A Model of Phase Loss due to Tram Priority at an Intersection

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March 2016

Abstract

A 4 phase abstraction of a signalised intersection is combined with the advertised dynamic movement parameters of the Urbos 3 tram to show the effects of a representative tram priority algorithm. The effect on cross traffic is to reduce the hourly cross traffic movements by 15% for regular services of 10 trams per hour, and by 22% for a service rate of 15 trams per hour. For an average dwell time at tram stops of 30 seconds, the expected journey time from Gungahlin to Civic is 27 minutes with priority and 31 minutes without priority.

1. Intersection Priority Model

Figure 1 shows a possible traffic signal cycle and phases for road traffic at an intersection.

t_c= cycle time at an intersection;

t_g= time allocated to green in the major flow direction, which is also corresponds to the to/from tram directions;

t_n= green time during any other normal phase;

t_p = inter-phase time (yellow and red signals).

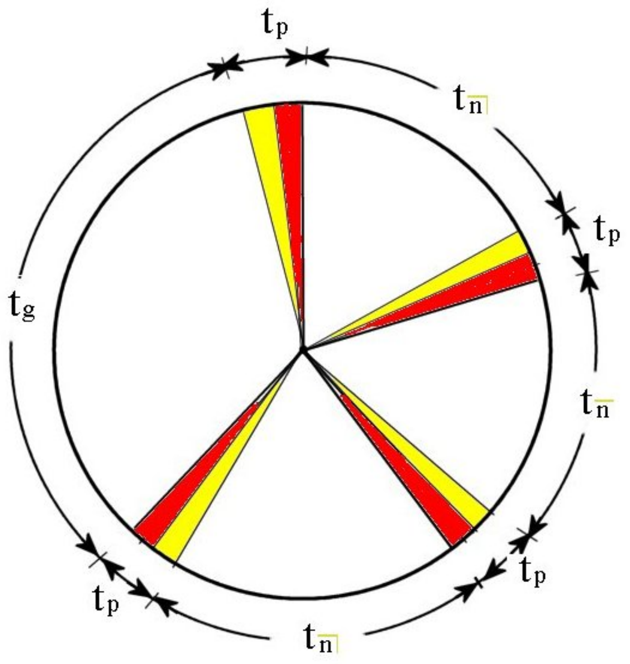

Figure 1. An example of four phases $t_c = t_g + 3*t_n\ 4*t_p$. The phase of green time length t_g is the phase for movement in the to/from directions of trams. The interval t_p is for road traffic signals only. There is a different traffic light and stop signalling for trams that approach the intersection in either direction.

All trams will approach the intersection at a safe speed (30kph). There is a detector for the approach of a tram to an intersection so that its presence can be detected in advance of it reaching the intersection. Then, if necessary, it may be signalled to stop at the stop line.

t_s= time taken for a tram travelling at safe speed to decelerate to stop;

t_d= t_s + safe driver reaction time + any delays from detection to a signal to stop being apparent to the tram driver.

t_w= time taken for the tram to cross the intersection at safe speed

So there would be a signal placed more than d metres before the stop line (where d is the distance that a tram would travel at safe speed in t_d seconds) normally indicating to tram drivers to stop at the stop line. This signal would indicate to drivers to continue at safe speed and cross the intersection in the circumstance described below.

For this reason there would be two sets of lights in each direction to control trams. The lights further away from the intersection force trams that cannot reach the stop line before the special phase begins to delay until the next special phase. So if a tram's trajectory is such that it would not be able to stop at the stop line before the special phase begins it must be detected far enough away from the stop line that it can stop or slow down and subsequently proceed to the stop line where it will wait for the next special phase.

The cut off is defined by a tram at a distance from the stop line such that the driver can react to a signal and stop at the stop line (the equivalent time in the cycle being t_d seconds before the special green phase begins). However what signal placement and form of signalling that is used is an operational matter that is of no concern in the modelling

If the approach of the tram to an intersection coincides with the early part of the phase for traffic movement though the intersection in the direction of the tram, then the tram would proceed at safe speed in unison with the road traffic in its direction and there would be no additional lost time to cross traffic queued at the intersection.

