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Intercollegiate MSc Course in Transport

RENOVATION OF TOTTENHAM COURT ROAD STATION

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A Special Study submitted as part of the requirements for the degree of Master of Science of the University of London

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Special thanks to Prof. Steven Glaister of Imperial College London for his guidance through all weathers. Without his ideas and academic support it would not have happened.

DECLARATION

I hereby declare that the dissertation, submitted in partial fulfilment of the requirements for the degree of Master of Science and entitled "Renovation of Tottenham Court Road Station", represents my own work. In it, I give references and citations whenever I refer to or use the published or unpublished work of other people.

Mustafa Helvacioglu

September 2006

ABSTRACT

Stations are one of the most significant parts of transport networks. The structure and the service of stations have a direct effect on the well being of managers, operators and passengers. A well designed station is a necessity of creating a successful railway system.

Railway stations vary enormously in regard to complexity depending on the type of railway, the location and the service. Underground stations are unique type of stations in various types of railway stations and there are many specific concerns of these stations such as capacity, accessibility, evacuation and emergency actions, safety, security, ventilation etc.. This project will focus on the capacity and accessibility problems of Tottenham Court Road Station which is one of the central located stations of London Underground network.

Firstly the station will be presented with its major elements. Some numerical calculations about the capacity of certain elements will be held to show which parts need priority in renovation. Moreover the observed conditions of the station will try to make us realise the problems of the station. Finally, the results will be questioned and some temporary and permanent engineering solutions will be presented that can help to ease the congested service of Tottenham Court Road Station.

I wish this study leads to further studies and it can be an example for the future MSc projects with its structure and content.

I apologise from the readers for any kind of literature and printing mistakes on this paper.

KEY WORDS

Renovation, Tottenham Court Road Station, London Underground, Central Line, Northern Line, CrossRail, Capacity, Accessibility

DEDICATION

To my beloved parents Mehmet and Ummahan Helvacioglu;

None of this would be possible without your love, support, and prayers.

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ABBREVIATIONS and WORDS

TCRS	Tottenham Court Road Station
JNP	Jubilee and Northern line Partnership
PW	Passageway
SW	Stairway
ESC	Escalator
TH	Ticket Hall
CA	Circulating Area

N	Passenger volume
A	Passenger load
T	Density
v	Speed
w	Width
b	Service time/ time spent
F	Passenger flow
S	Area
$\mathbf{S_U}$	Used area per person

Arrivals Arr.	Passenger who arrived by train and leaving the platform to the exit
Departures Dep.	Passenger who are waiting for the train or walking towards platforms
Interchange Int.	Passengers who are interchanging between lines
Entering	Means going inside the station and platforms
Exiting	Means going outside the station and platforms

1. INTRODUCTION

The topic of this project shows that the main target of this study is to improve the knowledge and engineering perspective about underground stations by figuring out the problems of an existing underground station and deriving applicable engineering solutions to these points. Tottenham Court Underground Station is considered convenient for this kind of study, since it is widely accepted that this station has severe congestion problems and needs some renovation. The local government bodies are also planning some renovation works for TCRS. TCRS is also a part of the future project CrossRail. In this work, extra care is taken into consideration when offering solutions to the problems in order to create consistent recommendations for these future planned works.

The objectives of this paper can be listed as follows;

- Improving the background knowledge on stations
- Learning the basic principles of station design
- Practicing on real and recent problems of stations
- Finding applicable engineering solutions for the congestion and accessibility problems of TCRS and similar stations
- Creating a brief tool for designers and engineers of TCRS and similar stations
- Creating a small scaled reference for similar projects and helping further studies
- Suggesting alternative and consistent ways of renovation to the future developments of TCRS.
- Achieving a high quality study for the MSc degree

This paper will start with short background about the literature review and general information about the station. The methodology of this work and the detailed definition and formulas of the calculations will be explained before presenting the observations and numerical data. After completing the calculations the results will be presented and according to the results solutions will be recommended. In the end, the conclusion part will review the whole paper and present a final report.

2. BACKGROUND

2.1. Literature Review

There are thousands of academic resources about railways, but majority of them are about the train services, tracks, signalling or rolling stocks. Many of the books about railway stations are presenting architectural data instead of engineering calculations like Ross's "*Railway Stations* (2000)" and Edwards's "*The Modern Station* (1997)". These books are very helpful for designing new stations. However they do not include any numerical information about calculating the problematic sections of existing stations. The basic properties of station layout and operation and their capacity requirements are obtained from Clifford Bonnett's "Practical Railway Engineering (2005)" which was the main sourcebook for my project. Prof. Anthony Swain's 2006 lectures about stations and his lecture notes were also used for understanding the basics of station elements.

The capacity calculations are closely related with pedestrian dynamics. The basics of crowd dynamics are learned from Keith Still's "*Crowd Dynamics* (2000)" which includes a case study about the ticket hall of Balham Station. The basic definitions and formulas are used from Tom Rallis's "*Capacity of Transport Centres, Ports, Railway Stations, Road Haulage Centres and Airports* (1967)". Although this resource book is an old pressed book it includes many of the calculation techniques about the capacity problems. This book also contains Nielsen's basic Traffic Load and Volume formulas which are used for acquiring the capacity of certain station elements in this project.

Apart from these academic source books, many internet sites are used particularly to obtain data about TCRS and its future developments. There are no detailed academic papers or books specifically about the congestion and accessibility problems Tottenham Court Road Station. This gave me the opportunity to present a first work about TCRS.

2.2. General Information about TCRS

2.2.1. Zone

The London Underground network is divided into six zones, for the purposes of regulating fares. Tottenham Court Road Station is a central station in Zone 1. *(Figure 1)*

2.2.2. Lines Served

Tottenham Court Road Station is a through station serving on Central Line and Charing Cross branch of Northern Line. By the completion of CrossRail Project this station will be connected to a CrossRail Line 1 (west-east) and in further future CrossRail Line 2 (northeast-southwest). *(Figure1)*

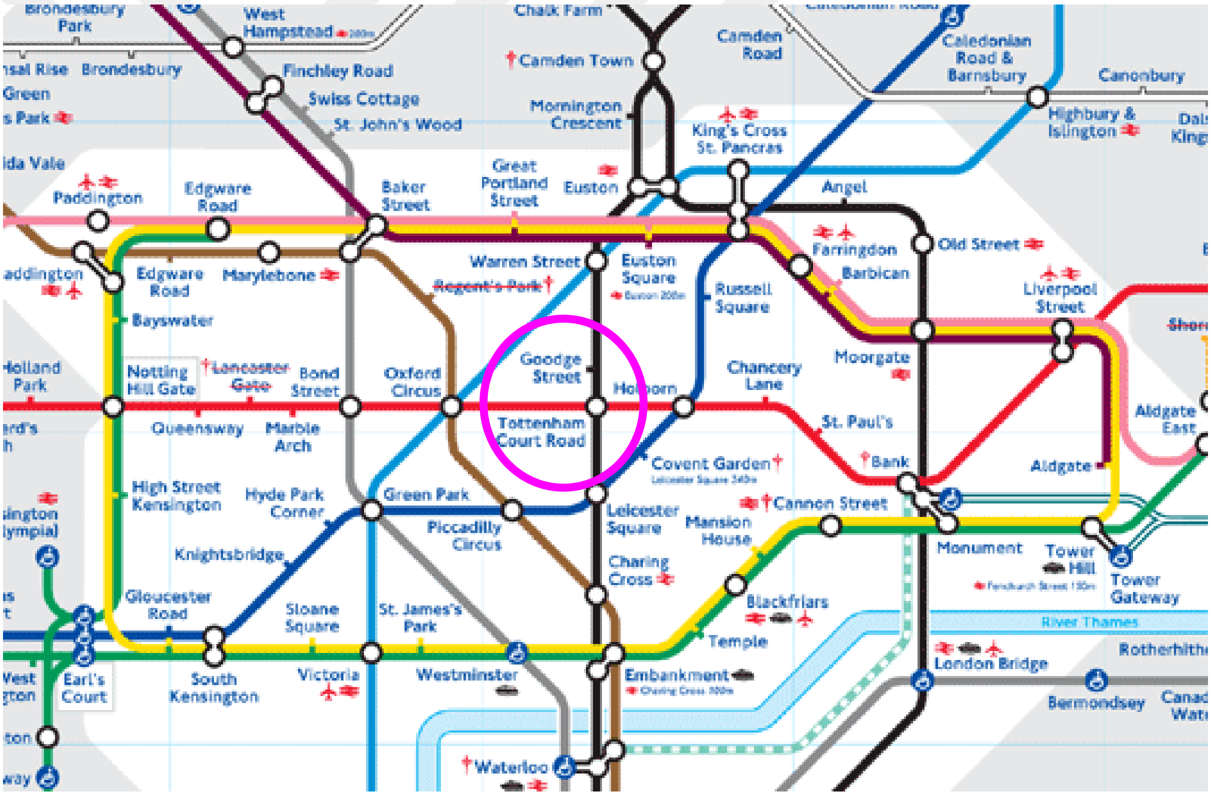

Figure 1 – London Underground Map

2.2.3. Location

Tottenham Court Road Station is located beneath the junction of Tottenham Court Road (north), Charing Cross Road (south), Oxford Street (west) and New Oxford Street (east). The Centre Point is a tower located on the southeast of this junction. *(Picture 1)*

2.3. History of TCRS

The station opened as part of the Central London Railway on 30th July 1900. The original station building was in Oxford Street and was designed in common with other Central London stations by Harry Bell Measures. The Charing Cross, Euston & Hampstead Railway (now called the Northern Line) arrived here on 22nd June 1907 but used the name *Oxford Street* until an interchange (linking the eastbound Central Line with the southbound Northern Line via the ends of the platform) was created on 3rd September 1908 from when the present name was used for both lines. The next station north on the Northern line was originally called Tottenham Court Road, but was renamed to Goodge Street at this time. In the 1984 the entire station was redecorated and the new design was that of a tessellated mural by Eduardo Paolozzi (whose signature appears at several places within the station), and is a distinct and noticeable feature of the station. ("Tottenham Court Road Tube Station", July 2006).

Paolozzi Mosaics

2.4. Future of TCRS

The North-East exit of the station surfaces immediately in front of the Dominion Theatre, whereas the North-West and South-West exits surface on Oxford Street. Because of this and its interchange, the station is one of the busiest on the entire network and peak periods of the day entrance to the station is often briefly barred due to the sheer weight of numbers.

To solve this congestion, Transport for London intends to drastically reconstruct large parts of the station. This will involve building under the forecourt of Centrepoint a much larger ticket office, as well as new sets of escalators to reach the centre of the northern line platforms from the ticket office, and the addition of greater Mobility Impaired Accessibility to the platforms. This has the benefit of removing a little used, badly cared for, and somewhat derelict underpass traveling south toward the east side of Charing Cross Road some way from the station. *(Figure 2)*

If the planned Chelsea-Hackney tube is built (currently this is planned in a reduced way as Crossrail 2) it will have a station at Tottenham Court Road, and the development plans include facilities to take account of this. *(Figure 3)*

Tottenham Court Road Station is the major station for interchanging between east-west and north-south routes. Fergusson (May 2001) claims that the existing station at Tottenham Court Station is one of the most congested in the Underground system, with significant increases likely in the future from proposed commercial developments in the vicinity. He believes that the relief of the existing congestion will be integrated with the CrossRail proposals.

