

## **Evaluation of the Luas System Using the TCQSM Method**

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**ABSTRACT**

A new light rail system, the Luas, has been introduced to Dublin, the capital city of Ireland. Two lines form the system, one from the south and the other from the south west to the city center. At present they are not joined but plans are in place to link them in the near future. The first line is a year open since the end of June 2005 and the second is coming up to its first anniversary. The aim of the paper is to evaluate the performance of the new Luas service using the Transit Capacity and Quality Service Manual. The results of the evaluation suggest that for the most part the service gives a high level of service for the indicators considered. This is the result of a good design but also quite high standards of operational service levels the criteria for which is founded in a performance based contract.

## BACKGROUND

The Transit Capacity and Quality of Service Manual (TCQSM) (1) will be the basis for evaluation of the performance of the Luas Green Line in Dublin. The use of TCQSM will provide a consistent set of techniques for evaluating capacity as well as a comprehensive set of methods for assessing public transport services, facilities, and systems.

### Public Transport Capacity Measures

Public transport capacity depends on the size of the public transport vehicles and the frequency at which they operate. It reflects the interaction between passenger traffic concentrations and vehicle flow. It also depends on the operating policy of the public transport agency which normally specifies service frequencies and allowable passenger loadings.

The TCQSM defines person capacity as the maximum number of people that can be carried past a given location during a given time period under specified operating conditions; without unreasonable delay, hazard, or restriction; and with reasonable certainty (1). The maximum number of trains that can operate over a section of track in a given period of time, typically 1 hour, is called the Line Capacity (1). Minimum train separation and dwell time at the station with the highest passenger volumes will constrain line capacity. Dwell time is frequently the dominant factor in determining the minimum train headway and, thus, the line capacity. The three main components of dwell time are a) door open and close time, and time waiting to depart once the doors close, b) passenger flow time, and c) time the doors remain open after passenger flow ceases.

The TCQSM (1) defines person capacity as the maximum number of people that can be carried in one direction over a section of track in a given period of time, typically 1 hour, under specified operating conditions without unreasonable delay, hazard, or restriction, and with reasonable certainty.

Loading diversity provides us with important distinctions between theoretical capacity and the more realistic person capacity i.e. the capacity that can be achieved on a sustained basis. Three different types of loading diversity have to be considered as passengers do not load evenly into cars and trains over the peak hour. The three types of loading diversity are: diversity within a car, diversity among cars of a train, diversity due to the unevenness of passenger demand during the peak hour. In diversity within individual cars, for example, people will stand around doorways for quick exits and so the doorways will have the highest standing densities while the lowest densities will occur at the ends of the cars. The second type of diversity occurs in uneven loading among cars of a train. For example, cars that are closer to station exits and entrances will be more heavily loaded than more remote cars. The third and most important type of diversity is the unevenness of passenger demand over the peak hour. This aspect of diversity is measured by the *peak hour factor* (PHF), which is defined as:

$$PHF = \frac{P_h}{4P_{15}} \quad \text{Eqn 1}$$

where:  $PHF$  = peak hour factor;  $P_h$  = passenger volume during the peak hour; and  $P_{15}$  = passenger volume during the peak 15 minutes.

The theoretical capacity is the number of cars per hour per direction over a given section of track multiplied by the maximum design load of each car. The person capacity is generally lower than the theoretical capacity as the theoretical capacity does not take into account the variations in passenger arrivals and distribution.

The method chosen to estimate station dwell times is the "Mean Plus Two Standard Deviations" (1). Since it is maximum capacity that is the ultimate objective, only the upper limit is of interest. Dwell time data for one of the Luas stops will be analyzed using an Automatic Vehicle Location System (AVLS). Two standard deviations are used to ensure that the calculated controlling dwell time contains a sufficient allowance or margin to compensate for minor irregularities in operation.

The number of door channels affects station dwell times also. Station dwell time is related to the time required to serve all passengers through the busiest door. The greater the number of door channels, the less time required to serve a given passenger flow. Door channels can be provided through a combination of the number of doors and the width of those doors.