If a tram approach is detected towards the end of the above phase, the phase will be extended (Figure 2) by a time necessary for the tram to travel to and across the intersection. There would be no extension if the tram is detected less than t_d seconds before the normal beginning of the next phase. The remote signal would have been set to stop, at least t_d seconds before the beginning of the next phase.

The road traffic end of extended phase signalling is shown in Figure 2. We assume that detection and signalling for trams will only permit one tram to cross an intersection during a cycle. We assume that a tram that has crossed the intersection is detected, thus allowing the next phase for road traffic to begin. The value for t_w and t_z (see below) should be adjusted so that there is a safe gap after the end of the tram has passed through.

There would be a period before the end of the green phase when it could be extended. Assuming that it is always extended by a period t_w, the expected time lost to road traffic crossing the tram line at an intersection per tram passing in either direction is (t_w^2/t_c) .

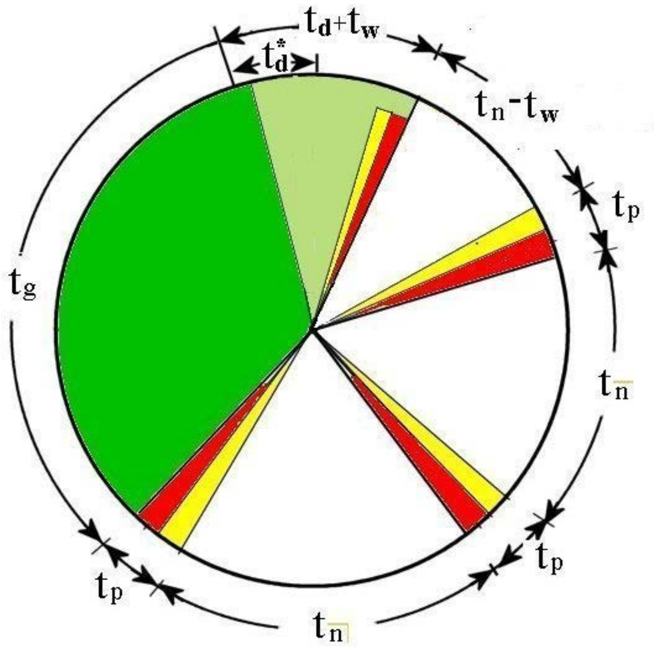

Figure 2. Extending the main phase for tram movement, the diagram shows the maximum extension. The yellow and red timings are for road traffic only.

In the above case a tram that is signalled to stop before the end of the phase or up to t_d seconds before the end of the next phase would stop at the stop line. The special tram phase would then be invoked at the end of that phase and the following phase would be truncated (Figure 3). The expected time lost to traffic at an intersection per tram passing in either direction is $t_z*(t_p+t_n)/t_c$ where

t_z= time taken for the tram to cross the intersection from stopped at the stop line.

