only a few instances of announcements trying to deter the problem.

Passengers carrying bulky items also influence dwell times. There are a surprising number of passengers with excessively large baggage, such as suitcases and packages. Although one could ban large items from the Central Line or provide luggage areas in place of current passenger space, this would be highly unlikely as it could decrease revenue for TfL. Walking support items may also cause passenger flow issues if the passenger is more slow or takes up a larger amount of space. These items are more uncommon and also do not currently have a reasonable solution.

Another factor that increases dwell time is door reopening, which is mostly caused by passengers or their items being caught in doors. Instances of strollers directly causing increased dwell times were noted during station observation. Door reopening is common, especially on crowded trains, as passengers block the doors by boarding at the last second and passengers holding the doors for the remainder of their group of family or friends.

The different types of passengers, such as commuters, tourists, and shoppers, also play a role to increase dwell times. Commuters typically ignored signs and announcements during station observation, perhaps because they automatically assume that the stations have not changed since their daily commute the day before. Many commuters stand on the platform by the yellow line and are not afraid of pushing into a crowded train. According to some informal employee interviews, some passengers will go out of their way to be more comfortable in the commute by planning around peak hours or waiting until a less crowded train arrives.

On the other hand, tourists were observed to rely on maps, signs, and announcements. They often disrupt the flow of more experienced passengers and also hold train doors for their group. Casual passengers and shoppers tended to move more slowly than commuters during station observation. Many passengers also wore headphones and were mostly oblivious to their surroundings, especially announcements. Although there are not particular solutions for the differences in types of passengers, the frequency of differing behaviors of the passengers may lead to a necessity of change within certain system constraints.

1.2 System Constraints

Passenger flow is partially hindered by multiple aspects of system constraints, which vary at each of the 49 stations of the Central Line. The layouts of each station possess the same aspects, but the organization of some stations does not condone easy passenger flows. Long, narrow passageways between the escalators and the platforms can easily become blocked and slowed because of the volume of passengers. The layout of the stations themselves were not very deeply studied, as this project focuses on the platforms and the trains. The most direct aspect of a station layout that does lead to increased dwell times is the passageways to the entrance of the platforms. Straight passageways can unintentionally encourage rushing passengers to run onto trains while the doors are closing because they are able to visualize the departing train car.

The placement of entrances and exits greatly vary at each station and this considerably influences the passenger flow along platforms. The platforms also have differences in signage placement, bench placement, platform width, amount of advertisements, visual decorational differences, and which train doors open at the platform. As identified in the Appendix B, the trains at Stratford westbound open their doors on both sides because of the platforms on either side. There is no indication that one platform is for alighting and one for boarding, which causes some confusion during peak times.

Another notable station, Leytonstone, has extremely high dwell times, despite being an external station outside of central London. As indicated by conversations with TfL employees, the issues at Leytonstone are the switching of drivers and the track change. The tracks must change because Eastbound trains may be heading towards Epping, Woodford via Hainault, or the depot. A Central Line Control Room staff member suggested a specific solution, which is explained in 4.1 Further Solutions Research. One highly technical aspect that may influence dwell times is the current signalling system. The Victoria Line has recently upgraded to an entirely new signalling system, which may prove beneficial to the Central Line, but is more technical than this study permits.

The display of information, such as signage and maps, may not seem to cause a large impact on dwell times, but when used efficiently, can inform passengers to not exhibit behaviors that do increase dwell times. During station observation at Stratford, one major blockage of passenger flow was by the top of the stairs when entering the platform. Passengers would be looking at the information on the dot matrix screen, which is directly in front of the stairs. The placement of this particular sign caused notable passenger flow issues, which can cause increased dwell times. Another similar aspect in terms of helping decrease dwell times is the role of employees, such as station staff, platform attendants, and train operators. These types of employees can help alleviate confusion and encourage good behavior in passengers.

One of the most expensive and extensive system constraints is the physical size of the tunnels. Because the Central Line is over a century old, the narrow and curved tunnels restrict the potential increase in size for the rolling stock. TfL is not likely to increase the tunnels in the near future because of many restraints, such as funding and time. Expanding tunnels to allow for implementation of a larger rolling stock is extremely expensive and would lead to shutting down large sections of the service for extended periods of time.

The layout of the rolling stock also may lead to increased dwell times because of the passenger flow within the train cars themselves. During train observation, passengers were unlikely to stand between seated passengers, as they prefered to stay near the doors. The clustering of passengers at the doors causes issues with boarding and alighting, as alighters had difficulty exiting the train car. The internal organization of the rolling stock as well as the relatively small size of the train cars may be hindering passenger flow.

2. Key Factors

2.1 Uneven Platform Crowding

Uneven platform crowding is the one of the most prevalent factors that influences dwell time greatly especially at busy stations such as Oxford Circus, Holborn, and Chancery Lane. From the CCTV observation data, we found that during peak hours, a significant amount of passengers enter the platform and wait for the train near the entrance instead of moving to emptier section of the platform. The entrances are not spread out along the platform due to the nature of platform layouts; entrances are typically only at one section of the platform, usually at the front or at the back of the platform. Passengers crowded near the entrance cause more uneven crowding as they disrupt smooth passenger flow along the platform.

On top of entrance crowding, frontline interviewees validated that everyday commuters going to specific station tend to use the same carriage of the train so that they alight right in front of the exit of their destination station. Therefore, for example, experienced passengers going to Chancery Lane crowd the front end of the platform and use the front end of the train because the exit at Chancery Lane is at the front end of the platform. On the other hand, experienced passengers going to Oxford Circus crowd the front-middle section of the platform and use the front-middle part of the train because the exit is placed front-middle section of the platform.

The more crowded sections of the platform cause increased dwell times because it leads to a longer period of the doors being open compared to the less crowded sections. Uneven passenger density boarding the train causes some carriages to experience boarding and alighting processes of PCL of four or five; whereas, other carriages experience PCL of one or two. The differences at each carriage influences overall dwell time significantly which can be reduced if passengers spread themselves out along the platform more evenly.

Controlling the flow of passengers along the platform allows for an equal distribution of passengers boarding across the platform preventing one area from being more congested than others. It is important to draw passengers' attention down the platform to move them effectively away from entrances and ensure the use of all available space. Passengers need to be able to navigate themselves along the platform and find the best place to stand on the platform to have an effective control of passenger flow. Signage is a part of controlling passenger flow as it allows passengers to find their own way but still follow the desired flow.

2.2 Boarding & Alighting Issues

Obstructed boarding and alighting is another one of the most common factors on the Central Line. From our observations, we determined that obstructed boarding and alighting has three key aspects: problem passengers, rolling stock, and provision of information. Poor passenger behavior, such as boarders blocking alighters, slows passenger flow in and out of the train. The longer it takes to get on and off, the longer the dwell time. The presence of large luggage also slows passenger flow because people who have suitcases or packages typically move slower and slow down others. People rushing onto the train last minute and holding the door also bogs down the process and increases dwell time.

The current design of rolling stock does little to accommodate bad passenger behavior. From our passenger surveys, we discovered that many people were dissatisfied with the size of the coaches on the Central Line. The small cars of the Central Line do not give enough space for passengers to board and alight as freely as they might on other lines. Many passengers also prefered the SSL Lines due to their larger coaches. Sub-surface stock is some 40% larger in cross-section than tube stock and this has a significant impact on the design of the interior environment and packaging of electrical and system equipment (Parry, 2008). On the other hand, 1992 stock has a much smaller cross-section than subsurface stock and this, combined with the steeply curved roof profile, often creates a more intimate environment. The claustrophobia is especially noticeable when 1992 stock is crowded with customers in the summer months, when heat builds up and retention in the system exacerbates the issue. The small amount of area on the coach makes it very difficult for passengers to move, thereby hindering passenger flow and increasing dwell time.

The provision of information also fails to prevent bad passenger behavior; rushing onto the train last minute happens at every station despite signage or announcements that try to deter it. Keeping the passengers informed is an important part of passenger flow as passengers who are misinformed cause obstruction as they stop to look for the information needed. Simple changes to provide passengers with the information they need can reduce obstructions in passenger flow and improve dwell time.

3. Possible Solutions

3.1 Station Platforms

In order to appease overcrowding issues and uneven platform crowding, one solution is to replace the metal benches along the platform with folding seats like the ones installed on S7 stocks. We have observed that with trains running every two minutes, especially during peak times, most of the passengers, excluding those that must sit down, choose to stand near the edge or the back of the platform and wait for the next train. Replacing the benches with folding seats provides more space on platforms for the passengers to move along, and they provide seating for those in need like elderly, disabled, or exhausted passengers.

Figure 20: Platform with current metal benches

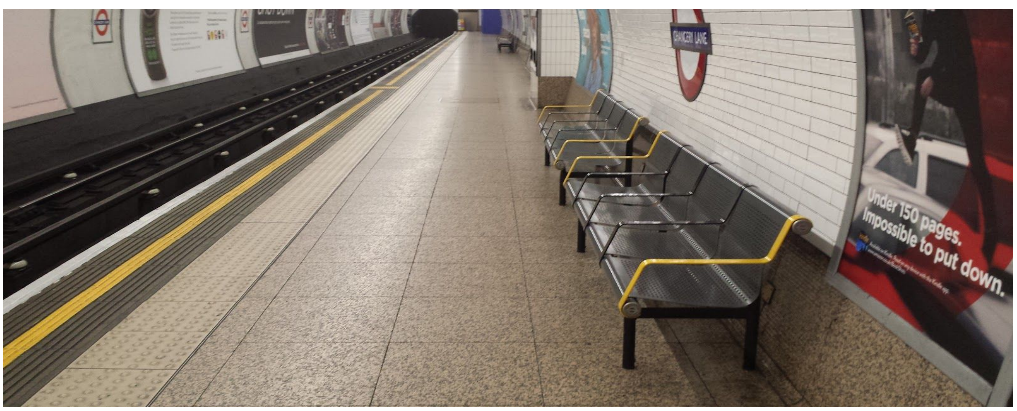
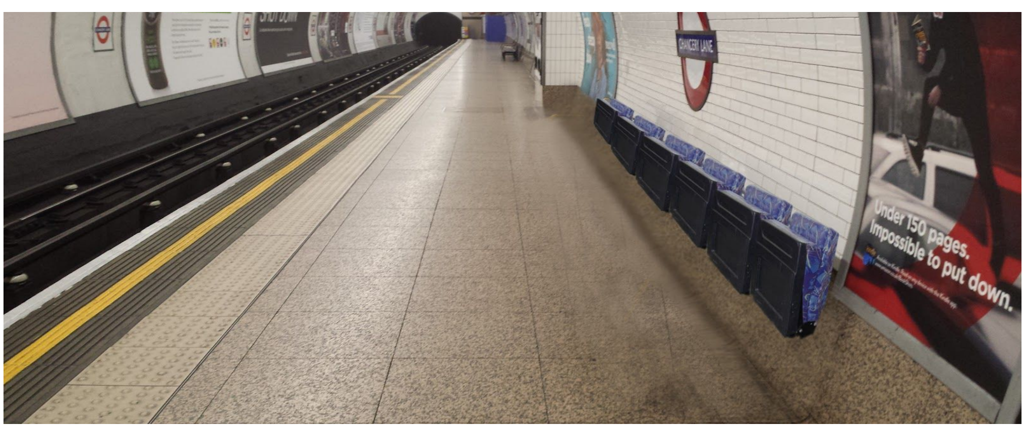


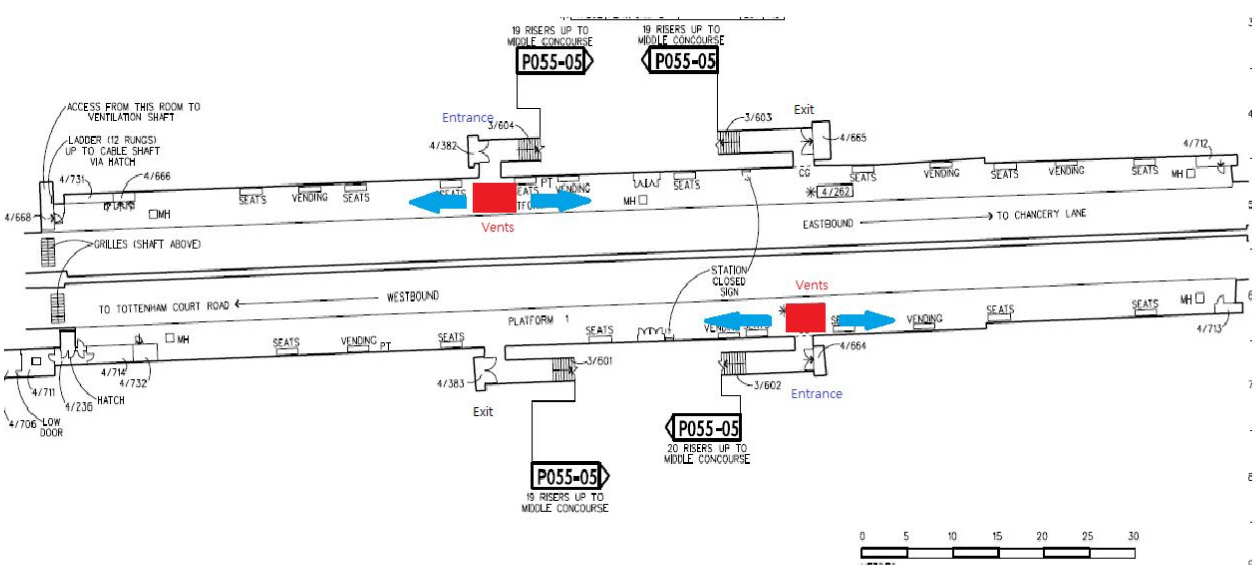
Figure 21: Platform with folding seats



For example, at Chancery Lane station, the width of the platform is about 2.5 meters. The metal benches shown in Figure 20 are about 0.6 meters long. The walkable width of the platform where benches are installed is about 2 meters wide. Assuming the average person's shoulder to shoulder width is half of a meter, about three to four passengers can walk side to side along the platform. Replacing the metal benches with folding seats give an extra half a meter for another person to walk along the platform which will significantly increase the amount of passenger flow along the platform when it is very crowded during peak hours.

Although probably less effective, another solution is to manipulate the ventilation system that emits heated air from the underground tunnels. A strong wind or hot temperature at the platform entrances would encourage passengers along the platform to avoid the unpleasantness near the vents. One aspect to consider with this option is to not compromise passenger safety, as some winds could unintentionally push passengers closer to the tracks. The air vents would be placed either on the wall so that the wind blows down the platform from the entrance or on the ceiling so that the wind blows downwards on to the target area to encourage passengers out of the area. The vents should never push air towards the tracks.

Figure 22: Platform Diagram of Holborn with Vent Exhaust Placement



At Holborn station, for example, the ideal place for the exit vent could be placed on the ceiling above the entrance as shown in Figure 22. Heated air generated from the tunnels would flow through the vents and exit through vent placed overhead near the entrance. Hot wind would blow from above into the platform as well as heat up the general area to create discomfort among near the entrance and encourage passengers in that area to move away from the entrance and along the platform.

The final platform related solution is decreasing train visibility for passengers entering the platforms. The most frequent type of problematic passengers is the last minute boarders, as we observed 223 instances of rushers in the two morning peak times during CCTV observation. In stations where passengers are physically able to see the train doors open through the passageway have a higher chance of rushing onto the train last minute, which can cause door reopening and increased delays. At stations like Notting Hill Gate, the passageway to the platforms curves and passengers are less encouraged from running onto the train. Some stations like Liverpool Street have a fence-like structure between the entryway and the dwelling train in order to discourage rushing passengers. We suggest implementing means of decreasing train visibility in more stations, especially those with many rushers like Oxford Circus with 3.1 rushers per Eastbound train.

