Optimisation and Evaluation of Traffic Signal Control in the UK

Presented by Alastair Maxwell
Transport Consultant - TRL
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Overview of presentation

• TRL
• Junction types and capacity
• Traffic signal control
• Optimising signal timings and evaluation
  • Isolated and linked control
• SCOOT
TRL – Transport Research Laboratory

• Established in 1933 by the UK Department for Transport
• Privatised in 1996
• 450+ staff including many world recognised experts
• Head office in Crowthorne, Berkshire
  • Offices in Scotland and Wales
  • Project offices overseas

Our Work

- Transportation
- Transport Infrastructure
- Safety
- Investigations and Risk Management
- International Development
- Vehicle Safety and Engineering
- Environment
Alastair Maxwell

Alastair is a highly experienced transport researcher and qualified project manager; he joined TRL in 1997. His speciality is traffic signal control, but has worked in many other transport areas.

Alastair has a Masters degree in transport engineering, and spent over three years working for the Traffic Control section of Devon County Council.

Junction overview

- Allow vehicles to transfer from one road to another
- Importance
  - Usually control the delay and capacity in an urban area
  - UK - About 60% of personal injury accidents in urban areas occur at or near junctions (within 20m)
  - Significant contribution to fuel consumption and emissions
Choice of junction type

- Priority (give-way)
- Roundabout
- Grade separated

- Cost, safety, and capacity all increase.
- Software programmes such as ARCADY, PICADY, OSCADY can assess capacity and safety.
- Other considerations – land take, control, consistency, road hierarchy, visual, severance, road user,…

Junction Capacity

- The maximum volume of traffic that can pass through a junction (usually per hour) for the given set of turning movements and traffic composition. Determined by:
  - Type of junction
  - Geometric design
  - Control configuration for traffic signals

- Rapid increase in vehicle delay and queue lengths as approach capacity
- Design target is typically 85% ratio of flow to capacity (RFC)
Example of delay at traffic signals

Average delay per vehicle (s), 1800 vehicles per hour maximum flow during green ('saturation flow'), 30 s vehicle green, 60 s cycle time (capacity therefore = 900 veh/h) (85% RFC = 765 vehicles/h)

Junction analysis programs

- Large amount of research to determine empirical relations between junction type, geometry, control, traffic flows and turning proportions.
- Large statistical study into factors affecting the number of personal injury accidents.
- Coded into TRL junction analysis programs
  - PICADY for priority junctions
  - ARCADY for roundabouts
  - OSCADY for 'isolated' traffic signals
- Alternatives*: Microscopic simulation; LINSIG (for traffic signals); overseas packages e.g. SIDRA
  - *None include accidents
Traffic Signals

Traffic signal stages and phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Cycle</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>Red</td>
<td>Red</td>
</tr>
</tbody>
</table>

Intergreen
Traffic signal terminology

- Saturation flow – average maximum flow over the stopline. Depends on number of lanes, gradient, turning radius. Can be calculated or measured.

- Effective green – the period available for vehicles to discharge at saturation flow. Typically one second greater than actual green.

- Cycle time – time for a complete sequence of stages, e.g. from start of stage 1 to next start of stage 1

Traffic flow inputs

- Need traffic flows and turning movements

- Counts ideally ‘classified’ and in time segments over the assessment period (e.g. 15 minutes segments over an hour period).

- Classified counts allow absolute flow counts to be converted to ‘Passenger Car Units’ which take account of vehicle composition by using equivalent values (standard values given below)

<table>
<thead>
<tr>
<th>PCU factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Cars/light goods (3/4 wheels)</td>
</tr>
<tr>
<td>1.5</td>
<td>Medium goods (two axles but &gt;4 tyres)</td>
</tr>
<tr>
<td>2.3</td>
<td>Heavy goods (more than two axles)</td>
</tr>
<tr>
<td>2.0</td>
<td>Buses/coaches</td>
</tr>
<tr>
<td>0.4</td>
<td>Motorcycles</td>
</tr>
<tr>
<td>0.2</td>
<td>Bicycles</td>
</tr>
</tbody>
</table>
Types of control

- Isolated Fixed Time (no detectors)
- Isolated Vehicle Actuation (detectors)
- Isolated Adaptive control (e.g. MOVA)
- Linked Fixed Time (Cable or Cable-less)
- Urban Traffic Control Fixed Time (control room)
- Urban Traffic Control – Adaptive (e.g. SCOOT, SCATS)

Optimum signal timings

- Webster and Cobbe in 1966 first published methods of calculating optimum signal timings
- Ratio of flow to saturation flow, $\gamma = \frac{q}{s}$
  - Where $q$ = flow and $s$ = saturation flow
- For optimal conditions (balancing degrees of saturation), $g_1/g_2 = \gamma_1/\gamma_2$
  - $g$ = effective green
- Degree of saturation = ratio of to maximum flow that can pass over the approach for the given green times.
- Capacity = $(g \cdot s) / C$
  - Vehicles per hour
  - $C$ = cycle time
Optimum signal timings (2)

