

# Estimation of Capacity of Escalators in London Underground

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## **Abstract**

In this paper we discuss a deterministic model for computing the capacity of the escalator in London Underground. We develop this model from fundamental principles of engineering by separating the capacities of standing and walking side of the escalator. By collecting real world data, we find the accuracy of this capacity computation. We also develop a multiple regression model that considers the effect of rise of the escalator with the capacity. We discuss the technical and behavioural reasons for differences in capacities of two methods.

# 1. INTRODUCTION

Transport for London (TfL), is an executive arm of the Greater London Authority (GLA) reporting to London's Mayor. It is made up of many predecessor organisations covering almost all transport modes in London, including the tube. London Underground (LU) manages the day-to-day tube operations, serving 275 stations and 3 million customers each day. There are 409 escalators on the LU system – the longest one is 60 metres at Angel station. The Operational Department of the London School of Economics (LSE) has undertaken a study of escalator capacity on the tube. LU provided advice and support during the LSE study.

There is a little information on the dynamics of passenger behaviour on and around escalators. This is accentuated by the fact that escalators in the London Transport system are almost unique in that they have both standing and walking sides rather than just standing on both sides. This not only reduces the applicability of work done on escalators elsewhere but also complicates the problem considerably. There has been little work done in the past, which separates the walking and standing sides of an escalator. Below is a list of the questions, which are addressed in this paper.

- 1) What is the capacity of an escalator?
  - LU Guidelines use a figure of 100 passengers per minute (ppm) whilst pedestrian simulation models accept that for short periods of time this figure is 120 ppm.
  - Are the guidelines accurate or should a change to them be recommended?
  - Is a single figure for escalator capacity justifiable or are escalators different enough to warrant more than one figure?
  
- 2) What factors affect the capacity of an escalator?
  - Is there a difference in capacity between up and down escalators?
  - Does the approach to an escalator have an effect on capacity?
  - Does the rise of an escalator affect its capacity?
  - Does a double escalator have a lower capacity than two single escalators?
  - Does the purpose of the journey have an effect on capacity?
  
- 3) Would capacity be increased if both sides of an escalator were for standing passengers only?
  - Would this conclusion be different for different escalators?

Section 2 introduces an escalator in brief. Section 3 is a summary of the interesting studies on and around the subject of escalator capacity. In the following section (section 4), there is a description of the work done for this project and details on how the work was done. This includes a section on how the data was collected, with an emphasis on making the data from different escalators comparable. Section 5 deals with the theoretical work, all done prior to the collection of any data. Section 6 looks at the data on up escalators and finds some relationships as well as finding reasons for those relationships, whilst Section 7 does the same for the down escalators. Section 8

discusses the question of whether people should be encouraged to stand on both sides or the present policy of walking on one side should continue to be followed. Finally the conclusions are presented at the end.

## **2. A SHORT INTRODUCTION TO ESCALATORS**

Mayo (1996) describes Escalators are a form of vertical transportation; essentially they are moving stairs. Passengers can either stand on an escalator and be transported at the speed at which the escalator travels, or walk and increase the rate at which they are transported. Escalators are particularly prominent on underground train systems such as the London Underground because of the need to transport large numbers of people from underground up to street level or vice versa.

The first recognisable patents for escalators were lodged in 1892, independently filed by Jesse Reno and George Wheeler. Elisha Otis combined these two patents to design a viable escalator. The first railway escalators were installed on the London Underground at Earl's Court in 1911, based on a design by Charles Seeburger. By the middle of 1920's the escalator was well established and since the 1930's escalators have been the preferred method of high volume passenger transportation between levels.

Escalators are the only viable option for high volume transportation but they do pose problems for those carrying bulky loads or for the mobility impaired. The escalators used in underground stations are all Heavy Duty Public Service escalators. These escalators are designed to take very high levels of traffic and to last for a long period of time. All London Underground escalators are at a 30 degrees angle of inclination in keeping with all modern railway escalators. The greatest rise of a London Underground escalator is 27.4 metres at Angel Station and 25 metres is generally considered to be a practical maximum. A typical service life for a heavy-duty machine is 40 years although several London Underground escalators have seen 50-60 years of continuous service.

Escalators on the London Underground system have a step depth of 400mm and are 1000mm wide. These escalators travel at an average speed of 43.2 metres per minute, although this can vary slightly. Passengers on the London Underground system are usually encouraged to stand on the right side of the escalator and walk on the left side. London is almost unique in this policy.

### 3. LITERATURE SURVEY

In this section, we discuss the previous studies on and around the subject of escalator capacity. We found however that very little, if any, work has been done which has separated the standing and walking sides of an escalator.

#### 3.1. *Passenger space on escalators*

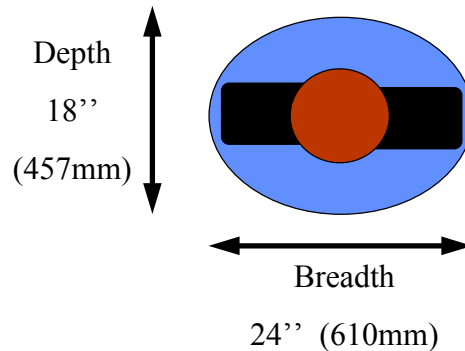


Figure 3.1 - The Human ellipse

Fruin (1987) discusses the concept of passenger space. Above is a diagram of the human ellipse. The person is represented by a round head and rectangular shoulders and the space a person needs to feel comfortable (termed the human ellipse) is also shown. It is possible that the measurements would be different in the different countries, although any difference is unlikely to be great. It is known that people in the Far East have considerably smaller human ellipses both because they are physically smaller on average but also because they have less need for personal space, presumably due to cultural and other differences. It should be noted that the additional space around the shoulders is not as great as that directly in front or behind an individuals' face.

#### 3.2. *Standing on escalators*

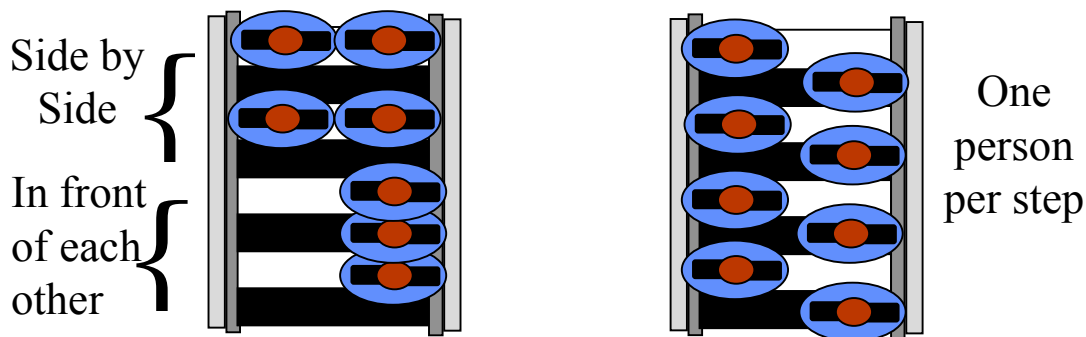


Figure 3.2 - The effect of the human ellipse

The diagram above shows the effect of this human ellipse on escalator travel. The diagram on the right (which assumes that everybody stands) shows how human contact can and often is avoided on an escalator. Only one person stands on each step and people do not stand in front of each other. The diagram on the left shows two situations. Firstly, people standing side by side, this involves only a small overlap of personal space and is therefore often tolerated. Fortunately, this does allow people to walk past each other on the escalator without causing too much discomfort. People are

also shown standing directly in front of one another. This clearly causes an invasion of personal space and is something that people tend to avoid. Certainly, three people standing directly in front of each other on an up escalator as shown in the diagram is very unusual unless the people know each other very well!!

Therefore, standing people will invariably leave one empty step between them and the person in front meaning that on average people stand on every second step. Further research is necessary to ascertain whether this is a true average.

In his work, Fruin (1987) also addresses passenger sub-optimising behaviour. Passengers will generally attempt to optimise their own escalator experience but this does not lead to optimisation of the escalator experience for all passengers as a whole. As passengers are waiting to board an escalator they no doubt wish that people would stand closer together. However, when a passenger actually comes to board an escalator, the time saving he can make by stepping on the step behind the person in front is so minimal as to not warrant consideration when compared against the issues of personal comfort and space. This is a classic case of user optimisation not leading to system optimisation.

### ***3.3. A study of escalators and associated flow systems***

The work by Mayo (1966) is perhaps the most interesting work on the subject of escalator capacity. The bulk of this study is looking at the controllable aspects of an escalator, which can affect capacity. Mayo lists these controllable factors as:

- Escalator speed
- Geometry of approach
- Ticket gates

According to the study, the ticket gate is usually unimportant. This study is most successful in finding an optimum escalator speed. Mayo then proceeds to list those variables he considers to be uncontrollable:

- Walk:stand Ratio
- Vertical rise
- Total flow of passengers
- Distance of escalator from platform

With respect to walk stand ratio, an interesting claim in this study is that “in a crush condition, passengers enter the system at the same rate whether with walking or standing intentions, and what they do on the escalator has no effect on capacity.”