### **Quality of Service Measures**

Quality of service reflects the public transport-user perspective and should be measured by a quantitative measurement or prediction of how a public transport route, facility, or system is operating under specified demand, supply, and control (1). The TCQSM will be the basis for this evaluation. The quality of service indicator measures how successful an agency is in providing service to its customers. The TCQSM uses the concept of level of service (LOS) to quantify quality of service. Each quality of service measure is expressed on a scale from A to F, with A denoting the best quality of service and F representing the worst quality of service. The level of service ranges should reflect a user's point of view. Therefore, LOS A is not necessarily representative of optimum conditions from a public transport operator's point of view. The LOS F represents an undesirable condition from a user's point of view.

In evaluating the quality of the service provided by Luas the following factors will be investigated:

*Measures of availability:* Frequency of Luas, Hours of Service, Service Coverage of Luas and Accessibility of Luas

*Measures of quality:* Passenger loads.

*Measures of reliability:* Headway Adherence and missed trips.

## **Measures of Availability**

### ***Frequency***

The service frequency is defined by the Kittelson et al (1) as the number of public transport units (vehicles or trains) on a given route or line, moving in the same direction, that pass a given point within a specified interval of time, usually 1 hour. Headways of less than 10 mins represent a LOS A, between 10-14 mins LOS B, between 15-20 LOS C, 21-30 mins LOS D, 31-60 LOS E and greater than 60 mins LOS of F.

Timetables provided by Luas will be consulted in order to measure the frequency LOS of the Luas. From these the theoretical frequency of the Luas can be calculated. By evaluating AVLS data (location logged every 10 secs), supplied by the RPA, it will also be possible to determine the actual frequency of the Luas through statistical analysis of the headways between trams.

### ***Hours of Service***

The hours of service of operations are simply the number of hours during the day when the public transport service is provided along a route. The hours of service LOS are based on the number of hours the service is provided at least once an hour (corresponding to a minimum LOS E for service frequency). If a service is run for 19-24 hours per day it has LOS A, for 17-18 hours LOS B, for 14-16 hours per day LOS C, for 12-13 hours per day LOS D, 4-11 hours per day LOS E and 0-3 hours per day LOS F.

It is worth noting that hours of service LOS can vary by day and that the week day LOS would usually be higher than the LOS at weekends as schools/workplaces are usually closed on the weekends. Timetables provided by the Luas operator will be consulted in order to measure the hours of service LOS.

### ***Service Coverage of Luas***

Service coverage is a measure of the area within walking distance of the public transport service. The population or employment densities of area need to be taken into account when calculating the service coverage in an area. The TCQSM (1) defines the public transport-supportive area as the portion of service area that provides sufficient population or employment density to require service at least once per hour. When combined with frequency and hours of service, it helps identify the number of opportunities people have to access public transport from different locations.

### ***Accessibility of Luas***

Accessibility measures seek to define the level of opportunities and the transport options available to reach them (2).

## **Measures of Quality**

### ***Passenger Loads***

As with all public transport modes, passenger loads will vary at different times of the day. Peak times will have higher passenger loads than non-peak times. A poor level of service (i.e. crush load) may indicate the need to increase service frequency or vehicle size in order to reduce crowding and to provide a more comfortable ride for passengers. Passenger load LOS can be measured by time of day (peak and off-peak) or by the amount of time a certain condition occurs (some passengers must stand for up to 10 min).

By calculating the load factor and comparing this with the criteria of the Batelle Institute (3) and those of Pushkarev (4), an estimate of passenger load LOS can be found. The load factor is the number of passengers per seat.