If the long-proposed Crossrail project goes ahead, it too will add additional interchange facilities at Tottenham Court Road, as well as a new exit at Dean Street (leading from both the Crossrail platforms, and the parallel Central line platform), and require the demolition of the original Central line exit and the Astoria theatre in order to expand the western side of the original ticket office to include escalators down to Crossrail ("Tottenham Court Road Tube Station", July 2006) *(Picture 2)*

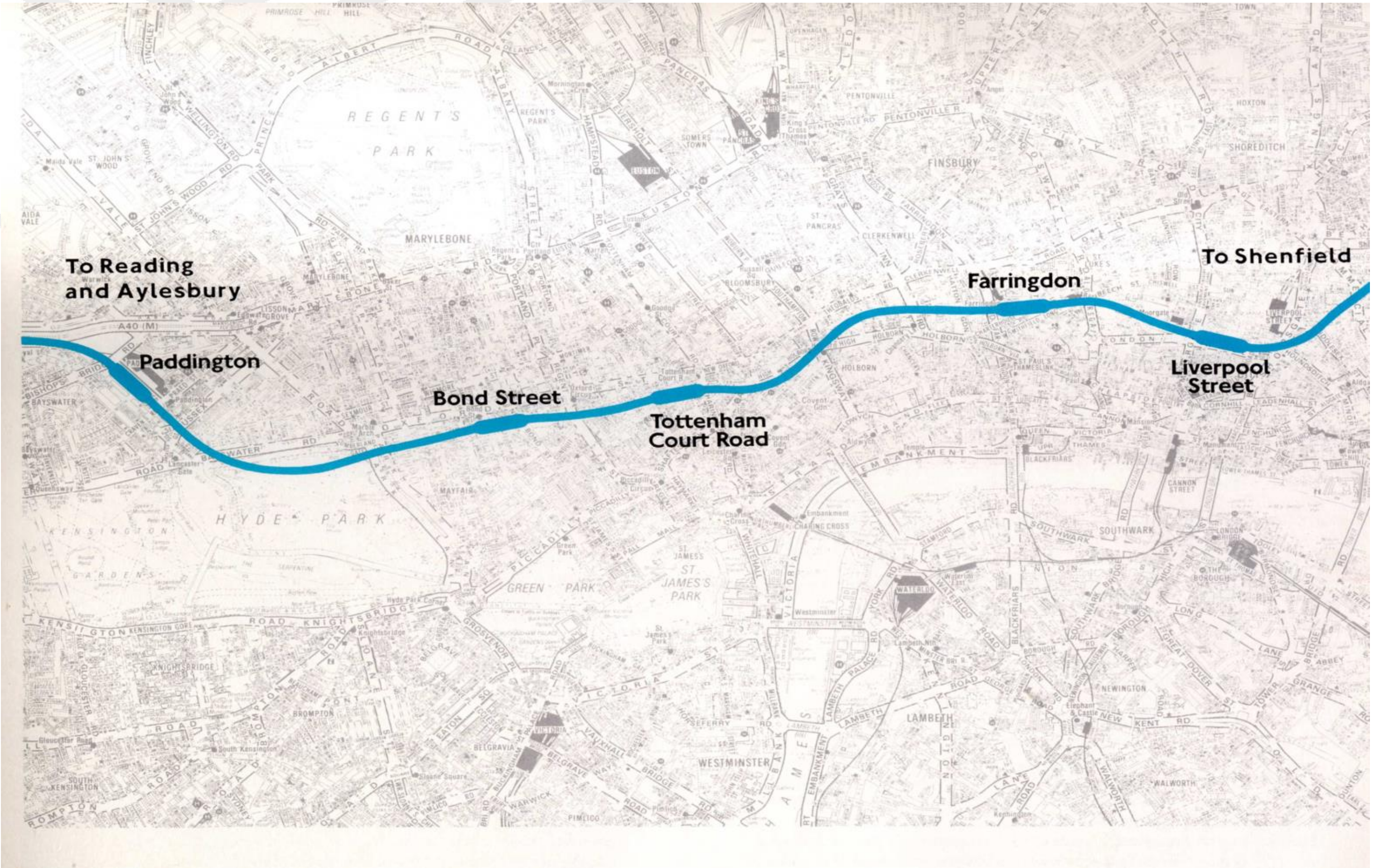

Figure 3. Central Area Route Plan

Figure 2 – Central stations of CrossRail (Retrieved from CrossRail Environmental Statement pg.15)

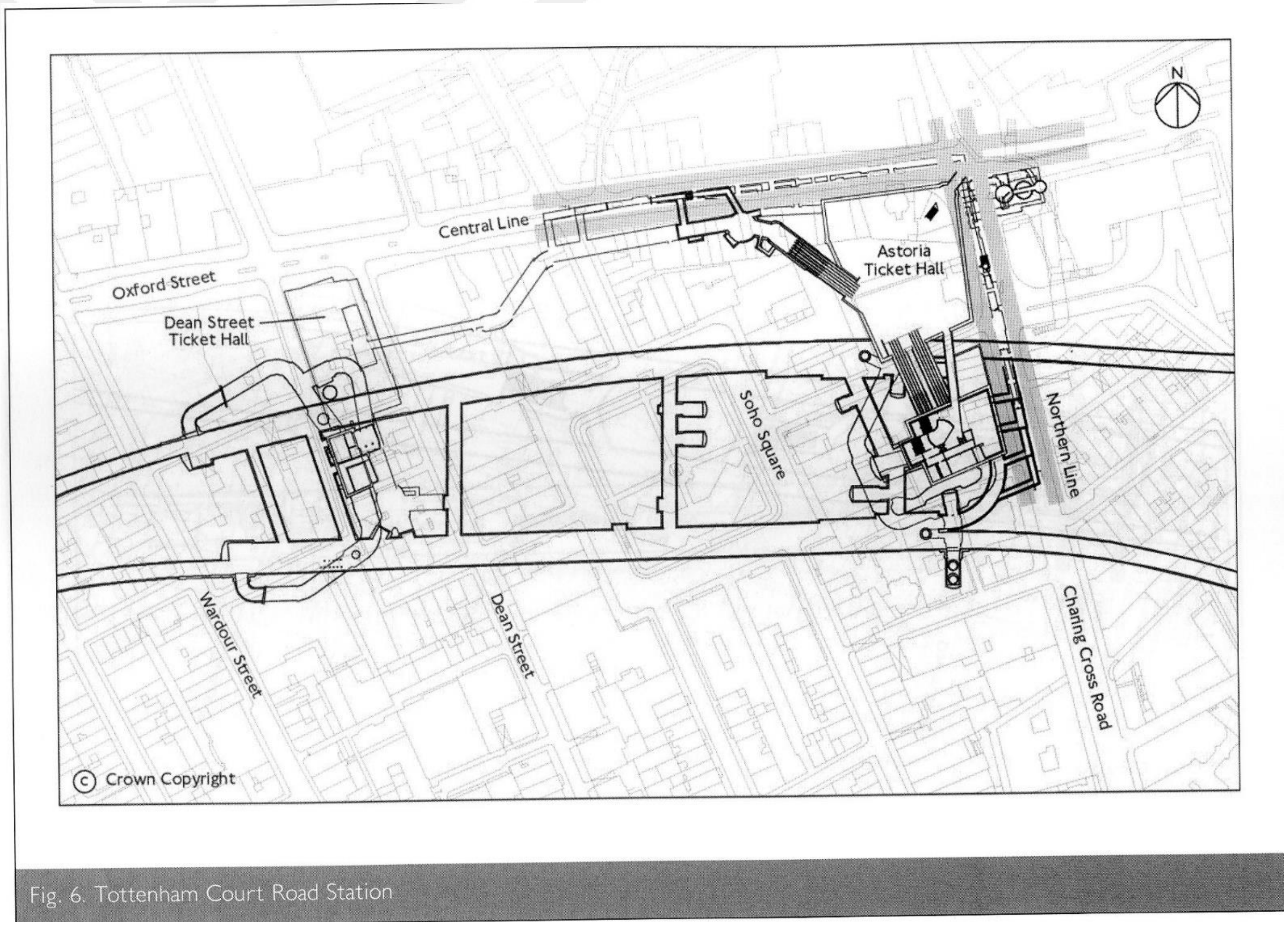

Figure 3 – CrossRail plan of TCRS (Retrieved from Transport 147, Issue 2, pg.76)

3. METHODOLOGY

3.1. Stages of the study

The stages of preparing this paper are listed below:

- Deciding the topic as "Renovation of Tottenham Court Road Station"
- Finding suitable resource books about railway stations and searching web sites about the topic.
- Literature review and understanding the approaches
- Contacting related authorities and having appointments
- Gathering numerical data
- Visiting the station and observing the key points
- Drawing the station layout and working the problems on it
- Applying learned techniques to the data provided
- Obtaining results and comparing them with station limitations
- Deciding the problematic sections of the station
- Offering solutions to specified problems
- Coordinating the solutions with future developments of TCRS

3.2. Capacity Calculation Methods

Rallis (1967) compared some methods of capacity calculations and suggested some of them for particular transport centres. According to his studies *traffic load* and *traffic volume* can be used to find out the capacity of a section of a station. It is important to mention that all the passenger data used in capacity calculations belong to A.M. and P.M. peak hours, because the off-peak capacity will always be lower than the peak hour capacity. The calculations are done for both peak hours and then the appropriate one is chosen for comparing with the limits.

Traffic Volume, "N" ***(units per unit time)*****:** It is broadly defined as the number of units on a way. However in our case we can redefine traffic volume as "Passenger Volume" or "Pedestrian Volume" since we are interested in the passenger effect on station sections. It is the number of passengers occupying a way or location per unit time, say per minute.

In station calculations N represents the arriving passengers who are trying to leave the station, the departing passengers who are trying to access to the platforms or interchanging passengers who are walking between platforms. The unit of N is passengers per hour and passengers per minute.

$N = w \cdot v \cdot T$ where,

w, width of the corridor in meters

v, speed in meters per minute

T, passenger density in passengers per sq meter.

Traffic Load, "A" ***(persons)*****:** Traffic load is the effect or the pressure of the crowd on the area. In this work the traffic load can be defined as "Passenger Load" and it is used as a step to obtain the used space per unit. The unit of A is passengers.

$A = N \cdot b$ where,

N, passenger volume in passenger per minute

b, service time or time spent in the area in minutes

Used Space per Person, "S_U" ***(sq meter per person)*****:** This is the area used by each passenger in the system in a particular section. It can easily be found by dividing the usable total area of the section by the passenger load in that section. The unit of S_U is sq meter per passenger.

$S_U = \frac{S}{A}$ where,

S, is the total usable areas of the section

For the capacity of station platforms, main circulating areas and ticket halls, S_U is calculated and compared with the required levels.

Traffic Flow, "F" ***(units per unit time per unit width)*****:** Traffic flow is defined as the number of units passing through the unit width in unit time. In our case it can be defined as "Passenger Flow". The unit of F is passengers per minute per meter.

$$F = \frac{N}{w} = v \cdot T$$

Since the data of the passenger speeds are not given to us we used N/w as a formula to obtain passenger flows. For the capacity of station passageways, stairways and escalators, F is calculated and compared with the required levels.

4. DATA

4.1. Data gathering and sources

This work mostly based on observed data and measurements. Especially the position and size of the station layout is completely observed and measured by the author, because the engineering drawings of the station were not provided by the authorities. Only the plans for station staff are shown to the author and no copies are allowed. All the numerical data is provided from JNP records and Transport for London web page published statistics.

4.2. Layout Data

4.2.1. Levels

We can list the levels of the station as follows starting from the top level;

- Level 1 – Street level
- Level 2 – Ticket Hall
- Level 3 – Circulating area
- Level 4 – Central Line, Platform 1 & 2
- Level 5 – Northern Line, Platform 3 & 4

4.2.2. Entrances and Exits

There are six exits to this station. All of them are serving two ways.