• Sum of y values for the junction \( Y = \Sigma y \)

• Minimum cycle time = \( L / (1-Y) \)
  • Where \( L \) = total lost time at junction

• Practical cycle time \( 0.9L/(0.9-Y) \)
  • (90% capacity)

• Optimum cycle time = \( (1.5L + 5) / (1-Y) \)

• Optimal effective green \( g_1 = y_1/Y \times (C – L) \)

Example

• Approach 1: flow = 600 v/h, sat flow = 1800 v/h
• Approach 2: flow = 900 v/h, sat flow = 1800 v/h
• Intergreens = 5 secs, effective green = \( G +1 \)

• Lost time for junction thus = 10 – 2 = 8 secs

• \( y_1 = \frac{600}{1800} = 0.3 \)
• \( y_2 = \frac{900}{1800} = 0.5 \)
• \( Y = 0.3 + 0.5 = 0.8 \)
• Cycle min = \( L / (1-Y) = \frac{8}{1-0.8} = 40 \) seconds

• \( y_1/y_2 = 0.3/0.5 = 0.6 = g_1/g_2 \)

• Optimal effective green \( g_1 = y_1/Y \times (C – L) = 0.3/0.8 \times (40-8) = 12 \) secs

• Optimal effective green \( g_2 = 0.5/0.8 \times (40-8) = 20 \) secs
  • i.e ratio = 12/20 = 0.6
  • Actual green \( G_1 = 11 \) and \( G_2 = 19 \) seconds
OSCADY PRO

Junction Diagram Screen

- Graphical representation of junction

- Allows editing of:
  - Arms
  - Traffic Streams
  - Lanes
  - Phases
  - Stages
  - Positions
Stage and Sequence Generation

- Do not have to define any stages or sequences
- OSCADY PRO can generate all possible optimal stages and potentially optimal sequences
- User then given the ‘optimal’ solution plus alternatives for consideration

E.g., this Intergreen Matrix leads to these optimised phase timings:
OSCADY PRO Signal Optimiser

- The OSCADY PRO signal optimiser finds the best signal timings for three separate objectives:
  - critical cycle time
  - maximum capacity
  - minimum delay.
- A separate set of phase timings is generated for each of these objectives.

### Optimisation objectives

- **Critical cycle time**
  - Minimum cycle time where the junction operates within maximum practical capacity (default = 90%)

- **Maximum practical capacity**
  - Cycle time and signal timings that give the largest practical reserve junction capacity

- **Minimum delay**
  - Cycle time and signal timings that give the lowest overall junction delay
Optimisation options include:

- Fixed/maximum cycle time
- Phase minimum and maximum green
- Stage minimum green
- Max degree of saturation (traffic stream)
- Max queue (traffic stream)
- Delay weighting (traffic stream)
- Phase constraints (pairing start or end times)

Performance results

<table>
<thead>
<tr>
<th>Arm</th>
<th>Traffic Stream</th>
<th>Arrival Rate (PCU/hr)</th>
<th>Controlling Phase</th>
<th>Effective Green (s)</th>
<th>Average Delay (s)</th>
<th>Rate of Delay (PCU)</th>
<th>Degree of Saturation (%)</th>
<th>Practical Reserve Capacity (%)</th>
<th>Queue at End of Green (PCU)</th>
<th>Queue at End of Red (PCU)</th>
<th>Uniform Queue (PCU)</th>
<th>Geometric Delay (PCU-min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>400</td>
<td>1</td>
<td>16.00</td>
<td>45.88</td>
<td>5.10</td>
<td>87.99</td>
<td>2.75</td>
<td>3.38</td>
<td>10.09</td>
<td>6.71</td>
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<tr>
<td>2</td>
<td>1</td>
<td>50</td>
<td>2</td>
<td>37.00</td>
<td>7.98</td>
<td>0.11</td>
<td>5.08</td>
<td>9999.00</td>
<td>0.00</td>
<td>0.49</td>
<td>0.49</td>
<td>0.00</td>
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<tr>
<td>2</td>
<td>2</td>
<td>360</td>
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<td>16.00</td>
<td>46.43</td>
<td>4.64</td>
<td>86.72</td>
<td>3.78</td>
<td>3.10</td>
<td>9.09</td>
<td>5.99</td>
<td>0.00</td>
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<tr>
<td>3</td>
<td>1</td>
<td>500</td>
<td>3</td>
<td>24.00</td>
<td>36.96</td>
<td>5.13</td>
<td>86.16</td>
<td>4.46</td>
<td>3.24</td>
<td>10.57</td>
<td>7.33</td>
<td>0.00</td>
</tr>
</tbody>
</table>
HTML Reports