Using the guidelines set out in the TCQSM and the equation set out below, the amount of area each passenger is allowed, the number of passengers per seat and thus the passenger load LOS can be calculated.

$$V_c = \left[ \frac{((L_c - 0.5L_a)W_c - 0.5D_n W_s D_w)}{S_{sp}} \right] + N \left[ \left( 1 - \frac{S_a}{S_{sp}} \right) \right] \left( \frac{L_c - La - D_n(D_w + 2S_b)}{S_w} \right) \text{Eqn2}$$

Where,

$V_c$  = Vehicle Capacity

$L_c$  = Vehicle Interior Length

$L_a$  = Articulation Length for Light Rail

$W_c$  = Vehicle Interior Width

$D_n$  = Number of Doorways

$W_s$  = Step Well Width

$D_w$  = Doorway Width

$S_{sp}$  = Space per Standing Passenger (m<sup>2</sup>)

$N$  = Seating Arrangement

$S_a$  = Area of Single Seat

$S_b$  = Single Setback Allowance

$S_w$  = Seat Pitch

The Batelle Institute (3) recommends comfort levels for public transport vehicles. The level of comfort is comfortable if the number of passengers per m<sup>2</sup> is 2-3, uncomfortable if the number of passengers is 5 per m<sup>2</sup> and unacceptable if this measure goes above 8. Pushkarev (4) suggests that gross vehicle floor area can be used as a readily available measure of car occupancy. He recommends that a 0.5 m<sup>2</sup> gross vehicle area per passenger is adequate, 0.35 m<sup>2</sup> is tolerable with difficulty and < 0.2 m<sup>2</sup> is totally intolerable.

### ***Measures of Reliability***

Headway adherence will be the main area used to evaluate the reliability of the Luas. This is a measure of the consistency of the interval between successive trams.

### ***Headway Adherence***

For a public transport service operating at headways of 10 minutes or less, headway adherence is used to determine reliability. The Luas is timetabled to run every 5 minutes at peak times, 7.5 minutes at certain times and 10 minutes at off-peak times. Here headway adherence - the time interval between the passing of the front ends or successive

public transport units (vehicles or trains) moving along the same lane or track in the same direction - becomes very important (*I*).

The measure is based on the coefficient of variation of headways of transit vehicles serving a particular route arriving at a stop. LOS A has a CV of <0.21, B has a CV of 0.22-0.3, LOS C 0.31-0.39, LOS D 0.4-0.52, LOS E 0.53-0.74 and LOS F >0.75. The headways of trams serving the Beechwood stop will be investigated using the AVLS data and the corresponding coefficient of variations will be calculated. The Coefficient of variation, CV, is determined as follows:

$$C_v = \frac{\text{standard deviation of headways}}{\text{mean scheduled headway}} \quad \text{Eqn 3}$$

Statistical analysis will be carried out on the AVLS data to determine headway adherence. As the frequencies of the trains differ during the day and on different days of the week the data will be split up into 3 sets: Weekdays (Monday-Friday), Saturday and Sunday.

### ***Missed trips***

Missed trips are those where the vehicle does not show up. From a user's perspective, a public transport system is reliable if the vehicle shows up when scheduled. On the Luas service, a user may not be able to obtain a trip either because the trip is denied or because the vehicle does not show up for the scheduled trip. Some trips can be denied if there is inadequate capacity. Trips not served must be assessed separately from denials. Frequent trip denials indicate that the system does not have enough capacity. Frequent missed trips can arise for a number of reasons, including trip scheduling that is too tight, an inadequate number of vehicles due to breakdowns, defects, or other reasons, insufficient number of drivers or a combination of these factors.

## **RESULTS**

### **Public Transport Capacity Measures**

Insufficient capacity can impact public transport service availability. If the train is full when it arrives at a stop, then this service is not available to the people waiting there. The effective service frequency for these passengers is reduced from what is implied by the schedule. They are forced to wait for the next vehicle or find another means of making their trip. The findings for the section between the Beechwood and Ranelagh stops on the Green line for the period 8.00 – 9.00 on a weekday are presented in Table 1. The data also suggests that there is a definite peak between 08:30 and 08:45 within the morning peak hour period. Outside this time there is spare capacity.