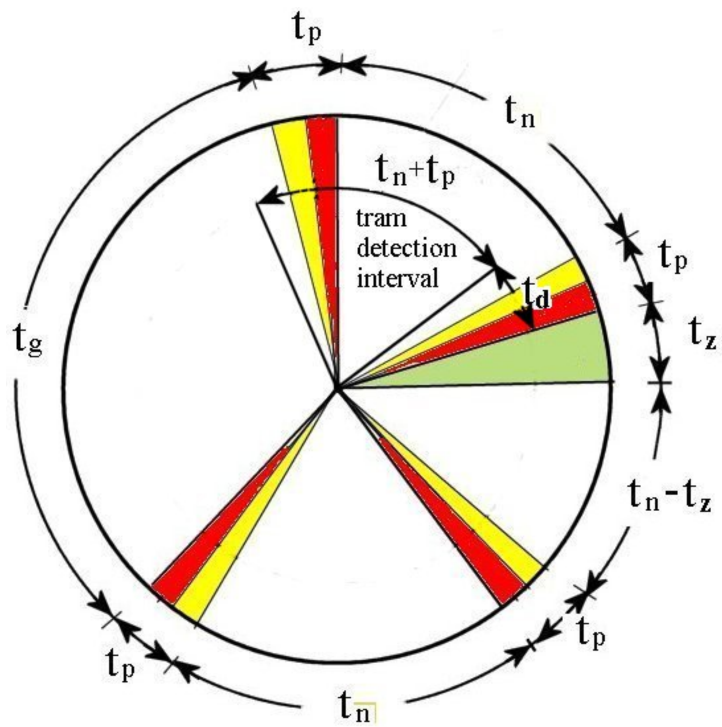

Figure 3. The special tram phase at the end of the first phase after movement in the tram direction.

Similarly a tram detected during the interval of length t_n+t_p shown in Figure 4 would be delayed at the stop line waiting for a special tram phase at the end of the next phase. The expected time lost to traffic at an intersection per tram passing in either direction is the same as for the situations in Figure 3.

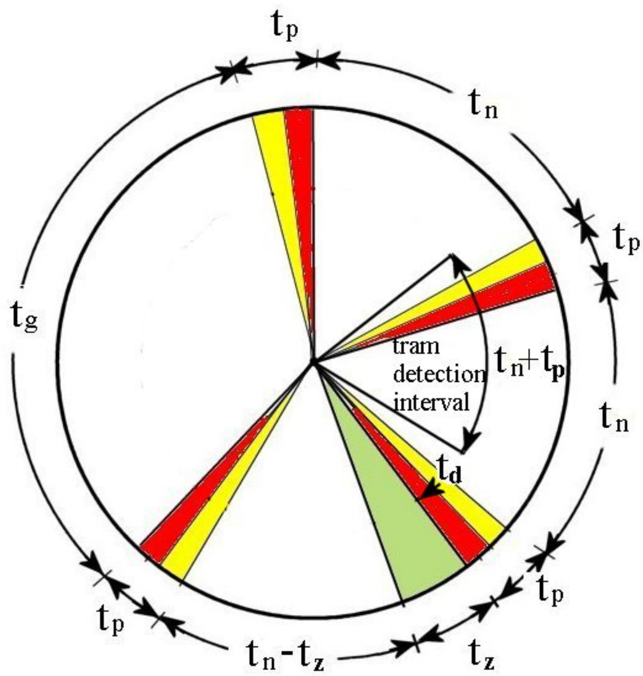

Figure 4. Another special tram phase.

Similarly if a tram detected during an interval of length t_n+t_p shown in Figure 5 in the phase that precedes the phase for movement in the tram direction, that phase will be truncated by a time t_z . Thus the green phase in the direction of the tram may start t_z seconds early if a tram is detected early in the previous phase. Trams detected in this case would stop at the stop line for a period before proceeding on the early green. Extending by any more than t_z would not advantage many trams and would be wasteful of scarce time for the phase being truncated. The expected time lost to traffic at an intersection per tram passing in either direction is the same as for the situations in Figure 3.