- Exit 1 – Oxford Circus: Located on the southwest corner of the junction.
- Exit 2 – Tottenham Court Road: Located on the northwest corner of the junction.
- Exit 3 – British Museum, Dominion Theatre, YMCA, and New Oxford Street: Located on the northeast corner of the junction.
- Exit 4 – New Oxford Street South: Emerging on to a side road round the south side of Centre Point Tower

- Exit 5 – Charing Cross Road East and Andrew Borde Street: Emerges onto Charing Cross Road, to the south of Centre Point, at the junction with Andrew Borde Street
- Exit 6 – The Centre Point Plaza: Emerging on to a side road round the east side of Centre Point Tower

Exit 4, Exit 5and Exit 6 share a subway, which enters the east side of the concourse. *(Picture 3-9) (Drawing 1)*

4.2.3. Ticket Hall

All six exits are connected to a main concourse. Both entrance and exit automatic ticket barriers, ticket sales machines, ticket office, station security and phones located on this main concourse. *(Drawing 2)*

The ticket sales machines and the boots are located in the eastern section of the concourse. *(Picture 10)*

Automatic ticket barriers form three sides of a rectangle next to the south wall of the main concourse. The automatic ticket barriers at the eastern end of this rectangle are entrance gates located opposite the ticket sales machines and next to the ticket office and station security. There is a larger manual gate for passengers with baggage and pushchairs on the left of the entrance automatic gates line. There is an L shaped queuing area for the ticket office just before these entrance automatic gates. *(Picture 11 & 12)*

There are coin and card operated phones on the north wall of the main concourse and on the north east wall between the stair cases of Exit 3 and Exit 4.

4.2.4. Platforms

There are four platforms in the station.

- Central Line Platforms: Platform 1 and Platform 2 are sharing an island platform serving westbound and eastbound Central Line, approximately on the east-west axis of the station. Platform 1 lies to the south of Platform 2. Platform 1 has a length of approximately 127 meters and Platform 2 is approximately 130 meters long. These platforms are located 26.2m below the street level. *(Picture 13) (Drawing 3)*

- Northern Line Platforms: Platform 3 and Platform 4 are sharing an island platform serving northbound and southbound Northern Line, approximately on the north-south axis of the station. Platform 3 lies to the west of Platform 4. Both Platform 3 and 4 have a length of approximately 98 meters. These platforms are located 29.8m below the street level and at a lower level than the Central Line Platforms. *(Drawing 4)*

The widths of all four platforms are approximately 2.5 meters in the narrowest sections. However, there is 0.3m of unused width along the platform which is a result of passengers trying to stay away from incoming trains. The areas of each platform and ticket hall are given on *Table 1*.

<table>
<tr><th colspan="2"></th><th>Full Area</th><th>Obstacles</th><th>Total Usable Area</th></tr>
<tr><th colspan="2">Ticket Hall</th><td>360</td><td>20</td><td>272</td></tr>
<tr><th rowspan="2">Central Line</th><th>Platform 1</th><td>365</td><td>5</td><td>288</td></tr>
<tr><th>Platform 2</th><td>377</td><td>5</td><td>298</td></tr>
<tr><th rowspan="2">Northern Line</th><th>Platform 3</th><td>280</td><td>5</td><td>220</td></tr>
<tr><th>Platform 4</th><td>275</td><td>5</td><td>216</td></tr>
</table>

Table 1 – Areas of ticket hall and platforms in m²

Arriving and departing traffic flows are combined. There are several vending machines and card only phones on each platform.

Accesses to the platforms are by stairs except for the single way-out escalator on Northern Line platforms.

Properties of these stairs are given on *Table 2*.

<table>
<tr><th colspan="2" rowspan="3"></th><th colspan="4">Width of Platform Stairs (m)</th><th colspan="4">Number of Platform Escalators</th></tr>
<tr><th colspan="2">Platform-end</th><th colspan="2">Mid-platform</th><th colspan="2">Platform-end</th><th colspan="2">Mid-platform</th></tr>
<tr><th>Entry</th><th>Exit</th><th>Entry</th><th>Exit</th><th>Entry</th><th>Exit</th><th>Entry</th><th>Exit</th></tr>
<tr><th rowspan="2">Central Line</th><th>Platform 1</th><td></td><td>2</td><td rowspan="2">1.5</td><td rowspan="2">1.5</td><td colspan="4"></td></tr>
<tr><th>Platform 2</th><td colspan="2">2</td><td colspan="4"></td></tr>
<tr><th rowspan="2">Northern Line</th><th>Platform 3</th><td>2</td><td colspan="3"></td><td colspan="3"></td><td rowspan="2">1</td></tr>
<tr><th>Platform 4</th><td>2</td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

Table 2 – Position, service and width of platform stairs and number of platform escalators

4.2.5. Stairs, Escalators and Lifts

There is no step-free access through the Tottenham Court Road Station. Accesses to the platforms are by stairs.

A spiral staircase connects all the platforms with the main concourse. This spiral staircase was constructed as an emergency stairs. However these stairs are often used as access down to the ends of the Northern line platform, as there are currently insufficient escalators for the volume of traffic using the station especially during peak times.

Escalator tunnels were built at the station in 1933 ("Tottenham Court Road Tube Station", July 2006). Beyond the ticket barriers there are three escalators two of which serve upwards during peak hours, connecting the main concourse and the circulating area leading to platforms. Two escalators connect the southern part of circulating area and the Northern Line platforms. Note that the widths of all escalators in the station are 1m.

The properties of all the stairs and escalators at the station are given on *Table 3 & 4*. Note that the series of stairways are shown on the same row on *Table 3.* As general design criteria the maximum number of steps on a pair of stairway is 16 (Edwards, 1997). However most of the stairways at TCRS do not satisfy this limit. *(Picture 14 & 15)*

	From (up)	**To (down)**	**Pedestrian Use**	**Width (m)**	**Vertical Rise (m)**	**Incline Length (m)**
ESC1	CA	PL3	Exit	1.0	5.16	10.31
ESC2	CA	PL4	Entry	1.0	5.16	10.31
ESC3	TH	CA	Exit	1.0	15.57	31.15
ESC4	TH	CA	Entry/Exit	1.0	15.57	31.15
ESC5	TH	CA	Entry	1.0	15.57	31.15
ESC6	CA	PL3&4	Exit & Int.	1.0	9.03	18.06

Table 3 - The location, pedestrian use and dimensions of escalators in TCRS

There are no lifts serving at this station. The original, vacant lift shafts are now being used for offices and station facilities.

				→ Up → Down →								
	From (up)	To (down)	Pedestrian Use	Section 1		Section 2		Section 3		Section 4		Total Risers
				Width	Risers	Width	Risers	Width	Risers	Width	Risers	
SW1	Exit 1	TH	Two Way	3.0	9	4.0	8	2.5	13	2.5	10	40
SW2	Exit 2	TH	Two Way	2.0	19	2.0	17					36
SW3	Exit 3	TH	Two Way	2.0	19	2.0	19					38
SW4	Exit 4	TH	Two Way	3.0	10	3.0	10					20
SW5	Exit 5	TH	Two Way	2.5	8	2.5	14	2.5	6			28
SW6	Exit 6	TH	Two Way	2.5	13	2.5	13					26
	TH	CA	One Way Exit	Escalator 3								0
	TH	CA	Two Way	Escalator 4								0
	TH	CA	One Way Entry	Escalator 5								0
SW7	CA	Platform 1	One Way Exit	2.0	19							19
SW8	CA	Platforms 1 & 2	One Way Exit	1.5	20							20
SW9	CA	Platforms 1 & 2	One Way Entry & Int.	1.5	20							20
	CA	Platform 3	One Way Exit	Escalator 1		2.0	20					20
	CA	Platform 4	One Way Entry	Escalator 2		2.0	9	2.0	14			23
	CA	Platforms 3 & 4	One Way Exit	Escalator 6								0
SW10	CA	Passageway 3	One Way Entry & Int.	2.0	17							17
SW11	IntA	Platform 2	Two WayEntry & Int.	2.0	3							3
SW12	IntA	Platform 4	One Way Int.	2.0	8	2.0	8	2.0	18			34
	Total Number of Risers in the Station											344

Table 4 - The location, pedestrian use, width (in meters), and partial & total number of risers of fixed stairways in TCRS

4.2.6. Passageways

A subway joins the east end of the Central Line platforms to the west end of the circulating area. Another subway joins the north end of the Northern Line platforms to the north end of the circulating are. There is an intersecting another subway connecting the east end of the Central Line platforms with the north end of the Northern Line platforms at the foot of the spiral staircase. A clockwise passenger circulation is tried to be achieved with the current directions. Passenger circulation of the circulating are is shown in *Drawing* 4. The passageways which carry the major passenger traffic are described below. Their properties are mentioned on *Table 5*.

Passageway 1 (PW1) – Connecting the way-out escalator of Northern Line platforms (Escalator 6) with the circulating area. This passageway is the main way-out corridor of Northern Line platforms. It also transfers the Northern Line passengers to Central Line.

Passageway 2 (PW2) – Connecting the circulating area with the fixed stairways of Central Line platforms through two foot bridges. More than a half of this passageway is split into two walking directions with a centre handrail. The way-out part of PW2 is named PW2.1 while the access to platform section is named PW2.2.

Passageway 3 (PW3) – Connecting the east end of the Central Line platforms with the north end of the northern line platforms. This is a one way interchange channel between two rail services. There are several fixed stairways on this path.

The properties of these major passageways are shown in the *Table 5.*

	Use	Walking	Narrowest Section (m)	Longest Section (m)	Min. Height (m)
PW1	Exit & Int.	One way	1.5	40.4	3
PW2.1	Exit	One way	1.5	35.3	3
PW2.2	Entry	One way	1.5	52.2	3
PW3	Int.	Two way	2	20.5	2.5

Table 5 - The main passageways and their properties

4.3. Passenger Data

The average number of entering and exiting passengers at Tottenham Court Road Station in 2005 is given in *Table 6.* These figures show that the station accommodates around 110,000 passengers a day.

	Hours	Entry	Exit
Early Period	05:30 - 07:30	129	478
A.M. Peak Period	07:30 - 10:30	1,319	13,838
Inter Peak Period	10:30 - 16:30	11,974	16,926
P.M. Peak Period	16:30 - 19:30	16,926	10,064
Evening Period	19:30 - 00:30	15,658	5,992
Weekday Total	05:30 - 00:30	46,006	47,298

Table 6 - Peak hours and number of passenger entries and exits (2005)

Two passenger matrices are created to find the amount of passengers related with capacity calculations. These passenger matrices are created from the 2004 passenger flows of TCRS provided by JNP Station Management. The source sheet is taken back by the authorities after the calculations. The passenger matrix in *Table 7* shows the passenger flows of in the busiest hour of A.M. peak and *Table 8* shows the flows in the busiest hour of P.M. peak hours.

From	To

	TH	P1	P2	P3	P4
TH	0	163	179	82	115
P1	2089	0	0	371	159
P2	1702	0	0	279	189
P3	2646	284	375	3	4
P4	1128	939	957	3	4

Table 7 - Passenger flow matrix for the peak (07:30 - 10:30)
of morning peak hours (08:30 - 09:30)

From	To				
	TH	**P1**	**P2**	**P3**	**P4**
TH	0	1609	2844	961	1489
P1	1636	24	13	612	439
P2	1039	15	4	580	298
P3	894	157	297	0	2
P4	620	431	431	2	4

Table 8 - Passenger flow matrix for the peak (17:30 - 18:30)
of evening peak hours (16:30 - 19:30)

4.4. Train Data

All Central Line trains consist of London Underground 1992 Tube Stock and all Northern Line trains consist of London Underground 1995 Tube Stock. There is a horizontal gap of approximately 10cm and a vertical gap of 15cm between the platforms and the trains.