Table 2 shows the boardings and alightings at the St Stephens Green stop, the city center terminus, throughout the day:

### ***Peak Hour Factor***

The peak hour factor of 0.69 is comparable when compared with peak hour factors found in other cities. In Calgary, the PHF on the CTS is 0.62, in Denver on the RTD it is 0.75, in Philadelphia it is 0.75 and on TriMet in Portland it is 0.8.

### ***Dwell Times***

The estimated dwell time, using the mean plus two standard deviations method as explained earlier for the inbound trains was 46 secs. The estimated outbound dwell time was 43 secs. The mean dwell time was 28 secs for the inbound trains and 25 secs for the outbound trains. The maximum was 169 secs. Comparisons with estimated and actual dwell times in other systems, as shown in Table 3, confirm the Luas is performing well with only Edmonton having a shorter dwell time.

### **Quality of Service Measures**

#### ***Frequency of Luas***

Looking at the timetable, on weekdays the Luas runs every five minutes at peak times 7am-10am and 4pm-7pm giving a LOS of A. The service runs every 7.5minutes (8vehicles/hour) between the hours of 10am-4pm and 7pm-10:30pm, again with a LOS of A. A LOS of B is recorded between the hours of 5:30am-7am and 10:30pm-12:30am as the Luas runs every ten minutes. The service does not run between the hours of 12:30am and 5:30am giving a LOS of F. On Saturdays, Sundays and public holidays the Luas operates at different frequencies from weekdays. On Saturdays, the system runs every ten minutes between the hours of 6:30am-9:30am and from 7:00pm-12:30am. This gives a LOS of B. From 09:30am-7:00pm it runs every 7.5minutes giving a LOS of A. The service does not run between the hours of 12:30am and 7:00am on a Sunday morning resulting in a LOS of F. A LOS of B is provided on Sundays. Table 4 shows the measured inbound frequencies compared with the timetable times of the Luas.

#### ***Hours of Service***

The Luas service runs from 5:30am-12:30am for a total of 19 hours on weekdays, Mondays-Fridays giving a LOS of A. This means the service is available for most of the day. Workers who do not work traditional 8am to 5pm jobs receive service. Also late-evening public transport service is provided. On Saturdays and Sundays, a LOS of B is provided, meaning a late evening service is provided as well as through the day. On Saturdays the Luas is available 18 hours, from 6:30am-12:30am and on Sunday from 7:00am-23:30pm, a total of 17.5hours.

#### ***Service Coverage of Luas***

The service coverage is a measure of the area within walking distance of a public transport service. Combined with the other availability measures, the service coverage that a service provides gives a good indication of the opportunities people have to access the service. Along the Green Line there are 13 stops spread out along the 9km track at an average of 700m apart. This means that passengers living along the route will, on average, have to walk approximately 350m to their nearest stop. A total of 2000 park-and-ride spaces are located at Balally, Stillorgan and Sandyford on the Green Line. Sandyford has over 100 spaces for cars, Stillorgan over 300 and Balally over 400. There is also space for bicycles at Sandyford and Stillorgan.

Data showing employment and the population of zones in the area of the Luas was consulted. The census indicates that the overall population of Dublin increased from 1,058,264 in 1996 to 1,122,821 in 2002. The number of people employed in the area between St Stephens Green and Sandyford is 158,000 (5). Using the results from the



different electoral areas it has been calculated that Luas line B will be available, within 500m, to 75,434 persons over the age of 15 who live in the area.

The Green Line has an average weekly passenger number of 157,055 or 3020 passengers a day. According to the Railway Procurement Agency (6), 3,769,326 people used the Luas in 2004 (two lines), ranging from 130,504 to 216,211 passengers per week. Table 5 shows the number of passengers using the Green Line at particular times. Table 6 shows the average number of passengers to board the Luas at each stop along the Green Line between the hours of 8am and 9am.

### ***Accessibility of Luas***

Accessibility is defined as the measure of the capacity of a location to be reached by, or to reach a different location (7). Figures 1 and 2 show the accessibility before and after the opening of the Luas line. Noticeably the area with a yellow designation is much larger after the Luas has been implemented. Table 7 shows the number of residential units within each of the journey time zones; before the opening of Luas, after the opening of Luas Line B and the change between both sets of figures.

