Traffic signal-controlled intersections

Course AH2171,

Traffic Engineering and Management

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Traffic signal-controlled intersections

- Introduction
- Advantages/disadvantages of traffic signal control
- Usage and some design considerations
- Traffic signal control strategies
- Terminology
- Traffic signal stages and phases
- Delay and capacity
- Cycle and green times
- LHOVRA

Introduction

- Intersections under traffic signal control operate on the basis that separate time periods are allotted to conflicting traffic movements so that each can make safe and efficient use of the carriageway space available.
- Traffic signals are usually installed only at at-grade intersections in built-up areas.

Advantages/disadvantages of traffic signal control

Properly installed and operated signals have the following advantages:

- They reduce the frequency of vehicle-pedestrian and right-angle vehicle-vehicle accidents
- They can increase the traffic-handling capacities of congested non-signalised intersections
- Can be programmed to increase the people-handling capacities of intersections (by giving priority to pedestrians and public transport)
- Under conditions of favourable intersection spacing they can be coordinated to provide for nearly continuous vehicle progression through intersections in linked or area-wide urban traffic control schemes
- They can be programmed to give priority to movements through particular arms of an intersection
- Their capital costs and land take needs are usually less than for roundabouts of similar capacity.

Disadvantages of traffic signals include:

- They usually result in an increase in rear-end vehicle collisions (more so with fixed time signals than vehicle-actuated ones)
- They can increase total delay (and operating costs) to vehicles, particularly in uncontested non-peak periods
- Signal instillations need to be continuously maintained and their operations monitored
- Signal failure, although infrequent, can lead to serious and widespread traffic difficulties especially during peak traffic periods.

Usage

The decision as to whether a traffic signal should be used at a particular intersection depends very much upon the conditions prevailing at the site, such as:

- the type of intersection,
  - three- or five-way intersections are better treated by roundabouts than by traffic signals, especially when the flows are balanced and the junction is Y-shaped
- how close the intersection is to the next intersection(s) , and whether it is within the linking orbit of an urban traffic control scheme,
  - About two out of every five traffic signals in Britain are eventually expected to be part of area-wide schemes
- the number and types of accident previously experienced (if it is an existing intersection)

- the speed, volume and composition of vehicular traffic,
  - Note: On well trafficked dual carriageways, for similar flows on both roads a signalised intersection will generally have more accidents than a roundabout
- the (turning) destinations of the traffic,
  - Note: When the proportion of right-turning vehicles (in Britain) is greater than, say, 30-40 per cent a roundabout may be preferred
- the volumes of pedestrians and cyclists,
  - Note: Traffic signals represent much less of a hazard for cyclists than roundabouts)
- the site topography,
  - Signalised intersections located on the crests of hills may be difficult to perceive for drivers approaching uphill while those following steep downhill approaches will require carriageway surfacings with high skid resistance)
- the land take available.

Some design considerations

- Turning vehicles should be provided (where space permits) with auxiliary lanes where they can slow down and be stored clear of the through traffic,
- For safety reasons, drivers on any given approach should always be able to see at least two signal heads, usually a primary and a secondary signal,

Traffic signal control strategies

The methods to control the traffic signals can be divided in two main categories:

- Isolated traffic signal control, in which the signal timing decisions are based solely on the traffic demand in the approaches to that intersection.
- Coordinated traffic signal control, in which the signal timing decisions are based with consideration also to other adjacent traffic signals to which the intersection controller is connected in order to facilitate passage of the signalized system.

Isolated Traffic Signal Control

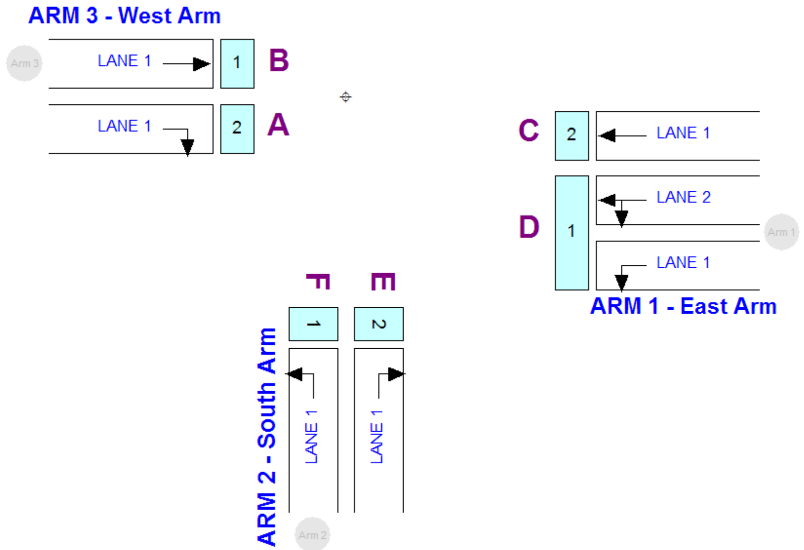
a. **Fixed time signal control (FT):** Predetermined, fixed signal timing (called time plan) calculated to minimize overall intersection delay for the traffic demand during the studied period. Separate time plans can be developed for different periods during the day, e.g. morning peak, mid-day, afternoon peak, night, for which the signal timing plan is designed.