3.2 Provision of Information

According to the passenger surveys that were conducted as part of this research, a majority of passengers are satisfied with the signage that guides them around. However, while observing passenger behavior in the ten key stations, signage was very inconsistent from station to station. Many signs were barely visible and were drowned out by advertisements. Having signage that possess bright colors is important as it can make it more noticeable. Color can be used to emphasize an object within a person's view as they cannot process every object at once. The use of color in signage helps to sustain a passenger's interest long enough to relay information to them as black and white may only hold interest for less than two-thirds of a second, while colors may sustain interest for two or more seconds (Morton, 2010). Updating the signage across stations will allow for easier navigation of unfamiliar stations. Adding signs to inform inexperienced passengers of common information prevents them from making a last minute decision to board the train. Signs informing passengers about where trains from that platform goes would inform them of what train to take as signs could display what trains go to popular stations.

Confused passengers that stop to read the dot matrix signs inhibit passenger flow as they stop in the middle of the platform to read the sign and then move closer to the sign to be able to read it. Changing the dot matrix signs to a newer type of passenger information display would allow for clearer text display that would be brighter and more visible across the platform. Improving the passenger information display on the platform to include other kinds of information would allow passengers to make an informed choice on what train to take. Based on the passenger survey results, a majority of passengers would wait for a later train if they knew that it would be less crowded. Adding an indicator on the passenger information displays to inform passengers of the crowdedness of trains would allow passengers to make an informed decision of boarding the next train or waiting for an emptier one sooner than if they have to wait and see the train. This would allow passengers to move out of the way if they are planning to wait for a later one sooner than they currently would.

Announcements are another way to provide passengers with the information they need. When observing at stations, it was noted that the announcements being made for the passengers on the platform could barely be heard because of the poor audio quality. The announcements at some stations were hard to hear because of the overlapping announcements from other nearby platforms or inside the train. Updating the audio system to allow clear announcements to be made will help passengers to obtain information better, preventing them from stopping in one place to try to understand an announcement, and it would further encourage people to move along the platform. In addition, signage to guide passengers to spread evenly across the platform would improve the distribution of boarders across the train.

Informing passengers on how to get where they want to go is important for keeping passenger flow consistent. Passengers who stop on the platform to look for directions to another line or the exit cause the flow of passengers to become disrupted. Signs directing passengers to another line or the exit are typically above the average eye level of passengers. When walking, people tend to glance down to make sure that they do not step on or trip over anything. Lines drawn on the platform to guide passengers along the platform would be seen when people look down. These lines can be used to inform passengers about many different aspects of not only navigating but waiting on the platform as well.

Lines on the platform can also be used to control issues with boarding and alighting as they can inform passengers where to stand while waiting for a train. A major issue with boarding and alighting is passengers who are boarding do not let passengers who are alighting off the train first before they board. Having lines on the platform to indicate where to stand while waiting for the train would encourage passengers to wait in a spot where they would not block the train doors, giving alighters space to get off before the boarders try to get on.

3.3 Rolling Stock

Trains have a long service life, usually about 40 years, with a mid-life refurbishment (Parry, 2008). This is often the only opportunity to update the interior style, layout and overall ambience. The 1992 rolling stock is now 23 years old and could use updates to decrease dwell time. Refurbishment programs, by their nature, vary in scope. However, it is essential to ensure that the new materials and finishes meet the latest LU Standards and Policies. The refurbishment should aim to improve the level of compliance of these elements in all cases.

Horizontal handrails and vertical grabpoles are primarily provided for the convenience and safety of passengers, providing an easy and comfortable handhold to stabilise themselves from vehicle accelerations, jolts and movement. However, their placement can have a great effect on dwell time. In the 92 stock, the handrails are placed directly next to and above the doors as seen below in Figure 23. Besides these door handles, there are no other handles in the entrance/exit section of the car. This encourages standing passengers to crowd by the doors, obstructing boarding and alighting.

Figure 23: Current Rolling Stock Handle Placement

Our first solution for the rolling stock is to install strategic handle placement away from the doors, such as a ceiling rail or central grabpole so that passengers can move into the car and still have support. By moving passengers into the middle, space can be opened up for better passenger flow. We recommend handrails because traditional individually suspended handgrips (straphangers) are increasingly subjected to vandalism and are a maintenance liability. Over a number of years these have been removed from all vehicles and replaced with longitudinal handrails and vertical grab poles. The design, specification and arrangement of interior handrails and handholds are strictly governed by the Standard for rolling stock. They must also meet the requirements of RVAR with regard to positioning (Parry, 2008).

Currently, boarding and alighting happens through the same doors. As previously detailed, this causes major congestion in passenger flow and increases dwell time. A possible solution to this is to have passengers board and alight at different doors. For example, boarders could get on the train through the single doors at each end of the train and alighters could get off through the double doors in the middle. Once passengers have boarded, they would be encouraged to move into the train towards an exit door in preparation for alighting, giving more space for other boarders. Once customers adjust to the new system, there would be considerably more space for passengers to move freely.

Figure 24: New Tube for London Rolling Stock Design

Looking ahead, TfL will eventually need to replace the 92 stock in the 2030's. They are already planning to do this with their New Tube for London plan, as seen above in Figure 24. The plan includes a 25% capacity upgrade (the equivalent of up to 12,000 more customers per hour) and an open car design, much like the S-stock, which will open up space for easier passenger flow. The plan also currently includes a vertical grabpole in the door area of the car as we previously suggested.

3.4 Platform Attendants

Both our CCTV observations and frontline interviews confirmed that platform attendants help to improve passenger flow on the platform. Every driver that we interviewed praised the attendants for their dwell time decreasing benefits and recommended that there should be more attendants. The current system places one platform attendant on the busy platform of the major stations, such as Oxford Circus and Bank, during peak times. Our solution is to place an attendant on every station platform in Zones 1 and 2 since these stations have higher dwell times than the rest of the line due to their central location.

The attendants help mitigate uneven platform crowding by ushering people down the platform and away from the entrances. The attendants also police poor passenger behavior and typically prevent last second rushers from boarding the train. Having human involvement in the dwell time process can be more effective than automated announcements. Attendants are also able to provide supplemental information and announcements to promote better passenger behavior. Currently, staff must adhere to a specific script when making announcements, but we suggest adding more flexibility in the wording of the announcements to engage the waiting passengers more often.

4. Recommendations

4.1 Further Solutions Research

This project concentrated on the factors associated with the problem of increased dwell times instead of the solutions to those factors. If this project had a longer time frame, the next step would be to conduct further research on these solutions. For options like differing train car handles, testing the solutions directly would not be advisable, but one could conduct additional interviews. The team could ask different employees their opinions on the feasibility and practicality of each of the proposed solutions. Less expensive options, such as altering signage, could be physically tested to observe the effects of those solutions on dwell times.

In the future, either Transport for London or future students from Worcester Polytechnic Institute should look into further solutions research to either expanding on the solutions in this report or to cover the more lacking areas. We suggest that TfL elaborates on our platform and train passenger flow observations by additionally researching more station-based passenger flow. While not as directly involved in dwell time, the flow of passengers from the streets to the platforms is not ideal in many of the Central Line stations. Another aspect to study is the flow of transferring passengers, especially at Mile End, Stratford, and Ealing Broadway. Train operators noted these stations as problematic because of the rush of people from other lines trying to board the Central Line trains.

This project also only skimmed the surface of how employees can minimize dwell times, as we focused on the passenger behaviors. Some interviewees indicated that there is a disconnection between the different types of employees, which causes some unwelcome animosity within TfL. Further study on relationships of individuals and the level of communication should be at least considered.

During station observation and CCTV observation, some key stations had noticeable issues and points of interest that should be further explored by TfL. One notable station is Leytonstone because of the crew release and the depot nearby. Trains with crew release have significantly high dwell times because the train operators typically chat while switching. Another reason to look into Leytonstone is the high dwell times caused by tracks changing for the depot or the two route options. Employees in the Central Line Control Center recommended that the track change could be moved to before the platform and the tracks could run on either side of the platform. This would be expensive but possible as the land to the side of the current end of the platform is currently a car park for the station. The improvement of Leytonstone could lessen dwell times and increase train flow.

The last major aspect that was not included in this project was the number of trains that run on the Central Line. Because of the crowdedness in the central zones during peak times, one suggestion is to increase the number of trains that run between White City and Leytonstone. This may cause issues with logistics and passengers in the outer zones, but this may be a solution to help appease the problems caused by overcrowding in central London. Similarly, further research into the effects of updating technical aspects, such as the signalling system, may prove helpful in the future.

4.2 Future IQPs with Transport for London

Thank you to everyone involved in this project (See Acknowledgements), but we would specifically like to thank Eric Wright for being a liaison between TfL and WPI. As this is the first IQP with Transport for London, Eric has opened doors to a vast field of future IQP projects

in TfL and the related field. Projects can develop from any of the branches within TfL, not only within the London Underground. We hope that future IQPs can come from this new connection and can benefit the sponsoring organization, Worcester Polytechnic Institute, the sponsor, and the individual students.

For future IQPs, we would like to encourage a more specific goal to lessen the scope of the project in order to be able to complete the goal fully. In addition to the recommendations in the previous section, we also have formed ideas for more London Underground related IQPs. The first is to create an interactive display to assist passengers with directions and options to get to their destination from their current station. The goal could be creating the product, but we suggest that the goal should be to create detailed plans that can be handed to a professional. The second train related IQP idea could be a study on any of the myriad stations in the LU. From our studies, we suggest studying the efficiency and passenger flows at Bank/Monument, track changes and crew release at Leytonstone, and transfer passenger flows at Stratford or Mile End.

References

Barron, A. (2015, December 2). Dwell time reductions: Good design plus people management. *Rail Technology Magazine*. Retrieved from: http://www.railtechnologymagazine.com/Comment/dwell-time-reductions-good-design-plus-people-management

Bentley, G. and Ehrenberg, B. (2015, January 7). London Underground tube delays worst on central,Jubilee and Victoria Lines as overcrowding strains network. *City A.M.* Retrieved from:http://www.cityam.com/206622/london-underground-tube-delays-worst-central-jubilee-and-victoria-lines-overcrowding-strains

Blau, R. (2015, May 18). MTA to speed up time 6, 7 and F trains spend at each station to reduce overcrowding delays. *Daily News.* Retrieved from: http://www.nydailynews.com/new-york/mta-speed-time-6-7-f-trains-spend-station-article-1.2227285

Briginshaw, D. (2015). Revitalizing Tokyo Metro. *International Railway Journal, 55*(8), 24.

Buchmueller, S., Weidmann, U., & Nash, A. (2008). Development of a dwell time calculation model for timetable planning. *Computers in Railways XI*, 105-114.

Campoli, N., Johnstone, J., & Szafarowicz, J. (1999). Surveying. *Safer Stations,* 28. Retrieved from: http://www.wpi.edu/Pubs/E-project/Scanned/99D018I.pdf

Coxon, S., Burns, K., Bono, A., Napper, R. (2011, September). An examination of three approaches to metro rolling stock design to ameliorate extended dwell times due to passenger growth and associated crowding. Retrieved from: http://www.atrf11.unisa.edu.au/Assets/Papers/ATRF11_0007_final.pdf

Fairfax County Department of Neighborhood and Community Services (2012, August). Common pitfalls to conducting a survey. Retrieved from: http://www.fairfaxcounty.gov/demogrph/pdf/pitfalls.pdf

Department of Transport. (2015, September 2). National travel survey: England 2014. Retrieved From: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/457752/nts2014-01.pdf

Donohue, P. (2015, December 15). MTA stats show more subway trains are late. *Daily News.* Retrieved from: http://www.nydailynews.com/new-york/mta-stats-show-subway-trains-late-article-1.2046071

Doyle, J. (1994). Chapter 10: Introduction to Survey Methodology and Design *Handbook for IQP Advisors and Students*. Worcester Polytechnic Institute. Retrieved from: http://www.wpi.edu/Images/CMS/IGS/IQP-Handbook-one-file.pdf

Duffy, M. C. (2003). *Electric railways: 1880-1990.* Retrieved from: https://books.google.com/books?hl=en&lr=&id=cpFEm3aqz_MC&oi=fnd&pg=PR7&ots=avmvFBvP85&sig=eA3pud-npXpASblASHeIJjd8mp8#v=onepage&q&f=false

Dwell time [Def. 1]. (2016). *Oxford Dictionaries Online.* Retrieved from: http://www.oxforddictionaries.com/us/definition/american_english/dwell-time

Eagling, J., & Ryley T. (2015, May). An investigation into the feasibility of increasing rail use as an alternative to the car. *Transportation planning and technology, 38.* doi:10.1080/03081060.2015.1039234

Falzon, E. (2103, January 9). What are the world’s best metro systems? CNN Travel. Retrieved from: http://travel.cnn.com/explorations/life/10-best-metro-systems-746919/

Gelbart, H. (2015, December 4). Oxford Circus Tube Station 'closes Every Three Days' for

Overcrowding. BBC News. Retrived from: http://www.bbc.co.uk/news/uk-england-london-34997203

Greater London Authority Intelligence. (2015). Population Growth in London, 1939-2015.

Hibino, N., Yamashita, Y., Kariyazaki, K., & Morichi, S. (2010). A study on characteristics of train station passenger flows for train delay reduction. In *Proceedings of the 12th World Conference on Transport Research*. Retreived from: http://www.wctrs.leeds.ac.uk/wp/wp-content/uploads/abstracts/lisbon/general/03106.pdf

Karekla, X. & Tyler, N. (2012, July). Reduced dwell times resulting from train–platform improvements: The costs and benefits of improving passenger accessibility to Metro trains. *Transportation Planning and Technology, 35*(5), 525-543. doi:10.1080/03081060.2012.693267

Lam, W. H., Cheung, C. Y., & Poon, Y. F. (1998). A study of train dwelling time at the Hong Kong mass transit railway system. *Journal of advanced transportation*, *32*(3), 285-295.

Lewis, A., Sommerfeldt, C., & Rivoli, D. (2015, June 22). Subway delays increase as overcrowding spreads to weekend. *Daily News.* Retrieved from: http://www.nydailynews.com/new-york/subway-delays-increase-overcrowding-spreads-weekend-article-1.2267417

London's Councils. (2015, December). Living on the edge: The impact of travel costs on low paid workers living in outer London.

London's Poverty Profile. (2015, October 15). London's population by age. Retrieved from: http://www.londonspovertyprofile.org.uk/indicators/topics/londons-geography-population/londons-population-by-age/

LSE Cities. (2016). Urban Age Cities Compared. Retrieved from: https://lsecities.net/media/objects/articles/urban-age-cities-compared/en-gb/

Lyons, G., Jain, J., & Holley, D. (2007). The use of travel time by rail passengers in Great Britain. Transportation Research Part A: Policy and Practice, *41* (1), 107-120.

Martinez, I., Vitriano, B., Fernandez, A., & Cucala, A. P. (2007). Statistical dwell time model for metro lines. *Proceedings of Urban Transport XIII*, 223-232.

MasterCard. (2016). Number of international overnight visitors in the most popular city destinations worldwide in 2015. In *Statista - The Statistics Portal*. Retrieved from http://www.statista.com/statistics/310355/overnight-visitors-to-top-city-destinations-worldwide/.