### **Quality of Service**

#### ***Passenger loads***

Using the method described earlier, a value of  $0.24\text{m}^2$  standing space per passenger at peak times and  $0.3\text{m}^2$  standing space per passenger at other times were calculated. This passenger load is described by Pushkarev (4) as "tolerable with difficulty". With 80 seats in a tram, at peak times (08:30-08:45) there are 3.7 people per seat and 3 people per seat at all other times. This is considered comfortable (3) passenger load for the Luas as "comfortable" while according to the TCQSM the passenger loading is at LOS of E. The Luas system has 4 passengers per square metre. This is par for LRT as both the Nottingham Express Transit (8) and the Manchester Metrolink (9).

#### ***Passenger Waiting Area LOS***

The passenger waiting areas at the Luas stops contain no steps or barriers to impede access. The platforms are 50m in length raised to 320mm and 3m in width. The Luas platforms provide  $0.85\text{m}^2$  space per standing passenger on the platform which is a LOS of C. These results are assuming 50% maximum occupancy on platforms and at these high levels standing and restricted movement would not be possible without disturbing others.

### ***Headway Adherence***

#### ***AVLS Results***

Statistical analysis of the headways for both inbound and outbound analysis was investigated from the 6th of October to the 21st of October 2004 at the Beechwood stop. The data was provided by the Railway Procurement Agency (6). The statistical analysis carried out included calculation of means, standard deviations, median, and the inter-quartile range. Of the AVLS data on which the statistical analysis was carried out there were a total of 4811 trains, of which 2413 were inbound and 2398 were outbound. The numbers of trains inbound and outbound on each day are presented in Table 8.

The theoretical headways are the frequencies advertised by Luas and are shown in Table 9. The actual inbound frequencies for weekdays are also compared with the

theoretical in Table 9. The coefficients of variation and LOS levels for inbound services are presented in Table 10.

### ***Missed Trips***

Missed trips are those service trips expected but which do not arrive. Table 11 shows the percentage missed trips for the period 14<sup>th</sup> June until 27<sup>th</sup> February for the Luas. Table 11 shows that the Luas had a LOS 1 until 9<sup>th</sup> September 2004. This is excellent for a new system which would be expected to encounter minor difficulties at the start of its operational life. From the 13<sup>th</sup> September until the 5<sup>th</sup> December a LOS of 3 was recorded. The service is still quite reliable and might entail one or two missed trips a month. From 6<sup>th</sup> December until the 27<sup>th</sup> February the Luas has a missed trips LOS of 1. This is a good results considering this period of time includes Christmas, the Christmas rush and higher patronage than usual.

## **CONCLUSIONS**

The evaluation of the new Luas system using a number of the TCQSM indicators has shown that generally the level of service presented is high. The level of utilization runs from between 48% to 88% during the peak periods. The measured dwell times are of the order of 25 secs. Timetabled frequencies are mainly in the LOS A and LOS B ranges and the measured frequencies are closely aligned to the timetabled ones. The measure of hours of service coverage is generally in the LOS A range. The missed trips LOS indicator gives Luas an LOS for some periods of measure and a LOS of 3 for others. The Luas system is run on the basis of a performance based contract. As this is a new method of public transport service delivery in Ireland, the performance results of the Luas, as measured here, indicate success and there is now interest in translating the lessons learnt in the delivery of the Luas system using this type of contract to other public transport services.

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## **REFERENCES**

- (1) Kittelson and Associates, KGH Group, Parsons Brinckerhoff Quade and Douglas, Hunter-Zaworski, K. TCRP Report 100. Transit Capacity and Quality of Service Manual, Produced for Transit Cooperative Research Programme, Second Edition, 2003.
- (2) Scottish Executive. Accessibility: Review of Measuring Techniques and their Applications. Scotland (2002).

