CIV2282 Transport & Traffic Engineering (Part 1)

Contents

1. Introduction.........................................................................................................................................................1
   1.1 Transport System Elements.........................................................................................................................1
2. Transport Systems...........................................................................................................................................2
3. Traffic Flow Fundamentals...............................................................................................................................3
   3.1 Time-Space Diagram....................................................................................................................................5
   3.2 Determining Space-mean Speed................................................................................................................6
4. Traffic Flow Theory...........................................................................................................................................8
   4.1 Relationship of Traffic Flow Variables.........................................................................................................8
   4.2 Measuring Speed/Flow/Density in practice .................................................................................................11
   4.3 Traffic Jams................................................................................................................................................12
   4.4 Representing Shockwaves..........................................................................................................................13
5. Traffic Headway Distributions & Queuing Theory.........................................................................................17
   5.1 Poisson Distributions..................................................................................................................................17
   5.2 Application of Traffic Random Distributions............................................................................................19
6. Queuing Theory................................................................................................................................................20
   6.1 D/D/1 Queuing Process..............................................................................................................................21
   6.2 M/D/1 Queuing Process................................................................................................................................23
   6.3 M/M/1 Queuing Process................................................................................................................................23
7. Unsignalised Intersection...............................................................................................................................25
   7.1 Analysis of Unsignalised Intersection.........................................................................................................27
8. Roundabouts....................................................................................................................................................30
   8.1 Roundabout Analysis Process.....................................................................................................................31
9. Signalised Intersections..................................................................................................................................32
   9.1 Types of Traffic Signals.............................................................................................................................32
   9.2 Signal Phases...............................................................................................................................................32
   9.3 Definitions...................................................................................................................................................34
   9.4 Saturation Flow............................................................................................................................................34
   9.5 Yellow & All-Red Times..............................................................................................................................35
   9.6 Pedestrian Crossing Times..........................................................................................................................35
   9.7 Calculating Phase Timings.........................................................................................................................36
   9.8 Procedure for Signal Timing Design.........................................................................................................37
   9.9 Delays at Signalised Intersections..............................................................................................................40
10. Capacity & LOS............................................................................................................................................41
   10.1 Freeway Capacity & LOS Analysis............................................................................................................42
   10.2 Multi-Lane Highway Capacity & LOS Analysis.........................................................................................46
   10.3 Two-Lane Highway Capacity & LOS Analysis.........................................................................................48
**CIV2282 Transport & Traffic**

**Introduction**

Transport modes include:
- Passenger i.e. road/cars, rails, air, water
- Goods/freight i.e. road/trucks, rail, air, water, pipeline

The 3 elements of the transport system...............................

**Transport systems may fail**
- Soft failure = demand exceeds supply
- Hard failure = transport system completely breaks down

**What is Transport Engineering?**

Required to "Plan, design, operate and manage transport systems, balancing the needs of society, the economy and the environment".

Prior to undertake transport projects, **planning** work is essential, this involves:
- Forecasting the impact of the projects on the system performance (e.g., engineering, environmental, etc.)
- Setting up the specifications of the project
- Determining the benefits and costs
- Interacting with the decision makers to achieve final decisions

**Design** refers to the specification of all the features of a project so that it can be built. It involves:
- geometric design (horizontal and vertical)
- pavement design (thickness/layers, most cost effective means)
- determination of right of way, drainage structures, fencing, etc. In fact, a part of the design process focuses on the production of construction plans (e.g., plans, profiles, details).

**Issues in Transport Engineering**

Transportation produces not only the desired outputs of passenger trips and freight shipments, but also numerous adverse side effects:
- Congestion, Fatalities and injuries, Aging infrastructure, Diminishing petroleum reserves (peak oil), Effectiveness of public transport, Local air quality and noise, Global atmospheric impacts, Health impacts, Equity

Potential solutions to these critical issues include:
- Infrastructure expansion/renewal – High cost, – Political, – Limited resources e.g. land
- New techniques – More intelligent use of available resources, – Intelligent Transportation Systems (ITS), – Demand management
Transport Systems

i.e Highway Systems, Aviation, Maritime & Rail Systems etc.

The goal of a transport system is to provide the safe and efficient mobility and accessibility to society

Transportation impacts every facet of our lives; economical, social, recreational, cultural etc.