	Number of Cars	Total Passenger Capacity	Frequency (trains/hr)
Central Line Trains	8	1652	30
Northern Line Trains	6	1040	30

Table 9 - The train properties

5. CALCULATIONS

5.1. The Capacity of Ticket Hall

In order to find the capacity of the ticket hall, the used space per person (S_u) is calculated according to the A.M. and P.M. peak hour passenger flow matrices. The minimum of the results are compared with the required limits.

N_{ext}, Total number of passengers leaving through ticket hall during peak hour
N_{ent}, Total number of passengers entering through ticket hall during peak hour
N_T, Total number of passengers occupying ticket hall during peak hour
b, Average time spent by each person at the ticket hall during peak hour
A, Passenger load at the ticket hall
S_T, Total usable area of the ticket hall in sq meters
S_U, Used space per person at the ticket hall

$$N_T = N_{ext} + N_{ent}$$
$$A = N_T \cdot b$$
$$S_U = \frac{S_T}{A}$$

We can easily obtain N_{ext} and N_{ent} from the passenger flow matrices. The average time spent by per person is given as 1.75min including the waiting time on the ticket queue, time to buy ticket and time to walk through the ticket gates. Some of the passengers don't buy any ticket while others wait a longer time to buy their tickets from the ticket office instead of using automatic ticketing machines. Note that both inside and outside of ticket barriers are considered for the area S_T.

A limit of 0.8 sq m per person is recommended for ticket halls. (Bonnett, 2005)

Ticket Hall

For the A.M. peak hour	
N_{ext} (pass./hr) =	7565
N_{ent} (pass./hr) =	539
N_T (pass./hr) =	8104
b (min) =	1.75
A (passengers) =	236.4
S_T (m²) =	306
S_U (m²/passenger) =	1.3

For the P.M. peak hour	
N_{ext} (pass./hr) =	4189
N_{ent} (pass./hr) =	6903
N_T (pass./hr) =	11092
b (min) =	1.75
A (passengers) =	323.5
S_T (m²) =	306
S_U (m²/passenger) =	0.9

Results

These results show that the ticket hall is serving on its limits during the evening peak hours. The ticket hall has is overcrowded and with the increasing passenger figures the ticket hall will be exceeding its capacity limits in a close future. A new ticket hall or an enlargement work for the ticket hall is needed for TCRS.

(Picture 16)

5.2. The Capacity of Platforms

In order to find the capacity of each platform, the used space per person (S_u) is calculated according to the A.M. and P.M. peak hour passenger flow matrices. The minimum of the results are compared with the required limits.

N_{arr},	Total number of arrivals on the platform during peak hour
N_{dep},	Total number of departures on the platform during peak hour
N_T,	Total number of passengers occupying the platform during peak hour
b,	Average time spent by each person on the platform during peak hour
A,	Passenger load on the platform
S_T,	Total usable area of the platform in sq meters
S_U,	Used space per person on the platform

$$N_T = N_{arr} + N_{dep}$$

$$A = N_T \cdot b$$

$$S_U = \frac{S_T}{A}$$

We can easily obtain N_{arr} and N_{dep} from the passenger flow matrices. The average time spent by per person is given as 1.25min including the waiting time on the platform and the time spent for walking through way out passages and stairways.

A limit of 0.8 sq m per person is recommended for platforms. (Bonnett, 2005)

Central Line, Platform 1

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	2619	**N_{arr} (pass./hr) =**	2724
N_{dep} (pass./hr) =	1386	**N_{dep} (pass./hr) =**	2236
N_T (pass./hr) =	4005	**N_T (pass./hr) =**	4960
b (min) =	1.25	**b (min) =**	1.25
A (passengers) =	83.4	**A (passengers) =**	103.3
S_T (m²) =	324	**S_T (m²) =**	324
S_U (m²/passenger) =	3.9	**S_U (m²/passenger) =**	3.1

Central Line, Platform 2

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	2170	**N_{arr} (pass./hr) =**	1936
N_{dep} (pass./hr) =	1511	**N_{dep} (pass./hr) =**	3589
N_T (pass./hr) =	3681	**N_T (pass./hr) =**	5525
b (min) =	1.25	**b (min) =**	1.25
A (passengers) =	76.7	**A (passengers) =**	115.1
S_T (m²) =	298	**S_T (m²) =**	298
S_U (m²/passenger) =	3.9	**S_U (m²/passenger) =**	2.6

Northern Line, Platform 3

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	3312	**N_{arr} (pass./hr) =**	1350
N_{dep} (pass./hr) =	738	**N_{dep} (pass./hr) =**	2155
N_T (pass./hr) =	4050	**N_T (pass./hr) =**	3505
b (min) =	1.25	**b (min) =**	1.25
A (passengers) =	84.4	**A (passengers) =**	73.0
S_T (m²) =	220	**S_T (m²) =**	220
S_U (m²/passenger) =	2.6	**S_U (m²/passenger) =**	3.0

Northern Line, Platform 4

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	3031	**N_{arr} (pass./hr) =**	1488
N_{dep} (pass./hr) =	471	**N_{dep} (pass./hr) =**	2232

N_T (pass./hr) =	3502	**N_T (pass./hr) =**	3720
b (min) =	1.25	**b (min) =**	1.25
A (passengers) =	73.0	**A (passengers) =**	77.5
S_T (m²) =	216	**S_T (m²) =**	216
S_U (m²/passenger) =	3.0	**S_U (m²/passenger) =**	2.8

Results

These results show that Central Line, Platform 2 is the busiest platform during morning peak hours while Northern Line, Platform 3 is the busiest during evening peak hours. However, compared with the capacity limit of the platforms they are still serving in a good way. Although the number of passengers on the platforms are too much, the frequent train service enables periodic circulation on platforms and decreases "b" the time spent by passengers on the platform significantly. *(Picture 17 & 18)*

5.3. The Capacity of Passageways

In order to find the capacity of each passageway, the passenger flow (F) through each passageway is calculated according to the A.M. and P.M. peak hour passenger flow matrices. The maximum of the results are compared with the required limits.

A limit of 50 persons per minute per meter width for the one way passageways and 40 persons per minute per meter width for the two way passageways should be applied to the passageways of the stations. (Bonnett, 2005)

N_{arr}, Total number of passengers leaving through the passageway during peak hour
N_{dep}, Total number of passengers entering through the passageway during peak hour
N_{int}, Total number of passengers interchanging through the passageway during peak hour
w, Width of the passageway
F, Passenger flow through the passageway

Still (2000) says that the Green Guide states that the capacity of an exit system is limited by its narrowest element. The width of the passageway is determined according to this idea.

It is assumed that 60% of the related passengers are using the same passageway to leave the platforms or to access to the platforms if there is one alternative way for the passengers. This assumption is reasonable to assign the current limits of the passageways. This assumption is 100% for the passageway if there is no alternative of the passageway. Then the flow is:

$$F = \frac{N_{T1} \cdot 0.7 + N_{T2}}{w}$$

We can easily obtain N_{arr} , N_{dep} and N_{int} from the passenger flow matrices.

Passageway 1 (PW1)

This passageway both carries all of the interchanging passengers from Northern Line to Central Line and 60% of the exiting arrivals of Northern Line platforms.

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	2642	**N_{arr} (pass./hr) =**	1060
N_{int} (pass./hr) =	1789	**N_{int} (pass./hr) =**	921
N_T (pass./hr) =	4430	**N_T (pass./hr) =**	1981
w (m) =	1.5	**w (m) =**	1.5
F (pass./min/m) =	29.4	**F (pass./min/m) =**	11.8

Passageway 2.1 (PW2.1)

Only the 60% of exiting arrivals use this passageway. There is a loss of 0.15m on the width of the passageway because of the handrail.

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	2654	**N_{arr} (pass./hr) =**	1873
w (m) =	1.35	**w (m) =**	1.35
F (pass./min/m) =	32.8	**F (pass./min/m) =**	23.1

Passageway 2.2 (PW2.2)

This passageway is used by all the departing and interchanging passengers to access Platform 1 and 60% of the departing and interchanging passengers to access Platform 2.

For the A.M. peak hour		For the P.M. peak hour	
N_{dep} (pass./hr) =	270	**N_{dep} (pass./hr) =**	3315
N_{int} (pass./hr) =	2022	**N_{int} (pass./hr) =**	1025
N_T (pass./hr) =	2293	**N_T (pass./hr) =**	4340
w (m) =	1.35	**w (m) =**	1.35
F (pass./min/m) =	28.3	**F (pass./min/m) =**	53.6

Passageway 3 (PW3)

This passageway is only used by the interchanging passengers from Central Line to Northern Line.

For the A.M. peak hour		For the P.M. peak hour	
N_{int} (pass./hr) =	998	**N_{int} (pass./hr) =**	1929
w (m) =	2.0	**w (m) =**	2.0
F (pass./min/m) =	8.3	**F (pass./min/m) =**	16.1

Results

These results show that PW2.2 has severe problems dealing with the crowd in P.M. peak hours. The number of passengers directed to this passageway is too much. *(Picture 19)*

5.4. The Capacity of Fixed Stairways

In order to find the capacity of each stairway, the passenger flow (F) through each stairway is calculated according to the A.M. and P.M. peak hour passenger flow matrices. The maximum of the results are compared with the required limits.

A limit of 35 persons per minute per meter width for the one way stairways and 28 persons per minute per meter width for the two way stairways should be applied to the stairways of the stations. (Bonnett, 2005)

N_{arr}, Total number of passengers leaving through the stairway during peak hour
N_{dep}, Total number of passengers entering through the stairway during peak hour
N_{int}, Total number of passengers interchanging through the stairway during peak hour
w, Width of the stairway
F, Passenger flow through the stairway

Still (2000) says that the Green Guide states that the capacity of an exit system is limited by its narrowest element. The width of the stairway is determined according to this idea.

It is assumed that 60% of the related passengers are using the same stairway to leave the platforms or to access to the platforms if there is one alternative way for the passengers. This assumption is reasonable to assign the current limits of the stairways. This assumption is 100% for the stairways if there is no alternative of the passageway. Then the flow is:

$$F = \frac{N_{T1} \cdot 0.7 + N_{T2}}{w}$$

We can easily obtain N_{arr}, N_{dep} and N_{int} from the passenger flow matrices.

Stairway 7 (SW7)

Used only by arrivals of Platform 1 to exit the platform.

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	1253	**N_{arr} (pass./hr) =**	982
w (m) =	2.0	**w (m) =**	2.0
F (pass./min/m) =	10.4	**F (pass./min/m) =**	8.2

Stairway 8 (SW8)

Used by arrivals of Central Line platforms.

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	2275	**N_{arr} (pass./hr) =**	1605
w (m) =	1.5	**w (m) =**	1.5
F (pass./min/m) =	25.3	**F (pass./min/m) =**	17.8

Stairway 9 (SW9)

Used by all of the Platform 1 departures and interchange passengers from Northern Line and also 60% of the Platform 2 departures and interchange passengers from Northern Line.

For the A.M. peak hour		For the P.M. peak hour	
N_{dep} (pass./hr) =	270	**N_{dep} (pass./hr) =**	3315
N_{int} (pass./hr) =	2022	**N_{int} (pass./hr) =**	1025
N_T (pass./hr) =	2293	**N_T (pass./hr) =**	4340
w (m) =	1.5	**w (m) =**	1.5
F (pass./min/m) =	25.5	**F (pass./min/m) =**	48.2

Stairway 10 (SW10)

Used by 60% of the departures and interchange of Platform 2.