McCahill, M., & Norris, C. (2002). CCTV in London. *Report deliverable of UrbanEye project*. Retrieved from: http://www.urbaneye.net/results/ue_wp6.pdf

Metropolitan Transportation Authority. (n.d.a). How to ride the subway. *Metropolitan Transportation Authority.* Retrieved from: http://web.mta.info/nyct/subway/howto_sub.htm

Metropolitan Transportation Authority. (n.d.b). Introduction to subway ridership. *Metropolitan Transportation Authority.* Retrieved from: http://web.mta.info/nyct/facts/ridership/

Metropolitan Transportation Authority. (n.d.c). Subways. *Metropolitan Transportation Authority.*
Retrieved from: http://web.mta.info/nyct/facts/ffsubway.htm

Metropolitan Transportation Authority. (2010, April 23). MTA Capital Program 2010-2014. *Metropolitan Transportation Authority.* Retrieved from: http://www.mta.info/news/2010/04/23/mta-capital-program-2010-2014

Metropolitan Transportation Authority. (2013, July). MTA capital program. *Metropolitan Transportation Authority.* Retrieved from: http://web.mta.info/capital/pdf/CapitalConstruction_1014.pdf

Metropolitan Transportation Authority. (2015, October 28). MTA Capital Program 2015-2019. *Metropolitan Transportation Authority.* Retrieved from: http://web.mta.info/capital/pdf/CapitalProgram2015-19_WEB%20v4%20FINAL_small.pdf

Morton, Jill. (2010). Why Color Matters. *Colorcom.* Retrieved from: http://www.colorcom.com/research/why-color-matters

[Mr railfan]. (2012, May 13). *Rare R160 - R143 (NTT) NYC Subway Announcements vol 2 - BMT / IND announcements.* [Video File]. Retrieved from: https://www.youtube.com/watch?v=ZNfGyjEaCW0&feature=youtu.be

[Mr railfan]. (2015, April 15). *R142 - Updated Experimental 5 train announcements [Flatbush to Dyre Av].* [Video File]. Retrieved from: https://www.youtube.com/watch?v=KDaRRmUWUZI&feature=youtu.be

[mtainfo]. (2015, November 16). *Platform Controller Program.* [Video File]. Retrieved from: https://www.youtube.com/watch?v=Tlc9Q5MVZXw&feature=youtu.be

Network Rail. (n.d.). Delays explained. *Network Rail*. Retrieved from: http://www.networkrail.co.uk/timetables-and-travel/delays-explained/

Office for National Statistics (UK). (2014). Forecasted regional population of London (UK) from

2012 to 2037 (in 1,000)*. In *Statista - The Statistics Portal*. Retrieved from: http://www.statista.com/statistics/379035/london-population-forecast/.

Passenger Focus. (2009, February). Employers' Business Travel Needs from Rail. *Passenger Focus*. Retrieved from: http://www.transportfocus.org.uk/research/publications/employers-business-travel-needs from-rail

Parry, R. (2008, October). Train Design Guide. *Transport for London.*

Partington, G. (2001). Qualitative research interviews: identifying problems in technique. Issues in Educational Research, 11(2) 32-44.

Puong, A. (2000). Dwell time model and analysis for the MBTA red line. *Massachusetts Institute of Technology Research Memo*. Retrieved from: http://dspace.mit.edu/bitstream/handle/1721.1/35716/1-258JFall-2003/NR/rdonlyres/Civil-and-Environmental-Engineering/1-258JPublic-Transportation-Service-and-Operations-PlanningFall2003/D9613FBC-9279-4F31-A46D-8DB2E037E9E4/0/a3_dwelltim.pdf

The Golden Whistles. (2016, March). Station dwell times: A peril to performance? *Modern Railways.*

Transport for London. (n.d.). Average excess time to complete a scheduled London Underground journey from December 2013 to January 2015 (in minutes)*. In Statista - The Statistics Portal. Retrieved from: http://www.statista.com/statistics/412807/london-underground-excess-journey-time/.

Transport for London (2007, March). Rolling Stock Data.

Transport for London (2013, March 18). Research Guide No 16: A Brief History of the Central

Line.

Transport for London. (2014). *Fit for the Future* [Brochure]. London

Transport for London. (2014, June 30). Victoria line upgrade helps to deliver most frequent train service in UK. Retrieved from: https://tfl.gov.uk/info-for/media/press-releases/2014/june/victoria-line-upgrade-helps-to-deliver-most-frequent-train-service-in-uk

Transport for London (2016a). CCTV. *Transport for London*. Retrieved from: https://tfl.gov.uk/corporate/privacy-and-cookies/cctv

Transport for London. (2016b). Facts and Figures. *Transport for London.* Retrieved from https://tfl.gov.uk/corporate/about-tfl/what-we-do/london-underground/facts-and-figures

Transport for London. (2016c). Four Lines Modernization. *Transport for London.* Retrieved from https://tfl.gov.uk/travel-information/improvements-and-projects/four-lines-modernisation

Transport for London. (2016d). London Underground. *Transport for London*. Retrieved from: https://tfl.gov.uk/corporate/about-tfl/culture-and-heritage/londons-transport-a-history/london-underground#on-this-page-1

Transport for London. (2016e). Plan a Journey. *Transport for London.* Retrieved from: https://goo.gl/Vp4gwb

Transport for London. (2016f). Tube. *Transport for London.* Retrieved from https://tfl.gov.uk/maps/track/tube

Transport for London (2016g). Underground services performance. *Transport for London.* Retrieved from https://tfl.gov.uk/corporate/publications-and-reports/underground-services-performance

Tzanakakis, K. (2013). *The railway track and its long term behaviour: A handbook for a railway track of high quality* (Vol. 2). Retrieved from: http://au4sb9ax7m.search.serialssolutions.com/?ctx_ver=Z39.88-2004&ctx_enc=info%3Aofi%2Fenc%3AUTF-8&rfr_id=info:sid/summon.serialssolutions.com&rft_val_fmt=info:ofi/fmt:kev:mtx:book&rft.genre=book%20item&rft.title=The+Railway+Track+and+Its+Long+Term+Behaviour+%3A+A+Handbook+for+a+Railway+Track+of+High+Quality&rft.atitle=History+of+Railways%E2%80%94A+Quick+View&rft.date=2013-01-01&rft.isbn=9783642360510&rft.externalDocID=6869100012&paramdict=en-US

United Nations, Department of Economic and Social Affairs, Population Division (2014). World Urbanization Prospects: The 2014 Revision, Highlights *(ST/ESA/SER.A/352).*

Weidmann, U., Kirsch, U., & Schreckenberg, M. (2012). *Pedestrian and Evacuation Dynamics 2012* (Vol. 6). Retrieved from: https://books.google.com/books?id=AmG4BAAAQBAJ&dq=London%20Underground%20dwell&lr=&source=gbs_navlinks_s

Wolmar, C. (2012). The Subterranean Railway: How the London Underground was built and how it changed the city forever. doi:

Wong, Maggie H. (2015, March 31). Hong Kong's MTR: Taking a ride on the world's most envied metro system. Retrieved from: http://www.cnn.com/2015/03/29/travel/hong-kong-mtr-success-story/

Wong, K. K., & Ho, T. K. (2007). Dwell-time and run-time control for DC mass rapid transit railways. *IET Electric Power Applications. 1* (6). doi:

Wright, E. (2015). Scope of Works for Central Line Dwell Time Study. Email, 2 Dec. 2015.

Yamamura, A., Koresawa, M., Adachi, S., & Tomii, N. (2014). Taking effective delay reduction measures and using delay elements as indices for Tokyo's metropolitan railways. *Computers in Railways XIV: Railway Engineering Design and Optimization*, *135*, 3.

Appendix

Appendix A: Employee Interview Template

1. Can you tell me about your work on the Central Line?
    - or to reduce delays?
    - or to reduce dwell times?

2. What do you feel is the largest contribution to dwell time currently on the Central Line?

3. What are other notable factors that increase dwell times in the London Underground?

4. Do you feel that the necessary steps to reduce dwell time are being taken?

5. What do you feel Transport For London could do better to reduce dwell time?

Appendix B: Station Observation

Station: Notting Hill Gate

Time of Observation: 12:30-1:00 Tuesday 24 May 2016

Station Layout
From ticket gate to westbound - 1 up escalator and 1 down and 1 stairs
From westbound to eastbound - 1 up escalator and 1 down
Short and narrow curved passages for entrance/exit
Supposedly one way traffic but not very supported?

Platform Layouts
Entrance/exit passageways ⅓ towards back of platform
Exit/entrance stairs at back of platform
Width about 7 passengers across

Information Display
Stand free zone at exits/entrances marked with yellow on the floor but no signs
1 dot matrix display and map across from entrance
Mind the gap announcements

Passenger Notes
Crowding near entrances and not moving toward center of the platform
Blocking a clear path for walking by crowding in a group
One group of 7 with suitcases
More casually clothed passengers than businessmen
Much more crowded on the front cars of the train, most alight from there
Most board on the rear of the train by entrance/exit

Train Crowdedness Levels Westbound: 3 → 2 → 2 → 1 → 2
Train Crowdedness Levels Eastbound: 3 → 2 → 2 → 2 → 2

Average Dwell Time Westbound: 27.54 seconds
Average Dwell Time Eastbound: 24.88 seconds

Nearby Areas: Kensigton Palace, Embassies, farmers market

Station: Oxford Circus

Time of Observation: 12:45-13:15 Tuesday 24 May 2016

Station Layout
Tunnel led to escalators
Less simple passageways
Combination of stairs and escalators
Platforms are fairly far from the station entrance

Platform Layouts
2 exits/entrances (stairs) in middle of platform
1 Tunnel exit/entrance
Width: about 7 passengers across

Information Display
1 dot matrix display
Repeated "good service on all lines" announcement

Passenger Notes
Crowding near entrances and not moving toward center of the platform
Blocking a clear path for walking by crowding in a group
Standing both by the edge of the platform and the back walls
Long wait between trains causes crowding on platform
Half businessmen and half more casual
Most exit from the center of the train
4 boarder per 1 alighter
Some passengers did wait for the more empty trains

Train Crowdedness Levels Westbound: 4 → 3 → 2 → 4 → 4
Train Crowdedness Levels Eastbound: 2 → 1 → 4 → 1 → 2

Average Dwell Time Westbound: 28.16 seconds
Average Dwell Time Eastbound: 31.15 seconds

Nearby Areas: shopping, Hanover Square, Caverdish Square Gardens

Station: Tottenham Court Road

Time of Observation: 13:15-13:45 Tuesday 24 May 2016

Station Layout
Tunnel led to escalator
Many paths and stairs to platforms
Escalators from ticket gate

Platform Layouts
1 standard exit/entrance in middle
1 tunnel exit/entrance at end of platform
Width about 5 passengers across
Benches are only in setback areas

Information Display
2 dot matrix displays evenly spaced along platform
2 maps

Passenger Notes
All stand by the walls until a train is arriving
Crowding near entrances and not moving toward center of the platform
Blocking a clear path for walking by crowding in a group
More casual riders, families, spanish speakers, young adults
Flow issue at bottom of stairs when picking if they want eastbound or westbound

Train Crowdedness Levels Westbound: 3 → 1 → 1 → 3 → 4
Train Crowdedness Levels Eastbound: 2 → 4 → 2 → 2 → 2

Average Dwell Time Westbound: 27.07 seconds
Average Dwell Time Eastbound: 28.66 seconds

Nearby Areas: The British Museum, gardens, theaters, Soho

<u>Station:</u> <u>Holborn</u>

Time of Observation: 11:30-12:30 Tuesday 17 May 2016

Station Layout
3 Up / 1 Down Escalators at 11:30
2 Up / 1 Down escalators at 12:30
No noticeable lifts
Exit/entrance 7 people wide
Fairly short compared to most passages

Platform Layouts
Enter/exit middle of platform
Platform is 7 people wide

Information Display
Way out signs only on the walls
Announcements about trains while the train is incoming/exiting → cannot hear any of the announcements

Passenger Notes
Passengers tended not to move far from entrance
More towards the front of the train
Demographics, speed, number, groups, luggage
Run in last minute businessman caused door reopening and increased dwell time
Mostly formal passengers, a few children
Alighters will be stuck trying to get through borders if they aren't very quick at getting off

Train Crowdedness Levels Westbound: 3 → 2 → 3 → 3 → 2
Train Crowdedness Levels Eastbound: 3 → 3 → 1 → 2 → 1

Average Dwell Time Westbound: 27.7 seconds
Average Dwell Time Eastbound: 24.3 seconds

Nearby Areas: universities and businesses

<u>Station:</u> <u>Chancery Lane</u>

Time of Observation: 11:25-11:42 Wednesday 25th May 2016

Station Layout
2 sets: 1 up/1 Down to Eastbound and 1 up/1 Down to Westbound
Stairs in middle on both
Entrances/exits head to passages - Westbound

Platform Layouts
1 entrance/exits: middle of platform
Width about 7 passengers across by entrance, 5 elsewhere

Information Display
1 dot matrix board a third towards front of train
Fairly frequent announcements
1 map across from entrance
No noticeable "help point" area

Passenger Notes
Crowding around entrances/exits
Most bunching at the back end of platform - Westbound
Crowding near entrances and not moving toward center of the platform
Blocking a clear path for walking by crowding in a group
Mostly commuter/formal passengers
More alighters than boarders

Train Crowdedness Levels Westbound: 3 → 1 → 1 → 3 → 4 → 2
Train Crowdedness Levels Eastbound: 3 → 2 → 1 → 2 → 2 → 3

Average Dwell Time Westbound: 46.53 seconds
Average Dwell Time Eastbound: 27.76 seconds

Nearby Areas: various universities and businesses

<u>Station:</u> <u>Bank/Monument</u>

Time of Observation: 12:15-12:45 Monday 23 May 2016

Station Layout
Escalators: 1 up, 1 down, 1 out of service
No noticeable lifts
Large entrance/exit with exit flow is mostly one way
Some passengers took alternate exits through smaller passages
Narrow passageways to Northern Line

Platform Layouts
One “Exit” at one end of platform and one small exit to another line
Two main entrances and one small entrance from another line
Width: about six passengers
Only platform that we observed that was not straight - half pretty steeply curved
Large gap on the curved areas

Information Display
Mind the gap announcements - needed because of large gap

Passenger Notes
Crowding near entrances to platform
Standing in walk ways
Flow of passengers across the platform was often disrupted by another passenger standing instead of moving down
More passengers towards front of trains
Singular businessmen moved quickly down the platform
Groups of 2-4 moved down the platform but were a bit slower
Many had small bags- purses/briefcases
2 boarders per 1 alighter

Train Crowdedness Levels Westbound: 3 → 1 → 2 → 2 → 3
Train Crowdedness Levels Eastbound: 4 → 2 → 1 → 3 → 2

Average Dwell Time Westbound: 26.7 seconds
Average Dwell Time Eastbound: 28.1 seconds

Nearby Areas: Guildhall, banks and businesses

Station: Liverpool Street

Time of Observation: 11:45-12:15 Monday 23 May 2016

Station Layout
Weekday only entrance for Central Line in addition to the larger ticket area
Two options/areas for entry towards Central Line
Main entrance is further away with a longer escalator

Platform Layouts
2 entrance/exits: 1 at front of train and on at the back
Width about 7 passengers across

Information Display
Way out signs all point to the back end of the train even though there is an entrance/exit at the front end
No announcements other than line service status announcements
No way out signs towards front of train
Two dot matrix display signs

Passenger Notes
Crowding near entrances and not moving toward center of the platform
Blocking a clear path for walking by crowding in a group
Bars in center of platform by entrance/exit caused more bunching as people leaned on them
Large mix of passenger types and ages
Shopping bags, business bags, backpacks, two dogs, one stroller
Shoppers- many with multiple small shopping bags
Eastbound: 4 boarders per 1 alighter
Most bunching at the back end of platform - Eastbound