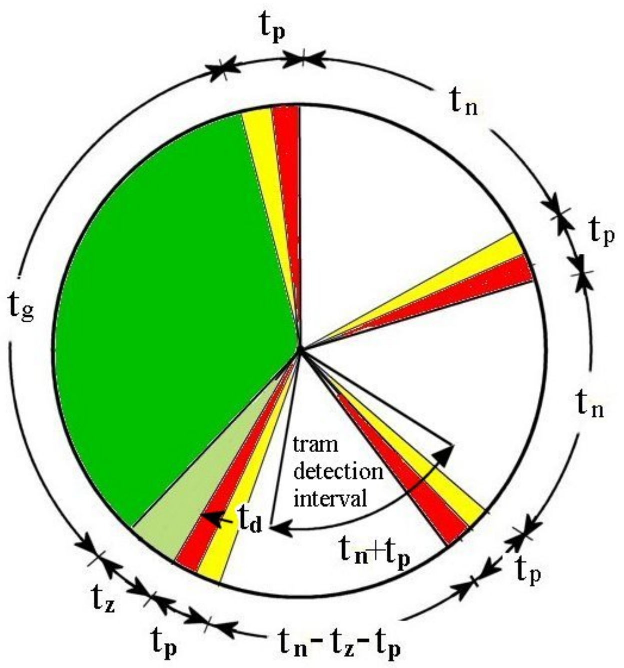

Figure 5. Early start of the phase for traffic in the direction of the tram.

Ignoring the possibility that trams travelling in opposite directions will cross at an intersection the expected time lost to traffic at each intersection per tram travelling in the “from” direction is the same as the situations analysed above.

Assuming that the safe speed for a tram approaching an intersection is 30 kph (8.3 metre/sec), and the width of an intersection is 25 metres, the time for a 33 metre tram to cross an intersection is 7 seconds. Allowing for a 3 second safety gap before starting the road phase,

t_w = 10 secs

Tram stops are located at intersections, stops in the to and from directions being located on the same side of the intersection. Therefore a tram which has to stop before the intersection to wait for a green signal will have to accelerate and decelerate into the stop.

Assuming that the acceleration and deceleration rates are 1.3 metre/sec/sec, the time to cross an intersection from stopped and then stop at the tram station is 13.4 seconds. If the tram is stopped at a station, the time to cross an intersection from stopped before proceeding on to the next intersection is 10.8 seconds. As these situations occur pair-wise we will use the mean value of 12 seconds for the movement.

Allowing for a 3 second safety gap before starting the road phase,

t_z = 15 secs

2. Movement Time Loss caused by Phase Loss

The time lost to traffic movements crossing the major flow per hour is

$T_L = f * 2 * (t_w^2/t_c + (n_p - 1)*t_z*(t_p+t_n)/t_c)$.

where f = number of tram services per hour, $f < 1 / t_c$

n_p = the number of phases in a signal cycle excluding the special tram phase.

The time available to movements crossing or turning across the major flow direction per hour when there are no tram movements

$T_M = (t_c - t_g - t_p - (n_p - 1)* (t_p - t_y)) * 3600 / t_c$

where t_y= yellow time during which movements occur at the end of a phase.

Table 1 Percentage of time available for cross traffic movements after phase loss

f	$(T_M - T_L) / T_M *100$
10	89%
12	87%
15	83%

3. Queue Discharge Loss caused by Phase Loss

Acelik and Besley have developed and calibrated a model for queue discharge at an intersection:

$n_s = q_n/3600[(t-t_r) - (1 - e(-m_q(t-t_r))/m_q)]$

where n_s = cumulative discharge flow (number of vehicles) t seconds after the start of the displayed green period;

q_n = maximum discharge flow rate (vehicles per hour);

t_r = start response time (a constant value) related to the average driver response time for the first vehicle to start moving at the start of the displayed green period (seconds);

m_q = a parameter that can be observed at an intersection

Average site values observed for 18 intersections in Sydney and Melbourne are:

Site	m_q	q_n
Right turn (isolated)	.582	2033
Through (isolated)	.369	2086

The green time lost to any phase interrupted as shown in Figures 3, 4 and 5 is t_z.

Substituting $t_r = 1$ and $t_z = 15$ as above, Table 2 shows the number of vehicles to pass through a saturated intersection per lane with and without a priority interrupt.

t_n (normal green time for phase)		25		21		17	
Priority Interrupt		NO	YES	NO	YES	NO	YES
n_s (number of vehicles passing per lane)	Right turn (isolated)	12.6	4.1	10.3	1.6	8.1	0.1
	Through (isolated)	12.3	3.7	10.0	1.6	7.7	0. 1

4. Vehicle Movement Loss caused by Phase Loss

The number of phases available per hour for movements crossing the major flow is given by