For the A.M. peak hour		For the P.M. peak hour	
N_{dep} **(pass./hr) =**	107	N_{dep} **(pass./hr) =**	1706
N_{int} **(pass./hr) =**	799	N_{int} **(pass./hr) =**	437
N_T **(pass./hr) =**	907	N_T **(pass./hr) =**	2143
w (m) =	2.0	**w (m) =**	2.0
F (pass./min/m) =	7.6	**F (pass./min/m) =**	17.9

Stairway 11 (SW11)

Although this staircase consists of only 3 risers, it has a significant position in the station. It serves in two directions to the all the interchanging passengers from Central Line platforms to Northern Line platforms and also serves to 60% of the Platform 2 departures.

For the A.M. peak hour		For the P.M. peak hour	
N_{dep} **(pass./hr) =**	107	N_{dep} **(pass./hr) =**	1706
N_{int} **(pass./hr) =**	998	N_{int} **(pass./hr) =**	1929
N_T **(pass./hr) =**	1105	N_T **(pass./hr) =**	3635
w (m) =	2.0	**w (m) =**	2.0
F (pass./min/m) =	9.2	**F (pass./min/m) =**	30.3

Stairway 12 (SW12)

Used by all of the interchanging passengers from Central line platforms to Northern Line platforms.

For the A.M. peak hour		For the P.M. peak hour	
N_{int} **(pass./hr) =**	998	N_{int} **(pass./hr) =**	1929
w (m) =	2.0	**w (m) =**	2.0
F (pass./min/m) =	8.3	**F (pass./min/m) =**	16.1

Note that the staircases on the exits of the station are not calculated here. The six station exits have many stairways but their capacities are not calculated, because of not having the number of passengers entering/exiting through each station exit. On the other hand, these stairways on the way to station exits are not affected with the crowd since their number is too much. According to Bonnett (2005), there must be at least two exits for a station each of which can cope with the all passengers at the station in case of emergency evacuation. In our case the number and the dimensions of exits are fair enough to cope with such cases.

Results

These results show that SW9 is highly congested and SW11 is about to reach its limits. *(Picture 20)*

5.5. The Capacity of Escalators

In order to find the capacity of each passageway, the passenger flow (F) through each passageway is calculated according to the A.M. and P.M. peak hour passenger flow matrices. The maximum of the results are compared with the required limits.

A limit of 100 people per minute for escalators one metre wide should be applied to the escalators of the stations. (Bonnett, 2005)

N_{arr},	Total number of passengers leaving through the escalator during peak hour
N_{dep},	Total number of passengers entering through the escalator during peak hour
N_{int},	Total number of passengers interchanging through the escalator during peak hour
w,	Total width of the escalators in the same position and servicing same direction
F,	Passenger flow through the escalators

It is assumed that 75% of the related passengers are using the escalator to leave the platforms or to access to the platforms if there is one alternative stairway for the passengers. Although the passengers would likely to use the easier and less tiring way to move inside the station, the alternative ways to the escalators in TCRS is a stairway-escalator combination. That's why this rate is not considered higher. This assumption is 100% for the escalators without any other alternatives such as the 3 large escalators next to ticket hall. Then the flow is:

$$F = \frac{N_{T1} \cdot 0.7 + N_{T2}}{w}$$

We can easily obtain N_{arr} , N_{dep} and N_{int} from the passenger flow matrices.

Escalator 1 (ESC1)

Used by 75% of the arrivals of Northern Line platforms.

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	2831	**N_{arr} (pass./hr) =**	1136
w (m) =	1.0	**w (m) =**	1.0
F (pass./min/m) =	47.2	**F (pass./min/m) =**	18.9

Escalator 2 (ESC2)

Used by all the departing passengers of Northern Line platforms.

For the A.M. peak hour		For the P.M. peak hour	
N_{dep} (pass./hr) =	197	**N_{dep} (pass./hr) =**	2450
w (m) =	1.0	**w (m) =**	1.0
F (pass./min/m) =	3.3	**F (pass./min/m) =**	40.8

Escalator 3 (ESC3)

Used by all the arrivals exiting the station. Note that ESC4 works on the parallel of ESC3 and serves towards the same direction in the morning time. That's why the width is considered 2m instead of 1m in the A.M. peak calculation.

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	7565	**N_{arr} (pass./hr) =**	4189
w (m) =	2.0	**w (m) =**	1.0
F (pass./min/m) =	63.0	**F (pass./min/m) =**	69.8

Escalator 5 (ESC5)

Used by all the departures entering through the ticket barriers to access all the platforms. Note that ESC4 works on the parallel of ESC5 and serves towards the same direction in the afternoon and evening time. That's why the width is considered 2m instead of 1m in the P.M. peak calculation.

For the A.M. peak hour		For the P.M. peak hour	
N_{dep} (pass./hr) =	539	**N_{dep} (pass./hr) =**	6903
w (m) =	1.0	**w (m) =**	2.0
F (pass./min/m) =	9.0	**F (pass./min/m) =**	57.5

Escalator 6 (ESC6)

Used by 75%of the arrivals on the Northern Line platforms and also used by all the interchanging passengers from Northern Line platforms to Central Line platforms.

For the A.M. peak hour		For the P.M. peak hour	
N_{arr} (pass./hr) =	2831	**N_{arr} (pass./hr) =**	1136

N_{int} (pass./hr) =	2555	**N_{int} (pass./hr) =**	1316
N_T (pass./hr) =	5386	**N_T (pass./hr) =**	2452
w (m) =	1.0	**w (m) =**	1.0
F (pass./min/m) =	89.8	**F (pass./min/m) =**	40.9

Note that ESC4 is not calculated. The reason is the different uses of ESC4 according to peak hours. ESC4 serves upwards like ESC3 in A.M. peak hours and serves downwards like ESC5 in P.M. peak hours. The effect of this additional escalator is added to the system by simply adding its width to the width of ESC3 in A.M. peak and to the width of ESC5 in the P.M. peak calculations.

Results

These results show that the application of changing the service direction of ESC4 is very helpful for the service of ESC3 and ESC5. ESC6 is quite busy during the morning peak and it is about to reach its limits.

It is recommended the readers to look at the drawings in Appendix 2 before reading the next chapter. *Drawing 2, 5 & 6* will be very helpful for the readers. It is suggested that readers refer to the pictures in this chapter in order to illustrate the problems and their solutions in a healthy way.

6. SOLUTIONS AND RECOMMENDATIONS

In the previous sections the problems of Tottenham Court Road Station are pointed according to the observed and calculated data. In this section, the solutions to these problems will be presented as a preliminary suggestion. The detailed discussions on these renovation options can be held and presented in another paper in future by engineers and academicians.

It is worth mentioning that a good engineering solution should also consider the economical perspective of the work. Unfortunately, the costs and benefits of these solutions are not presented in this paper because of time limits and the limitations about the size of this MSc thesis.

Since there are planned renewal projects for TCRS and further development projects related with CrossRail it is useful to divide the solutions into two groups. In the first part I will try to emphasize the temporary solutions and in the second part I will present permanent and sustainable solutions for TCRS.

6.1. Temporary Solutions and Recommendations

These solutions are small changes that can ease the current congestion of TCRS and they can be reconsidered or cancelled once the future developments take place.

6.1.1. Ticket Hall

There is one automatic ticketing machine for using credit/debit cards and one for using both cash and credit/debit cards and five for using coins. There long queues for the first two during peak hours, while few people are using the machines with coins. Two of these coin operating machines can be replaced with card operating machines. This will decrease the length of the queues in ticket hall. *(Picture 21-23)*

The six phones located between Exit 3 and Exit 4 is very rarely used by the passengers since there are four other phones between the two columns between in and out ticket gates. 3-4 of these phones can be removed and a new automatic ticketing machine operating both with cash and credit/debit cards can be installed in their place. This will split the crowd of the ticket queue in two and help to spread the people around the ticket hall. *(Picture 24 & 25)*

There is a decision area between Exit 2 and Exit 3 when you come out through the two pairs of exit ticket gates. People decide which exit to take and they hesitate at this point for some time. In the same area there are maps of the London Underground tube network. Incoming people are standing there and looking for their travel path. This are is also the main corridor for the people who are entering the station from Exit 1 and Exit 2. That's why this area is really crowded especially in peak hours. As a suggestion to this the London Underground tube network maps can be removed from that location and a large sign about the exits can be arranged just in front of the exit ticket gates. London Underground network map can be arranged in the entrance or the corridors of Exits instead of this area. Also a stand for the small pocket tube maps can be arranged in the ticket hall to inform people. *(Picture 26-28)*

6.1.2. Platform 2, Stairway 10 and Stairway 11

Platform 2 is one of the busiest platforms and in case of delays it becomes very congested and dangerous for the passengers. The main reason for this is the limited number of exits from this platform. SW8 is the only way out from Platform 2. If we reverse the service direction of SW10 as an exit and change the use of SW11 as one way exit this corridor starting from the end of Platform 3 will work as an extra exit and will help to evacuate the amount of arrivals on Platform 2 quickly. Moreover, the results of stairway capacity calculations showed that SW11 a very congested stairway mainly because of serving two directions at the same time. *(Picture* Furthermore, SW10 is used as a shortcut by many arrivals on Platform 2, although the "Way Out" sign is not through this stairway. *(Picture)* On the other hand, if these changes are done the passenger burden of very congested passageway PW2.2 will increase. That's why this upgrade must be considered together with the further suggestions about PW2.2 (Refer text 6.2.2)

6.2. Permanent Solutions and Recommendations

These solutions are fundamental changes that can erase the congestion and accessibility problems of TCRS. They solutions can be considered as a part of the future developments for this station.

6.2.1. Exits

Exit 3 consist of one 19 steps and one 17 steps staircase following each other. This exit is almost straight and mostly consists of stairs. A suitable escalator can be introduced for this exit. The area and the length covered by the escalator is more but it will enable a good accessibility option for the partially mobility impaired people for old people, women with children, women with pushchairs and people with luggage. This exit will still exist on the new ticket hall project for TCRS so it may be useful for the future too.

6.2.2. Passageway 2.2 and Stairway 9

This passageway is very congested during peak hours. The problem is its width. On the layout plan it seems that there are no constructions on the south of this passageway. So it can be enlarged with an engineering application. A minimum enlargement of 1.0 meters will be very helpful to the regular passenger flow of this section also benefiting the PW2.1, because the whole passageway is currently split into two with a handrail. On the other hand, this enlargement will not help the congestion problem of SW9 which is at the end of this passageway. A better solution is to extend the length of this passageway along with its width. The extension must be through the west of the Central Line platforms and two more platform exits can be introduced passing with a footbridge above the westbound tracks. Alternatively, a completely new passageway tunnel can be opened from the circulating are to these exits. *(Picture 31)* These two new exits may work as an access point to the platforms while the old middle platform exits can be converted into way out points.

Some passengers walking towards Central Line platforms prefer to have a shortcut by using the entrance of PW2.1 and the stairs SW7 although these parts are not for departure passengers. Applying the solutions above will solve this leakage problem too. *(Picture 32)*

6.2.3. Platform 3 and New Exit

Platform 3 is the second the busiest platform at TCRS and in case of delays it becomes very congested and dangerous for the passengers. The main reason for this is the limited number of exits from the station. A completely new exit should be introduced on Northern Line platforms preferably from the south ends of Platform 3 & 4. Along with this new exit a parallel entrance can be constructed to increase the accessibility. It is recommended that this new exit way from Northern Line platforms will be served by escalators. However, the conditions of the station do not allow this new exit to be connected to the ticket hall. That's why this idea must be considered along with the new ticket hall project of TCRS.