As far as vertical rise is considered, Mayo states that more people are prepared to walk up a shorter escalator (obviously!!). The total flow of passengers also affects the walk/stand ratio. The distance from the platform to the escalator also affects the elevator. If the passengers come straight from the platform onto the escalator they are bunched and pass on in a mass. Passageways however tend to smooth out the trainload, depending on their length and complexity”<sup>i</sup> and therefore passengers will reach the escalator over a longer period of time.

This study (Mayo, 1996) looks at the escalator as only part of a flow system from the platform to the ticket gates. The only part of interest to this report is that concerning escalators. Mayo found a correlation between the capacity of an escalator and the speed at which it is travelling. He found that people stand closer together on a slower moving escalator but there are more steps per unit time with a faster moving escalator (obviously!!). When these two factors are taken into account a regression line of capacity against speed is produced which shows maximum capacity to be obtainable at approximately 150 feet/minute.

In doing this Mayo produces a multiple regression equation, which includes the regression factors, escalator speed in feet per minute (s), vertical rise in feet (h) and traffic flow in passengers per hour (t). He finds that:

$$\text{Capacity (max.)} = 1.329s - 0.0055s^2 - 0.875h + 0.0112t + 0.0075hs - 11.20$$

and

$$\text{Capacity (mean)} = 1.553s - 0.0059s^2 - 0.265h + 0.0163t + 0.032hs - 68.33$$

Where capacity (max.) is the maximum reading at an escalator in passengers per minute and capacity (mean) the average reading, also in passengers per minute. Mayo uses the traffic flow regression factor to take into account the fact that some escalators are busier than others.

Mayo then proceeds to look at the problem of the approach to the escalator. He tries to simplify the problem by looking at escalators in isolation and by merely looking at the geography of the approach rather than the possibilities of traffic flow which occur due to the existence of other escalators. He comes to the conclusion that open approaches (unrestricted access) result in the highest capacity, explaining this by the fact that passengers are able to approach the escalator five or six abreast. He does not have enough data for his results to be statistically conclusive.

### ***3.4. Escalator handling capacity: standards versus practice***

The work by Al-Sharif (1996) is an attempt to estimate the number of passengers using an escalator through the amount of power being taken up by the escalator. He found that because some people walk up (or down) escalators, people (even those of the same weight) do not consume the same amount of energy on an escalator. Those who walk up an escalator are partially using their own energy to get to the top. Interestingly, once there are enough people on a down escalator, the escalator actually starts to generate power back into the system.

In his paper, Al-Sharif discusses the concept about the human ellipse, which is discussed earlier. The he considers walking on escalators. He uses walking speeds found by Andrews & Boyes (1977) and also the percentage of passengers who walk, to find a walking factor, which, if divided into the standing capacity, can be used to find the true capacity.

### **3.5. *Pedestrian planning and design***

The work by Fruin (1987) is one of the most complete study regarding the dynamics of pedestrian movement. This work was done in the USA, where the passengers stand on both sides of the escalator, and the speeds of the escalators and size of the passengers are different. The most relevant aspects of this work is described below.

- 1) The “empty step” phenomenon. This is an explanation of the fact that capacity on an escalator is never as high as it should be in theory (if two people were standing on every step). Even in the heaviest of traffic with the most agile commuters, empty steps still appear on escalators, which reduce capacity. There are two reasons for this. The first the inability of the users to board the unit quickly enough. This refers to peoples slight hesitancy in boarding an escalator. The second is a simple personal desire for a more comfortable human space or personal space. To achieve this personal space, passengers like to keep other passengers out of their human ellipse.
- 2) On stairs, people generally keep two vacant steps between themselves and the person in front. Whilst Fruin does not discuss walking on escalators it is assumed that people behave the same way on escalators. Fruin also states that the capacity of stairs are not greatly affected by the volume of traffic because, as long as people have two steps in front of them they are easily able to move, stairs rarely get congested in the same way walkways do and people are therefore not forced to ‘shuffle’

### **3.6. *Study at Road Research Laboratory***

Study at Road Research Laboratory (1969) deals with road traffic (i.e. cars, lorries, buses etc.) rather than pedestrian traffic, but there is one central idea in this study is related to roundabouts. In discussing the capacity of a junction to a roundabout, it is found that in addition to the traffic on the roundabout and the diameter of the roundabout, the entry width to the roundabout is a very important parameter. In other words, for each extra metre width of the entrance, the number of vehicles able to pass on to the roundabout increases. The width need not be enough to allow an extra car through, as that would obviously increase capacity. This can perhaps be likened to people approaching escalators (and most probably to people approaching stairways or passageways). If people have more space from which to approach, capacity will be increased. This agrees with Mayo’s findings.



## 4. RESEARCH METHODOLOGY

In this section, there is a description of each phase of this study. This description is in rough chronological order. Each phase merges into the next phase but in this description there is an attempt to keep the phases separated for purposes of clarity.

### 4.1. *Analysis and application of theory*

This includes an application of queuing theory to the problem of escalator capacity using assumptions from past studies. One reason for doing this work is to establish what data needs to be found to both improve the assumptions and to cover those areas of the problem which are currently not covered.

### 4.2. *Collection of the data*

All data was collected in 10 of the busiest underground stations, all in central London. All stations are characterised by high numbers of commuters in the morning and varying proportions of leisure travellers in the evening. Many of the stations have several escalators and data was collected only at the busiest escalators.

As the intention was to study capacity flows of passengers the only times of interest were the morning and evening peak times. In the morning this lasted from 08:00 to 09:30 and in the evening from 17:15 to 18:45. The biggest peak is between 08:45 to 09:00.

Data collection was more fruitful on the up escalators than the down escalators, the reason for this is explained below:

- The highest levels of traffic are generally caused when people get off trains because they get off in large batches rather than when people arrive from street level, which they do over a period of time.
- Therefore the highest levels of traffic occur either when people are exiting stations or when they are interchanging (either between underground lines or from other rail systems to the underground).
- As a consequence, most capacity situations occur in the morning when people, who have come from a large number of stations around London, exit at a relatively small number of stations in central London. As a result, most capacity situations concern only up escalators. When people return to their homes in the evening, they arrive at the station over a period of time rather than in batches.
- The exceptions to this are the interchange stations. At Victoria Station people interchange between British Rail and the underground, at Holborn and Green Park people interchange between different underground lines and at Bank people interchange between the underground and the Docklands Light Railway.
- Down escalators were usually busiest in the afternoon and many of the busiest escalators were in stations with a high proportion of non-commuters travelling. Non-commuters, in particular tourists, may turn out to have a significant effect on escalator capacity and should not be forgotten as a factor.

The down escalator data is not as useful as would be desired since capacity situations are rarely reached. The bottlenecks on the stations are usually deliberately held back from the escalators and are at the ticket gates. This is to ensure that the numbers of people on the platforms are not allowed to approach unsafe levels.

Below is a description of how data was collected; the points are listed in chronological order.

- The first thing to do is to gain an understanding of passenger movement around the escalator and establish what a ‘good sized queue’ at that escalator looks like. Some escalators generate crush queues whilst other queues are more orderly. It is necessary to understand the sort of queues generated in order to establish at what point the escalator is approaching capacity.
- Data was only collected when the escalator appeared to be approaching capacity. This was done by waiting for the build up of a queue, starting the clock once the queue got beyond a certain size and counting until the queue got small again. The reason for this being that it is with the longest queues that people are most likely to be encouraged to maximise the potential capacity of the escalator. This also made it easier to compare different escalators.
- Passengers were counted simultaneously on both sides of the escalator, ensuring that standing and walking data were kept separate. Passengers were counted as they passed a particular point (marked either by the ‘stand on the right’ signs or by a specific advert), which was usually some 2.0 to 2.5 metres above ground level in order that people passing the point could be easily seen and distinguished from other people at all times.
- Time was also spent watching passengers in order to try and explain particular behaviour patterns and explain why some escalators have a greater capacity than others. Any unusual passenger behaviour was noted.
- The rise of the escalator was noted and a sketch of the approach to the escalator was made.

All the quantitative data were put into a spreadsheet. All the qualitative data were either explained in words or in diagrams, or stored on the computer to be referred to later.

### ***4.3. Analysis of the results***

This phase can be separated into two sections, which were completed simultaneously.

#### **1. The statistical analysis of the data**

The data was collected together with information on the rise; the approach and other aspects of the escalator, which it was thought may turn out to be important. These factors were included in a multiple regression in different ways to find the most likely causes of varying escalator capacities.

#### **2. The diagrammatic/logical analysis of the data**

Rather than simply show that certain factors were significant in affecting escalator capacity, there was also an attempt to explain why these factors were of importance and in what way they affected capacity. This was largely done through the use of logical argument backed up with diagrams.

As an example of how these two methods were combined, statistical tests showed some escalators to have unusually low capacity? An examination of the diagram of approach to the escalators may show a common feature. If it can be logically argued that this feature could have a detrimental effect on capacity, it would be worthwhile to include it as a regression factor in the final model.

## 5. ANALYSIS AND APPLICATION OF THEORY

The theoretical capacity of an escalator, assuming that two people stand on every step and that the escalator is travelling at 43.2 metres per minute, is 216 ppm. This section deals with the reasons why this is never achieved.

### 5.1. Capacity of the standing side of an escalator

In this section only half of the escalator is dealt with, that half where people stand only. An estimate is found for the capacity of the escalator, although it should be appreciated that there is a necessity for a certain amount of queuing before capacity will be reached.