Efficient and safe movement of people and goods is important for our quality of life

Transport engineers strive towards 2 goals;
> Provide high level of service (LOS), ↓ travel times and delays
> provide high level of safety

These goals are mutually exclusive i.e ↑ speeds ↓ travel times but ↓ safety

Transport constraints/rules are constantly changing
> Economic; cost of construction & maintainance
> Political; community impacts
> Environmental; air, water & noise pollution

Mobility refers to movement of people or goods
  Passenger travel measure by no. of people/cars moved
  Freight travel measured by no. of heavy vehicles or ton-miles moved

Accessibility refers to the ability to reach desired goods, services, activities and destinations

Challenges in Transport Engineering

In an attempt to meet a high LOS, both technical and behavioural challenges are considered

Technical
  Infrastructure; maintenance, make better use of existing infrastructure
  Vehicles Technologies; Performance and motivation for advances (↓ pollution, ↑ safety)
  Traffic control; Signal devices (New timing strategies or low tech approach i.e roundabouts)

Behavioural
  Need clever approaches to encourage usage of alternative modes but still give travellers reasonable
departure times and destination options
Traffic Flow Fundamentals

Cannot efficiently describe traffic flow has each driver behaves differently hence we model traffic flow like fluid but still need quantitative techniques to assess operational measures of highway performance, so we can analyse and evaluate

Traffic Flow Variables…………………………………………………………………………………………………….:

Flow, \( q \) [veh/min]

Flow is the number of vehicles passing any specified road location per unit time

\[ q = \frac{n}{t} \]

Volume (hourly flow) = [veh/hr]

Time Headway, \( h \) [sec/veh]

Time headway is the time between consecutive vehicles passing a fixed roadside location

The time each vehicle passes observer; \( t_1, t_2, t_3, \ldots \)

Corresponding headways; \( h_1 = t_2 - t_1, h_2 = t_3 - t_2, \ldots \)

\( h_i = \) time headway between vehicles \( i \) and \( i+1 \)

For multiple vehicles:

\[ \frac{1}{h} = 1 \sum_{i=1}^{n} h_i \]

Relating \( q \) and \( h \)

\[ q = \frac{1}{h} \]

E.g. circular track of 1 kilometre, one car travels at 60 km/h, the other at 30 km/h, assume \( q = 90 \) veh/hr

\( hbar = \frac{1}{90} \) hr/veh = \( \frac{3600}{90} \) sec/veh = 40 sec/veh

Speed, \( v \) [km/hr]

Distance that vehicles travel per unit time

Need a measure of the average (or mean) speed of the traffic stream, we can do this in space or time

i.e the average speed at a particular time, and the average speed at a particular location

\( Pace = \) inverse of speed [sec/km]

Density, \( k \) [veh/km]

No. of vehicles in a unit length of roadway at a particular time

Also called ‘concentration’

Spacing, \( s \) [km]

Distance between successive vehicles

Measured from the front of each vehicle, taken at a specific moment in time

\[ l = 1 \text{ km} \text{ and there are two vehicles} \implies sbar = \frac{2}{1} = 0.5 \text{ km} (= 500 \text{ m}) \]

Relating \( k \) and \( s \)

\( \frac{k}{l} = \frac{1}{s} \)

*average spacing = measure of length per vehicle

*density = measure of vehicles per length

Commented [tr1]: Traffic can be classified as either uninterrupted or interrupted flow

Uninterrupted flow:

- A traffic stream that operates w/out traffic control devices i.e Freeways
- Key variables and characteristics remain constant over time

Interrupted flow:

- A traffic stream that operates under the influence of traffic control devices i.e Key variables and characteristics change over
**D/D/1 Queueing process**

<table>
<thead>
<tr>
<th>Deterministic arrival and service rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>D/D/1 Queuing process has arrivals &amp; service rates that are deterministic (not subject to probability distribution)</td>
</tr>
<tr>
<td>i.e. headways between vehicles &amp; time to 'process' them are both uniform at a particular time</td>
</tr>
</tbody>
</table>

At time, \( t \), we know the no. of vehs that have arrived
and the no. of vehs that have departed
\[ \therefore \] difference is the no. of vehs currently in the queue

**Maximum No. of Vehicles (Maximum Queue Length)**

= max difference between arrivals and departures numbers

For a vehicle, we know what time it arrives and departs (assuming FIFO)
Difference = delay (waiting time) experienced by that vehicle

**Maximum Delay in the queue (Maximum Waiting Time)**

= max difference between departure and arrival times

**Total Delay** for all vehicles = area between arrival and departure curves
Can be found by trig, or by integration

<table>
<thead>
<tr>
<th>Average Delay (Average Waiting Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>= Total Delay / no. of veh passed through system, ( N )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Number of Vehicles (Average Queue Length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>= Total Delay / time for vehicles to pass through system, ( T )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ave no. of stopped vehicles in the queue</th>
</tr>
</thead>
<tbody>
<tr>
<td>= Total Delay / Total time the queue exists</td>
</tr>
</tbody>
</table>