6.2.4. Lifts

There are no lifts for the disabled people. I believe this is one of the most significant problems of TCRS. Lifts must be included in the development projects of TCRS. The position of the lifts must be considered according to the new ticket hall project and their capacities must be set carefully. There are suitable spaces for lift shafts on the north of Northern Line Platforms. If a good connection with the ticket hall can not be obtained, the fire escape stairs on the south of the ticket hall can be enlarged and a shaft can be installed here. If the other permanent solutions are applied there will be suitable spots to install lifts on Central Line.

Another different recommendation is to introduce a pair of lift shafts on the far west end of the Central Line Platforms and far south end of the Northern Line platforms, only to be used by disabled people that operates with Oyster Card. These lifts will be direct from the platforms to the street level. The size of these special lifts doesn't need necessarily to be very large. I believe enough space for on wheel chaired-person and two extra persons will be suitable, because their purpose is to give the equal chance to travel to the mobility impaired people.

On the other hand there is a very important thing to be considered about the platforms if new lifts are introduced in the system. None of the trains passing through TCRS are step free once they stop on the platforms. Especially the Central Line trains are almost 10cm away from platform and the vertical difference is about 15 cm. above the platform. Northern Line trains are very close to the platform horizontally but the vertical difference is the same as Central Line trains. *(Picture 33)* Therefore either the platforms or the tracks should be fixed in a position that is suitable for the step free entrance and exit to the vehicle before introducing lifts for mobility impaired people.

7. CONCLUSION

Tottenham Court Road Station as a major station in London Underground network is very old and can not cope with the expectations of current and future need. The location of the station will always update its importance of the station and will keep providing large numbers of passengers to the system. If the conditions of the station elements are detected and analysed carefully, the station will tell all the needs to us obviously. However, finding a good applicable solution is not always very easy. Especially the economical limits should always be considered and important decisions must be taken without delaying the developments and increasing the problems worse. Sometimes a small change in the station can increase the service level amazingly and sometimes very radical changes have to be done to change a small trouble.

I believe this study will reveal some of the problems of TCRS and will help to similar projects. My solutions can be taken into consideration by further studies and examined with detailed engineering in the perspective of economy, social life and environment.

In this work, I tried to work the problems of an exiting station with my limited knowledge and with limited provided data. At the end of this work I learned:

- Deciding and working on a topic systematically
- Finding suitable resources to learn more about a topic
- Determining and accessing needed data for a project
- Looking at the situations and reading the problems by frequent observations
- Supporting the detected problematic points by calculations
- Finding applicable and reasonable solutions for the problematic points
- Presenting the data, calculations and solutions I have discovered in a convenient academic way.
- Time management (because I had very severe difficulties in obtaining the data, contacting authorities and submitting the work on time)

Thank you

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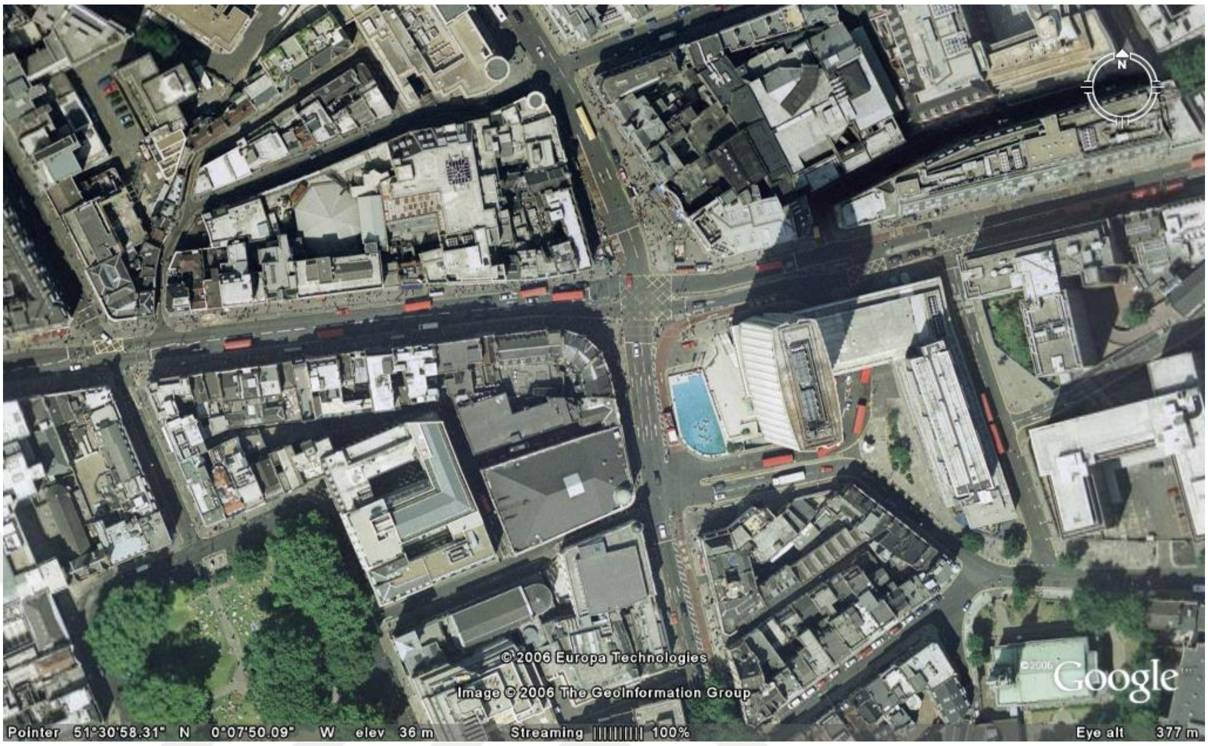
APPENDICES

Appendix 1 – Pictures



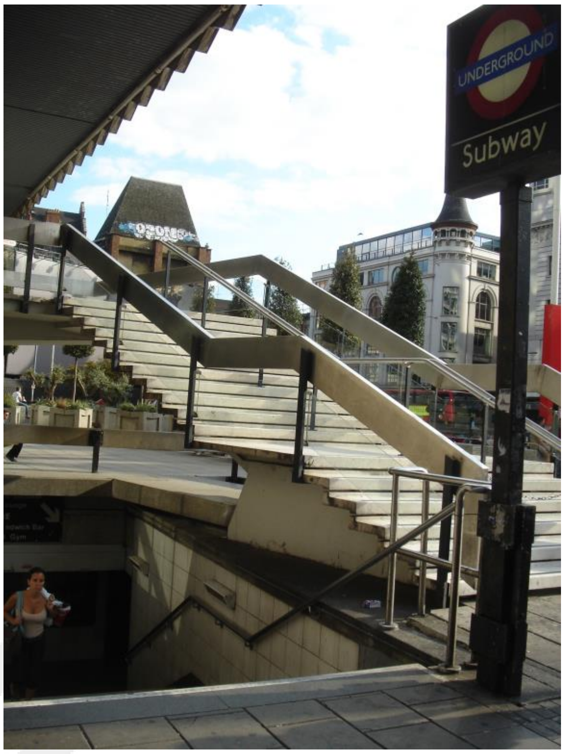
Picture 1 – Aerial view of the street level of TCRS (Retrieved from GoogleEarth)

Picture 2 – Aerial view of the street level of TCRS of CrossRail (Retrieved from CrossRail Environmental Statement pg.111)

Picture 3 – Aerial view of the exits of TCRS (Retrieved from GoogleEarth)

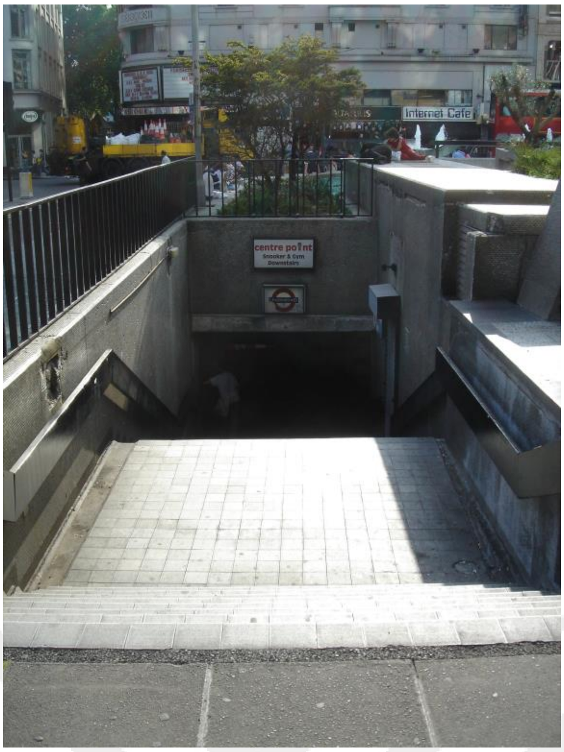
Picture 4 – Exit 1

Picture 5 – Exit 2



Picture 7 – Exit 4

Picture 6 – Exit 3



Picture 8 – Exit 5

Picture 9 – Exit 6

Picture 10 – Ticket Hall

Picture 11 – Automatic ticket barriers

Picture 12 – Ticket office and queuing area

Picture 13 – Central Line westbound platform (Platform 1)


Picture 14 – Escalator 3,4 & 5

Picture 15 – Escalator 1 & 2

Picture 16 – Congested Ticket Hall

Picture 17 – Central Line Platform 2

Picture 18 – Northern Line Platform 3

Picture 19 – Passageway 2.2

Picture 20 – Stairway 11

Picture 21 - Automatic ticketing machine for using credit/debit cards

Picture 22 - Automatic ticketing machine for using both cash and credit/debit cards and five other for using coins only.