Train Crowdedness Levels Westbound: 3 → 1 → 2 → 3 → 1
Train Crowdedness Levels Eastbound: 1 → 3 → 4 → 2 → 3

Average Dwell Time Westbound: 30.9 seconds
Average Dwell Time Eastbound: 37.9 seconds

Nearby Areas: Finsbury Circus, shopping centers

Station: Mile End

Time of Observation: 12:45-12:15 Wednesday 25 May 2016

Station Layout
Entrances and Exits were stairs with approximately 20~30 steps
No automatic vertical motions
Larger passageways with heavy traffic flow
Must go up stairs and over and down stairs to go from westbound to eastbound

Platform Layouts
1 entrance at the back of the train
1 exit ⅜ measured from back of the train
Island platform with pillars, benches, equipment rooms and stairs in the center
Central line on one end and Hammersmith & City on the other
3 shoulder-to-shoulder wide from back to exit and 5 from exit to front
1.5 shoulder-to-shoulder sized pillars

Information Display
Next train will arrive in ___ min headed ___ announcement for every train
Some announcements were said over each other or the noise of trains arriving/departing
Dot matrix Screen showing time table is only at the very back
Map on the narrowest side of platform, should be moved onto pillars or wider platform areas
Looks under construction or unfinished, no ads on walls

Passenger Notes
Equal amount of business people, casual travelers, shoppers
Few people needed extra information to use the train (Maps, signage)
Lady in front missed a train because she didn't know where the train was heading
Many ran from the Hammersmith & City Line train onto the Central Line train
Last minute run on causes doors to open and close if they get caught in door

Train Crowdedness Levels Westbound: 3 → 3 → 2 → 2 → 4
Train Crowdedness Levels Eastbound: 3 → 2 → 3 → 2 → 4

Average Dwell Time Westbound: 36.4 seconds
Average Dwell Time Eastbound: 25.43 seconds

Nearby Areas: schools and parks

Station: Stratford

Time of Observation: 13:00-14:30 Thursday 19 May 2016

Station Layout
Westbound- 2 staircases with walls and one lift entrance on island platform
3 entrance/exits from a building on the non-island platform
Eastbound- 2 staircases with glass walls, more narrow
Staircases were 6 passengers wide

Platform Layouts
5 entrances and exits for West bound
1 entrance for east bound?
Possible to leave station from platform (walk into the street)
Westbound- island platform where passengers can enter/exit both sides
Eastbound- normal platform
Big platforms but shared with another rail

Information Display
Information screens at top of stairs caused bunching
Large maps/signs at center area between stairs
Dot matrix display list of incoming trains with "mind the doors" flashing that was pointless

Passenger Notes
Shoppers with various sized bags
Tourists with baggage
Mothers with babies or small children
Running out because they forgot to tap in
More people on the front of train than the back

Average Dwell Time Westbound: 30.2 seconds
Average Dwell Time Eastbound: 31.4 seconds

Nearby Areas: Olympic park, Olympic stadium, shopping centers

<u>Station:</u> <u>Leytonstone</u>

Time of Observation: 12:00-12:30 Wednesday 25 May 2016

Station Layout
Stairs only for entrance/exit
Use stairs then go through fairly wide tunnels under the tracks
Small ticket gate area underground

Platform Layouts
Westbound - entrance/exit stairs at back of the train
Eastbound - entrance/exit stairs at front of the train
External station where crew release occurs- very long dwell times because of this
Very wide ranging from 6 to 10 passengers wide

Information Display
Eastbound- dot matrix signs with "→ next London train →" showing which side it would be on
Signs are slightly away from entrances

Passenger Notes
Mostly all exit the back of the train on Eastbound
Barely any passengers entering and exiting, esp. eastbound
Nearly each train had an extra TfL employee enter or exit

Train Crowdedness Levels Westbound: 1 → 1 → 1 → 1 → 1
Train Crowdedness Levels Eastbound: 1 → 1 → 1 → 1 → 1

Average Dwell Time Westbound: 36.53 seconds
Average Dwell Time Eastbound: 98.64 seconds

Nearby Areas: religious venues, schools, residential homes

Appendix C1: Train Observation: West Ruislip to Holborn

Thursday 26 May 2016 8:00-9:00am

Station	Dwell Time (seconds)	Train Crowdedness Level (TCL)	Passenger Flow Notes
West Ruislip	-	1	- 5-10 passengers per car rode Westbound and stayed on the train until it went East into the city
Ruislip Gardens	0:17.78	1	- 3 boarders
South Ruislip	0:23.61	1	- 1 non-commuter boarded
Northolt	0:27.95	1	- 2 commuters boarded
Greenford	0:27.79	1	- 8 boarders, mostly commuters - All stations and tracks are overground with large platforms and a small volume of passengers in these outer zones
Perivale	0:26.34	2	- 2 commuters entered - Filled nearly every single seat and leaning area
Hanger Lane	0:29.61	2	- 2 boarders, filled all seats
North Acton	0:44.25	3	- 5 alight and 20 board - Only a couple passengers standing between the seats, most at doors
East Acton	0:32.98	4	- 6 board and fill space between sitting passengers - Most physical space is occupied
White City	0:43.61	4	- Limited visibility of doors, even the double doors nearby were hard to see through people - Only easy to exit if near the doors
Shepherd's Bush	0:42.50	5	- 2 alight and 10 board

			- “please move down inside the cars to take up all available space” announcement was not effective
Notting Hill Gate	0:57.37	5	- 8 alight and 10 board - Doors reopened and closed because of unseen door blockage - Passengers within an inch of hitting their heads on the train doors as they close
Queensway	0:27.43	5	- 5 board, most must stay on platform - No passengers in the car move from their original position unless someone is exiting another space that they will claim
Lancaster Gate	0:43.08	5	- Awkward shuffle push for 5 alighters - 10 boarders all squish in by the doors
Marble Arch	0:59.02	5	- 10 alight and 15 board - One girl’s ponytail is stuck in the door → reopen and close doors
Bond Street	0:53.34	5	- 3 sitters and 5 standers alight - 10 or so boarders move into both area by door and between seats to fill gaps, 2 put backpacks in between feet on the floor
Oxford Circus	1:12.64	5	- 15 alighters and 15 boarders - Many on the platform unable to board - Door obstruction announcement by driver then departure
Tottenham Court Road	0:38.84	5	- 5 push to exit and 5 board
Holborn	-	5	- Train operator had stopped the train too early and had to inch forward - 25 alighters and 25 boarders - Many left on platform

Appendix C2: Train Observation: Epping to Holborn

Thursday 26 May 2016 8:00-9:00am

Station	Dwell Time (seconds)	Train Crowdedness Level (TCL)	Passenger Flow Notes
Epping	-	1	-
Theydon Bois	0:20.91	2	- Not many boarders
Debden	0:27.67	2	- Not many boarders
Loughton	3:14.54	3	- Late boarders - Delay due to signal failure
Buckhurst Hill	0:36.13	3	- Not many boarders - Driver made announcement about delay
Woodford	0:31.83	3	- Passengers moved inwards immediately opposed to crowding the doors (experienced commuters showing different behavior than average passenger) - Driver made announcement about delay - Most passengers had bags by feet
South Woodford	0:39.25	3	- Not many boarders - Driver made announcement about delay
Snaresbrook	0:30.58	3	- Not many boarders - Driver made announcement about delay
Leytonstone	1:39.86	3	- Not many boarders - Train had to wait at station for track to be clear because of other trains' delays
Leyton	0:42.65	4	- Many boarders - Driver made announcement about delay
Stratford	0:40.21	5	- Many boarders - Boarders not letting passengers off
Mile End	0:35.53	5	- Many boarders - Boarders not letting passengers off - Passengers blocked doors

Bethnal Green	0:32.16	5	- Many boarders - Boarders not letting passengers off
Liverpool Street	0:42.13	5	- Many boarders - Boarders not letting passengers off
Bank	0:44.70	5	- Many boarders - Boarders not letting passengers off - Passengers blocked doors
St. Paul’s	0:36.95	5	- Many boarders - Boarders not letting passengers off
Chancery Lane	1:25.88	5	- Many boarders - Boarders not letting passengers off - Something caught in doors multiple times to cause large dwell time
Holborn	-	5	- More alighters than boarders - Boarders not letting passengers off

Appendix D: CCTV Observation

Station	Bound	Time Start	Time End	# of Trains	Average Dwell times	PCL (front)	PCL (mid-frnt)	PCL (mid-bck)	PCL (back)
Notting Hill Gate	West	7:15	7:45	10	29.32	0.6	0.9	0.4	1.1
Notting Hill Gate	East	7:15	7:40	10	31.37	1.1	2.6	2.5	3.5
Oxford Circus	West	7:45	8:08	10	35.36	4.1	3.2	1.9	1.1
Oxford Circus	East	7:40	8:10	10	37.53	2.9	3.8	3.6	2.7
Tottenham Court	West	8:08	8:31	10	31.25	0.8	0.7	0.8	1.4
Tottenham Court	East	8:10	8:30	10	31.79	0.5	2.6	2.6	2
Holborn	West	8:31	8:50	10	31.85	0.7	1	1.3	1.2
Holborn	East	8:30	8:55	10	37.98	1.5	3.2	3.4	3.3
Chancery Lane	West	8:50	9:15	10	31.42	0.4	0.5	0.9	0.5
Chancery Lane	East	8:55	9:15	10	30.46	0.1	0.2	0.4	0.8
Bank	West	8:42	9:00	10	38.302	2.9	2.9	3.5	3.3
Bank	East	8:45	9:10	10	40.136	2	2.2	2.2	3.1
Liverpool Street	West	8:26	8:42	10	37.709	3.5	2	2.1	1.8
Liverpool Street	East	8:25	8:45	10	36.466	1.2	1.3	1	0.8
Mile End	West	8:09	8:26	10	31.016	3.4	3.3	3.4	3.2
Mile End	East	8:00	8:25	10	31.619	1.8	2.1	1.6	0.9
Stratford	West Rgt	7:44	8:09	10	36.087	3.2	4	3.8	3.2
Stratford	West Lft	-	-	-	-	1.8	3.1	3	1.8
Stratford	East	7:35	8:00	10	30.24	2.2	2.7	2.8	1.7
Leytonstone	West	7:01	7:44	10	48.737	2.2	0.9	1.2	1
Leytonstone	East	7:00	7:35	10	73.574	0.7	1	0.9	1.1

Station	Bound	Walking Support Items	Large Luggage	Accidental door reopening	Intentional door reopening	Aprox. # of alighters
Notting Hill Gate	West	1	1	0	0	100
Notting Hill Gate	East	1	3	1	0	70
Oxford Circus	West	1	2	0	0	80
Oxford Circus	East	1	14	2	3	80
Tottenham Court	West	0	0	0	0	60
Tottenham Court	East	1	3	0	1	40
Holborn	West	0	3	1	0	100
Holborn	East	1	6	1	5	80
Chancery Lane	West	1	4	0	2	90
Chancery Lane	East	0	1	0	0	100
Bank	West	0	11	1	1	80
Bank	East	0	17	1	0	100
Liverpool Street	West	0	5	0	0	60
Liverpool Street	East	0	17	0	0	100
Mile End	West	1	5	2	1	40
Mile End	East	0	3	1	0	25
Stratford	West Rgt	0	2	0	0	20
Stratford	West Lft	-	-	-	-	70
Stratford	East	0	0	0	1	80
Leytonstone	West	0	5	0	2	10
Leytonstone	East	0	0	0	0	15

Station	Bound	Type: rushing/ in a hurry	Type: oblivious/ obstructing	Type: groups/ chatting	Entrance/exits
Notting Hill Gate	West	3	1	1	Back end
Notting Hill Gate	East	11	4	0	Back end
Oxford Circus	West	18	4	1	Front end
Oxford Circus	East	31	2	0	Front end & main entrance only in center
Tottenham Court	West	8	0	0	Back end - passageway and stairs
Tottenham Court	East	6	0	0	Front end & entrance only in center
Holborn	West	11	0	0	1/3 from back end
Holborn	East	11	1	1	1/3 from back end
Chancery Lane	West	3	2	1	1/3 from back end
Chancery Lane	East	3	1	0	Back end
Bank	West	11	2	1	???
Bank	East	18	0	1	???
Liverpool Street	West	22	0	3	Back end & front end (3)
Liverpool Street	East	4	1	1	Front and Back
Mile End	West	12	0	0	Middle of platform ?
Mile End	East	2	1	3	Middle Front
Stratford	West Rgt	29	2	1	Multiple along both platforms ???
Stratford	West Lft	-	-	-	-
Stratford	East	5	3	1	Middle Front
Leytonstone	West	13	2	1	Front end - stairs only
Leytonstone	East	2	0	0	Front end

Station	Bound	Notes
Notting Hill Gate	West	High dwell times because of the high number of alighting passengers, many move down the platform but mostly not to the last carriage
Notting Hill Gate	East	Most passengers crowd by the entrance
Oxford Circus	West	Boarders step up towards door as soon as train is stationary, platform attendant arrives at 8am, one train had 10 people board the front carriage while the other 3 carriages had closed doors
Oxford Circus	East	Platform attendant began directing passenger flow in the middle of the platform at about 8:00, passengers spread out pretty evenly but it was more out of need than nature
Tottenham Court	West	Platform attendant arrives at 8:15 to make announcements/ hold paddle, stood by entrance/exit, directly stopped one rusher
Tottenham Court	East	Platform attendant was in the middle of the platform directing passenger flow, most passengers crowd by the entrance
Holborn	West	Platform attendant arrives at 8:35, some people inside train by doors exit then reenter to allow for alighters to exit
Holborn	East	Platform attendant was in the middle of the platform directing passenger flow but left at 8:50, most instances left boarders on platforms, most passengers crowd by the entrance
Chancery Lane	West	No platform attendant because there were few to no boarders for most trains
Chancery Lane	East	Many alighters(most of train disembarked) and very few boarders
Bank	West	Platform attendant at center of platform, cameras divided into each car instead of each carriage -> harder to estimate PCL
Bank	East	Attendant showed up at 8:50
Liverpool Street	West	Platform attendant at back 1/3 of train, 3/4 exit at front passages, police officer arrived at 8:40 and stood by wall across from platform attendant then left after a couple minutes
Liverpool Street	East	Fairly even distribution about the platform
Mile End	West	Platform attendant in center of platform, rushing over from District & Circle side of platform, pushing the crowd more towards the edge

Mile End	East	
Stratford	West	Platform attendant on left side of tracks, 3/5 board on right side of train, 2/3 alight on left side of train, video cameras only show edge of platform, waves of people coming from connections
Stratford	East	Most alighters disembark at middle of platform, a lot of the people on the platform were waiting for a different train
Leytonstone	West	Platform attendant arrived at 7:25, excessive dwell time once for switching track because of the other train on platform 2 that departed just before it, many walk towards front of train
Leytonstone	East	Most alighters disembark at back of train (front of platform)

Appendix E: Passenger Survey Questionnaire

Preamble:
We are students from the U.S. that are working with Transport for London to decrease delays. Would you like to partake in a short survey aimed to gather consumer information on delays in the Central Line? The survey is completely anonymous, and voluntary as you may choose to opt out or skip questions at any point.