*Both Arrivals & Departures don't have to be at constant rates
\[ \therefore \] arrival rate (\( \lambda \)) & departure rate (\( \mu \)) are fncs of time
We integrate these rates to give total arrivals and departures
Then, to get Total Delay, we integrate again

Commented [tr2]:
- Customer arrival is deterministic, NOT subject to a probability distribution
- Service duration is deterministic
- There is only 1 server
- There is unlimited system capacity
- The queue discipline is FIFO
Unsignalised Intersection

For an Unsignalised intersection (roundabout / stop / give way):

**Absorption Capacity** = max flow that can enter from a minor approach

These intersections operate by gap acceptance – w/ more suitable gaps in major stream, there is ↑ capacity of the intersection to handle the minor traffic.

- i.e low traffic volume on major road = more acceptable gaps for minor vehicles
- or, as traffic volume ↑ on major, no. of acceptables gaps ↓ → minor vehicles find it harder to enter stream

\[ P(k \geq t) = e^{-\frac{t}{k}} \]

**Gap Acceptance & Critical Gap**

The gap that is generally acceptable for minor vehicles depends on a **no. of factors**

- Time gap \( g \) between vehs depends on:
  - spacing/space headway \( (s) \)
  - time headway \( (h) \)
  - vehicle speed \( (v) \)

The average gap for a particular condition is called the **Critical Gap** \( (T) \)

Vehicles following other through a manoeuvre then require smaller additional gaps. This smaller additional gap is referred to as the **Follow-up Gap** \( (T_f) \)

\[ T_f < T \]

. If available gap is less than Critical Gap + Follow-up Gap, then following vehicle wont go through. Process then repeats, w/ that vehicle waiting for a gap > than critical gap \( (T) \)

*Note: Different manoeuvres require different Critical Gaps \( (T) \) and Follow-Up Gaps \( (T_f) \)

<table>
<thead>
<tr>
<th>Movement</th>
<th>Diagram</th>
<th>Description</th>
<th>( T )</th>
<th>( T_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left hand turn</td>
<td></td>
<td>Not interfering with A, Requiring A 15 slow</td>
<td>14-40 sec</td>
<td>2-3 sec</td>
</tr>
<tr>
<td>Crossing</td>
<td></td>
<td>4 sec</td>
<td>2 sec</td>
<td></td>
</tr>
<tr>
<td>Right hand turn from major road</td>
<td></td>
<td>4 sec</td>
<td>2 sec</td>
<td></td>
</tr>
<tr>
<td>Right hand turn from minor road</td>
<td></td>
<td>Not interfering with A One way</td>
<td>14-40 sec</td>
<td>2-3 sec</td>
</tr>
<tr>
<td>Merge</td>
<td></td>
<td>Acceleration lane</td>
<td>3 sec</td>
<td>2 sec</td>
</tr>
</tbody>
</table>

Commented [tr3]: Road geometry, Traffic and environment conditions (icy roads, wet, poor visibility all effect gap acceptance time), Manoeuvre type (left/right turn, or straight through), Driver capabilities

Commented [tr4]: Critical Gap, \( T = \) where half the headways are rejected and accepted
Roundabouts

Roundabouts are satisfactory intersection control treatments at a wide range of sites (i.e. urban local and collector roads, arterial roads in urban areas, rural roads, freeway ramp terminals)

Roundabouts work by gap acceptance so work where there is no obvious major or minor approach (i.e. where flow on each approach is roughly equal)

Roundabout Safety

The good safety record for vehicles at properly designed roundabouts can be attributed to:

- **↓** in speeds due to the curvature in the approach road
- **↓** in the no. of conflict points
- Simplicity of decision making as traffic only approaches from one direction (also provides good visibility giving advanced warning of intersection)
- **↓** in the angle of conflict: ensuring low relative velocities between conflicting vehicles

*Note: Research suggests roundabouts aren’t as safe for cyclists*

Other Advantages/Disadvantages

- **Capacity & Delay** where ↑ capacity: ↓ delay, but w/ differences in approach volumes, the system can become unbalanced meaning unacceptable LOS for lower volume approach
- **Design, Installation & maintenance** = Cost effective intersection treatment, avoiding need for traffic signal installation and ongoing maintenance
- **Road Space Requirement** where roundabouts require more real estate/road space
- **Large Vehicles** may have difficulties, particularly turning at smaller roundabouts or, on multi-lane roundabouts may require multiple lanes to turn creating a risk of collision (Use mountable islands to improve access)

“Ring of T’s”