- (3) Battelle Institute. Recommendations en vue di l'amenagement d'une installation de transport compte tenu de donnees authropometriques et des limites physiologiques de l'homme. Geneva 1973.
- (4) Pushkarev, B. and Zupan, J. Public Transportation and Land Use Policy, University Press, Bloomington Ind. (1977).
- (5) CSO (Central Statistics Office), Statistical Yearbook, Central Statistics Office, Dublin Ireland. (2002)
- (6) Railway Procurement Agency (RPA). Personal contact, RPA, Dublin Ireland, (2005)
- (7) RPA and DTO. Accessibility of Luas Report. Railway Procurement Agency and Dublin Transportation Office, 2004.
- (8) Nottingham Express Transit [www.thetram.net](http://www.thetram.net)
- (10) Manchester Metrolink [www.metrolink.co.uk](http://www.metrolink.co.uk)

Refs ([www.thetram.net](http://www.thetram.net) and [www.lrtta.org/Manchester/vehfact](http://www.lrtta.org/Manchester/vehfact)).

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<b>Time</b>	<b>Volume</b>	<b>Capacity</b>	<b>% Utilisation</b>
08:03	171	356	48%
08:08	165	356	46%
08:14	187	356	53%
08:17	194	356	54%
08:23	209	356	59%
08:35	293	356	82%
08:38	224	356	88%
08:43	281	356	79%
08:48	225	356	63%
08:58	269	356	76%

**Table 1. Level of utilizations between Beechwood and Ranelagh between 8:00 and 9:00am**

<b>Period</b>	<b>Inbound Passengers Off</b>	<b>Outbound Passengers On</b>
05:00 - 06:00	6	5
06:00 - 07:00	52	80
07:00 - 08:00	316	334
08:00 - 09:00	1446	432
09:00 - 10:00	1107	180
10:00 - 11:00	890	151
11:00 - 12:00	584	253
12:00 - 13:00	587	360
13:00 - 14:00	535	567
14:00 - 15:00	533	481
15:00 - 16:00	439	693
16:00 - 17:00	599	691
17:00 - 18:00	683	1113
18:00 - 19:00	906	896
19:00 - 20:00	764	853
20:00 - 21:00	340	783
21:00 - 22:00	195	686
22:00 - 23:00	97	369
23:00 - 00:00	96	382
00:00 - 01:00	71	242
<b>Total</b>	<b>10,246</b>	<b>9,551</b>

**Table 2. Passenger count at St Stephens Green (RPA, 2005)**

System & City	Mean	SD	Samples	Upper Limit (Mean + SD)	
				One SD	Two SD
BART (San Francisco)	46.3	12.0	290	58.3	70.2
CTS (Calgary)	35.7	15.7	91	51.5	67.0
ETS (Edmonton)	24.7	8.8	18	33.6	42.3
NYCT (New York)	30.7	20.9	380	51.6	72.6
PATH (New Jersey)	51.3	23.0	252	64.3	97.3
TriMet (Portland)	32.0	19.4	118	51.4	70.8
MTS (San Diego)	51.1	17.9	34	69.1	86.8
Muni (San Francisco)	50.4	21.8	75	72.2	93.9
TTC (Toronto)	36.6	23.2	322	59.8	83.0
SkyTrain (Vancouver)	30.7	7.2	82	37.9	45.1

**Table 3. Dwell times (TCQSM, 2003)**

<b>Day</b>	<b>Time</b>	<b>Theor Freq of Luas Inbound and Outbound</b>	<b>Actual Freq of Luas Inbound</b>	<b>Actual Freq of Luas Outbound</b>
Monday - Friday	05:30-07:00	10mins	8mins 42seconds	9mins 38 seconds
	07:00-10:00	5mins	5mins 20seconds	5mins 30seconds
	10:00-16:00	7mins 30seconds	7mins 18seconds	7mins 16seconds
	16:00-19:00	5mins	5mins 13seconds	5mins 17seconds
	19:00-22:30	7mins 30seconds	7mins 20seconds	7mins
	22:30-00:30	10mins	12mins 53seconds	10mins 31seconds
Saturday	06:30-09:30	10mins	10mins 33seconds	10mins
	09:30-19:00	7mins 30seconds	7mins 32seconds	7mins 35seconds
	19:00-00:30	10mins	9mins 49seconds	9mins 43seconds
Sunday	07:00-23:30	10mins	9mins 58seconds	9mins 57seconds