1. What is your primary reason for using the Central Line?
    - ❏ Commuting
    - ❏ Tourism
    - ❏ Shopping
    - ❏ Casual
    - ❏ Other: ___________________
2. If possible, do you typically run onto trains last minute?
    - ❏ Yes
    - ❏ No
    - ❏ I am not sure
3. If you knew that a later train is more empty than the next train, would you be willing to wait?
    - ❏ Yes
    - ❏ No
    - ❏ I am not sure
    - ❏ Other: ___________________
4. When you use the Central Line, do you typically ride the same train car?
    - ❏ Yes
    - ❏ No
    - ❏ I am not sure
5. What is your opinion on the provision of information such as announcements and signs?
    - ❏ Satisfied
    - ❏ Neutral
    - ❏ Dissatisfied
6. What is your opinion on Central Line platform layouts like size and entrance/exit placement?
    - ❏ Satisfied
    - ❏ Neutral
    - ❏ Dissatisfied
7. What is your opinion on the train size and passenger capacity on the Central Line?
    - ❏ Satisfied
    - ❏ Neutral
    - ❏ Dissatisfied

10. What is your favorite London Underground line? And why?
    - ❏ Bakerloo
    - ❏ Central
    - ❏ Circle
    - ❏ District
    - ❏ Hammersmith & City
    - ❏ Jubilee
    - ❏ Metropolitain
    - ❏ Northern

- ❏ Piccadilly
- ❏ Victoria
- ❏ Waterloo & City
- ❏ I am not sure

11. Comments: ________________________________

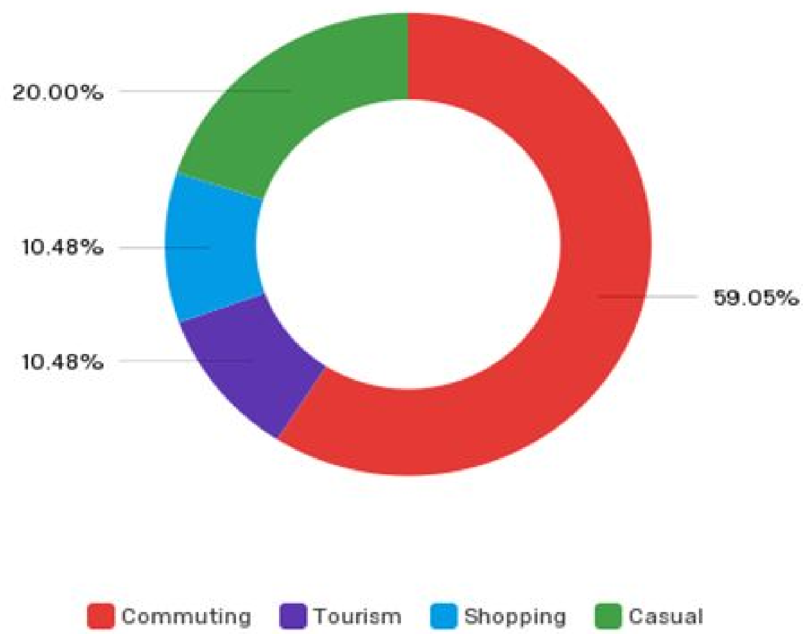
Appendix F: Passenger Survey Report

Overall Passenger Report

London Underground Passenger Survey

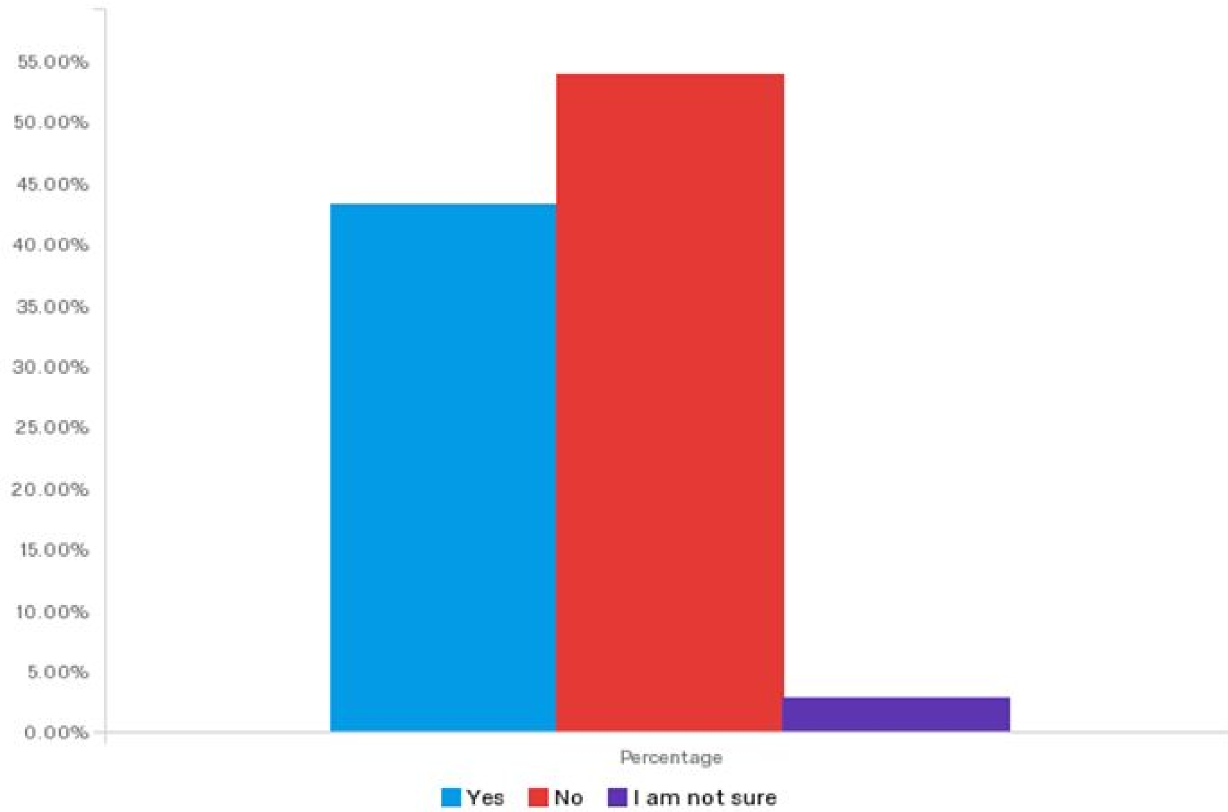
June 22nd 2016

Q1 - What is your primary reason for using the Central Line?



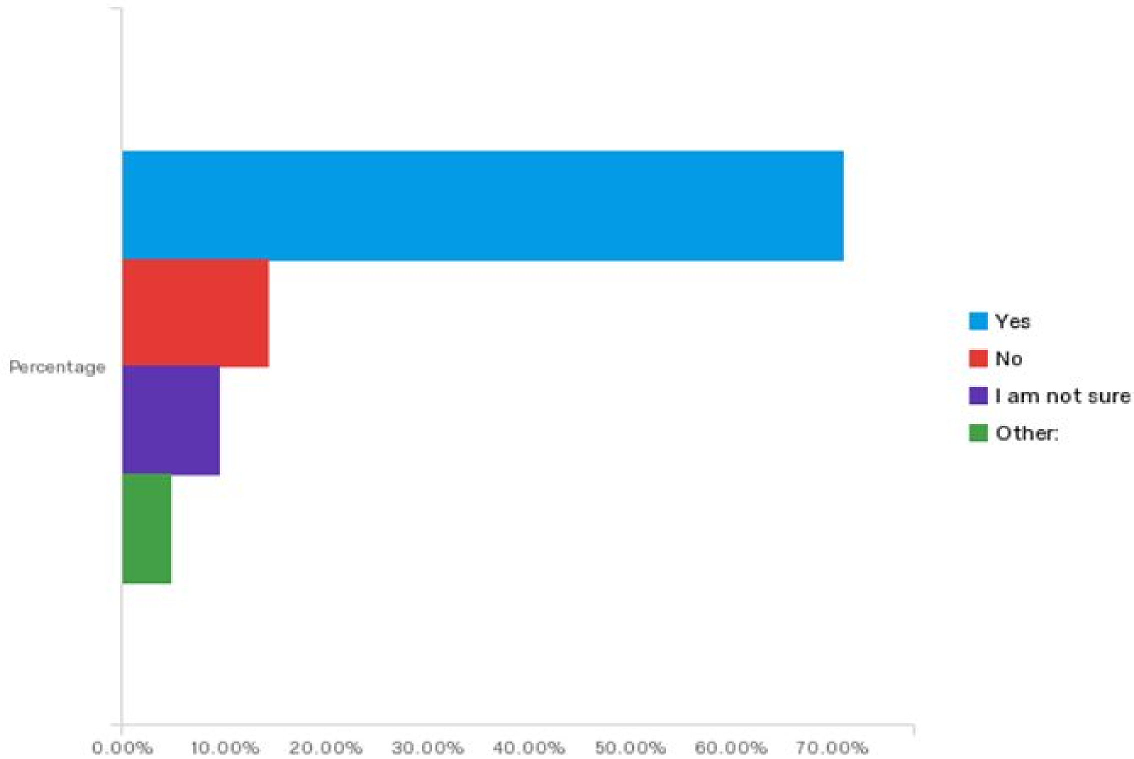
Answer	%	Count
Commuting	59.05%	62
Tourism	10.48%	11
Shopping	10.48%	11
Casual	20.00%	21
Total	100%	105

Q2 - If possible, do you typically run onto trains last minute?



Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
If possible do you typically run...	1.00	3.00	1.60	0.55	0.30	104	100.00%	100.00%

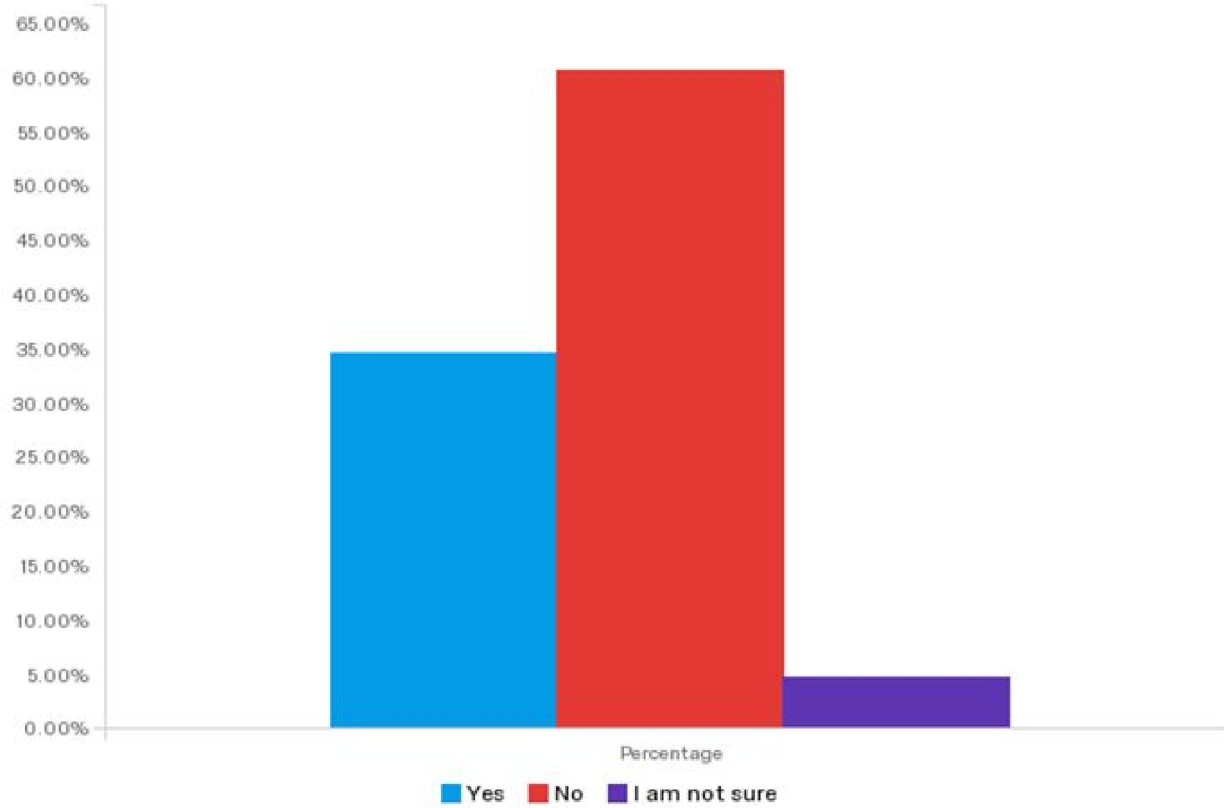
Q3 - If you knew that a later train is more empty than the next train, would you be willing to wait?



Answer	%	Count
Yes	71.15%	74
No	14.42%	15
I am not sure	9.62%	10
Other:	4.81%	5
Total	100%	104

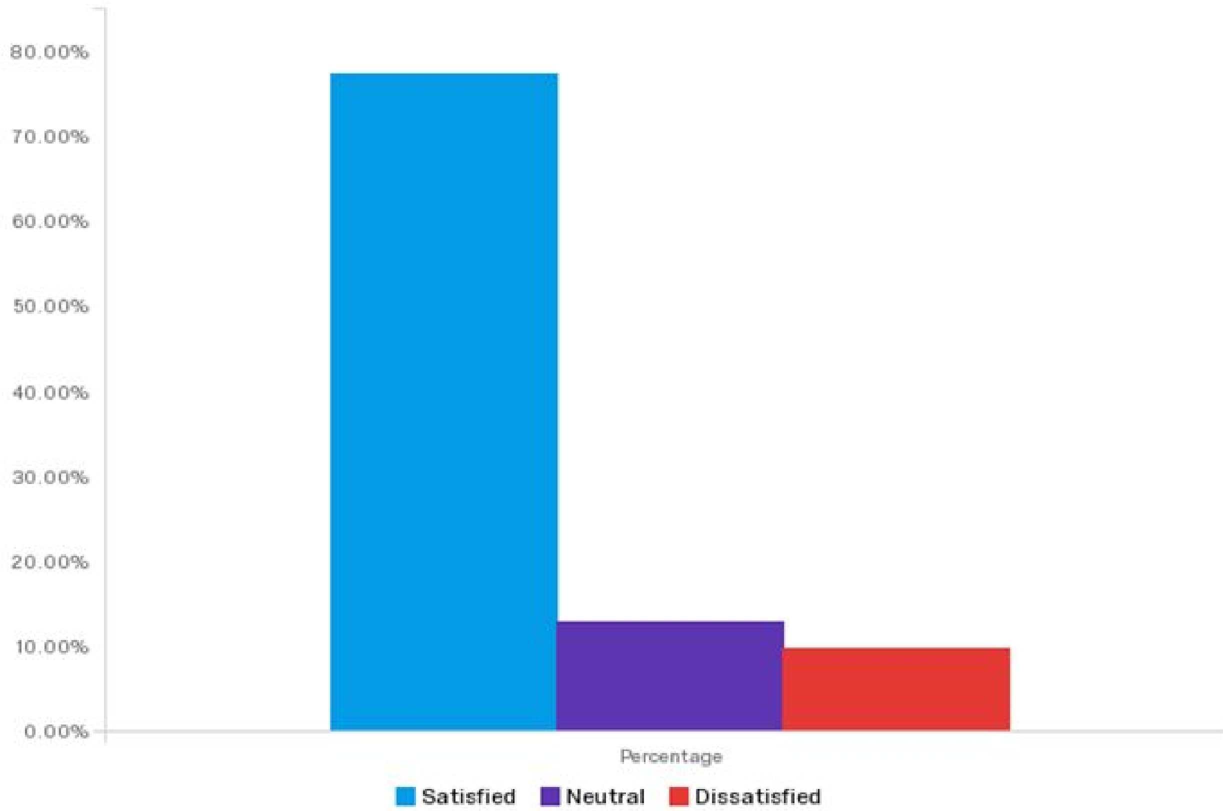
Other:
If not in a hurry
If she is in a hurry no. Otherwise yes.
Won't wait if ride is short

Q4 - When you use the Central Line, do you typically ride the same train car?