Consider a roundabout to act as a ring of intersecting T-intersections

Roundabouts operate by Gap Acceptance hence works like Unsignalised intersections

There are differences tho:

- Circulating traffic is unidirectional (1 direction of opposing traffic)

From the turning movement survey calculate entry & circulating flows

Unbalanced Flows

Roundabouts are best suited where volumes are similar

W/ differences in approach vols, this may cause large delays on the lower volume approach. To counteract this:

- We can signalise roundabout (expensive and time loss)
- Use metering to introduce gaps
- Slip lanes if available, ↓ amount of traffic on roundabout itself
## Contents

1. PT in Melbourne ......................................................................................................................... 1
2. PT Operations ............................................................................................................................ 2
3. PT Planning ............................................................................................................................... 4
4. Transport Data Collection ........................................................................................................ 6
   4.1 Traffic Surveys ................................................................................................................... 8
5. Travel Demand Forecasting ..................................................................................................... 10
   5.1 Trip Generation .................................................................................................................. 11
   5.2 Mode/Destination Choice .................................................................................................. 12
   5.3 Route Choice ..................................................................................................................... 13
6. Intelligent Transport Systems (ITS) ....................................................................................... 15
7. Non-Motorized Transport ....................................................................................................... 19
8. Road Safety & Crash Data Analysis ....................................................................................... 21
   8.1 Road Safety Auditing ......................................................................................................... 22
PT in Melbourne

Transport in Melbourne

Transport in Melbourne is car based w/ 75% of trips are in cars

Car ownership and use is also ↑

This ↑ car user-ship heavily contributes to congestion creating costs

Congestion itself is growing spatially to outer-suburbs and in time (peak hours spreading)

In AUS our economy is heavily affected by congestion w/ high car dependency but low urban density

Public Transport in Melbourne

**Buses**

Buses are Melb’s most widely used PT (2/3s of melb can only be serviced by buses)

W/ headways of 40-50mins and finish at 7, for being the most available PT service the frequency is too low

Hence Melb only provides the basic minimum for this PT service

Frequency drives ridership, so to improve use the service level must increase

**Tram**

services in Melb struggle in growing traffic congestion

Inefficient system w/ low flow vehicles (cars) mixed with our light rail systems (trams) i.e Mixed traffic impedes performance

Trams have low average speed due to congestion and low ridership due to low frequency

To improve performance new infrastructure is needed but Melbs solution was expansion

Expansion increased availability and complexity but only put more pressure on current system

How Transit Oriented is Melbourne’s Development?

Density: Concentration of development

Diversity: Mixing and balancing land use w/ various transport

Design: How land is combined, linked, presented

Perceived performance of Melb PT system is poor, with important factors such as safety, reliability, frequency, QOS all rated poorly

Drivers of Change

Growth in urban travel and car ownership is growing fed by our increasing population

This has caused congestion all over in Melb creating ‘rat runs’ and spreading

Trucks/road freight also growing immensely. This decreases road capacity and trucks move slower

Such delay are linked to effecting the economy and affordability of products

Exhaust immersions also generate health/environmental problems

(We require big change to meet the ‘Stern target’)

Our dependency on cars has also lead to less activity creating an obesity epidemic

With a lack of PT available in fringe urban areas there is also a forced car ownership hence these people are most likely impacted by fuel prices

The Future

Melb has steadily increased PT services over the years but population growth continues at a faster pace

So in fact the relative service level per head has been found to decrease recently

And as Melb is expected to increase in population serbice levels must increase accordingly

A number of capacity upgrades are being developed w/ underground rail systems, rail seperations, bus priority lanes etc.
### PT Operations

#### Terminology
- **Dwell Time (D)** – Time (in sec) that a PT veh is stopped to serve passengers
- **Standees** – No. of standing passengers on a PT veh
- **Crush Capacity** – Max no. of passengers that can be accommodated on a PT veh
- **Clearance Time (t.c)** – Time need by PT veh to start up and travel it own length (clearing the stop)
- **Minimum headway (h.min)** - Min safe spacing between PT veh

#### Traffic Flow in Public Transport Networks

<table>
<thead>
<tr>
<th>Flow</th>
<th>If ( q ) = hourly flow ([\text{veh/hour}]) and, ( h = \text{headway} \ [\text{mins/veh}] ) : ( q = \frac{60}{h} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bus route operates on a headway of 10mins. What is the hourly flow of buses that route? ( q = \frac{60}{10} = 6 \text{ buses/hour} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line Capacity</th>
<th>W/ a min allowable headway ( (h) ) in mins, the capacity of the line to hand PT vehs ( (C,\text{line/veh}) ) is: ( q = \frac{60}{h} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light rail line has min operating headway = 4mins. What is the capacity of the line in terms of veh? ( C = \frac{60}{4} = 15\text{veh/h} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Passenger carrying capacity of a line (in pa/hour):</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{\text{LINE (pax)}} = C_{\text{LINE (veh)}} \times C_{\text{veh}} )</td>
</tr>
</tbody>
</table>

| Factor affecting V.ave = accel/decel rates, dwell times (D), no. of stops on the route, & spacing of those stops |

