LEES

MELBOURNE AND METROPOLITAN TRAMWAYS BOARD

ENGINEERING DEPARTMENT

PLANNING BRANCH

MAXIMUM CAPACITY OF A DOUBLE TRACK TRAMWAY.

JUNE, 1968.

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This study indicates that the ceiling for the capacity in one direction for a street tramway such as in Swanston Street is of the order of 11,000 passengers in one hour.

The corresponding capacities for an underground tramway as envisaged for Swanston Street would be 15,000 passengers in one hour for two bogie single unit trams and up to 25,000 passengers in one hour for coupled pairs of 3 bogie articulated trams.

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1. INTRODUCTION.

The purpose of this exercise is to determine the probable peak capacity of a double track tramway operated by trams of present day design, and to indicate the effect of duration of stop, length of vehicle and the number of vehicles that can be accommodated at a stopping zone at any one time.

2. PRESENT DAY TRAM PERFORMANCE.

The following results are taken from Testing Laboratory reports.

2.1 Braking.

Type of Braking	Speed	Mean Deceleration		
		No Load	Seated Load	Crush Load
Class SW6 Tram Car				
Max. service (full air and sand)	20 m.p.h.	7½ ft.sec.$^{-2}$	6½ ft.sec.$^{-2}$	4½ ft.sec.$^{-2}$
Emergency	20 m.p.h.	7½ ft.sec.$^{-2}$	9 ft.sec.$^{-2}$	7½ ft.sec.$^{-2}$
P.C.C. Tram Car No. 980				
Max. service (Dynamic)	20 m.p.h.	5.4 ft.sec.$^{-2}$	5.0 ft.sec.$^{-2}$	4.0 ft.sec.$^{-2}$
do	30 m.p.h.	5.3 ft.sec.$^{-2}$	5.0 ft.sec.$^{-2}$	3.9 ft.sec.$^{-2}$
Emergency	20 m.p.h.	10.3 ft.sec.$^{-2}$	8.9 ft.sec.$^{-2}$	7.3 ft.sec.$^{-2}$
do	30 m.p.h.	9.6 ft.sec.$^{-2}$	9.7 ft.sec.$^{-2}$	6.5 ft.sec.$^{-2}$

The following are considered to be a reasonable basis for scheduling of trams of present day design under "peak load" conditions.

Normal service braking (overall average)	4 ft.sec.$^{-2}$ (2.7 m.p.h.sec.$^{-1}$)
Emergency braking	7 - 10 ft.sec.$^{-2}$ (4.8 to 6.8 m.p.h.sec.$^{-1}$)

2.2 Acceleration.

A reasonable acceleration rate for present day trams is considered to be an average of 3 feet sec.$^{-2}$ (2 m.p.h.sec.$^{-1}$) from 0 to 30 m.p.h. This is however beyond the P.C.C. tram car No. 980 unless on a slight downhill grade. (Refer Planning Branch report "Preliminary Investigation of Track Curves Designed for Regions of Acceleration and Retardation - May 1966").

3. STOPPING DISTANCE.

Consider two cases for a vehicle making a service stop from a running speed of 44 ft.sec.$^{-1}$ (30 m.p.h.).

Case (i) The driver can overshoot a few feet without danger or inconvenience to passengers, such as pulling up at a stop with a clear track ahead. An overall deceleration of 4 $feet.sec.^{-2}$ has been assumed, to arrive at the following table of distances travelled.

Time After Brakes Applied	Speed	Distance Travelled After Brakes Applied
0	44 $ft.sec.^{-1}$	-
2 secs.	36 "	80 ft.
4 "	28 "	144 "
6 "	20 "	192 "
8 "	12 "	224 "
10 "	4 "	240 "
11 "	-	242 "

Case (ii) The driver has to stop immediately behind a vehicle already stationary. Assume that he brakes initially as if to stop say 50 feet short and when the speed has been reduced to 15 $ft.sec.^{-1}$ (10 m.p.h.) braking is eased off to extend the stopping distance the required amount. *(Refer diagram page 3)*

Distance X is given by $v^2 = 2AX$

if $A = 4\ ft.sec.^{-2}$

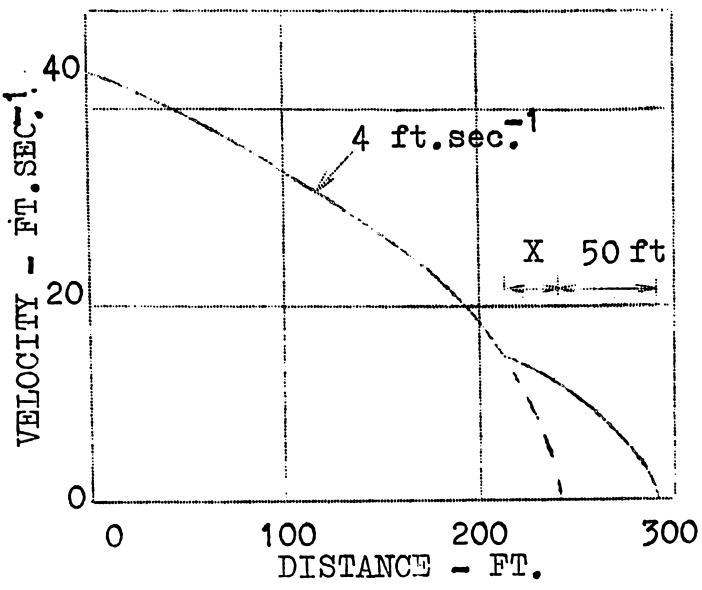
$$X = \frac{15 \times 15}{2 \times 4} = 28 \text{ feet.}$$