$v$  = speed of escalator (metres/minute)

$D$  = depth of an escalator step (this is the distance from the front to the back of a step, not the height.)

$q_s$  = proportion of steps used whilst standing

Steps per minute,  $S_s$                     =  $v/D$                     - the number of steps passing a point on the escalator each minute.

Capacity per minute,  $C_s$                 =  $S_s * q_s$                 - the number of people passing a point on the escalator each minute.

We know that:                     $v = 43.2$  metres/minute,

$D = 0.40$  metres,

And assuming:                     $q_s = 0.50$  - assuming that on average people stand on every other step.

Capacity,                     $C_s = 54.00$  ppm.

Therefore, capacity of the standing side of an escalator will be roughly 54 people.

### 5.2. Walking on escalators

Walking Passengers will almost always leave at least two clear steps between themselves and the person in front (Fruin) as shown in the diagram below.

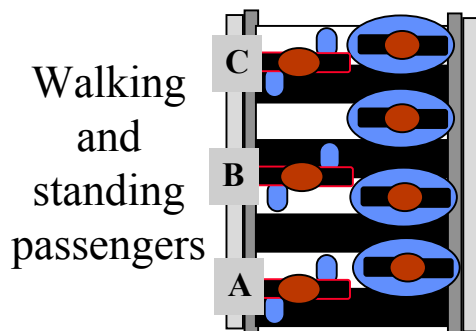


Figure 5.1 - Walking on escalators

Leaving two clear steps is necessary between two walking passengers because passenger A in his next step will move his left foot to the step behind passenger B's left foot. If passenger A were to take the next step even marginally before passenger B

and they were not so far apart, they would bump into each other. Therefore, whilst standing passengers only require two steps at any one time, walking passengers require three. This, taken in isolation will have the effect of leading to a reduced capacity. However, passengers generally walk at a speed fast enough to overcome this.

### 5.2.1. Capacity of the walking side of an escalator

Here, an estimate is found for the capacity of the walking side of an escalator, although it should be appreciated that there is a necessity for a certain amount of queuing for the walking side before capacity will be reached.

$u$  = speed at which passengers walk up escalator

$q_w$  = proportion of steps used whilst walking

Effective speed of the escalator	= $v+u$	- As people are walking, the effective speed at which they are walking.
Effective steps per minute, $S_w$	= $(v+u)/D$	- the effective number of steps is similarly increased.
Capacity per minute, $C_w$	= $S_w * q_w$	- the number of people passing a point on the escalator each minute.

We know that:  $v = 43.2$  metres/minute,

$D = 0.40$  metres,

And assuming:  $u = 36$  metres/minute, and

$q_w = 0.33$  - assuming that on average people require three steps each to walk up.

Capacity,  $C_s$  = 66.00 people per minute.

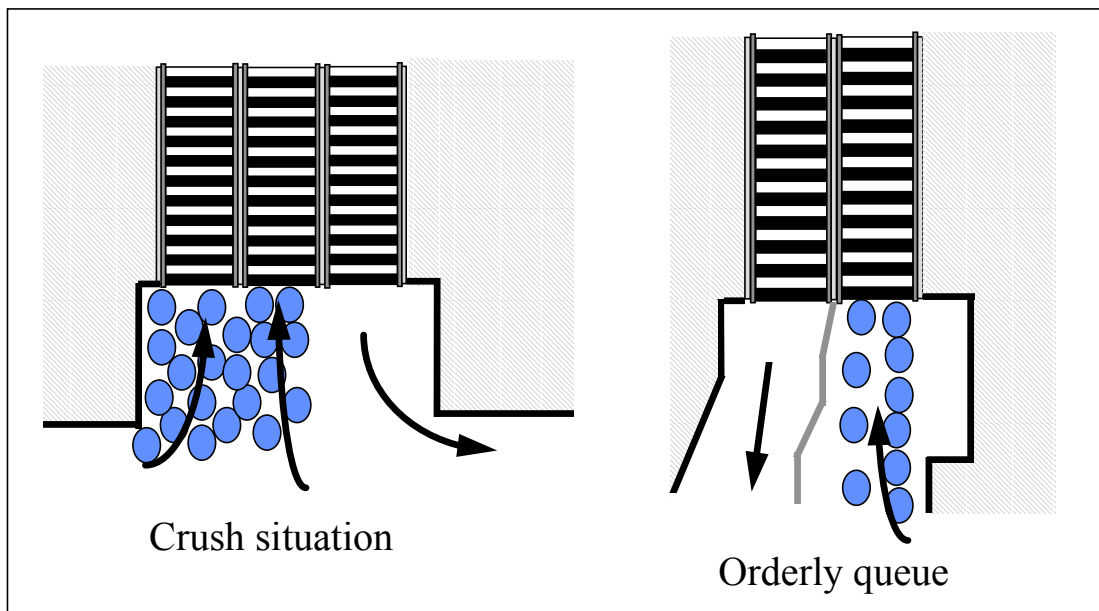
Therefore, capacity of the walking side of an escalator will be roughly 66 people. Total capacity, including both standing and walking sides, will be approximately 120 people per minute.

### 5.3. Passenger dynamics on and around escalators

In the previous sub-section some simple calculations were done regarding the theoretical capacity of an escalator. In this section the aspects of passenger behaviour, which will affect capacity of an escalator, are addressed. The reader is introduced to the behaviour of passengers on and around escalators. This will explain why the theoretical capacity is sometimes not reached and sometimes exceeded.

- Capacity on the walking side can only be achieved where there are enough passengers wishing to walk. Frequent users of escalators on the underground system will be aware that there are sometimes sizeable queues for the escalator and yet one side of the escalator is empty. It is possible that in a queue of passengers for the escalator, nobody will wish to walk. In such a situation, the potential capacity of the walking side of an escalator, as worked out above is of little consequence. Probably, the most important part of this project will be deciding what factors change the number of people who walk.
- Queues of passengers wishing to board an escalator can be of two main different types. These are shown in the diagram below. The crush situation is the most

extreme queue. It is more likely to occur where there is enough room at the approach of the escalator, where the escalator is close to the platform(s) and therefore less time for people to space themselves out and where people can arrive at the escalator from more than one direction. In the crush situation, there appears to be no separation of those wishing to stand and those wishing to walk. In the orderly queue, such a separation exists and the queue of those wishing to walk is therefore able to move considerably faster than those wishing to standing.



Only passengers going up are shown.

Figure 5.2 - Two types of queues

It would seem that in the case of the orderly queue there is considerably greater advantage to walking up the escalator than in the crush queue. However, people may equally well be encouraged to deliberately get in the wrong queue in order to jump the queue for the standing side of the escalator.

- People crossing between the two sides of an escalator are another common feature of escalator travel on the London Underground system. If both sides of an escalator were walking or standing there would be no advantage in crossing from one side to another but with the two sides subject to different policies, such an advantage can exist. Below is a list of the reasons why this occurs:
  - a) People deliberately enter the queue they can see is moving faster and then cross over onto the other side of the escalator as they reach the escalator,
  - b) People do not realise there is a difference between the two sides of an escalator until they get on it or have nearly reached it,
  - c) The queue is such that the passenger has little choice about how he or she moves forward.

The effect of people crossing over is often to disrupt the flow of traffic in some way. Ideally one would wish to be able to count the number of people crossing over on each escalator but that is not a practical option.

## 6. ANALYSIS OF UP ESCALATOR DATA

Data has been collected from all up escalators for which there is sufficient information and relationships have been found. The simplest and most obvious

relationship is that between capacity and the vertical rise of the escalator and that is the point at which this analysis starts.

### 6.1. *The effect of rise*

Factors other than rise may have an effect on capacity. For this section of the analysis it was desirable that any such effects should be minimised. This was done as follows:

1. Where there were two up escalators side by side, there always appeared to be significant differences between the two capacities (although the rise was the same). This is because of
  - The differing layouts (near a wall, near a down escalator, etc.)
  - The choice facing individuals on which escalator to use.

The result which most seems to describe capacity was used. This was usually the higher result (because we are interested in the maximum capacity) but was also the result which had the least complicating factors.

2. One set of data, escalator 6 at Embankment station, is highly coloured by the fact that there is a wide nearby staircase. It was noticed, whilst measurements were being taken, that many people, on seeing a queue for the escalator, decided to take the stairs. It is reasonable to assume that the proportion of 'walkers' to 'standees' in this stairs group will be significantly different to those who chose the escalator. The measurements from this escalator are highly unusual and are therefore not included in the analysis below.

Below is shown a scatter graph of total capacity versus rise of the escalator. Although there is a definite trend, the linear regression  $R^2$  value of 44% shows that the relationship is either more complex, or that rise only accounts for half the differences in capacity.