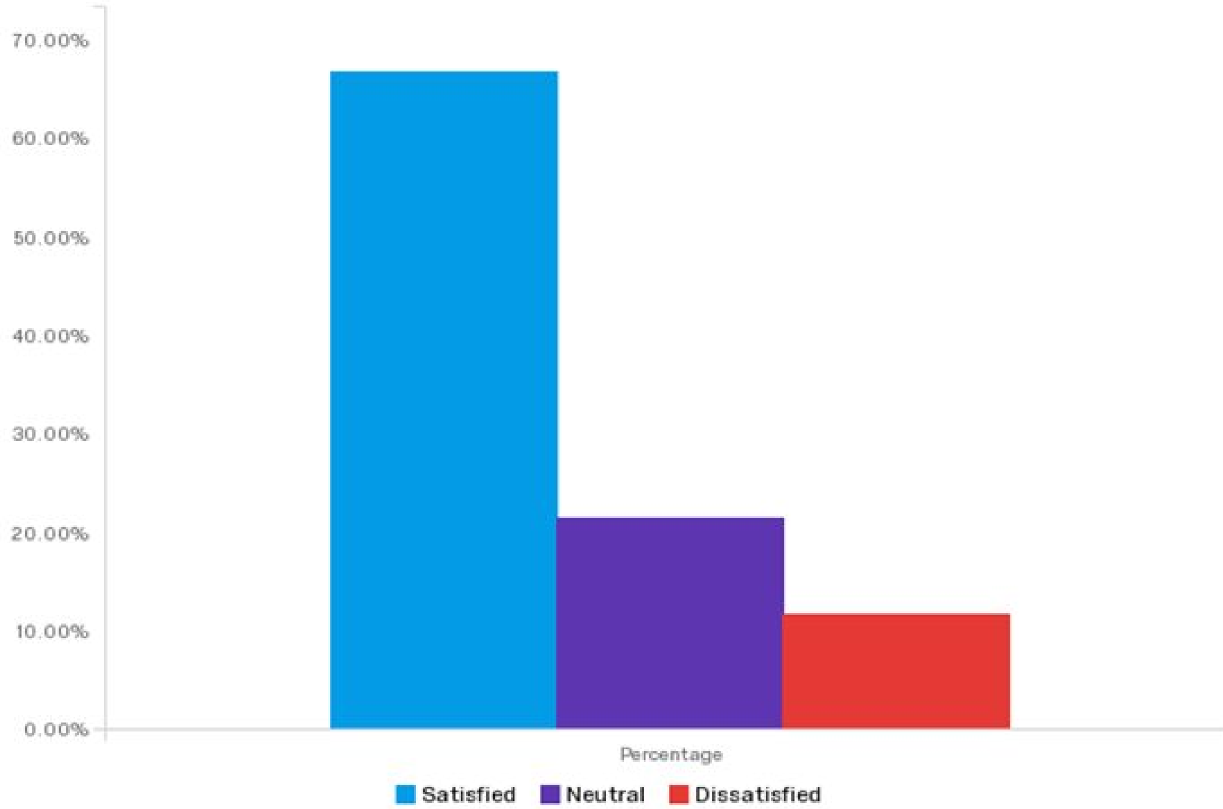
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
When you use the Central Line...	1.00	3.00	1.70	0.55	0.31	104	100.00%	100.00%

Q5 - Are you satisfied with the provision of information such as announcements and signs?



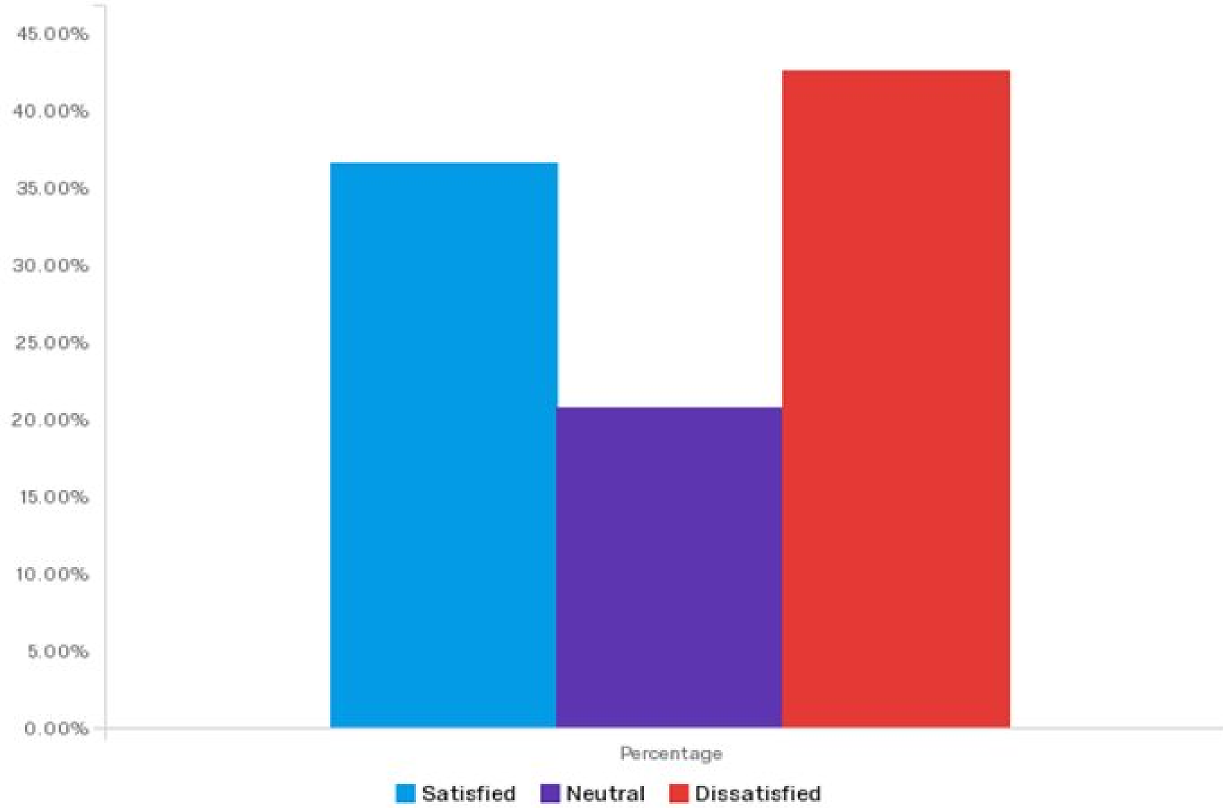
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
Are you satisfied with the provision of info...	1.00	3.00	1.33	0.65	0.42	101	100.00%	100.00 %

Q6 - Are you satisfied with Central Line platform layouts like size and entrance/exit placement?



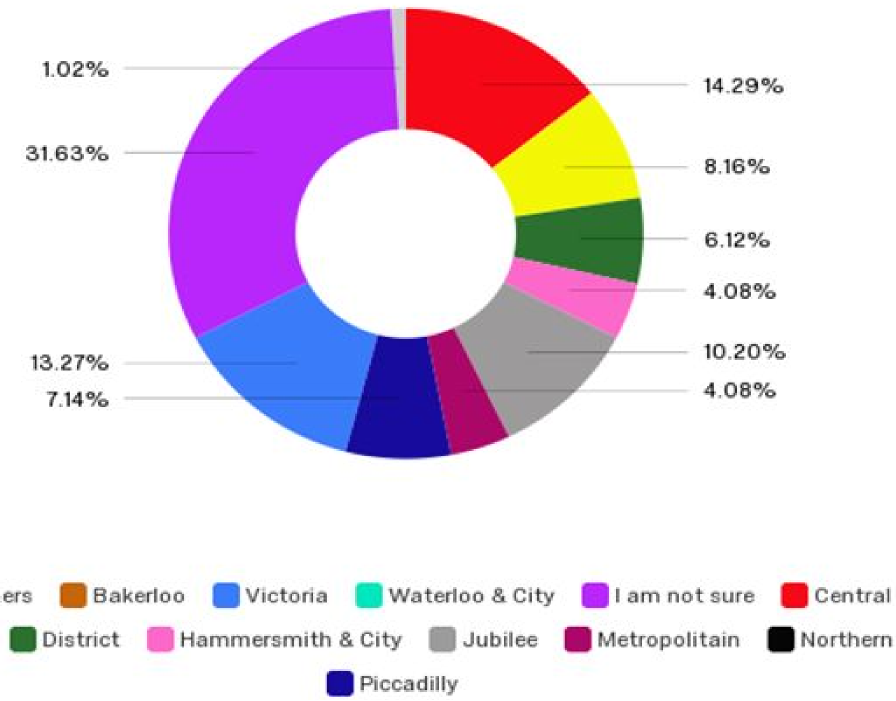
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
Are you satisfied with Central Line platform layout...	1.00	3.00	1.45	0.69	0.48	102	100.00%	100.00%

Q7 - Are you satisfied with the train size and passenger capacity on the Central Line?



Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
Are you satisfied with the train size...	1.00	3.00	2.06	0.89	0.79	101	100.00%	100.00%

Q8 - What is your favorite London Underground line?



Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
What is your favorite line?	1.00	12.00	7.65	3.88	15.02	98	23.47%	44.90%

Q10 - Why is that your favorite line?

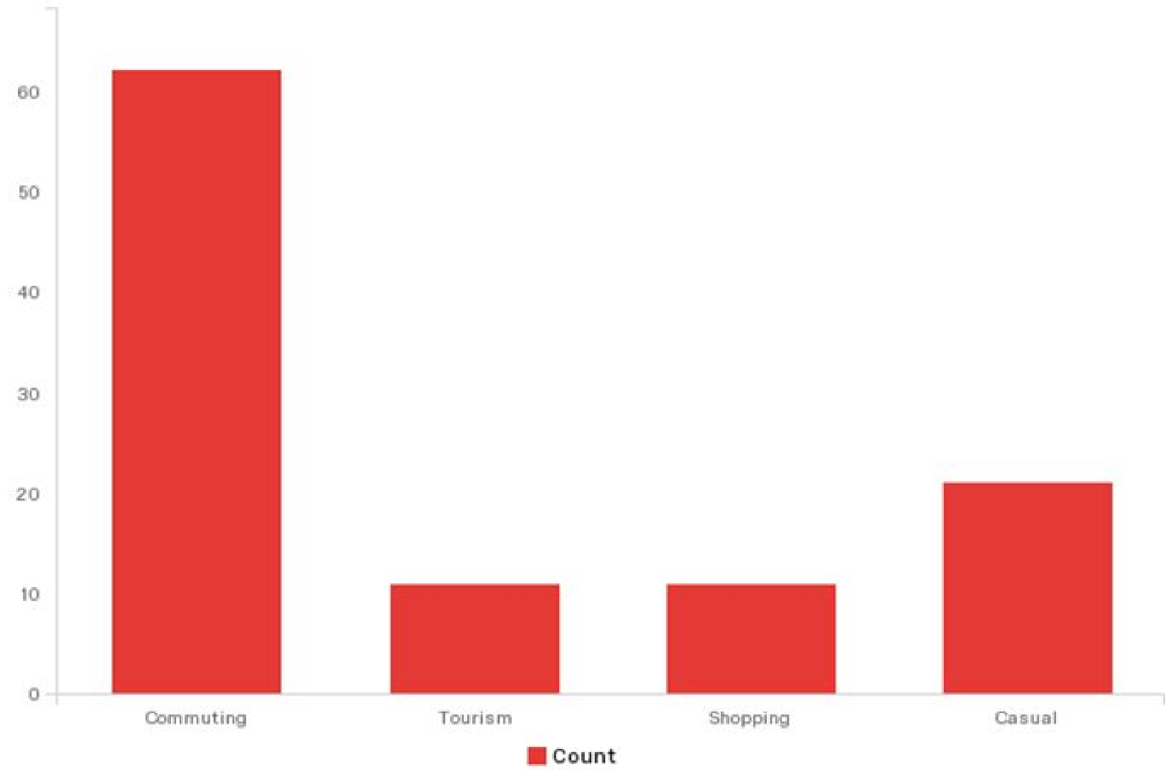
Q11 - Comments:

Passenger Break-Down Report

London Underground Passenger Survey

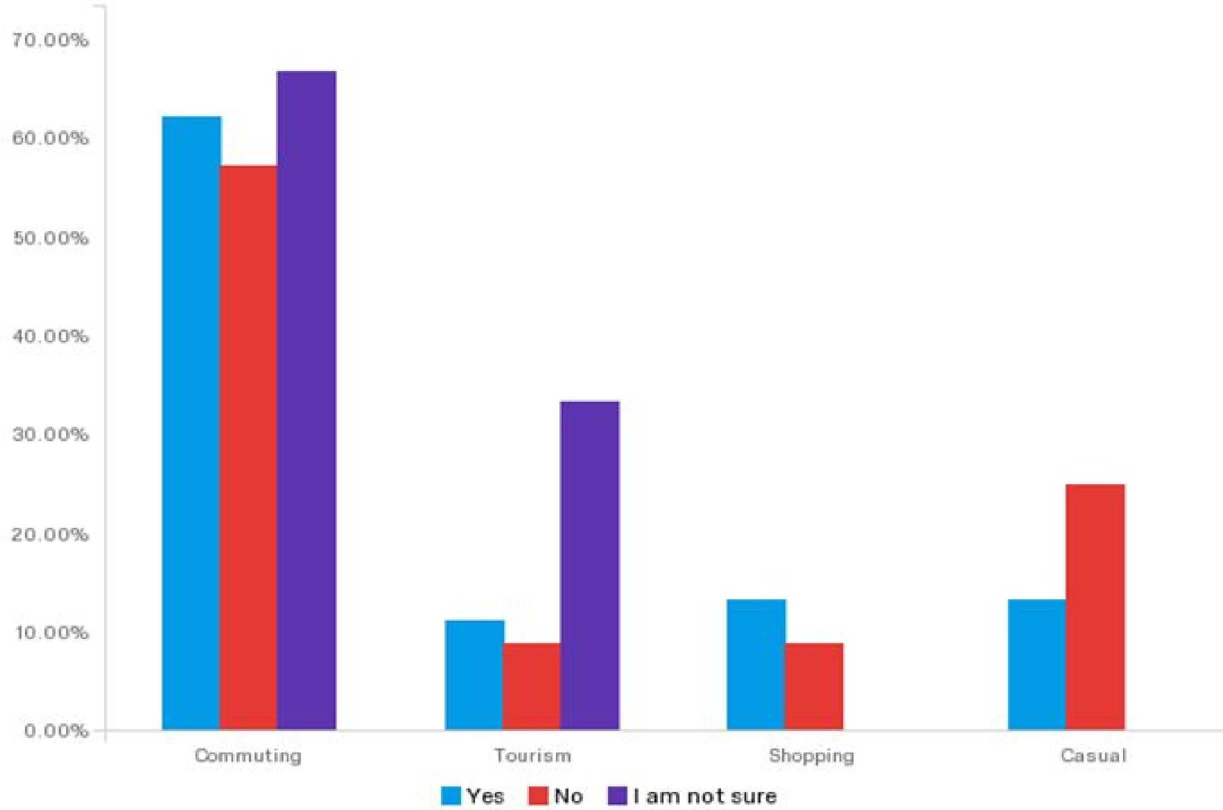
June 22nd 2016

Q1 - What is your primary reason for using the Central Line?