Deceleration to bring tram to rest from 15 $ft.sec.^{-1}$ in 50 + 28 feet is given by

$$A = \frac{15 \times 15}{2 \times 78} = 1.45\ ft.sec.^{-2}$$

From the above the following table of distances is derived.

Time After Brakes Applied	Speed	Distance Travelled After Brakes Applied
0	44 $ft.sec.^{-1}$	-
2 secs.	36 "	80 ft.
4 "	28 "	144 "
6 "	20 "	192 "
8 "	14 "	225 "
10 "	11 "	250 "
12 "	8 "	269 "
14 "	5 "	284 "
16 "	2 "	291 "
17.7	-	292 "



4. MINIMUM HEADWAY.

The minimum service headway should be such that a driver would be able to bring his tram to rest at any time using only normal service braking, without colliding with the tram ahead should it make an emergency stop. This will depend upon -

(i) the driver's reaction time,

(ii) the speed of the tram,

(iii) the speed of the tram ahead,

(iv) the grade of the track,

(v) the load on the tram,

(vi) visibility.

The driver's reaction time will depend on the position on the route such as -

(a) Leaving a Stopping Place.

An emergency brake application by the driver in front would be least expected, and an allowance of the order of 2 seconds is considered necessary.

(b) Coasting Towards a Stop.

The driver is anticipating brake applications but may be not an emergency stop. Allowance of the order of 1 second should be adequate.

(c) Brakes have Already been Applied.

The driver should already be concentrating on the tram ahead if it is also approaching the same stop, and the necessary allowance for reaction time would be very short.

The stopping distance in which the tram ahead will make an emergency stop will in turn depend upon its speed and hence the distance available for the following tram to make its stop.

Hence the minimum safe service headway should equal -

Distance travelled during reaction time

plus

Distance to make a reasonable service stop

minus

Distance that tram ahead may take to stop in an emergency.

The results of such calculations for minimum headways are as follows -

Speed of Tram Following	Speed of Tram Ahead			
	44 $ft.sec.^{-1}$	30 $ft.sec.^{-1}$	15 $ft.sec.^{-1}$	Zero
	2 SECONDS REACTION TIME			
44 $ft.sec.^{-1}$	240 ft.	290 ft.	320 ft.	330 ft.
30 $ft.sec.^{-1}$	-	130 ft.	160 ft.	170 ft.
15 $ft.sec.^{-1}$	-	-	45 ft.	60 ft.
	1 SECOND REACTION TIME			
44 $ft.sec.^{-1}$	190 ft.	240 ft.	275 ft.	290 ft.
30 $ft.sec.^{-1}$	-	100 ft.	130 ft.	140 ft.
15 $ft.sec.^{-1}$	-	-	30 ft.	45 ft.
	NIL REACTION TIME			
44 $ft.sec.^{-1}$	145 ft.	195 ft.	230 ft.	240 ft.
30 $ft.sec.^{-1}$	-	70 ft.	100 ft.	110 ft.
15 $ft.sec.^{-1}$	-	-	15 ft.	30 ft.

A minimum headway of 250 feet at 30 m.p.h. and 150 feet at 20 m.p.h. would be reasonable to cover all cases, for should a driver's speed be much in excess of that of the tram ahead he should quickly notice it and be on the alert.

5. TIME INTERVALS.

The capacity of a route is limited by the time cycle for the busiest stopping place. The length of this time cycle is the period from when the last tram of a group at the stopping place departs until the last tram of the next group departs (refer fig.2) and is made up as follows -

(i) Time interval from when the last tram of a group departs until the first tram of the next group stops.

This is determined by rate of acceleration of the former, the rate of deceleration of the latter, and the minimum acceptable headway. This is illustrated graphically on figure 1. Approximate minimum times are as follows -

Length of Tram	Number of Berths at Stopping Place			
	1	2	3	4
50 feet	17 sec.*	20 sec.*	20 sec.	23 sec.
100 feet	20 sec.*	23 sec.	26 sec.	
150 feet	20 sec.	26 sec.		

* Earlier brake application is necessary because of headway limitations.

(ii) Time interval of the stop of the second tram after the first has stopped.

