TRANSPORT FOR LONDON	
Subject:	**Greenwich Foot Tunnel**
Date:	**28th November 2016**

1 Background

1.1 Transport for London is seeking to understand the maximum capacity for carrying bicycles through the Greenwich Foot Tunnel at various times of the day and week. Cycling continues to grow in London, and the lift capacity at Greenwich Foot Tunnel represents a pinch point in the cycle network at peak times.

1.2 The aim of the surveys was to understand the following:

- Does queuing currently occur at peak times in the foot tunnel, and how significant are these queues?
- What proportion of cyclists and pedestrians choose to use the stairs rather the lift? Is this behaviour linked to the capacity of the tunnel?
- What is the relationship between the number of users, lift cycle times and the potential hourly throughput of the lifts?

2 Methodology

2.1 The Royal Borough of Greenwich enabled Transport for London to conduct observational surveys of the lifts using footage from its CCTV cameras in the tunnel and lifts. TfL staff conducted the observational surveys in the CCTV control room of the borough using footage from Tuesday 4th October, Wednesday 12th October and Sunday 9th October.

2.2 The following time periods were selected for observation from flow data collated from previous CCTV counts:

- Weekday morning peak 07:15 to 09:15 (northbound peak flow of cyclists towards Canary Wharf)
- Weekday evening peak 17:15 to 19:15 (southbound peak cycle flow from Canary Wharf)
- Sunday 12:00 to 18:00 (highest weekend flow occurs on Sunday afternoon)

2.3 Two forms of observational survey were conducted.

2.4 Firstly, the number of pedestrians and cyclists choosing to use the stairs or the lift were recorded in 5-minute segments over the survey period.

2.5 Secondly, the actual lift cycles were observed and the following information recorded:

- Time of doors closing

- Direction (up/down)
- Number of pedestrians and number of cyclists in the lift
- Time of doors opening
- Lift dwell time calculated from the time of doors opening and closing
- Coding of the number of times the lift doors start closing but re-open again because somebody presses the button or blocks the doors
- Coding of the number of pedestrians and cyclists left queuing to board the lift immediately after the lift departs

3 Use of stairs and lift

3.1 The proportion of pedestrians and cyclists using the stairs varies by time period and direction (Table 1). The definition of users who *choose the stairs* includes those who initially check to see if the lift is coming and then change their mind due to queues or the duration of the waiting time.

3.2 In peak periods, it is observed that around one third of cyclists choose to carry their bicycles down the stairs, and 20% up the stairs. The profile of cyclists at the weekend is different and less than 10% choose to carry their bicycles on the stairs.

3.3 The proportion of pedestrians choosing to use the stairs rather than the lift is much higher than the cyclists. In peak periods, two thirds of pedestrians choose the stairs (a higher proportion descending than ascending). This proportion drops to under 40% at the weekend.