b. **Vehicle actuated control (VA):** Variable green time allocations and cycle time based on detection of the traffic demand in the signalized approaches or groups of lanes (signal groups). The decision to extend green light or not is based solely on the conditions for the actual approaches or signal groups served by the ongoing green.

- **Self-optimized real-time control:** Variable green time allocation and cycle time based on real-time optimization of traffic performance with regard to the conditions for all the signalized approaches in the intersection.

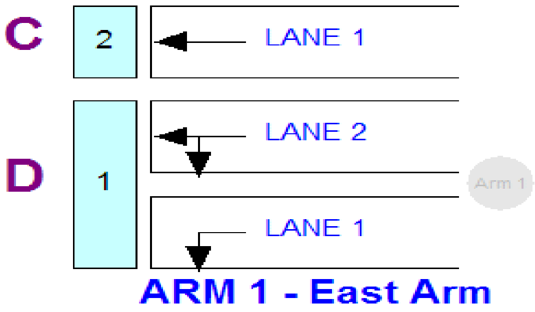
Terminology (From OSCADY PRO)

- Arm
  - A road carrying traffic towards and/or away from a junction. Each arm contains one or more traffic streams.
  - In OSCADY PRO arms are used
    - a) to conveniently group traffic streams and
    - b) to store data that applie arms as a whole, such as and exit speeds.



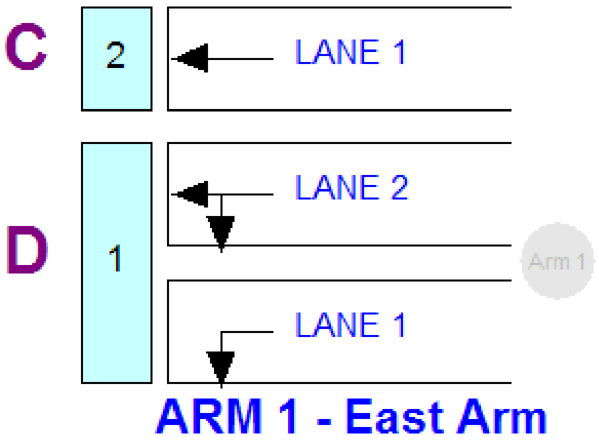
Terminology

- Traffic Stream
  - Traffic that can be regarded as forming a single queue.
    - Vehicular streams (cars, buses and cycles etc)
    - Pedestrian streams
  - Each arm contains one or more vehicular traffic streams
  - Each vehicular traffic stream contains one or more lanes



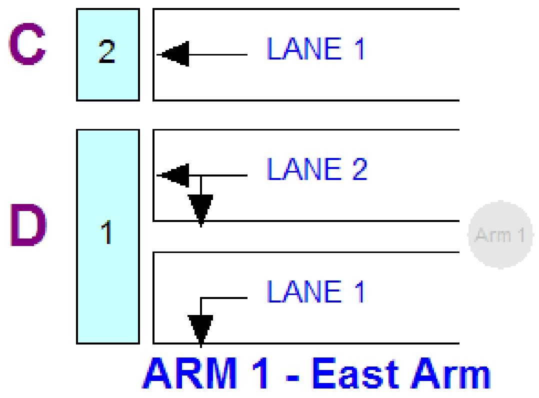
Terminology

- Lane
  - An area of road which can accommodate a single line of vehicles and which may have markings painted on the road indicating movements allowed from the lane.
  - Each vehicular traffic stream contains one or more lanes.
  - May be normal lane or **short lane**, where a short lane is a flare or bay attached to a normal lane.