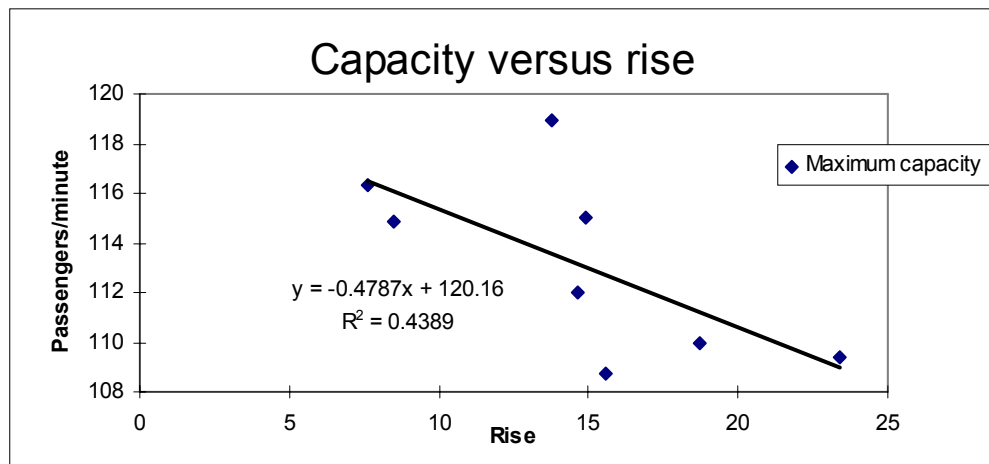


Chart 6.1 - Graph of capacity versus rise

The standing and walking data were then separated in an attempt to better understand the data.

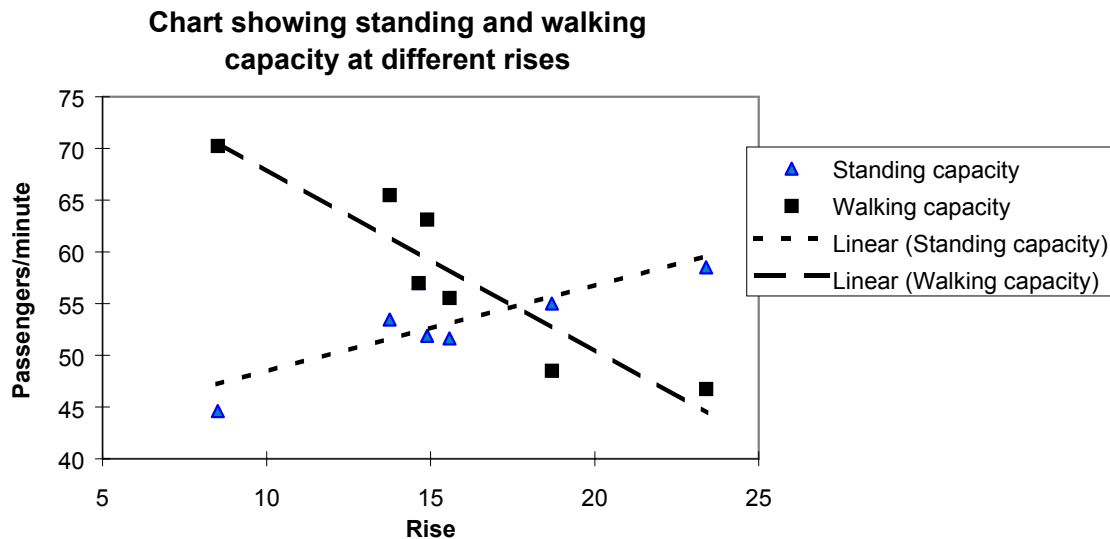


Chart 6.2 - Graph of walking and standing capacities versus rise

Both the walking and the standing data are very strongly explained by the rise of the escalator. One would expect the walking data to be strongly correlated to the rise because the greater the rise, the less people will want to walk. The standing data is less obviously related to the rise, and there is a suspicion that it is only indirectly related to the rise. More people stand per minute on a higher escalator because:

1) People do not arrive at the escalator in two distinct queues and therefore people step across from the walking queue to the standing queue at some point. This can be done:

- Before reaching the escalator (this is unlikely to have an effect on capacity)
- On reaching the escalator - on observation this can mean nipping ahead of someone else by taking the step directly behind another person. In the figure opposite, passenger B knows that passenger C will go for the next step (step 0 which has yet to appear). If passenger B wants to get on the standing side of the escalator he will need to get on step 1.
- On the escalator, this will entail fitting between two 'standees' (such as passenger D fitting himself between passengers A and E) who did not expect someone to come between them (and therefore did not account for it in their calculation of space needed for their personal comfort).

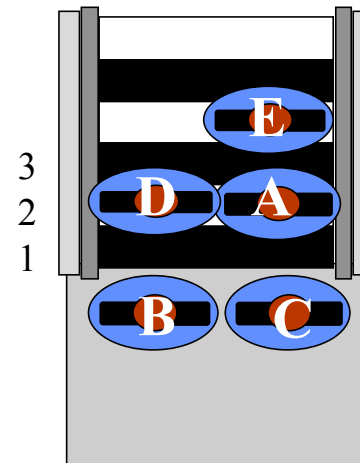


Figure 6.1- Boarding escalators

2) The opposite effect occurs on very short escalators, people step across from the standing side to the walking side, thereby decreasing the capacity of the standing side.

Therefore the variable standing data should be seen as a function of the number of people who want to walk, because if it were possible to completely separate the two sides, the standing data would be constant.

## 6.2. Factors other than rise

Whilst the relationship between rise and escalator capacity is shown above to be very strong, the data used only included those escalators considered not to be affected by other factors. If all the escalators are included in a regression, the  $R^2$  value falls to about 60% for the walking data and 55% for the standing data. On removal of the data from escalator 1 at Victoria due to its unusual standing data, the  $R^2$  value of the walking data remains roughly constant but for the standing data it improves to nearly 83%. It is concluded that the standing data for Victoria 1 is unusual (possibly due to mistakes in counting or to an unusual set of passengers such as lots of groups), and should therefore be ignored. The  $R^2$  values also suggest that for the walking data in particular there are other factors to be considered.

Escalator 6 at Embankment is once again not included in the data set for this section because of the wide staircase nearby which almost certainly results in a lower proportion walking on the escalator than would do otherwise.

Below is a graph of the percentage walking at each escalator in heavy traffic. A trend line has been included to help spot those escalators, which are unusual.

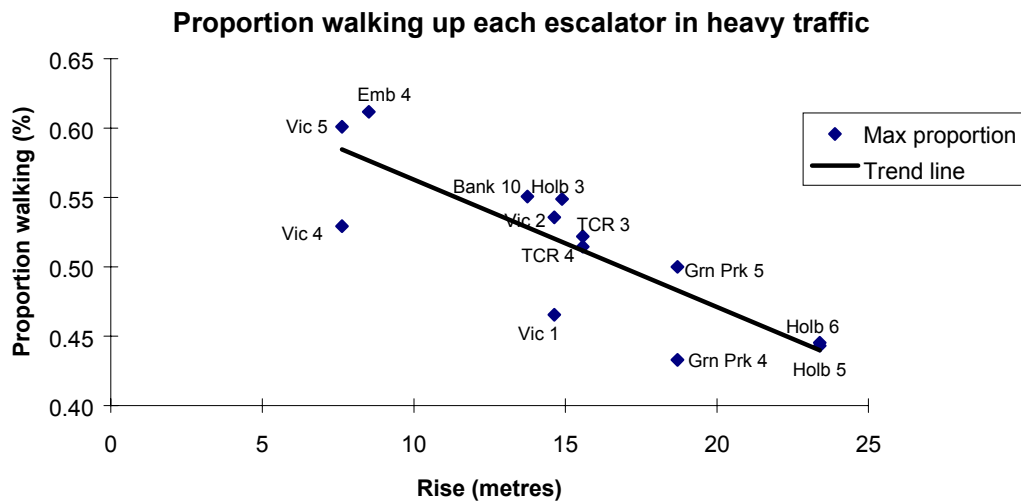


Chart 6.3 - Chart of Proportions walking up escalators

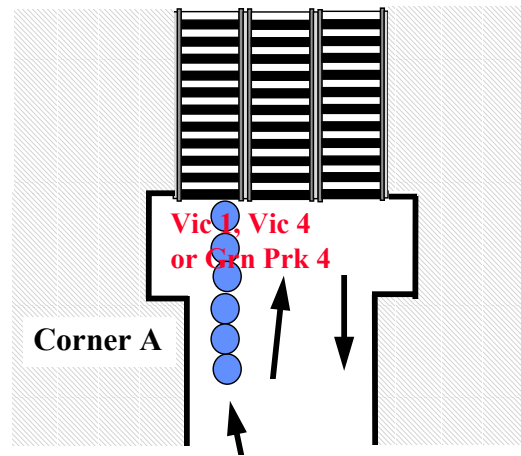
### 6.2.1. Corner A

Victoria 1, Victoria 4, and Green Park 4 are the three escalators that differ most from the trend line. In other words, they are the three escalators that appear, in terms of the proportion of people walking up them, to be affected by factors other than rise. A look at the layout of these escalators, compared with the other paired escalators shows one interesting factor. All are between another up escalator and a wall, and, unlike any other up escalators studied, they all have an interesting design feature, termed Corner A in the diagram below.



Figure 6.2 - The effect of a corner A

Corner A makes it comparatively difficult to walk up the escalator closest to the wall. The reason for this is because the walking side is on the left hand side of the escalator and once there are queues for the right hand side (as represented by the small circles in the diagram), it becomes difficult to reach the left side. If a dummy variable, Corner A is included in a multiple regression of the non-adjusted data this improves the regression. It gives an adjusted  $R^2$  value of over 87% (up from 56% for the non-adjusted data before the inclusion of Corner A) for the walking data. This gives a regression equation,



Walking capacity =  $81.68 - 11.07 \cdot \text{Corner A} - 1.46 \cdot \text{Rise (m)}$ .