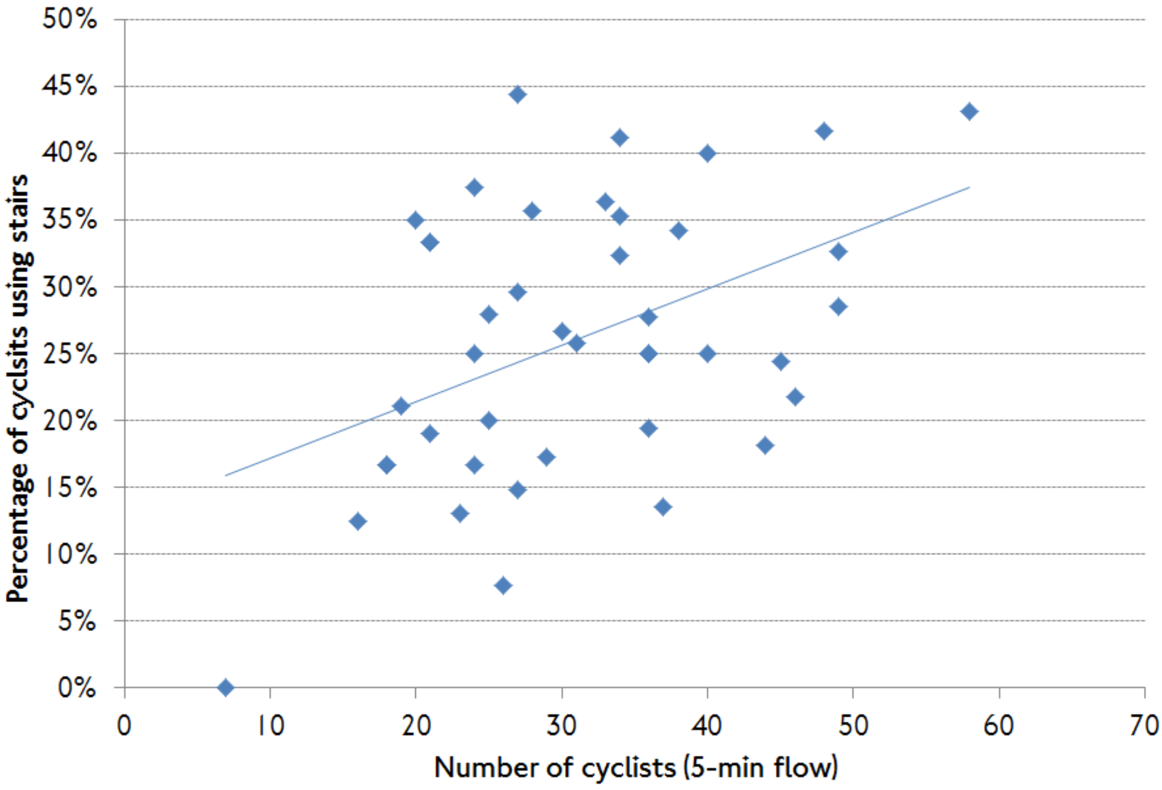
3.4 Note that users with mobility aids or pushchairs were recorded separately and all opted to use the lift.

Table 1 Use of the stairs by pedestrians and cyclists

Time period	Direction	No. of 5-minute periods observed	Proportion of cyclists using the stairs	Proportion of pedestrians using the stairs
Weekday AM	Up	13	22%	66%
	Down	13	34%	83%
Weekday PM	Up	13	21%	53%
	Down	13	33%	72%
Weekday total		**52**	**27%**	**66%**
Sunday	Up	25	8%	36%
	Down	26	10%	39%
Sunday total		**51**	**9%**	**38%**

3.5 There is a positive but statistically weak correlation between the proportion of pedestrians and cyclists choosing to use the stairs in a given 5-minute period and the total number of persons in that period. For example, the observed proportion of cyclists choosing the stairs in the morning peak is shown in Figure 1.

Figure 1 Proportion of cyclists (weekday morning peak)



4 Queuing

4.1 In these surveys *queuing* is defined as somebody who is left queuing for the next lift as the doors of the lift close. In the majority of cases, these are people unable to board the first lift due to crowding. Note that in practice this may also include some users who arrive as the doors are closing and choose not to re-open the doors as a matter of politeness to those already inside.

4.2 Table 2 shows the proportion of lift cycles where queues remain after the doors close by time period and direction.

4.3 The most intense peak of cycle flows occurs in the morning peak with the northbound commuter flow towards Canary Wharf. As shown above, willingness to use the stairs is less when travelling up. As a result, peak lift usage occurs in the ascending direction at the north bank of the Thames in the morning. Of the 140 peak lift observations, it was recorded that cyclists were left queuing in 31 cases (22% of lift cycles).

4.4 However, while the overall flow of lift users is lower, an even higher proportion of queuing (32%) was observed with cyclists travelling down on the south side. The latter fact could be explained by the fact that cyclists are arriving with a more random profile at the southern entrance, while their arrival rate at the northern lift is platooned by the southern lift. However, in the evening peak the pattern is reversed and the highest proportion of queuing (32%) is observed for cyclists waiting to travel up on the south side.