Here the second tram must make an earlier brake application so that it may safely stop immediately behind the first tram as set out in section 3 above. (Ref. fig 2). For a tram service with 6 to 7 stops per mile the maximum speed between stops would be approximately 30 m.p.h. If a headway of 250 feet at this speed is assumed, the time interval would be of the order of 10 to 11 seconds.

The spacing of stops in Swanston Street is 760 feet that is approximately 7 per mile.

Assume 11 seconds.

(iii) Time interval for subsequent trams.

This depends on the minimum service headway at the maximum running speed so that this time interval will be of the order of 6 seconds (ref. fig. 2).

Assume 6 seconds.

(iv) Duration of stop.

This will depend on number of tram entrances, and degree of congestion both within and immediately outside the tram.

Three cases are considered viz.

10 seconds (more idealistic than practical).

20 seconds.

30 seconds.

6. SUMMARY.

The results are summarized below and also illustrated graphically on figs. 3, 4 and 5.

PEAK TRACK CAPACITY

Equivalent Length of Tram Feet	Length of Stop sec.	Cycle Time Secs.	Trams per Hour	Passengers per Tram	Passengers per Hour
ONE BERTH STOPPING PLACE					
50	10	27	(135)	75	(10,000)
	20	37	95		7,500
	30	47	75		6,000
100	10	30	(120)	150	(18,000)
	20	40	90		13,000
	30	50	70		10,000
150	10	30	(120)	225	(27,000)
	20	40	90		20,000
	30	50	70		16,000
TWO BERTH STOPPING PLACE					
50	10	41	(170)	75	(13,000)
	20	51	140		10,000
	30	61	120		9,000
100	10	44	(160)	150	(24,000)
	20	54	135		20,000
	30	64	110		16,000
150	10	47	(150)	225	(35,000)
	20	57	(125)		(28,000)
	30	67	105		24,000
THREE BERTH STOPPING PLACE					
50	10	47	(230)	75	(17,000)
	20	57	190		14,000
	30	67	160		12,000
100	10	53	(200)	150	(31,000)
	20	63	(170)		(26,000)
	30	73	150		22,000
FOUR BERTH STOPPING PLACE					
50	10	56	(250)	75	(19,000)
	20	66	220		16,000
	30	76	190		14,000

Note: Time at busiest stop is considered inadequate for capacities indicated within brackets.

Tram capacities are taken at 3 persons per 2 feet of length as representative of reasonable average "peak" loading.

7. CAPACITY FOR STREET ROUTES WITH INTERSECTIONS CONTROLLED BY TRAFFIC LIGHT.

Most street routes would be limited by traffic light cycles combined with safety zone capacities. Hence for a 70 second traffic light cycle as in Swanston Street, the theoretical capacities become as follows -

Equivalent Length of Tram Feet	Trams per Hour	Passengers per Tram	Passengers per Hour
ONE BERTH SAFETY ZONES			
50	51	75	3,500
75	51	110	5,500
100	51	150	7,500
150	51	225	11,000
TWO BERTH SAFETY ZONES			
50	103	75	7,500
75	103	110	11,000
100	(103)*	150	(15,000)
THREE BERTH SAFETY ZONES			
50	154	75	11,000
75	(154)*	110	(16,000)
FOUR BERTH SAFETY ZONES			
50	(206)*	75	(15,000)

* Safety zone would be over 200 feet long.

Note that four trams cannot be scheduled to operate with a traffic light cycle of 70 seconds unless the stops are limited to 20 seconds. This is however not practical during periods when the average loading is of the order of 75 passengers for each two bogie tram.

8. COMMENTS.

8.1 The capacity of a surface tramway in Swanston Street would be of the order of 11,000 passengers in one hour.

8.2 The capacity of an underground tramway would be of the order of

15,000 passengers in one hour for 2 bogie trams

20,000 passengers in one hour for 3 bogie trams

20,000 passengers in one hour for 1 coupled pair of 2 bogie trams

25,000 passengers in one hour for 1 coupled pair of 3 bogie trams.

Refer graph. fig. 3.

8.3 Increasing the number of tram berths at a stop increases capacity approximately as follows -

1 berth to 2 berths	30 - 50%	increase in capacity
1 berth to 3 berths	70 - 100%	increase in capacity
1 berth to 4 berths	90 - 140%	increase in capacity

Refer graph. fig. 4.

8.4 The duration of stops as they are increased from 10 seconds decreases capacity as follows -

10 seconds to 20 seconds	20%	reduction in capacity
10 seconds to 30 seconds	35%	reduction in capacity

Reducing the duration of stop from 30 seconds to 20 seconds will result in an increase in capacity of the order of 20%.

8.5 Increasing the effective length of trams increases capacity as follows -

50 feet to 75 feet	40 - 50%	increase in capacity
50 feet to 100 feet	75 - 90%	increase in capacity
50 feet to 150 feet	150 - 170%	increase in capacity

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