**Table 4. Theoretical and actual inbound frequency of Luas**



<b>Period</b>	<b>Green Line Boardings</b>
05:00 - 06:00	30
06:00 - 07:00	243
07:00 - 08:00	1390
08:00 - 09:00	3585
09:00 - 10:00	2013
10:00 - 11:00	1127
11:00 - 12:00	1042
12:00 - 13:00	1168
13:00 - 14:00	1449
14:00 - 15:00	1322
15:00 - 16:00	1949
16:00 - 17:00	1976
17:00 - 18:00	2530
18:00 - 19:00	2271
19:00 - 20:00	1784
20:00 - 21:00	1245
21:00 - 22:00	1032
22:00 - 23:00	611
23:00 - 00:00	556
00:00 - 01:00	351

**Table 5. Number of passengers each hour (RPA, 2005)**

<b>Section (from stop to stop)</b>	<b>08:00 to 09:00</b>
Sandyford to Stillorgan	312
Stillorgan to Kilmacud	522
Kilmacud to Balally	798
Balally to Dundrum	1105
Dundrum to Windy Arbour	1660
Windy Arbour to Milltown	1706
Milltown to Cowper	1964
Cowper to Beechwood	2017
Beechwood to Ranelagh	2218
Ranelagh to Charlemont	1910
Charlemont to Harcourt Street	1708
Harcourt St. to St Stephens Green	1409

**Table 6. Passengers at each stop for 8-9am (RPA, 2005)**

<b>Journey time to City</b>	<b>Before Residential units</b>	<b>After Residential units</b>	<b>Change</b>
0-10mins	6591	7119	528
10-20mins	5655	9831	4176
20-30mins	13847	13064	-783
30-45mins	15455	14844	-611
45-60mins	10748	9189	-1559
60-80mins	12900	11926	-974
80-100mins	4429	4337	-92
100-120mins	699	697	-2
<b>Totals</b>	<b>70324</b>	<b>71007</b>	<b>683</b>

**Table 7. Numbers of residential units within specific journey time zones of the city center, before and after the opening of Luas Line B (RPA and DTO, 2004)**

<b>Day</b>	<b>Inbound</b>	<b>Outbound</b>	<b>Total</b>
Monday	336	335	671
Tuesday	332	330	662
Wednesday	471	470	941
Thursday	491	488	979
Friday	331	329	660
Saturday	251	246	497
Sunday	201	200	401
<b>Total</b>	<b>2413</b>	<b>2398</b>	<b>4811</b>

**Table 8. Number of trains recorded for analysis (RPA AVLS data, 2005)**

<b>Day</b>	<b>Time</b>	<b>Theoretical Headway (seconds)</b>	<b>Sample Size</b>	<b>Mean</b>	<b>Median</b>	<b>Min</b>	<b>Max</b>
Monday To Friday	05:30-07:00	600	127	522	550	136	1007
	07:00-10:00	300	400	320	302	90	761
	10:00-16:00	450	592	438	439	115	983
	16:00-19:00	300	415	313	303	88	736
	19:00-22:30	450	343	439	436	124	1526
	22:30-00:30	600	84	773	848	326	1352