Table 2 Proportion of lift cycles where queues remain after doors close

Time period	North or south bank	Queues left after doors close (% of observations)	
		Down	Up
Weekday AM	North	3%	22%
	South	32%	0%
Weekday PM	North	16%	2%
	South	13%	32%
Sunday	North	4%	10%
	South	4%	7%

5 Analysis of lift cycle times and total capacity

5.1 At the busiest times of the morning peak it is common that volumes of between 12 to 15 cyclists enter the lift each cycle, and the observations of queuing occur at these levels of cycle usage. Thus the practical maximum carrying capacity of the lift appears to be in the region of 15 cyclists.

5.2 Table 3 summarises the peak direction throughput of the foot tunnel. The practical limit on the number of lift cycles in the peak hour appears to be around 30 cycles (average of 2 minutes per cycle).

5.3 As described above actual queuing may be more likely to occur when cyclists arrive at the foot tunnel with a random arrival profile. However, due to the differential in willingness to use the stairs when ascending, it is the upward lift capacity that is used to define total lift capacity. The maximum hourly throughput was observed in the morning peak (306 cyclists).

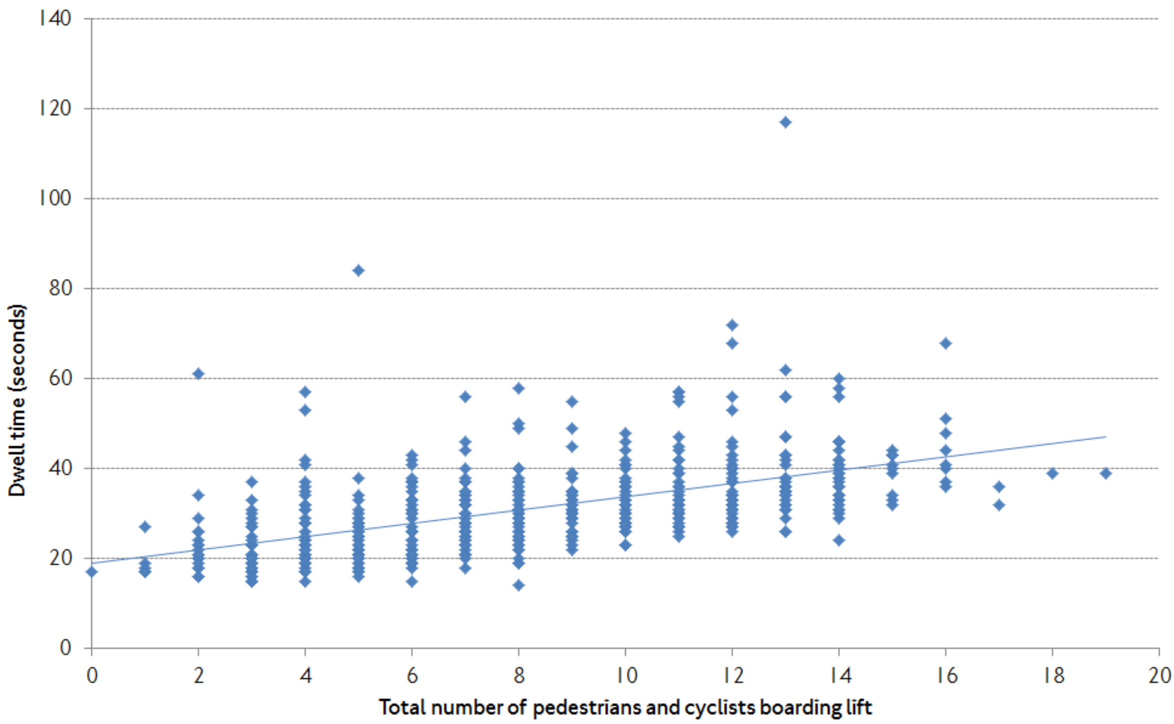
Table 3 Persons exiting the tunnel (peak directions by 15-minute period)