The effect of the corner A and the rise are both significant at the 1% level. The residuals look normal. In other words, the effect of corner A, before introducing other regression variables, is to reduce the capacity of the walking side by 11 ppm.

Ignoring the unusual standing data from Victoria 1, we can say that corner A has no effect on standing capacity and the effect of corner A is to reduce capacity of an escalator by approximately 10%.

### 6.2.2. Double escalators

It has been suggested that the capacity of two adjacent escalators is less than the sum of two single escalators. In order to verify this, dummy variables were included for two types of escalators. The first one are corner A escalators, for escalators which are one of a pair. The second for those escalators are next to corner A escalators. This is in recognition of the fact that a decrease in the number walking up a corner A escalator may encourage people to walk up the adjacent escalator.

The results of the multiple regression are as following:

- For the standing data, none of these factors had a significant impact on capacity.
- For the walking data, being one of a double set of escalators had a significant negative impact on capacity. All regression factors were significant with the exception of being next to a corner A escalator. This is discussed further in the conclusion to this chapter.

### 6.2.3. Open space at the approach to an escalator

It has been suggested, and indeed Mayo (1966) attempted to prove, that escalators with open access have greater capacity because people could approach from all directions. Conversely, it has also been suggested that an open approach reduces capacity because it stops a queue from being orderly and people find themselves in the wrong queue.

It is difficult to determine what constitutes an 'open' approach as there are so many different designs. It was decided that an open approach should be one that was not next to a wall and not next to a down escalator. The left and right hand sides should

be looked at separately. Below, an example is given of what is considered to be an ‘open’ approach.

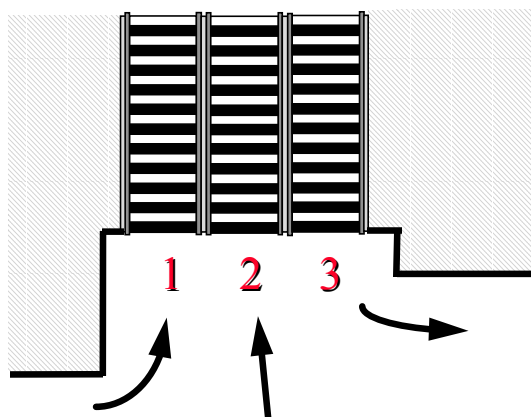


Figure 6.3 - Example of open and not open escalators

Escalator	Left side	Right side
1	Not open (next to wall)	Open
2	Open	Not open (next to down escalator)

The openness of the left and right sides of an escalator were included in a multiple regression with mixed results. The standing data suggested that an open right side might increase capacity of the standing side of the escalator by about 1.7 ppm. However, the results were not very significant. The walking data suggested that an open left side might increase capacity of the walking side by about 4 ppm. Once, again, the results were not very significant.

These results correlate with Mayo (1966). An open approach does seem to increase capacity but there is not enough data for the results to be significant at a 90% confidence level.

#### 6.2.4. A final examination of escalators showing unusual capacity

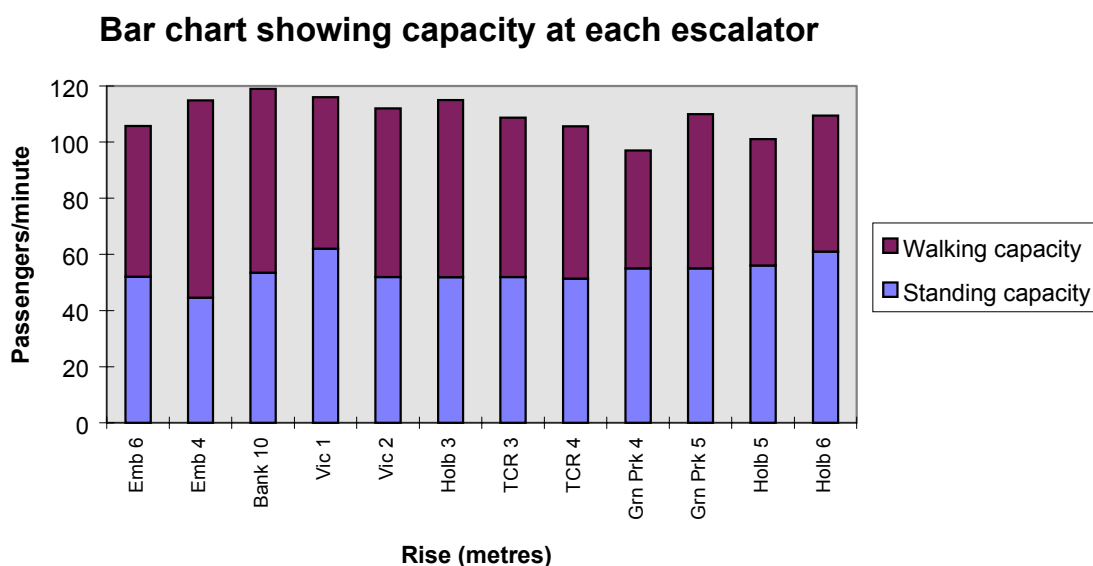


Chart 6.4 - Capacity at each escalator

- 1) Holborn 6 appears to have a higher capacity than the adjacent escalator, 5. This higher capacity is shown in both the walking and the standing figures. It is believed that this is because escalator 6 is close to the entrance from the Central line (entrance B) and there is little to slow the traffic in between, whereas people from entrance A have already been slowed down by the previous escalator, have to cross people from escalator 4

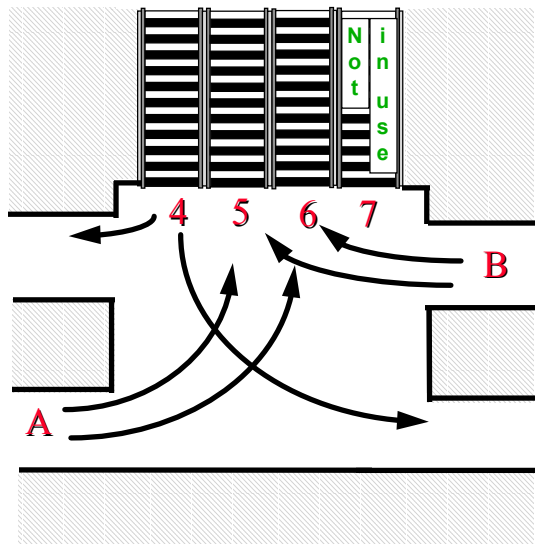


Figure 6.4 - Holborn escalators 4-7

and a lot of people from the Piccadilly line are actually changing on to the Central line anyway and therefore do not need to go up escalators 5 or 6.

- 1) One other escalator that is unusual in terms of its total capacity is escalator 10 at Bank station. This high capacity is due to a slightly higher than expected standing capacity and a higher than expected walking capacity. There are two possible reasons for this:

- the very simple layout of the station. There was no opportunity for passengers to go in different directions and cross each other, and there is only a straight corridor to be negotiated.
- the narrow stairs had the effect of taking a few of the people who want to walk. Therefore, the common problem of people stepping from the standing side to the walking side was reduced.

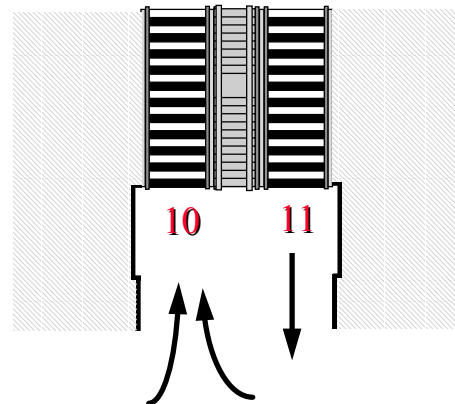


Figure 6.5 - Bank escalator 10

### 6.2.5. The effect of non-commuters

In this section the question examined is whether commuters are more efficient passengers than non-commuters. It is generally presumed that commuters will be able to best maximise capacity because of the following reasons:

- They know where they are going because they do the journey every day. Other passengers may stop in awkward positions to confer, read signs or maps.
- Time is of value to commuters. They either don't want to be late for work or want to get home as soon as possible, they want to minimise travel time as far as they can. Other passengers will usually not be in a hurry and are therefore less likely, for instance, to walk up escalators.
- Commuters are used to travelling on escalators and therefore are less likely to hesitate as they approach escalators.
- Commuters are less likely to be elderly, mobility impaired or travelling with children or luggage, all factors which may slow down passengers.

Unfortunately, there are not many stations and not many times of the week when escalators get very busy with the majority of travellers not being commuters. Two stations which fit the bill were Leicester Square and Tottenham Court Road, both on a Friday night. By contrast, all other readings at up escalators were taken at times when the great majority of the travellers were commuters.

The data was included in a multiple regression, the results of which are given below:

- Non-commuters are more likely to stand, the number of standees at capacity increases by 3.6 ppm. This result is significant with a p-value of 0.024.
- The number of walkers at capacity decreases by 10.9 ppm. This is a very significant result and tallies with the logical assumption that non-commuters, being in less of a hurry, are less likely to walk up escalators.
- Overall, therefore, the effect of non-commuters is to decrease the capacity of an escalator by over 7 ppm.