Drive on left or right
Linked traffic signals

- Where there are multiple traffic signal junctions the timings of the traffic signals can be linked in order to reduce the overall network delay.
- Traffic signal timing programmes like TRANSYT can be used to derive the timings and assess network performance.
Model with links and nodes

Network Representation in TRANSYT
**A traffic link in TRANSYT**

A TRANSYT link

Saturation flow

Inflow 1
Inflow 2
Inflow 3

Link number

Outflow

Length

Speed/time

**A signalled node in TRANSYT**

Node number

Signal timing details

- Stage minimums
- Interstage times
Measures of performance

It all adds to:
Wasted time; Running costs; Visual; Pollution

Fuel
Wear
Accidents
Noise
Pollution

Overall journey time along link
Cruise time
Delay

time
distance

STOP
START

Measures of performance

START

Measures of performance

TRANSYIPerformance Index

The P.I. is given by:

$$\sum_{\text{all links in network}} \left( W \cdot \text{delay on link } i + \frac{K \cdot \text{no of stops on link } i}{100} \right)$$

Values given in AG 48 are for 2003

$W = £14-20\text{p}$ per PCU hour of delay

$K = £2-60\text{p}$ per 100 PCU stops
Coordination

Distance

Platoon Disperses

Time

arbitrary zero time

cycle time

ONE WAY

Double cycling

80"

40"

80"

0

1 CYCLE
Cycle Time Graph

Performance Index (P_l) / network cycle time
Best (Practical) Cycle Time: 84 seconds
Lowest Network P_l: 850 (80 seconds) (Blue)

CT Graph (TRANSYT 12.1)

Research On Traffic Control Systems

Journey time saving (%) vs. Origin system complexity

Fixed-Time
FT + local adaptation
Plan generation
Fully adaptive

TRANSYT
EQUISAT
SIGOP
FLEXIPRO
ASCOT
RTOP
SCOOT
SCATS
Madrid PG
TRANSYT
2nd GEN (US)
3rd GEN (US)

System complexity

20
Example of TRANSYT interface

Example of signalised roundabout
Main outputs

- Signal timings
- Queues - max mean (PCUs)
- Delay (Secs) – network and link
- Stops (percentage/ PCU) – network and link
- Degree of saturation (%)

HTML reports
Adaptive UTC - SCOOT

SPLIT:  
CYCLE:  
OFFSET:  

OPTIMISING: (DELAY & STOPS)

TECHNIQUE: FREQUENT, SMALL ALTERATIONS TO:
- SPLITS
- OFFSETS
- CYCLE TIME

SCOOT System

20% reduction in delay over typical TRANSYT fixed time system

www.scoot-utc.com
Delay savings

- 12% saving in delay against up to date fixed time plans
- 20% saving in delay against 3 year old plans

Versus F.T.
Transyt up to date

<table>
<thead>
<tr>
<th>Location</th>
<th>am</th>
<th>OFF</th>
<th>pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glasgow</td>
<td>-2</td>
<td>14*</td>
<td>10*</td>
</tr>
<tr>
<td>Coventry - Foleshill</td>
<td>5</td>
<td>33*</td>
<td>22*</td>
</tr>
<tr>
<td>Coventry - Spon End</td>
<td>8</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Worcester</td>
<td>7</td>
<td>8*</td>
<td>19*</td>
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<tr>
<td>London</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Southampton</td>
<td>40*</td>
<td>1</td>
<td>48*</td>
</tr>
<tr>
<td>Worcester</td>
<td>31*</td>
<td>18*</td>
<td>20*</td>
</tr>
</tbody>
</table>

* = STAT. SIG.
### SCOOT Survey Results – Overseas Systems

<table>
<thead>
<tr>
<th>Previous System</th>
<th>Reduction in Delay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAO PAULO (AREA 1)</td>
<td>TRANSYT</td>
</tr>
<tr>
<td>SAO PAULO (AREA 2)</td>
<td>TRANSYT</td>
</tr>
<tr>
<td>NIJMEGAN</td>
<td>F.T.</td>
</tr>
<tr>
<td>TORONTO</td>
<td>F.T.</td>
</tr>
<tr>
<td>BEIJING</td>
<td>UNCOORDINATED</td>
</tr>
</tbody>
</table>

*result for SCOOT with ‘split weightings’ set to favour the main road.

### SCOOT Worldwide (2005)

- **North America**: Red Deer, Halifax, Toronto, Ann Arbor, Arlington
- **Europe**: Limerick, Cork, Nijmegen, Madrid
- **Asia**: Dubai, Bahrain, Delhi, Beijing, Dalian, Chengdu
- **Africa**: Johannesburg, Cape Town, Durban, Port Elizabeth
- **South America**: Fortaleza, Sao Paulo, Santiago
- **Australasia**: Tai Po, Hong Kong, Macau, Chiang Mai, Bangkok, Kuala Lumpur