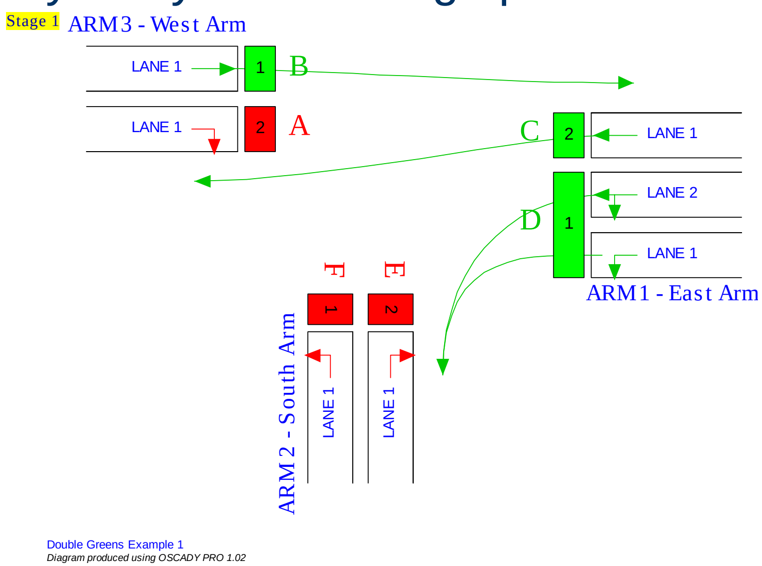
Terminology

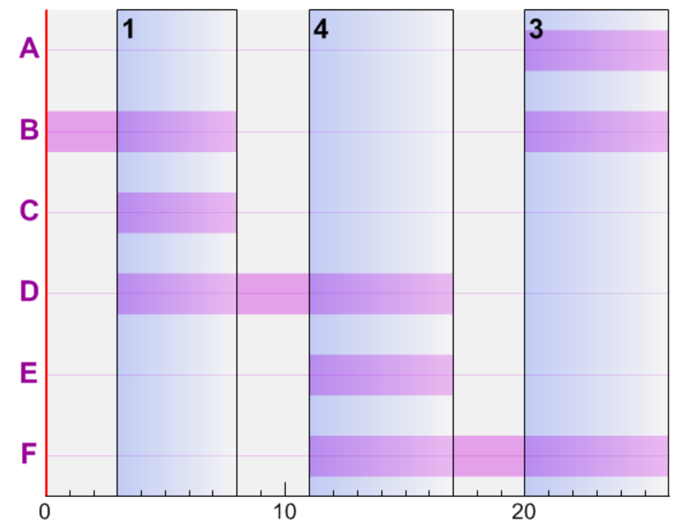
- Phase
  - A set of signal conditions given to one or more traffic streams (vehicular or pedestrian) so that each stream allocated to the phase receives identical signal indications.
  - All signal heads controlled by a particular phase will switch at the same time.
  - A phase can control more than one traffic stream providing it is acceptable that each traffic stream always receives the same signal indications.



Terminology

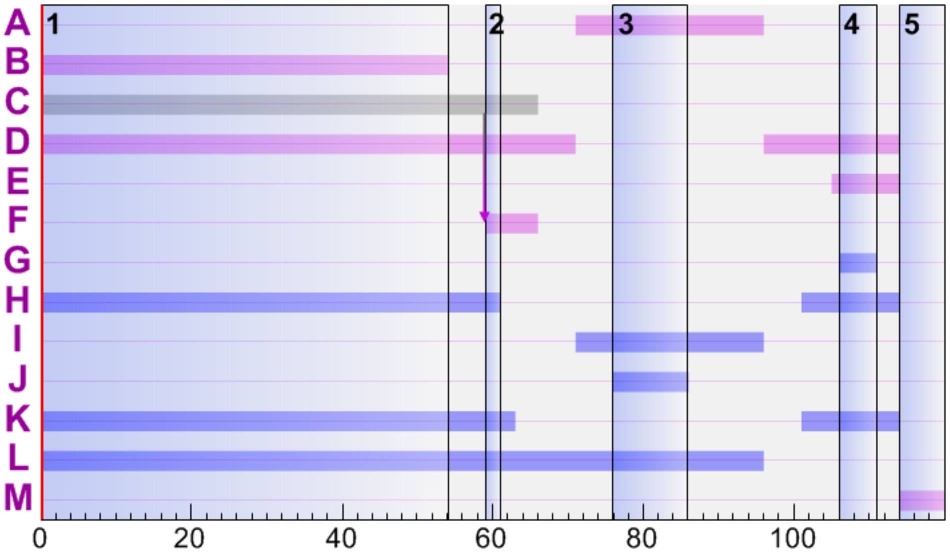
- Stage
  - Part of the signal cycle during which a particular set of non-conflicting phases receives green, and during which there are no phase changes.
  - Each two successive stages are usually separated in the signal cycle by an interstage period.