### **6.3. Conclusion**

In this section the main factors which have an effect on capacity are included in one multiple regression. The ‘open approach’ and ‘next to a corner A escalator’ factors are not included because they do not appear to be significant. Also the non-commuter escalator readings are not included because it is better to keep them separate and limit the number of regression factors. The regression factors therefore are:

- Rise (metres)
- Double escalator (where =1 means that an escalator is one of a pair, =0 otherwise)
- Corner A escalator (where =1 means an escalator is next to a corner A, =0 otherwise)

#### **6.3.1. Standing data**

As has already been established, only the rise significantly affects the numbers standing. The other factors discussed above have no impact. If the open approach on the right hand side is included this leads to an increase in capacity of about 1.8 passengers, but this is not a significant result, p-value = 0.14. If the majority of passengers are non-commuters, capacity will increase by 3.6 ppm.

Standing capacity (in terms of passengers per minute on a 1000 mm wide escalator travelling at 73.2m/min) =  $41.27 + 0.73 \cdot \text{rise (metres)}$

This gives an adjusted  $R^2$  value of 81.00% and normally distributed residuals. The factors are highly significant and there is also a 95% level of confidence that the effect of rise is between 0.49 and 0.96.

#### **6.3.2. Walking data**

Walking capacity (in terms of passengers per minute on a 1000 mm wide escalator travelling at 73.2m/min) =  $83.49 - 1.20 \cdot \text{rise} - 8.05 \cdot (\text{double escalator}) - 6.90 \cdot (\text{corner A escalator})$

The adjusted  $R^2$  value = 85%. The residuals are normally distributed. Once again, all the factors are significant at the 99% level but the 95% confidence intervals on the effect of the factors are larger than with the standing data. The findings are listed below:

- Having a double escalator reduces capacity by 8.05 ppm on each escalator, this is highly significant,

- The existence of a corner A reduces capacity of the closest escalator (the corner A escalator) by 6.90 ppm. Note that this is not as high as 11.07 passengers as previously stated, as much of the difference is due to the fact that these escalators are double escalators,
- There is some evidence to suggest that this is partly explained by the fact that the escalator next to the corner A escalator has an increased walking capacity of nearly three passengers, but this is far from conclusive. Even if this is not the case, it would seem that the effect of corner A is not as significant as the effect of having a double escalator.
- As no factor other than rise appears to have an effect on the capacity of the standing side of an escalator, it is reasonable to say that the effect these factors have on the walking capacity is roughly equal to the effect they have on total capacity.

Note, that if the open approach on the left side of the escalator is also included, the findings are as follows:

- The effect of a corner A reduces capacity by only 4.66 ppm. Note that this is lower than above as part of the difference can be attributed to the fact that a corner A escalator is not open on the left hand side,
- Having a double escalator reduces capacity by 10.12 ppm,
- Having an open left side increases capacity by approximately 4 ppm, although this is not significant, p-value = 0.13.

Finally, if non-commuters are largely using the escalator, the capacity of the walking side will be decreased by 10.9 ppm.

#### **6.4. Total capacity**

Total escalator capacity in terms of passengers per minute is the sum of the walking and standing capacity:= 124.76 - 0.47\*rise - 8.05\*(double escalator) - 6.90\*(corner A escalator).

This total capacity can be compared to that found by Mayo (1966). His regression equation, in passengers per minute, is:

$$\text{Capacity (max.)} = 1.329s - 0.0055s^2 - 0.875h + 0.0112t + 0.0075hs - 11.20$$

Where s = escalators speed in feet per minute, h = vertical rise in feet and t = traffic flow in passengers per hour.

Escalator speed is now fixed at roughly 145 feet per minute. Therefore:

$$\text{Capacity (max.)} = 65.8675 + 0.2125h + 0.0112t$$

This predicts that as vertical rise increases, capacity will increase which does not agree with the findings in the present report. Mayo's original equation should perhaps be further refined to ensure that the effect of height\*speed does not outweigh the effect of height. One possible such refinement would see - 0.875h +0.0075hs be replaced by - xh(1 - hs/K).

Where x is an unknown parameter and K is the reasonable maximum hs. This would ensure that the effect of vertical rise would always be negative but at higher speeds this effect would be less.

## 7. ANALYSIS OF DOWN ESCALATOR DATA

The down escalator data does not give the conclusive results that appeared in the up escalator data. A list of the differences in collecting data at up and down escalators is given in section 3.3. In the analysis below a total of seven escalators are considered because these were the only escalators where capacity was reached. Attempts were made to take data from fifteen escalators. See for a table of the full results

### 7.1. The non-walking 'walking' side

Once down escalators get beyond a certain traffic level, 'walking' passengers are, in fact, not walking. On reaching the bottom of the escalator passengers are not able to get away fast enough and as a result the passengers behind them have to stop walking to avoid bumping into them. This effect gradually works its way back up the escalator so that eventually the only time people can walk is when they first get on the escalator. This is the case on all escalators although on some escalators it happens with lower passenger flows than at others.

It should not be surprising that this happens because it can be shown that walking passengers are likely to be moving at a faster speed on the escalator than when they get off. The average vertical walking speed on down stairs is 0.34 metres/second and escalators are thought to have a very similar vertical walking speed to stairs.

- This works out as an average diagonal speed of 0.68 metres/second.
- Add this to the average escalator speed of 0.72 metres/second and we get a combined speed of 1.40 metres/second.
- Compare this with the horizontal walking speed of 1.34 metres per second and it should be clear that passengers will not be able to move away as fast as they come off the escalator.
- Passengers often pause briefly on alighting an escalator in order to ensure their foot placement is correct. This compounds the problem.
- As people find themselves having to stop on the down escalators, many people seem to move as far forward as possible which means standing directly behind the person in front. On reaching the end of the escalator they have to wait for that person to move well out of the way before being able to move themselves.
- Therefore, once one person has to stop before getting off the escalator, the problem will get worse rather than better.
- This does have the interesting side effect that people are generally standing closer together than the normal alternate step.

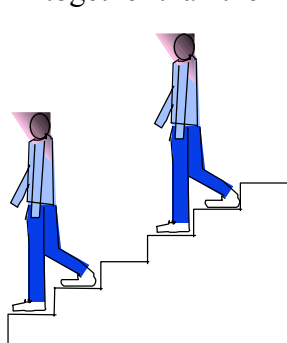


Figure 7.1a: Passengers walking down freely

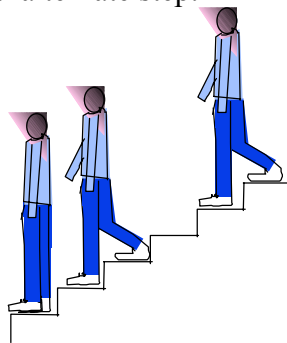


Figure 7.1b: One passenger stops and other passengers move as far forward as possible

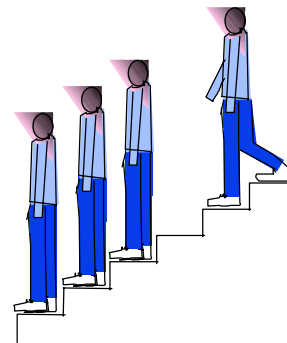


Figure 7.1c: More passengers have to stop, having moved as far forward as possible

Figure 7.1 - Passengers having to stop on down escalators

Figure 7.1 shows a passenger stopping and other passengers moving as far forward as possible and then standing directly behind him. Standing directly behind someone would appear to infringe his/her personal space (as discussed earlier) but this is perhaps less true on a down escalator. It could be argued that people are not so much bothered about having somebody close to them but rather that they do not want to have somebody immediately in front of their face.

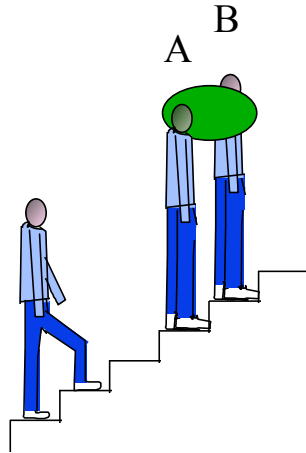


Figure 7.2a: Up escalator

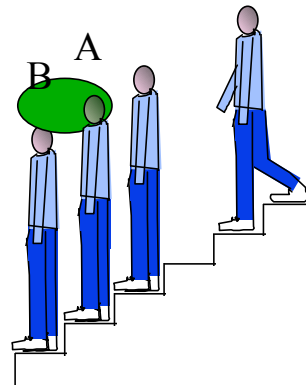


Figure 7.2b: Down escalator

*Figure 7.2 - Passengers facial ellipse*

If it is argued that the most important part of an individual's personal space is that bit directly in front of his/her face, then this can be represented by the ovals in the diagram above. On the up escalator, passenger B is directly in front of the face of passenger A, which people dislike and is a definite invasion of passenger A's personal space. However, on the down escalator, passenger A's head is clear. It is around the head where people are most concerned with maintaining their personal space and therefore people will stand closer together on down escalators than on up escalators. Note that this is a refinement of Fruins' human ellipse

That people do not generally stand closer together on the 'standing' side of a down escalator suggests that personal space is not the only reason why people do not stand on every step of an escalator. Another reason would be the time it takes people to board an escalator, people cannot board an escalator fast enough to get on the step behind the passenger in front. This can only be done by walking for the first few steps. This is what Fruin (1987) described as "the users inability to board the unit quickly enough".