Picture 23 – Unused ticket sales machines

Picture 24 – Unused phones

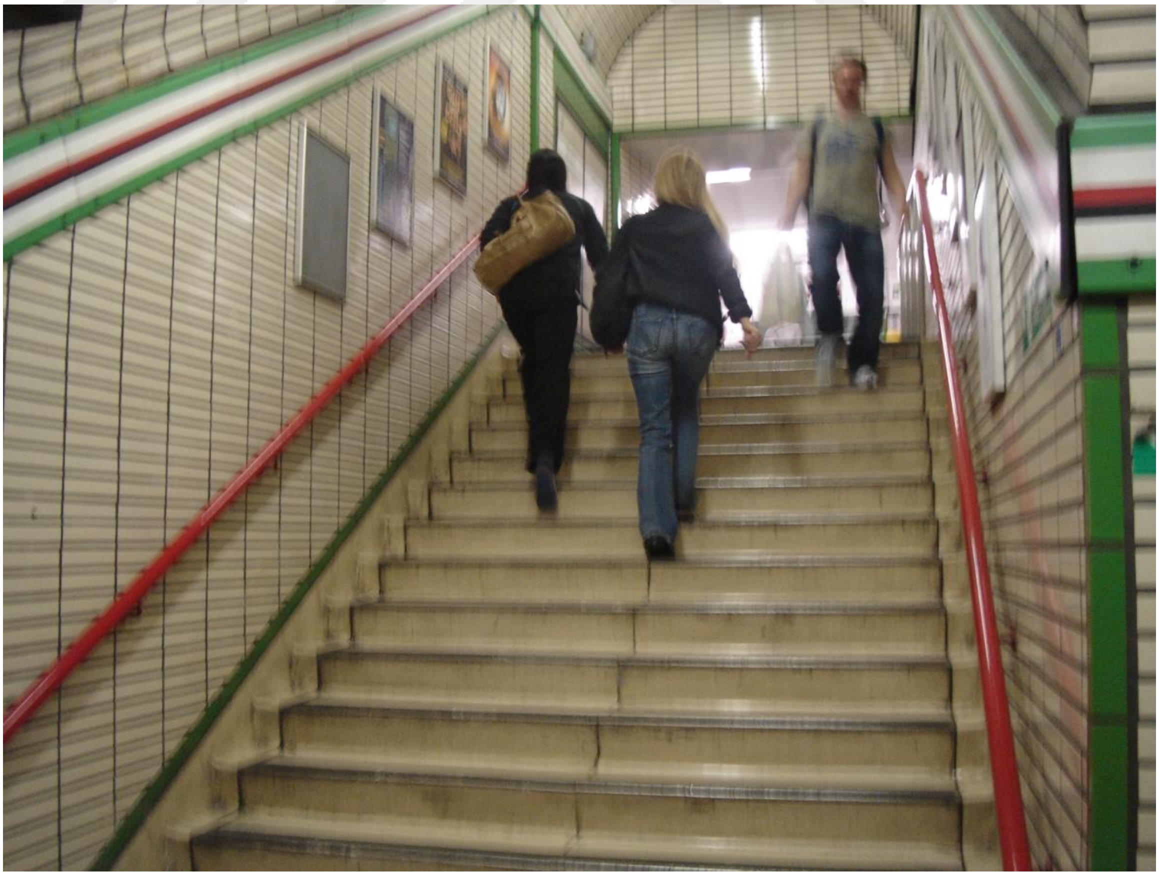
Picture 25 – Alternative phones

Picture 26 – Decision point before entering through the barriers

Picture 27 – Decision point after exiting through the barriers

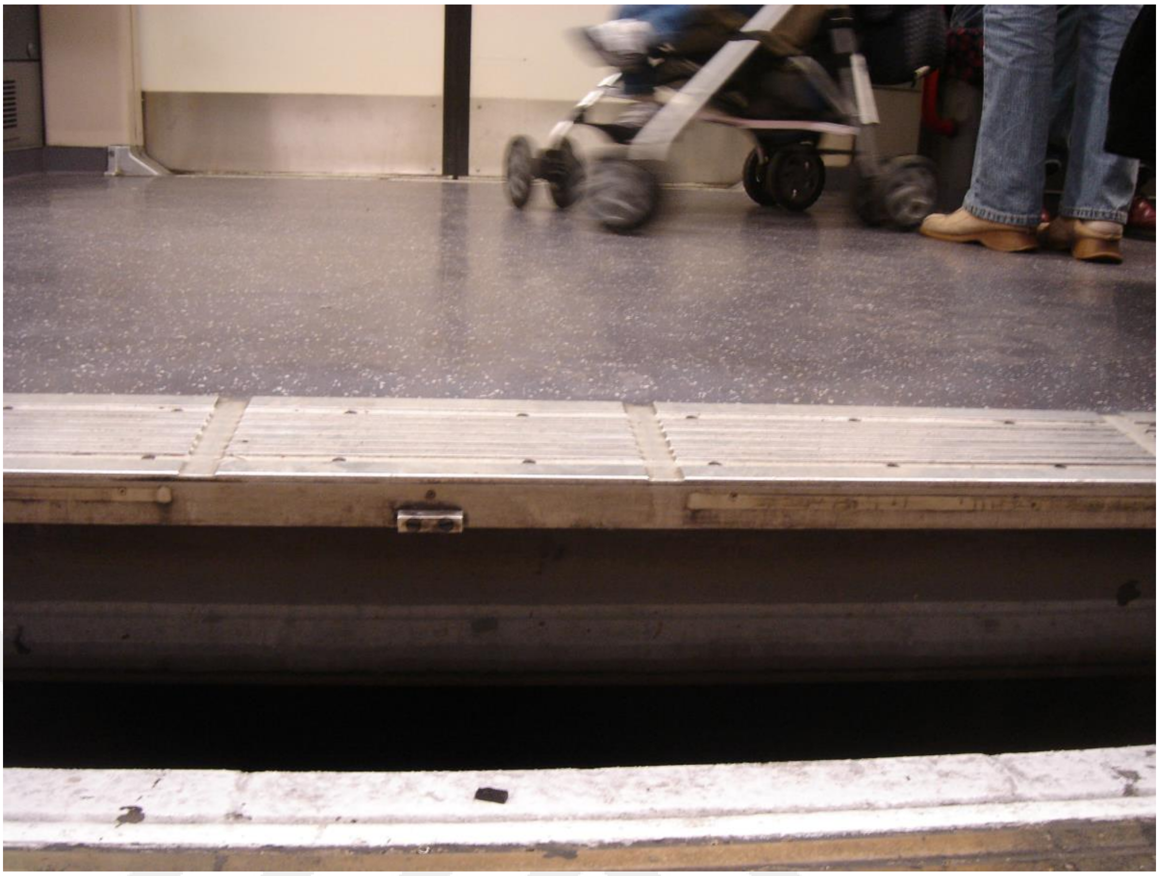
Picture 28 – Decision point and exit barriers

Picture 29 – Congested Stairway 11


Picture 30 – Passenger shortcut Stairway 10

Picture 31 – Circulating Area

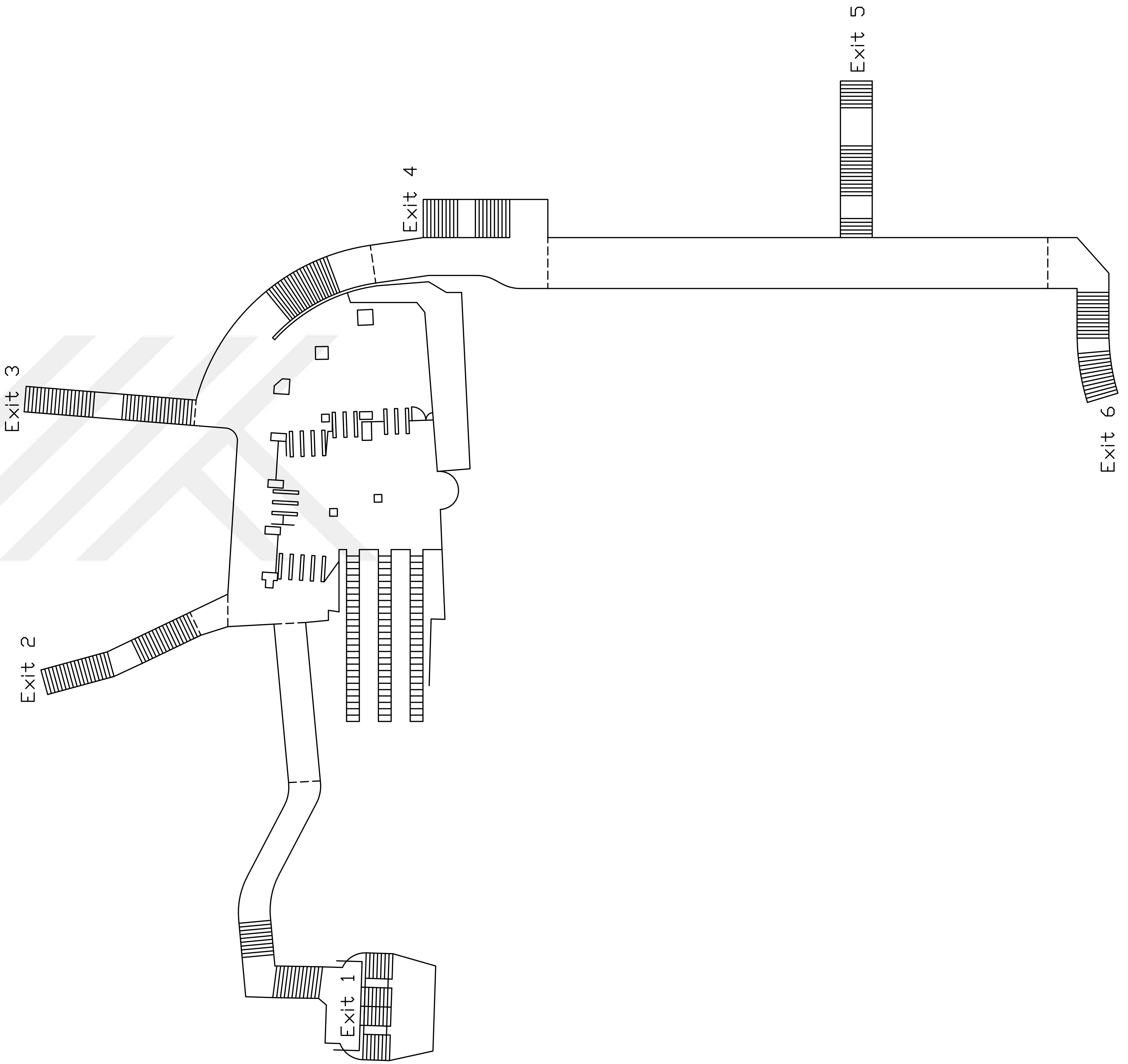
Picture 32 – Shortcut in the entrance of PW2.1



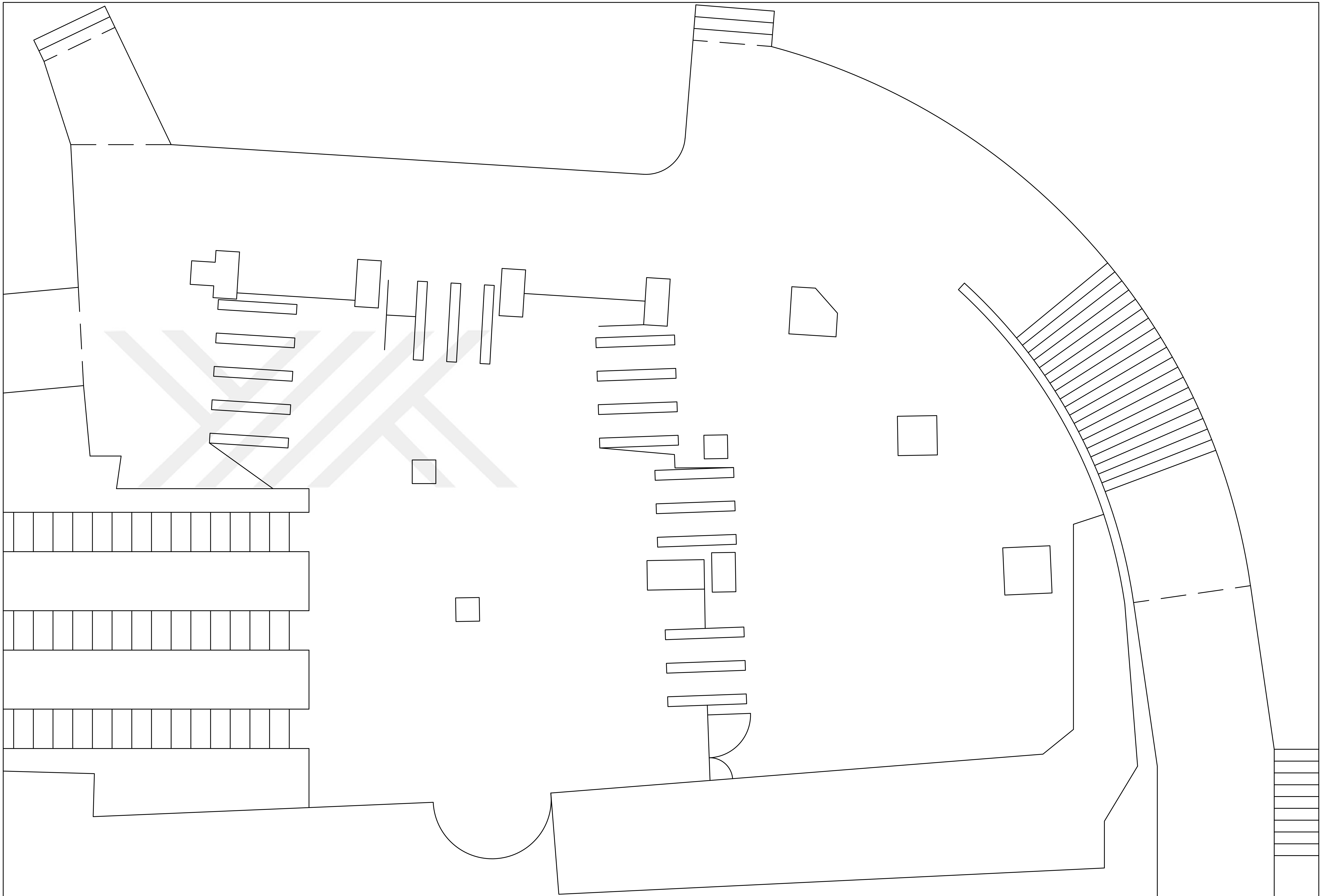
Picture 33 - The vertical gap between the train and the platforms