$n_M = (n_p – 1)*3600 /t_c$

The number of phases interrupted per hour for tram priority is given by

$n_L = f * 2 * [(t_w/t_c + (n_p – 1)*(t_p+t_n)/t_c)]$.

where f = number of tram services per hour, $f < 1 / t_c$

Defining N_M = the total number of vehicle movements per saturated lane per hour without trams

N_P = the total number of vehicle movements per saturated lane per hour with tram priority

$N_M = n_M *n_s(NO)$

$N_P = (n_M- n_L)*n_s\{NO\} + n_L *n_s\{YES\}$

where $n_s\{NO\}$ and $n_s\{YES\}$ are given in Table 1.

Using t_c = 120 sec, t_g = 45 sec, t_p = 6 sec, t_y = 2 sec, n_p = 4 we get

$t_n = 17$

f	N_P / N_M*100
10	85%
12	82%
15	78%

5. The Expected Delay at Intersections for Trams.

Any tram that passes though an intersection during the special phase of time length t_z shown in Figures 3, 4 and 5 will be delayed according to when its approach occurs (see tram detection interval). Also a tram that approaches after the detection interval shown in Figure 5 and before the start of the major phase will be delayed.

The expected delay per tram passing in either direction is

$$(n_p – 1)*(t_p+t_n)/t_c)*(t_p+t_n)/2 + t_d) + (t_d+t_z)/t_c)*(t_d+t_z)/2$$

Using the same parameter values as previously, t_s = 6.4 seconds, and allowing 1.6 seconds for signal response plus driver response, t_d = 8 seconds, the expected delay to a tram at each intersection is 13.4 seconds.

6. Time to Travel between Intersections

Travel between intersections consists of an acceleration phase, a cruising phase and a deceleration phase. We assume that the cruising speed is 65kph (18.1 metres/sec), the acceleration and decelerates rates are 1.3 metres/sec/sec, and the distance between intersections is 0.5 kilometre.

There are two cases to consider, one in which the tram stops at the intersection, either because there is a tram stop or because of signal delays, the other being when the tram passes through the intersection at 30 kph.

In the case of stopping, the time to accelerate to cruising speed from stationary is 13.9 seconds, the time to decelerate to stationary is 13.9 seconds. The distance travelled during acceleration is 125 metres and the distance travelled during deceleration is 125 metres, leaving 250 metres travelled at cruising speed in 13.9 seconds.

In the case of passing through an intersection at 30kph, the deceleration time is 7.5 seconds, and the acceleration time is 7.5 seconds. The distance travelled during acceleration is 99 metres and the distance travelled during deceleration is 99 metres, leaving 302 metres travelled at cruising speed in 16.7 seconds.

If an intersection does not have a tram stop then the likelihood that the tram passes through at safe speed is t_g+t_d/t_c .

Thus the expected travel time between 24 intersections, 12 with trams stops is:

12*(13.9+13.9+13.9) + 12*67/120*(13.9+13.9+13.9) + 12*53/120(7.5+16.7+7.5) = 948 seconds

7. Journey Time

For a journey of 12 kilometres having 12 tram stops each with a dwell time of 30 seconds, the total journey time crossing 24 intersections would be

24*41.7 + 24*13.4 + 12*30 seconds = 27 minutes

If the dwell time at stops averaged 20 seconds then the expected journey time would be 25 minutes.

8 Journey Time without Priority

The expected delay at an intersection without priority is given by integrating the expression x/t_c over the range 0 to t_c-t_g-t_y which gives $(t_c-t_g-t_y)^2/(2*t_c)$

Using the same parameters as above the expected delay is 22.2 seconds. This gives an expected journey time of 31 minutes

If the dwell time at stops averaged 20 seconds then the expected journey time without tram priority would be 29 minutes.

9 Reference

Akcelik R, and Besley M; Queue Discharge Flow and Speed Models for Signalised Intersections, 15th International Symposium on Transportation and Traffic Theory, Adelaide, 2002.