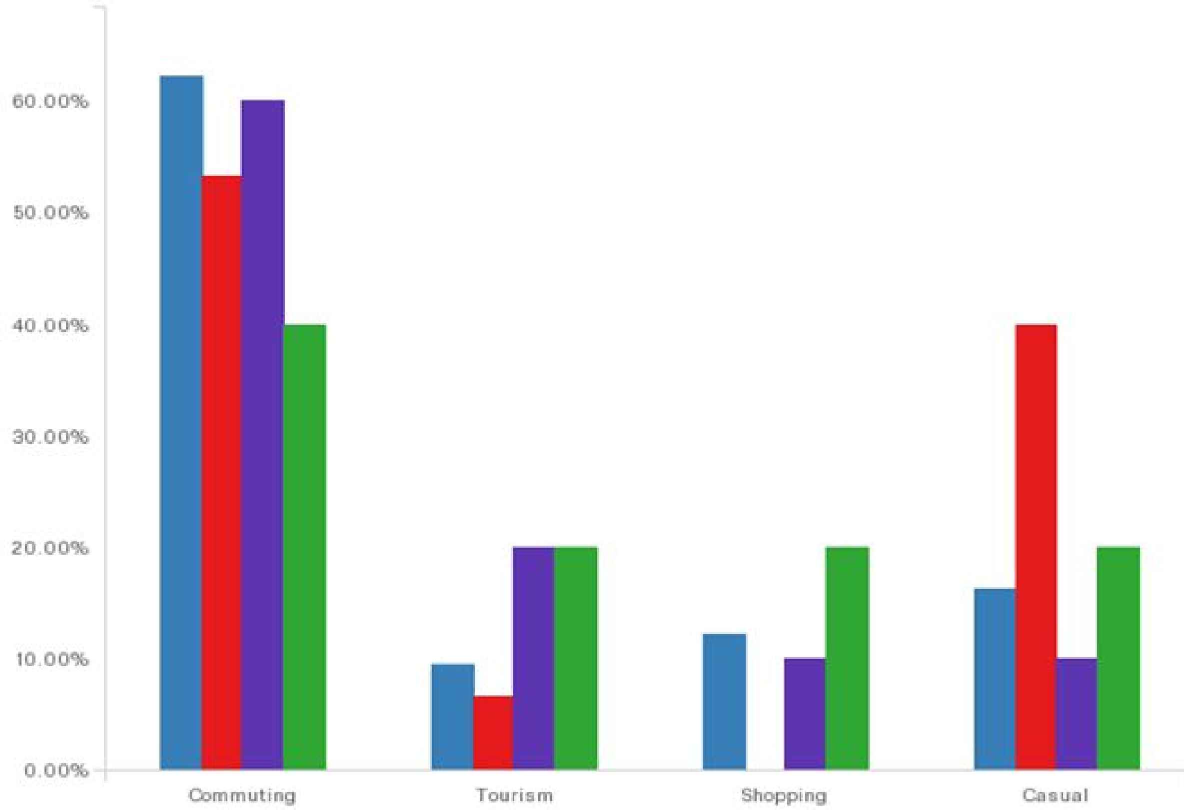
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
What is your primary reason for using the Central Line?	1.00	4.00	1.91	1.22	1.49	105	80.00%	40.95%

Q2 - If possible, do you typically run onto trains last minute?



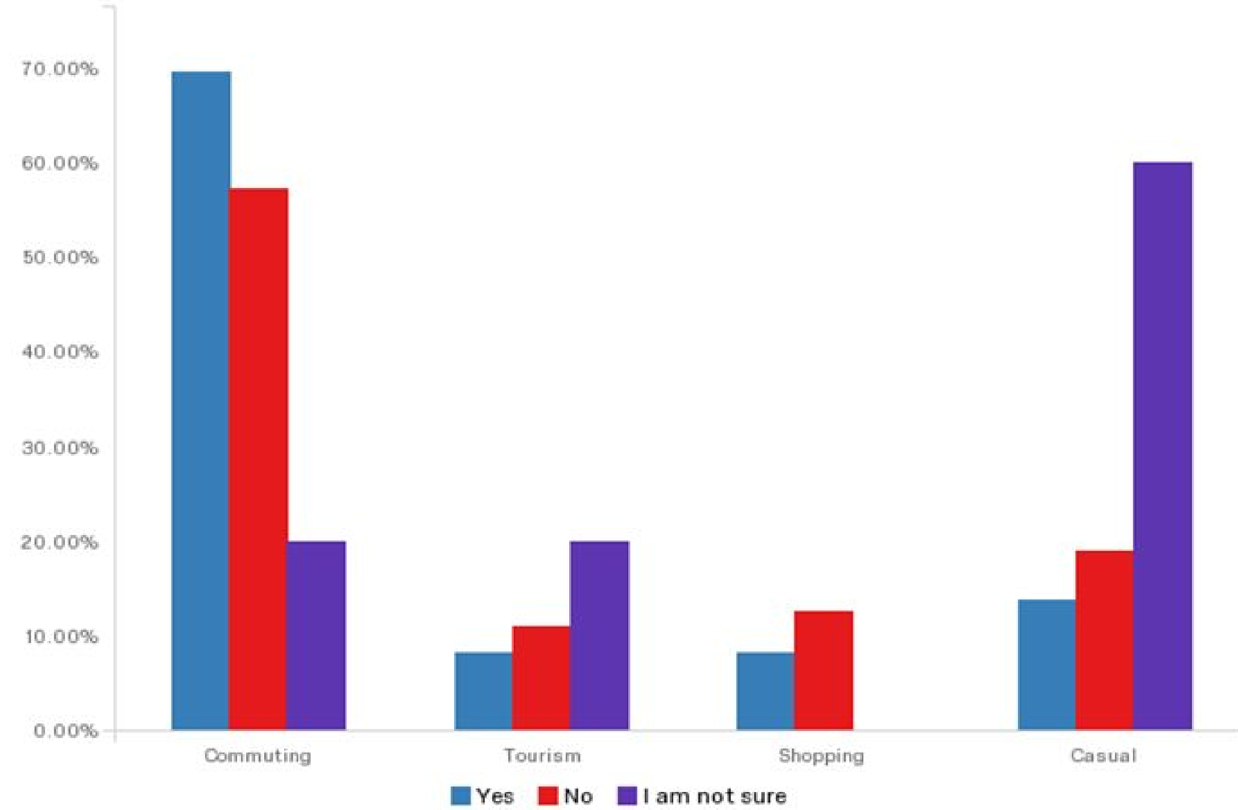
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
If possible, do you typically run...	1.00	3.00	1.60	0.55	0.30	104	100.00%	100.00%

Q3 - If you knew that a later train is more empty than the next train, would you be willing to wait?



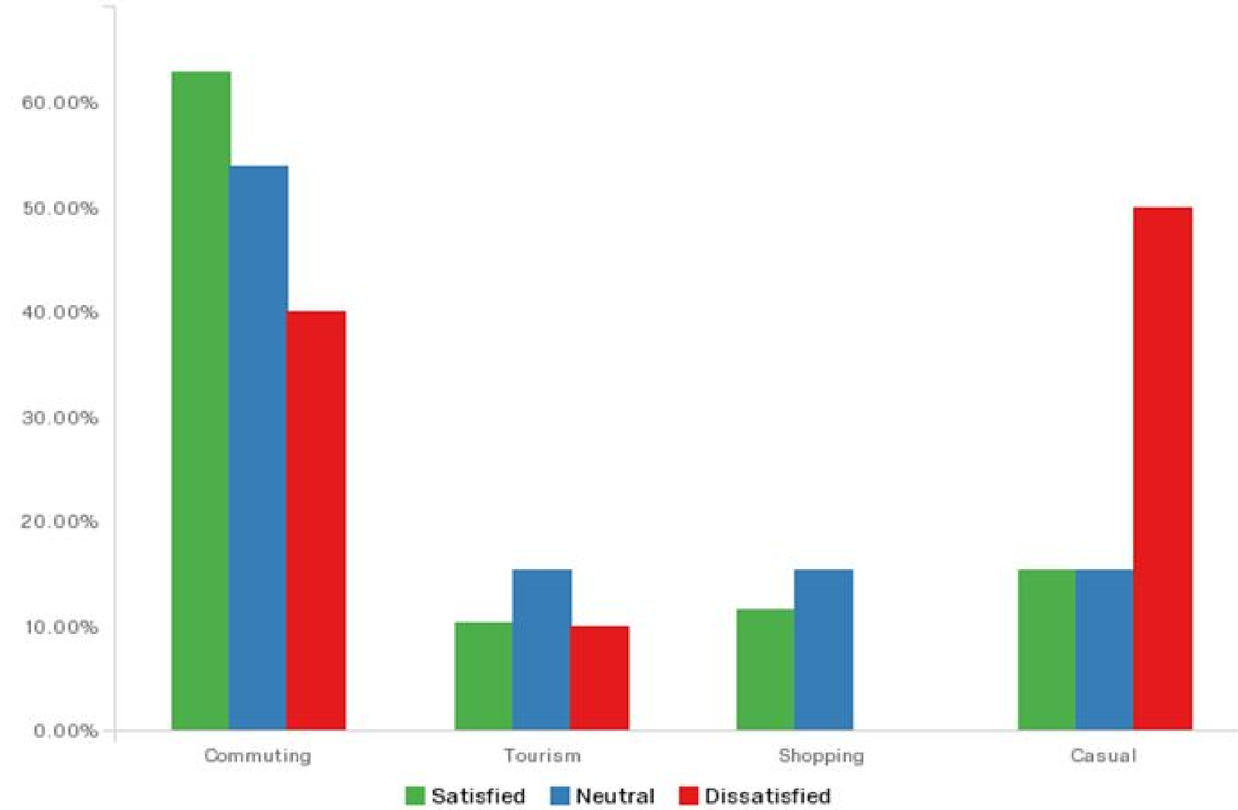
Question	Commuting		Tourism		Shopping		Casual		Total
Yes	62.16%	46	9.46%	7	12.16%	9	16.22%	12	74
No	53.33%	8	6.67%	1	0.00%	0	40.00%	6	15
I am not sure	60.00%	6	20.00%	2	10.00%	1	10.00%	1	10
Other:	40.00%	2	20.00%	1	20.00%	1	20.00%	1	5

Q4 - When you use the Central Line, do you typically ride the same train car?



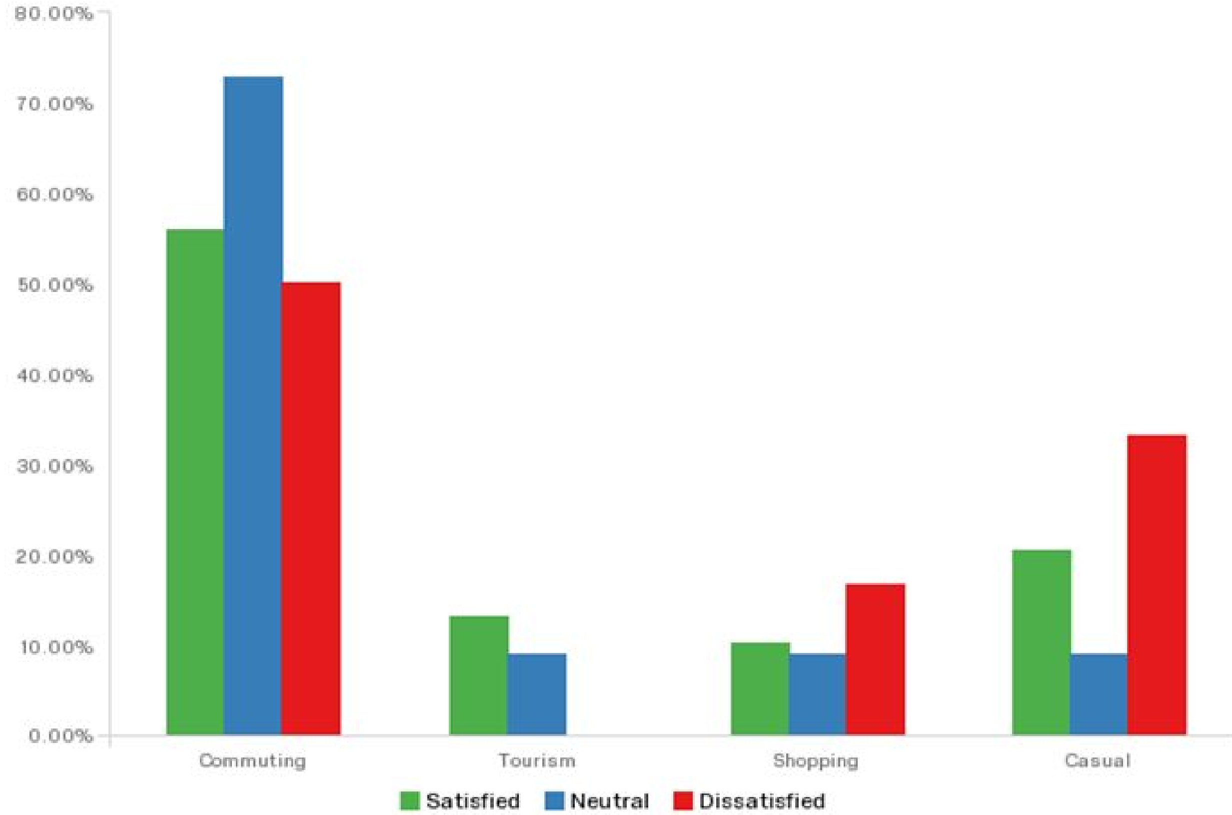
Question	Commuting	Tourism	Shopping	Casual
Yes	69.44%	8.33%	8.33%	13.89%
No	57.14%	11.11%	12.70%	19.05%
I am not sure	20.00%	20.00%	0.00%	60.00%

Q5 - Are you satisfied with the provision of information such as announcements and signs?