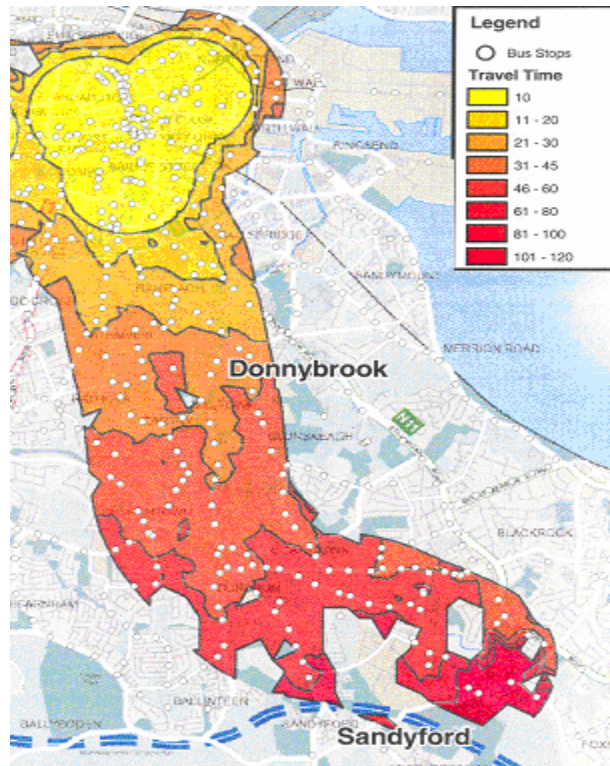
**Table 9. Theoretical headways as scheduled**

<b>Day</b>	<b>Time</b>	<b>C of V</b>	<b>LOS</b>
Monday To Friday	05:30-07:00	0.33	C
	07:00-10:00	0.37	C
	10:00-16:00	0.28	B
	16:00-19:00	0.33	C
	19:00-22:30	0.28	B
	22:30-00:30	0.29	B
Saturday	06:30-09:30	0.32	C
	09:30-19:00	0.27	B
	19:00-00:30	0.17	A
Sunday	07:00-23:30	0.16	A

**Table 10. Inbound Coefficients of Variation and LOS for Luas**

<b>Period</b>	<b>Percentage Trips Not Served</b>	<b>LOS</b>
14/6/04-17/7/04	0.08%	1
19/7/04-15/8/04	0.38%	1
16/8/04-12/9/04	0.52%	1
13/9/04-10/10/04	2.74%	3
11/10/04-07/11/04	2.89%	3
8/11/04-5/12/04	2.52%	3
6/12/04-2/01/05	1.00%	1
3/01/05-30/01/05	0.22%	1
31/1/05-27/2/05	0.55%	1

**Table 11. Missed trips LOS**



**Figure 1. Accessibility before Luas (RPA and DTO, 2004)**



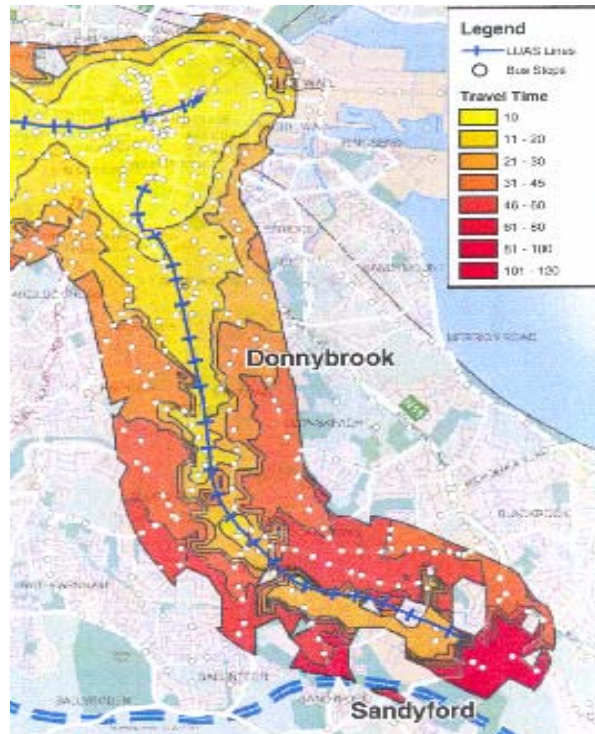


Figure 2. Accessibility After Luas (RPA and DTO, 2004)