## 7.2. The results

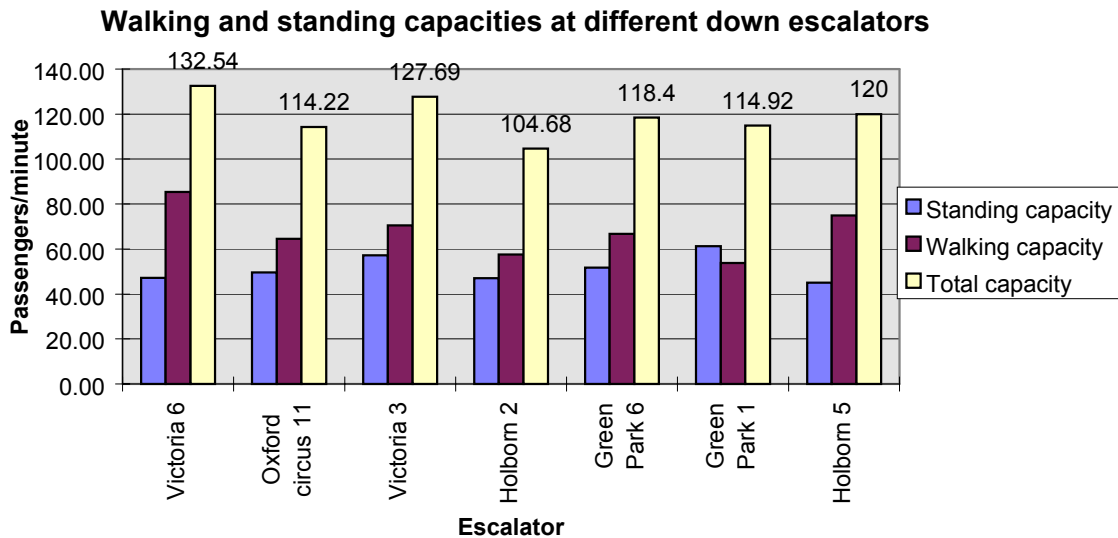


Chart 7.1 - Chart of capacities of different escalators

In the above chart the escalators are arranged in order of rise with the shortest being Victoria 6. There is no obvious relationship between rise and capacity. The total capacities do vary widely, between 104 and 132 ppm, as does the proportion walking. It is proposed in the following section to look at some of the individual escalators, find reasons why they give unusual readings and then try to find some uniformity in the results.

### 7.2.1. Holborn 2

This has a particularly low capacity despite being very busy because of the temporary layout of the approach to the escalator.

### 7.2.2. Green Park 1

This escalator is unusual in that it is the only escalator where more than half of the passengers choose to stand. While there were a lot of non-commuters (who certainly seem more likely to stand than commuters), there is no reason to suppose that the passengers would be any different from those using escalator 6 at Green Park as the two sets of readings were taken at similar times. Once again, it is believed that this is due to the approach to the escalator which encourages people to use the standing side rather than the walking side of the escalator. Once again these results will not be used in further analysis.

### 7.2.3. The effect of non-commuters

With the removal of two unusual results, we now have only five data points from which to derive conclusions. The effect of non-commuters would appear to be a large decrease in numbers.

	Commuters	Non-commuters
<b>Standing capacity</b>	49.81	50.69
<b>Walking capacity</b>	76.93	65.63
<b>Total capacity</b>	126.74	116.31
<b>Proportion walking</b>	0.61	0.56



### 7.2.4. The effect of rise

There is no obvious link between rise and capacity even after non-commuters are taken into account, such as in a multiple regression. The data from stations with mostly commuters and stations with mostly non-commuters are separated and is shown in charts 7.2 and 7.3.

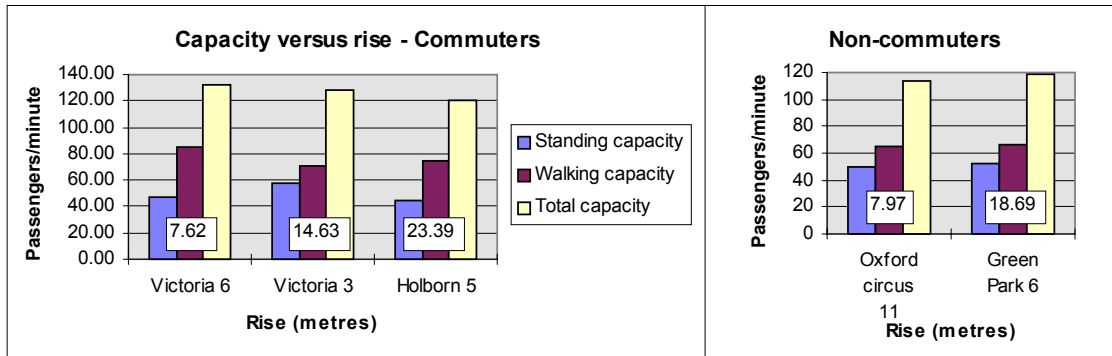


Chart 7.2 - Commuter escalators

Chart 7.3 -Non-commuter escalators

Once again, the escalators are in order of rise with the shortest escalator first. The data from the commuter escalators would appear to indicate that at a greater rise, capacity is slightly lower but this is far from significant and with only three data points no conclusions can be drawn. The data from the non-commuter escalators do not back up these findings.

### 7.3. Conclusion

In conclusion:

- there is not enough evidence to support the theory that rise has an effect on capacity of down escalators.
- there is also no indication that any permanent station layout has an effect on capacity except that the majority of passengers should approach an escalator from head on rather than from one of the sides.
- Passenger type does have a significant effect on capacity, non-commuters leading to a decreased capacity of about 10 ppm.

## 8. STANDING ON BOTH SIDES OR WALKING ON ONE SIDE OF AN UP ESCALATOR - WHICH IS BETTER?

The question being asked here is whether capacity would be greater if people stood on both sides of the escalator.

**Standing and Walking capacities at different rises**

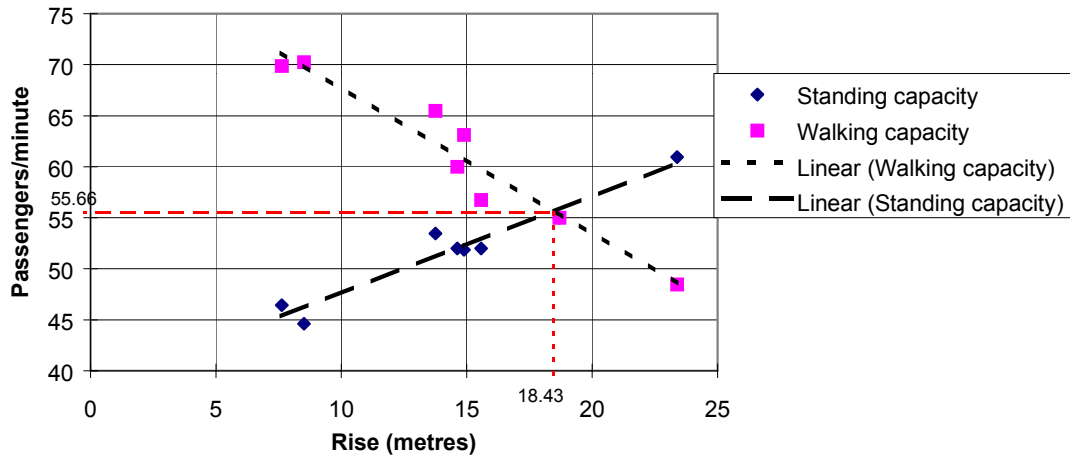


Chart 8.1 - Standing and walking capacities of up escalators

- At first glance the above chart would appear to indicate that until a rise of 18.43 metres, it would be beneficial to allow walking on one side of the escalator. This would give a capacity of 55.66 ppm on each side of an escalator.
- However, on further reflection it is clear that this is not the correct solution. As long as there is a walking side there will be interaction between the walking and the standing sides which explains why the standing data varies with the rise. Because of this variability there is no way of knowing what the standing capacity would be if there were no walking side.

### 8.1. Experiment at Holborn

One station, Holborn, does have a policy of asking passengers to stand on both sides of the up escalators once they get busy. The author, therefore, returned to Holborn station and asked the supervisor to emphasise this policy as far as possible. As a result, there were customer announcements approximately every two minutes when the escalators were busy, asking passengers to stand on both sides of the up escalators. However, passengers still refused to stand on both sides and it was only possible to take two readings when people were standing on both sides. Below is a list of the findings all made at escalator 3:

- 1) The great majority of people paid no attention to the customer announcement. This was not a reflection on the announcement which was clear and to the point. Passengers ignored it because
  - they thought it was wrong and that capacity would be greater if they walked, and/or
  - on reaching the escalator they wished to minimise their own travelling time and this was best done by walking rather than standing.
- 2) On the two occasions when passengers were standing on both sides the following results were found:

- an average of 49.4 passengers stand on the standing side per minute (comparable with the norm at escalator 3),
  - an average of 75.6 passengers stand on the walking side per minute (roughly ten passengers more per minute than would walk on the walking side).
- 3) That there were large differences between the two sides of the escalator shows that even during the two periods when people were standing on both sides, passengers were not treating both sides as standing sides. In fact:
- the reason passengers were standing was because one or two individuals stood and therefore forced everyone behind them to stand,
  - passengers on the walking side were continually trying to move forward and in both cases were eventually able to walk again as obstructing passengers were persuaded to either start walking or move over to the standing side,
  - The great majority of passengers wanted to walk and this was clear in their behaviour even when they were being forced to stand.
- 4) Having a walking side does have the advantage that people in a rush (who probably place a higher value on their time) can proceed quickly. It is perhaps a useful way of separating different types of passengers (commuters vs. non-commuters or those in a rush vs. those with time to spare) whilst keeping both happy.