Peak direction	Time period	Lift cycles	Cyclists	Pedestrians	Total
Exiting the tunnel northbound AM	07:45-08:00	7	78	7	85
	08:00-08:15	7.5	77	6	83
	08:15-08:30	7.5	78	9	87
	08:30-08-45	7	74	8	81
	Peak hour (07:45-08:45)	**29**	**306**	**29**	**335**
Exiting the tunnel southbound PM	17:45-18:00	7.5	67	13	81
	18:00-18:15	8	66	17	83
	18:15-18:30	7	66	19	84
	18:30-18:45	7.5	60	10	70
	Peak hour (17:45-18:45)	**30**	**258**	**59**	**317**

5.4 In addition to 306 cyclists using the lift, it was calculated that 67 northbound cyclists in the morning peak (22%) use the stairs (see Table 2). The resulting combined northbound peak hour flow of 373 cyclists is consistent with recent northbound peak hour measurements (345 in Thames screenline counts summer 2015, and 363 in September 2016).

5.5 The relationship between lift throughput and the number of users is not a simple linear relationship since the lift cycle time is sensitive to the boarding and alighting time for cyclists in particular. As shown in Figure 2, there is a visible trend in the relationship between lift dwell time and the number of persons boarding the lift. This is due to the time taken for more bicycles to enter and turn their bicycles around in the lift. The overall statistical relationship is weak (R^2 = 0.29), although it is strongest for the peak periods where longer dwell times are solely related to high usage.

Figure 2 Lift dwell time vs total number of persons boarding (peak direction only)



5.6 Furthermore, the lift cycle time can be affected by the fact that if the button is pressed as the lift doors are closing, they will re-open. The statistical relationship between the number of times the doors re-open and lift dwell time is actually weak because it tends to occur in quieter times, and so the overall loading time is still equal or lower to a peak period when the lift fills completely. In practice, at very high usage levels where the lift is full and queues do develop, there is no reason for those waiting at the front of the queue to force the doors to re-open.

6 Estimation of theoretical lift capacity

6.1 A simple regression model of lift cycle time was developed to estimate theoretical lift capacity in a 15-minute period relative to the number of persons boarding in the peak direction (based on the morning northbound peak, ascending in the lift on the north bank of the Thames).

6.2 The equation is defined as follows.

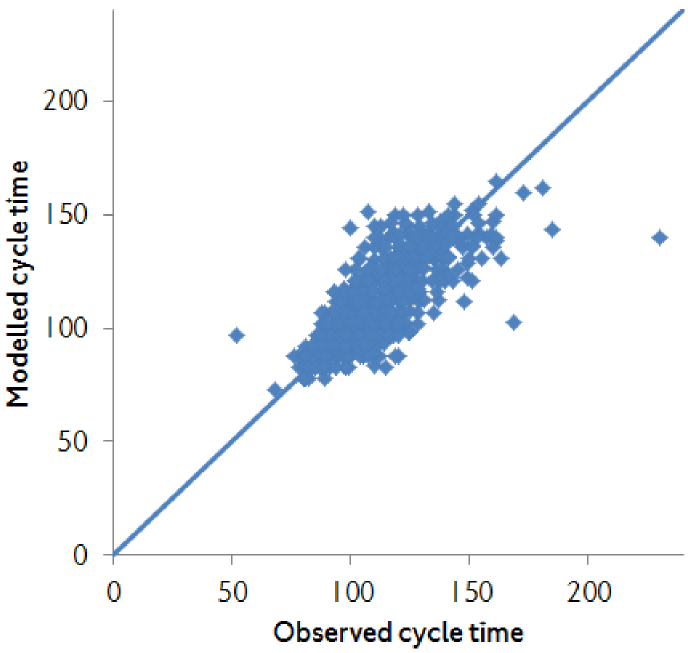
*Peak direction lift dwell time = fixed time + α * total persons + β * doors re-opened*

6.3 The following assumptions are made for the purpose of this calculation:

- The fixed time in the lift cycle needs is made up of
  - 23 seconds average lift running time in either direction (observed)
  - 35 seconds average lift dwell time in the counter-peak direction (observed)
  - 8 seconds assumed minimum lift dwell time
- The average number of pedestrians remains stable at 1 per cycle in the morning peak northbound
- The average number of door re-opens remain stable at 0.17 per cycle in the morning peak northbound

6.4 As shown in Figure 3, the regression model does explain variation in lift cycle time, although there are some outliers affecting the overall fit (R^2 = 0.55). This model uses a fixed time of 73 seconds, a value of 4.8 seconds per person boarding, and a value of 5.8 seconds per door re-opening.