Picture 34 – Shortcut is taken by departure passengers of Northern line

Appendix 2 – Drawings



Drawing 1 - Station Exits



Drwaing 2 - Ticket Hall

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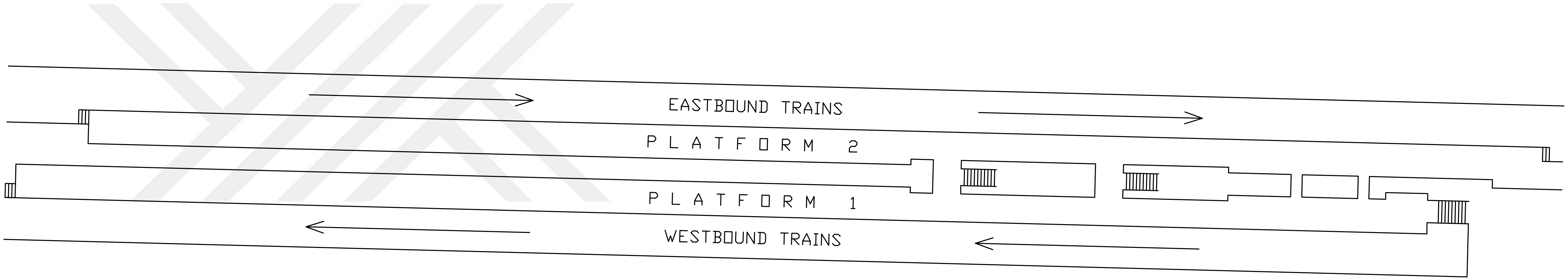
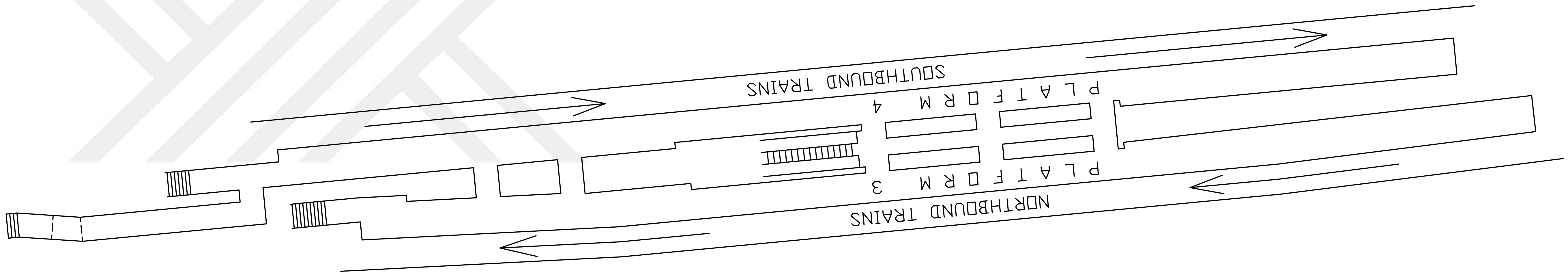
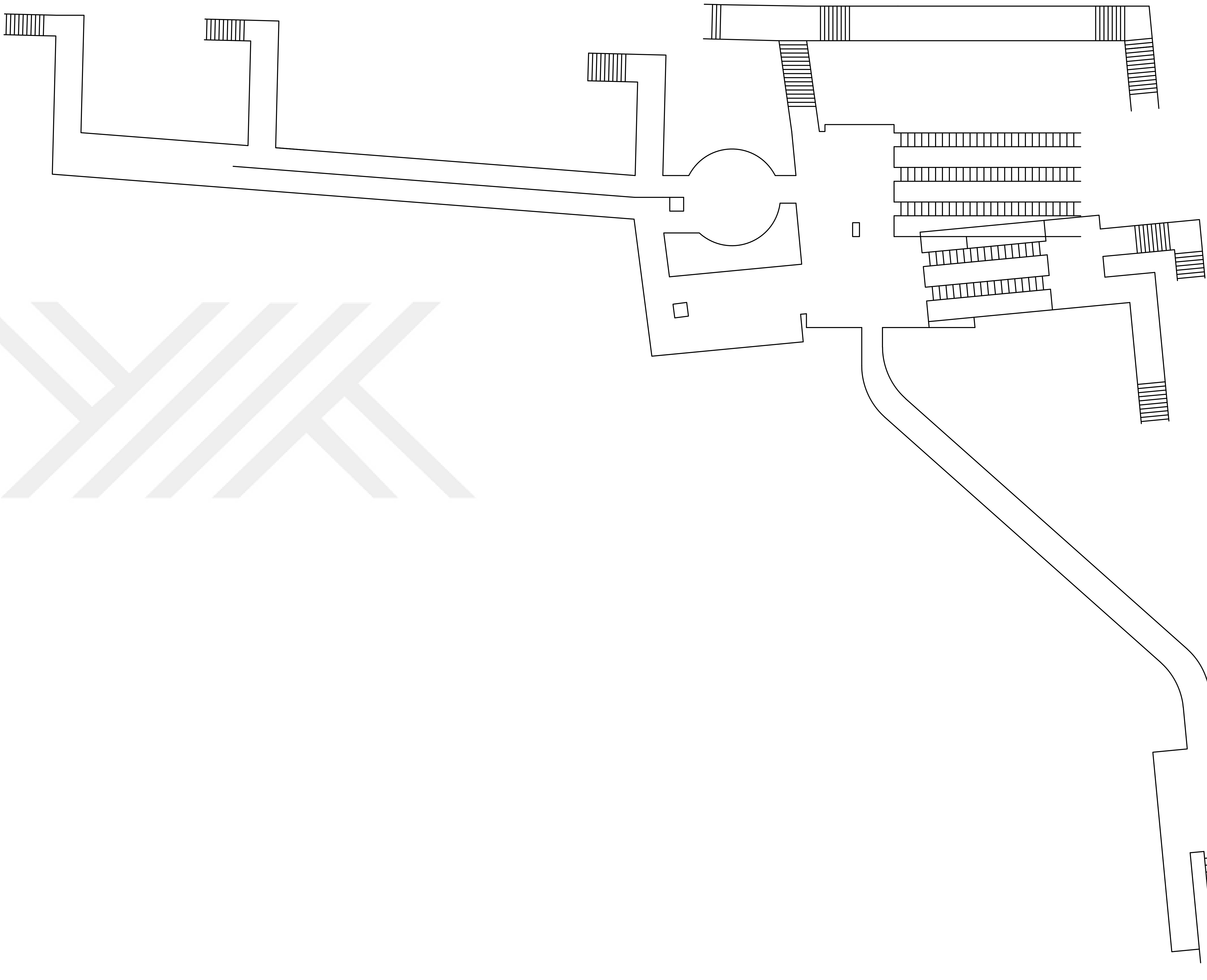


Drawing 3 - Central Line Platforms



Drawing 4 - Northern Line Platforms



Drawing 5 - Circulating Area

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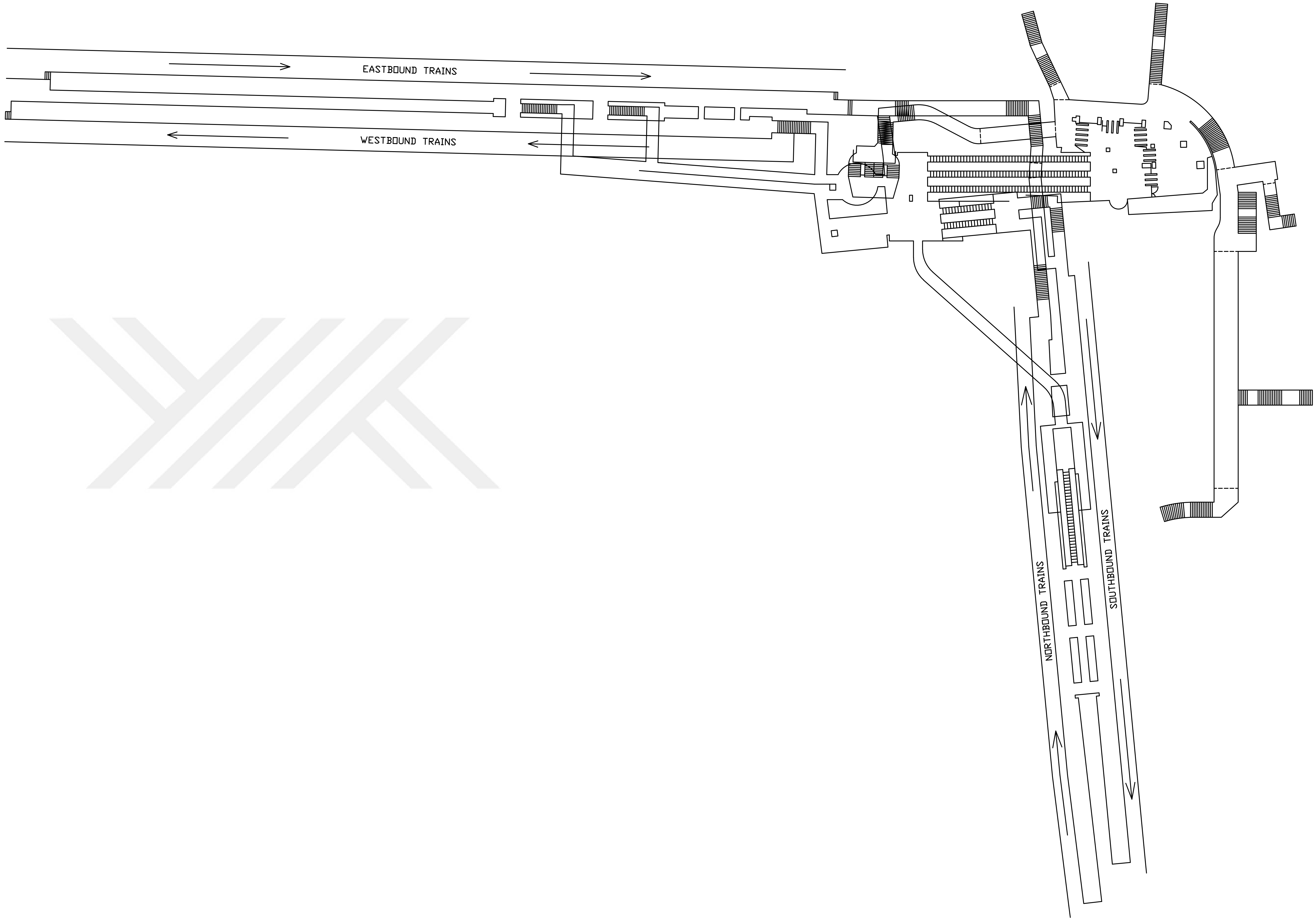

Drawing 6 - Overall Station