This experiment at Holborn was not successful in indicating what the capacity of an escalator would be if passengers were persuaded to stand on both sides for anything more than short periods of time. To find out the capacity if passengers treated both sides of an escalator as standing sides it would be necessary to:

1. use data from equally busy escalators on railway systems where it is the norm to stand on both sides of an escalator. This data would need to be collected in the same way and even then may not be equivalent to data collected with London commuters.
2. Collect sufficient data to allow the construction of a simulation model of pedestrian behaviour on and around escalators. Collection of such data would be very time consuming.
3. Try and find the capacity from the theory. An attempt is made below.

## 8.2. Theoretical capacity of people standing on both sides

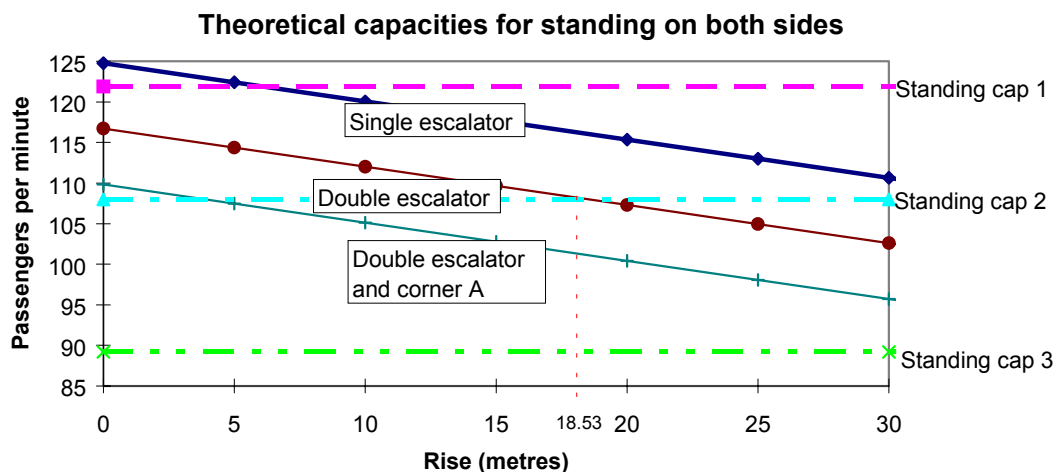


Chart 8.2 - Theoretical capacities for standing on both sides

The following table explains the lines on the above chart:

<i>Line name</i>	<i>Description</i>
<b>Single escalator</b>	This represents the capacity of a single escalator at different rises
<b>Double escalator</b>	This represents the capacity of one of a double bank of escalators
<b>Double escalator and corner A</b>	As above but also a corner A escalator
<b>Standing cap 1</b>	Double the maximum recorded capacity of the standing side
<b>Standing cap 2</b>	Capacity if each person uses two steps
<b>Standing cap 3</b>	Double the minimum recorded capacity of the standing side

Standing cap 1 and 3 represent the full range of possible capacities of an escalator with passengers standing on both sides. Both are unlikely in themselves because when they were recorded it was noted that people were stepping from the walking side to the standing side or vice versa. It is the belief of the author that capacity of an escalator, travelling at 43.2 metres/minute, where people stood on both sides would be 108 ppm (standing cap 2) because that would allow an average of two steps per person on each side. This figure is also approximately midway between standing caps 1 and 3.

If this assumption is correct, then for a single escalator there will never be a rise at which standing on both sides would be preferable. For a double escalator with a rise greater than about 18.5 metres, capacity would be greater if people could be encouraged to stand on both sides. Finally, for a double escalator with a corner A, at all levels of rise to be found on the London Underground system, it would be advantageous to persuade people to stand on both sides.

### **8.3. Conclusion**

It is therefore concluded that :

- Passengers will not stand on both sides of an escalator simply because they are asked to.
- When passengers do stand on both sides capacity is high but this is only because the majority of passengers do not treat the left hand side as a standing side.
- However, except for short periods of time, passengers will not stand on both sides unless they are persuaded (such as through an advertising campaign) to treat both sides as standing sides.
- If passengers could be persuaded to treat both sides as standing sides, capacity would not be so high and, if the assumptions made are correct, it would only be advantageous for high rise double escalators and for corner A double escalators.
- To impose such a selective policy would be even more difficult than persuading passengers to stand on all escalators and the benefit gained would be minimal.

## 9. EXTENSIONS AND SCOPE FOR FURTHER WORK

To move towards a policy of standing on both sides would be unpopular and would penalise those who are most rushed and those who place most value on their time.

The conclusions made in this paper are generic and can be applied to escalators of width 1000 mm, speed 43.2 metres per minute and where passengers stand on the right and walk on the left. It would be expected for the general results to be applicable to escalators at all speeds but the exact percentages may vary. These results are not applicable to escalators where passengers stand on both sides.

- 1) Rise affects the capacity of up escalators. Rise has a negative effect on the capacity of the walking side but a positive effect on the capacity of the standing side. The effect on the walking side is greater than the standing side and overall, for every metre in rise, capacity is reduced by 0.47 ppm.
- 2) Up escalators, which are one of a pair, do not have the same capacity as single escalators. Their capacity is approximately 7-8% lower than the equivalent single escalator, all of this effect is seen in the walking data.
- 3) The approach to an up escalator can have an effect on the capacity of that escalator
  - A corner A (explained in section 6.2.1) reduces capacity by about 5%, all on the walking side.
  - Escalators with an open approach seem to have higher capacity than average, both on the walking and standing sides, although this is neither significant in capacity terms or statistically.
  - There is some evidence, contrary to this, that a corridor effect tunnels people to the escalator and is able to provide higher capacity. This situation is achieved where up and down escalator flows are kept largely separate and there is only a single up escalator. This way, there is little interaction between passengers trying to go in opposite directions or crossing each other.
- 4) Passenger type has an effect on capacity. This is true for both up and down escalators. When passengers are largely non-commuters, capacity is reduced by 8-9%. The effect appears to be greater on down escalators because on up escalators some of the reduction in walking capacity is counterbalanced by an increase in the standing capacity.
- 5) An experiment at Holborn revealed that passengers are unlikely to be persuaded, on an ad hoc basis, to stand on both sides of an escalator even if that were considered to be advantageous. Through theoretical analysis, it is concluded that standing on both sides may be preferable in terms of maximising capacity at a limited number of escalators, but as it appears to be so unpopular, there would be little hope of imposing such a policy.

### 9.1. Recommendations

- The capacity figure of 120 ppm as used by pedestrian simulation models at present is at the upper limit for capacity of up escalators. If a single figure is to be used it should be 110 ppm.
- It is recommended that a variable rate be used because of the large differences in capacity. For instance, the predicted capacity of a 24 metre rise escalator which is

one of a pair and has a corner A is 98 ppm compared with 120 ppm for a single 10 metre rise escalator without a corner A.

- For down escalators, 120 ppm would appear to be an understatement, 125 ppm would be more accurate. Whether this need be a variable figure is not certain due to the lack of data.
- With the increasing importance of off peak flows, this report also highlights the fact that non-commuters lead to lower capacities than commuters, by approximately 8-9%.

Other recommendations are the following:

- To maximise the capacity of an escalator, the approach to an escalator should be kept open but should also be orderly. Whilst, it is helpful for people to approach the escalator from all angles and not be impeded by factors such as a corner A, it is also important that cross flows (caused by a combination of two escalators side by side and more than one angle of approach) and opposing flows (caused by passengers from an opposing escalator) are kept to a minimum.
- No attempt should be made to persuade passengers to stand on both sides of an escalator. Such a policy would only be advantageous at a limited number of escalators and would in any case be very difficult to enforce.

## **9.2. Recommended further work**

- 1) Further work could be done to establish the validity of the suggestion that an open approach increases capacity of an escalator. Both this study and Mayo's work suggest this but in both cases there is not enough data for this to be a significant result. However, the present study also suggests that even if this is true, the improvement may not be very large.
- 2) Further work needs to be done on the capacity of down escalators. The problem encountered by the author was that the down escalators rarely got busy enough to be at capacity. If more data at a wider range of escalators could be found there may turn out to be other factors affecting capacity. On the walking side of an escalator passengers always stop walking once capacity is reached and therefore, the capacity at which they are forced to stop walking is of importance. It is the suspicion of the author that the layout of the station as people get off the escalator could be of significance in determining escalator capacity. An open layout will allow people to get away faster and will therefore increase capacity.
- 3) It would be interesting, if enough data could be found, to quantify the effect of passengers going in opposite directions. In this report, the effect of two escalators side by side has been quantified, but the effect of opposing traffic flows has not.
- 4) Finally, it is recommended that more work is done in determining the true capacity of escalators where people stand on both sides. This would be most easily done by using data from escalators in transport systems where that is the common practice.

## **10. BIBLIOGRAPHY**

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