Figure 3 Observed versus modelled cycle time in calculation of theoretical lift capacity



6.5 Several options to improve the model fit could be considered:

- It has been suggested that the inclusion of separate pedestrian and cyclist boarding numbers would improve the model fit. Indeed the PM peak observation period was selected with a view to getting a sample of observations with a higher proportion of pedestrians in the peak cycle hour to verify this. Yet as shown in Table 3, the proportion of pedestrians in the peak hour is still very low compared to cyclists.
- It would also be possible to estimate the dwell time in the counter peak direction based on user numbers as well. This might capture some of the non-linear effect that is likely to happen as longer queues generate longer lift cycles and vice versa (equivalent to the bunching effect of buses).

6.6 Based on the regression model of lift cycle time, the theoretical lift capacity can be estimated (Table 4). This suggests that at the maximum practical capacity of 15 cyclists per lift cycle in the peak direction (with the average of one pedestrian per cycle), it is possible to achieve 9.6 lift cycles in a 15-minute period, giving a peak direction throughput of 144 cyclists in the lift. However, the observed maximum throughput in peak periods indicates that 7-8 lift cycles averaging 12 cyclists per lift in a 15-minute period is practically possible. This suggests that the linear model under-estimates the effect of crowding in the lift boarding areas, which may increase dwell times exponentially when queues develop.

Table 4 Estimation of theoretical lift capacity

Peak direction cyclists entering per cycle	Est round cycle time (seconds)	Max cycles per 15-min	Theoretical 15-min lift capacity
1	79.8	11.3	11
2	80.8	11.1	22
3	81.8	11.0	33
4	82.8	10.9	43
5	83.8	10.7	54
6	84.8	10.6	64
7	85.8	10.5	73
8	86.8	10.4	83
9	87.8	10.3	92
10	88.8	10.1	101
11	89.8	10.0	110
12	90.8	9.9	119
13	91.8	9.8	127
14	92.8	9.7	136
15	93.8	9.6	144

6.7 On the basis of the above analysis, there are several ways of estimating maximum lift capacity (Table 5). Under current conditions, the lift is operating very close to capacity. If the currently observed number of lift cycles (29) would all carry 15 cyclists the maximum capacity would be 435. An alternative method is to use the theoretical 15-minute lift capacity and factor this up to a peak hour based on observed flows, which gives a capacity estimate of 411.

Table 5 Alternative estimates of maximum lift capacity

Lift capacity	Cyclists in the lift	Total cyclists including 22% using the stairs
Observed current hourly capacity equating to 29 lift cycles with mean ascending occupancy of 10.5 cyclists	306	373
Observed hourly lift cycles (29) * observed practical carrying capacity of 15 cyclists	435	531
Theoretical 15-min maximum lift cycles * 15-min to peak hour profile (3.28) * observed practical carrying capacity of 15 cyclists	411	501

7 Conclusions

7.1 On the assumption that the proportion of cyclists choosing to use the stairs will remain at 22%, the absolute maximum peak direction capacity of the foot tunnel is estimated at between 501 and 531 cyclists. It is proposed that an absolute cap of 516 cyclists is therefore assumed in the Cynemon assignment model.

7.2 While this constraint can be thought of as an absolute capacity constraint, it should be noted that in practice users will increasingly experience significant delays as demand builds towards this limit. It was observed that under current conditions around one third of peak direction cyclists in the peak hour do not board the first lift. While a throughput of 500 cyclists may be possible, the majority of users would experience queues and significant journey time delays as a result.

7.3 This note does not consider the safety issues of queuing in the tunnel or at the entrances. In practice terms, the safe capacity limit may be lower than 500 cyclists if additional measures are required to regulate flows safely.