<table>
<thead>
<tr>
<th>Cycle Time (T)</th>
<th>Time required for a veh to complete a round trip and be ready to re-enter service</th>
</tr>
</thead>
</table>
| \( T = t_{rt} + t_{rec} \) | \( t_{rt} = \text{round trip travel time} \)
| \( t_{rec} = \text{recovery time at end of route or at the terminal} \) |

<table>
<thead>
<tr>
<th>Fleet Requirements</th>
<th>( N_f = \left\lceil \frac{T}{h} \right\rceil ) where ( h = \text{headway of the service,} ) ( T = \text{cycle time of the service,} ) and ( \lceil \rceil ) indicates rounding up to the next integer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Running time ( t_{rt} ) will depend on the length of the route ( (d) ) and the average speed ( (V_{\text{avg}}) )</td>
</tr>
</tbody>
</table>

| If service has a cycle time \( T = 90\text{min} \), headway \( h = 15\text{mins} \), how many vehs does this service require? |
| N.f = 90/15 = 6veh |

| If we can reduce cycle time \( T \) to 60mins we’d only require 4 vehs |
| \( t_{rt} = \frac{d}{V_{\text{avg}}} \) |

| Factor affecting \( V_{\text{avg}} \) = accel/decel rates, dwell times \( (D) \), no. of stops on the route, & spacing of those stops |

#
Guideway Effect on Ave Speed

Train speed profile is uniform as it operates w/ right of way.

Ave speed will depend on exclusivity of the guideway.

- Non exclusive guideway at grade (interaction with other vehicles), e.g a bus or tram sharing the road space with other vehicles.
- Exclusive guideway: At Grade or Grade Separated (above ground or underground).

The Type of right of way determines performance and the investment cost in the PT system.

(A non-exclusive guideway has: ↓ ave speed, Higher round trip travel time, ↑ fleet requirements)

Factors Influencing Public Transport Capacity

1. Vehicle Characteristics
   - No. of veh/carriages per train, size, seating config/capacity, no./size of doors
   - i.e double deck ↑ capacity, more doors = faster entry/exit
2. Right-of-Way Characteristics
   - No. of lanes/tracks (express or stopping services)
   - Degree of separation from other traffic
   - Intersection design (at grade separated, type of controls)
3. Stop Characteristics
   - Frequency and duration, Design (on-line blocks vehs, off-line allows other vehs to pass)
   - Method of fare collection (myki and off vehicle tickets ↓ boarding time)
4. Operating Characteristics
   - End of run layovers/Driver relief
   - Regularity of arrivals at stops (↑ reliability and capacity)
5. Passenger Traffic Characteristics
   - Pa concentrations/distributions, peaking of ridership, preparedness to board, mobility constraints
6. Street Traffic Characteristics
   - Volume/nature of other traffic, cross traffic @ at-grade intersection
7. Method of headway control
   - Policy on spacing of veh, automatic or human operator

PT Service Reliability

Reliability: Absence of variability in system performance

- Know exactly what you’re going to get i.e. consistent arrival times
- If drivers cant adhere to schedules it indicates poor reliability

Recently Melb PT has been fairly reliable besides V-Line seeing a decline

Reliability problem worsens as on proceeds along a route

- ex Bus 1 runs late, due to this it picks up some of bus 2's riders and is continually delayed
- Bus 2 now runs ahead of schedule due to less customers

Impacts of Unreliability:

- Reliability is important for Travellers decisions
- Poor reliability ↑ waiting times, and makes transfers difficult
- For operators, poor reliability ↓ productivity and ↑ costs

Control Strategies

- Deviations in travel times or dwell times are linked to delays
- Controlling delays helps prevent bunching and ensure schedule is met

This can be achieved by:

Vehicle holding

- Breaks up bunches based on headways and schedule

No. of stops

- ↑ Stop spacing (↓ dwell time variability) but there is a trade-off w/ accessibility
- Create stopping patterns; skip-stop or zone/express scheduling

Signal Pre-Emption

- Detect approaching PT veh and terminate/extend phase to help transit veh through intersection

Exclusive Right-of-Way

- Bus/Tram lanes ↓ traffic stream delays and ↑ reliability