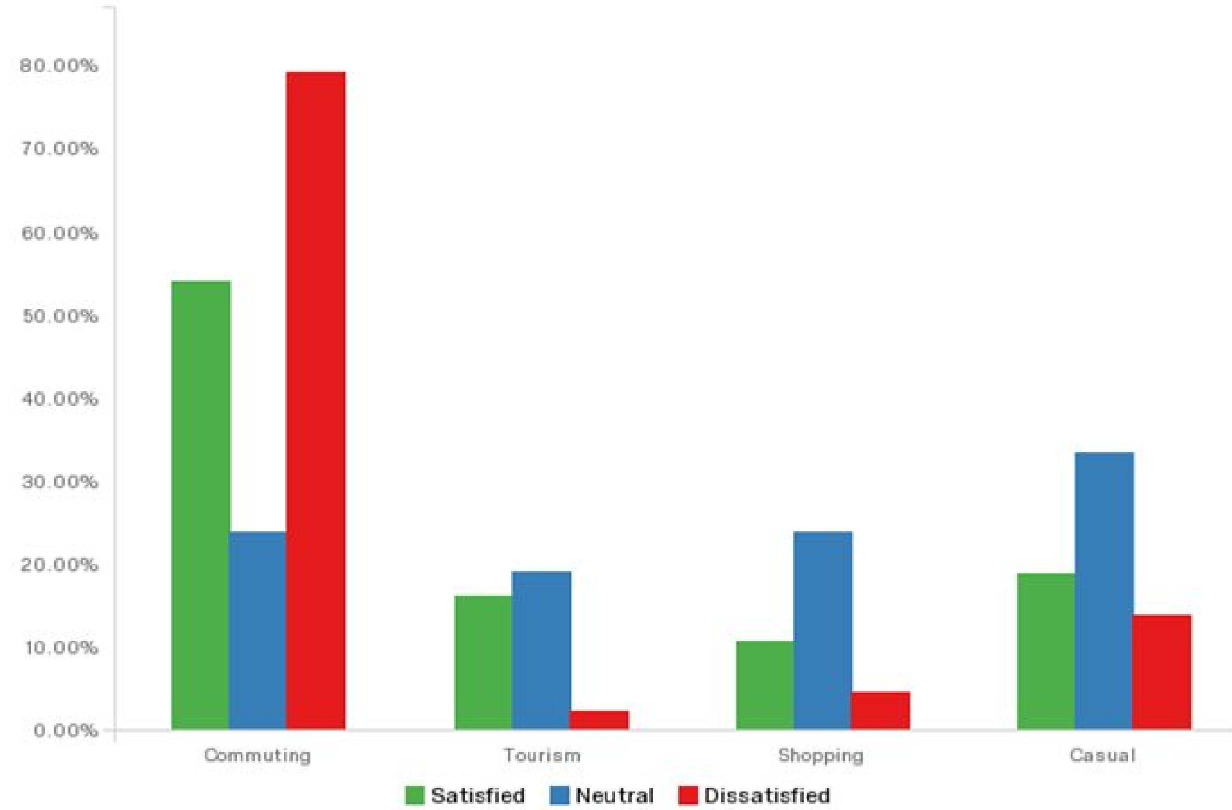
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
Are you satisfied with the provision of information such as announcements a...	1.00	3.00	1.33	0.65	0.42	101	100.00%	100.00%

Q6 - Are you satisfied with Central Line platform layouts like size and entrance/exit placement?



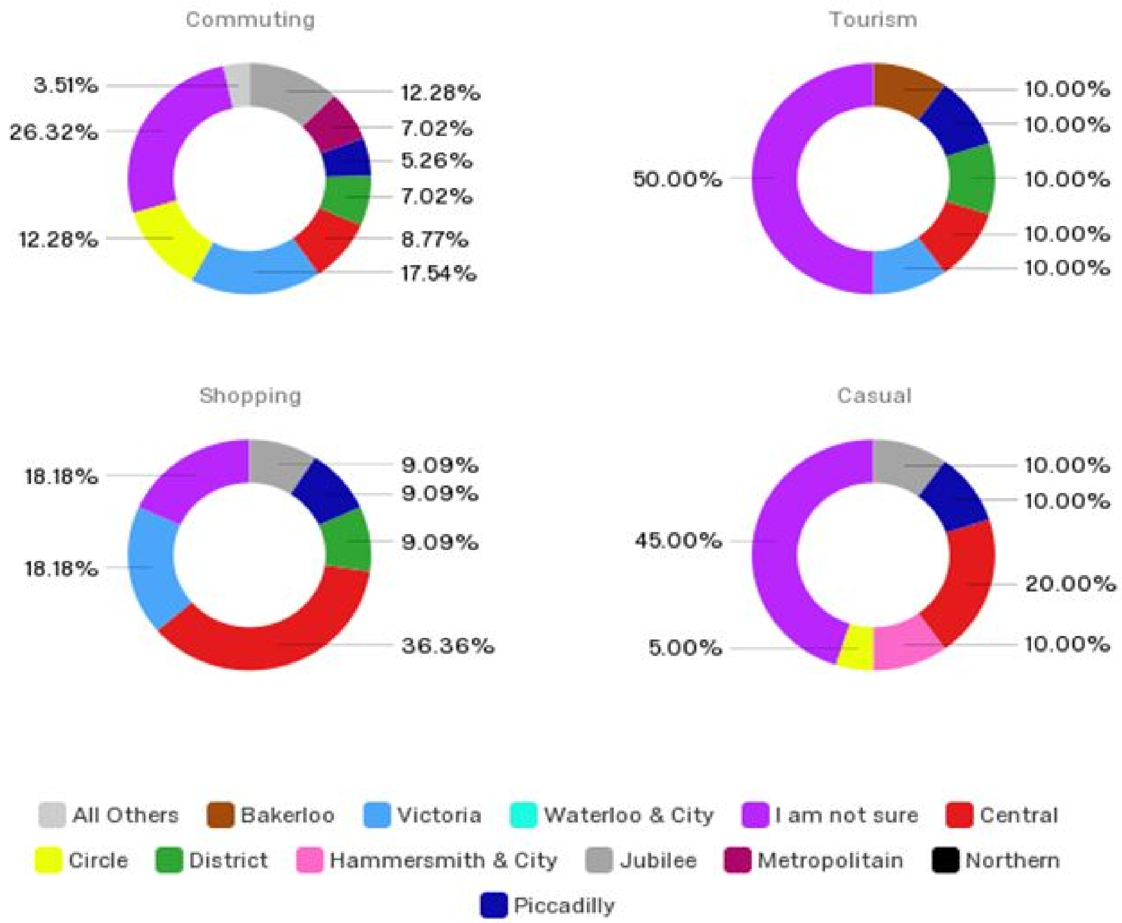
Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
Are you satisfied with Central Line platform layouts...	1.00	3.00	1.45	0.69	0.48	102	100.00%	100.00%

Q7 - Are you satisfied with the train size and passenger capacity on the Central Line?



Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
Are you satisfied with the train size...	1.00	3.00	2.06	0.89	0.79	101	100.00%	100.00%

Q8 - What is your favorite London Underground line



Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count	Bottom Box	Top Box
What is your favorite line?	1.00	12.00	7.65	3.88	15.02	98	23.47%	44.90%

Q11 - Why is that your favorite line?

Commuting

Big trains
Most convenient
Fast service and speed
It’s fast
Most is above ground and great trains and guaranteed a seat
Always runs well
Quick and always get a seat
Easy to find space on trains. Goes from center to very west of London
Connected carriages
Trains are much bigger
Easy to use
Not busy and bigger trains
Uses it a lot
Near her
Lives on it
Lives on it
Guarantee a seat
Spacious
Newest
Always a seat unlike central line

Air conditioning

Bigger cars

Only line used

Used for commuting

Tourism

Commute on it

It is close and convenient

Open train

Line goes to where she’s staying

Baker Street

Shopping

Fast and goes to Oxford circus easily

It's the fastest

Not noisy and goes above ground

Uses it the most

Quick and few delays

Good coverage. It goes everywhere

Most efficient

Casual

More overground

Used a lot

Good service

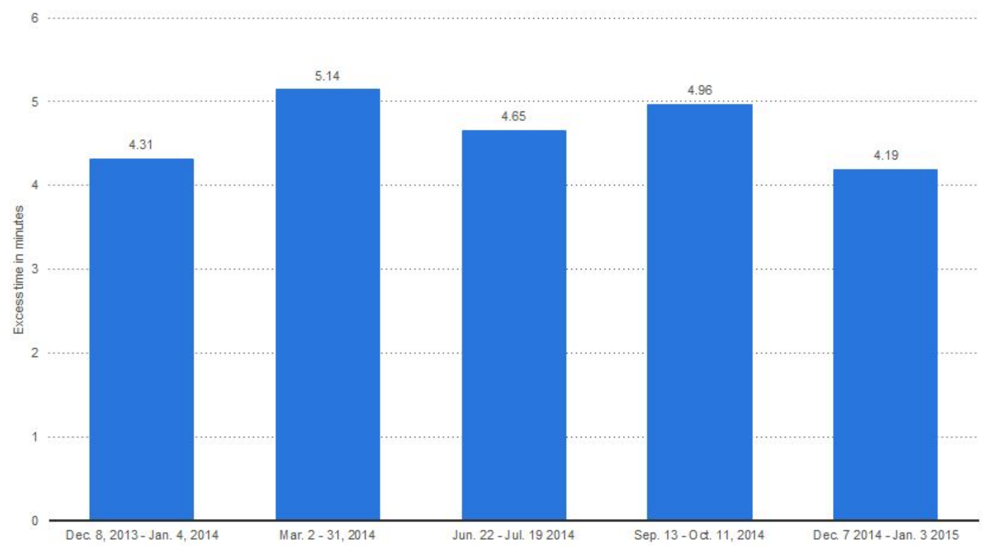
Used to it or jubilee

Faster

Not that crowded and runs well
Runs the best
Line goes to where he lives
Convenience/good coverage

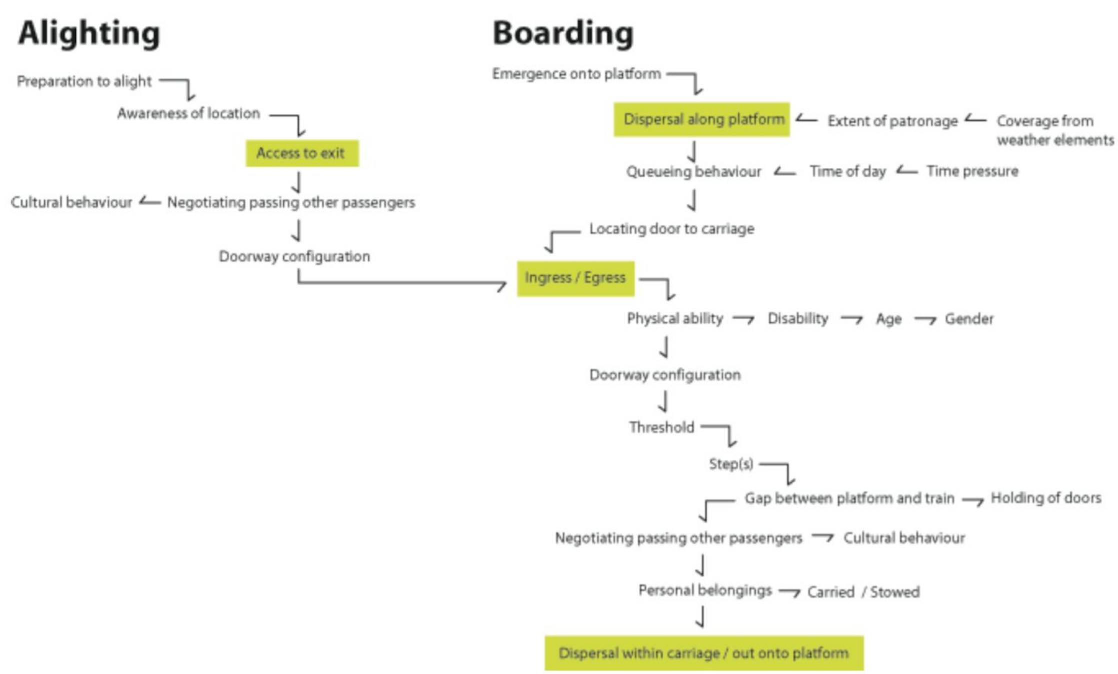
Appendix G: Additional Figures

Figure 1: Average excess to complete a scheduled journey time from Dec. 2013 to Jan. 2015



(Source: Transport for London, n.d.)

Figure 3: Qualitative variables in alighting boarding



(Source: Coxon, Burns, Bono & Napper, 2011)

Figure 6: London Underground map from May 2015

(Source: Transport for London, 2016f)

Figure 9: Train Crowdedness Level

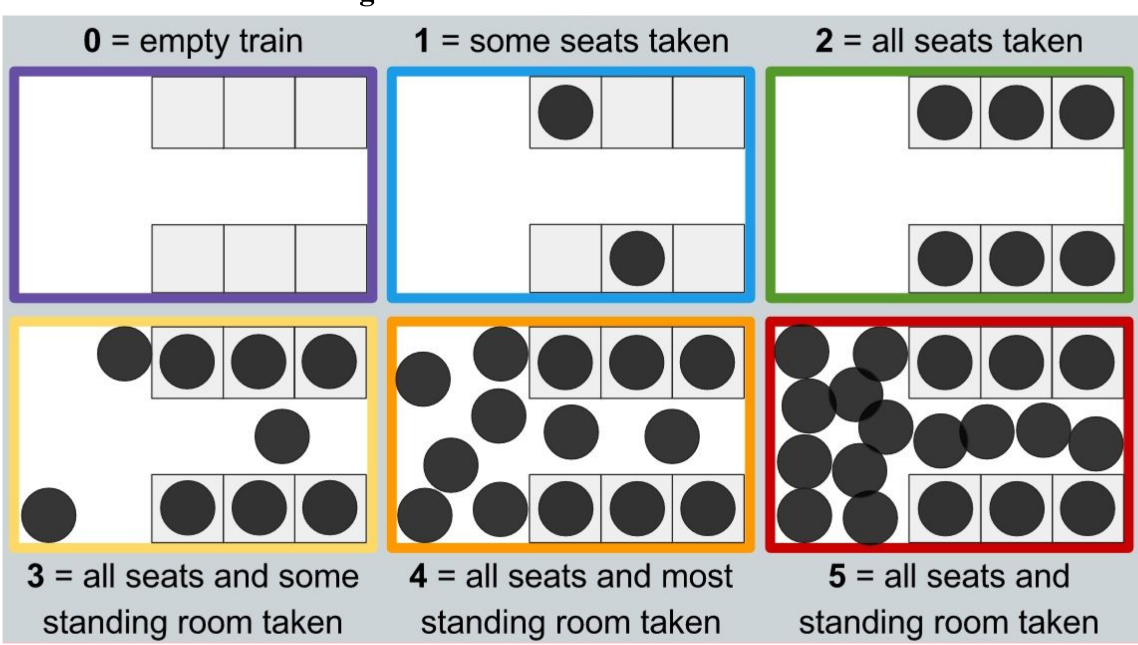


Figure 10: Platform Crowdedness Level

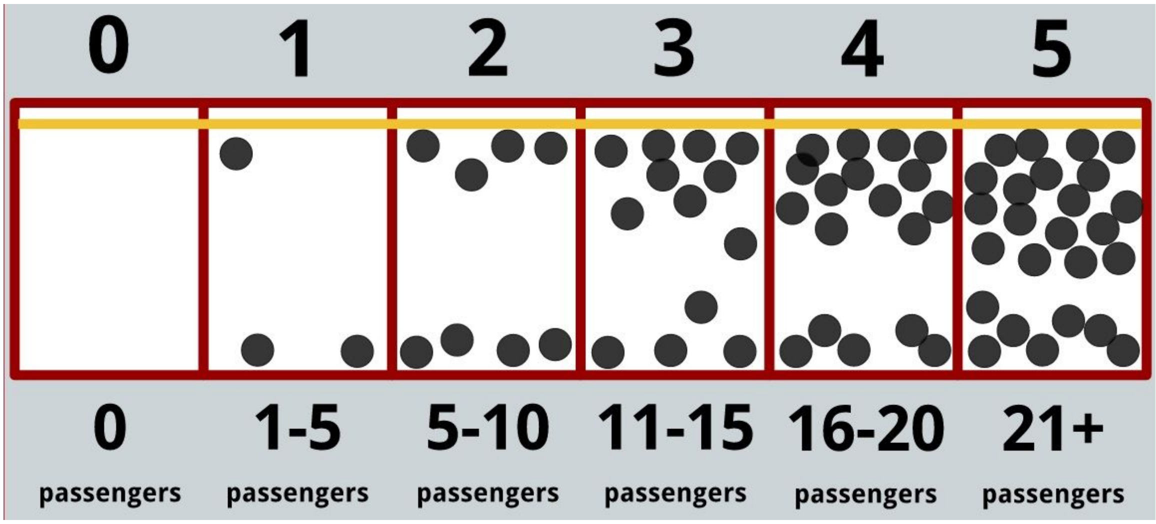


Figure 15: Observed Door Reopening Cause