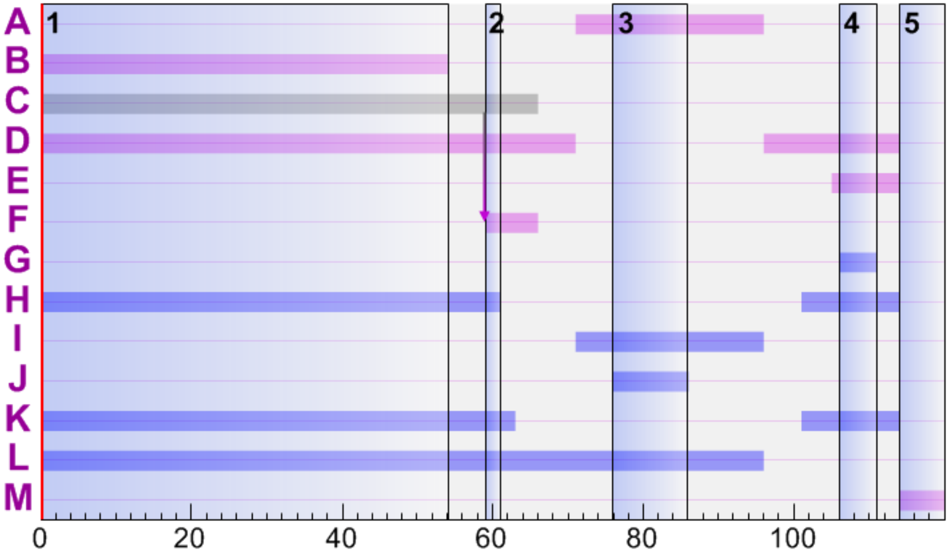
Terminology

- Stage (continued)
  - The start of a stage occurs when the last phase running in the stage turns to green, and the end of a stage occurs when the first terminating phase reaches the end of its green period.
  - Consistent with this definition, individual phases may continue to run beyond the end of the stage, or may start before the stage starts.



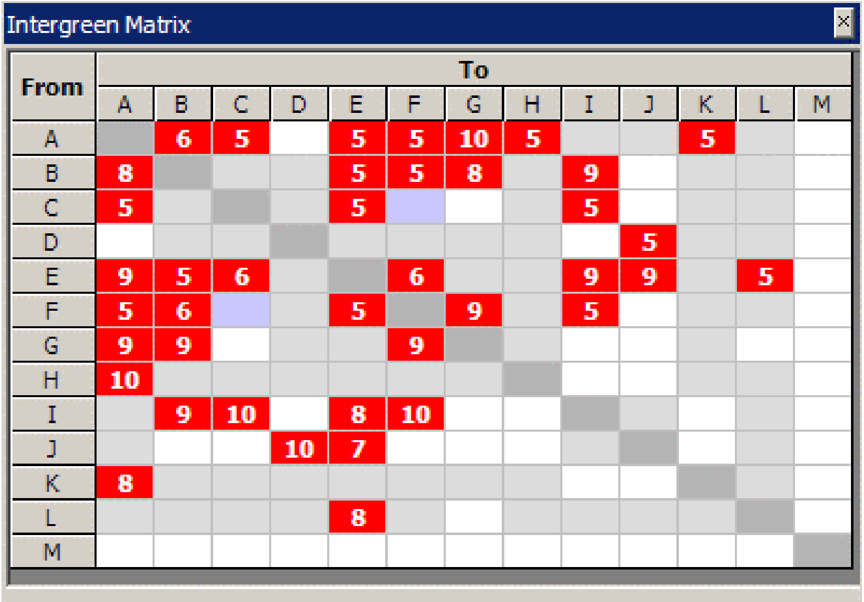
Terminology

- (Stage) Sequence
  - The order in which stages occur in a signal cycle.
  - In most contexts, the word “**sequence”** also simply means a particular run of the signal optimiser.
  - Found **AUTOMATICALLY** by OSCADY PRO

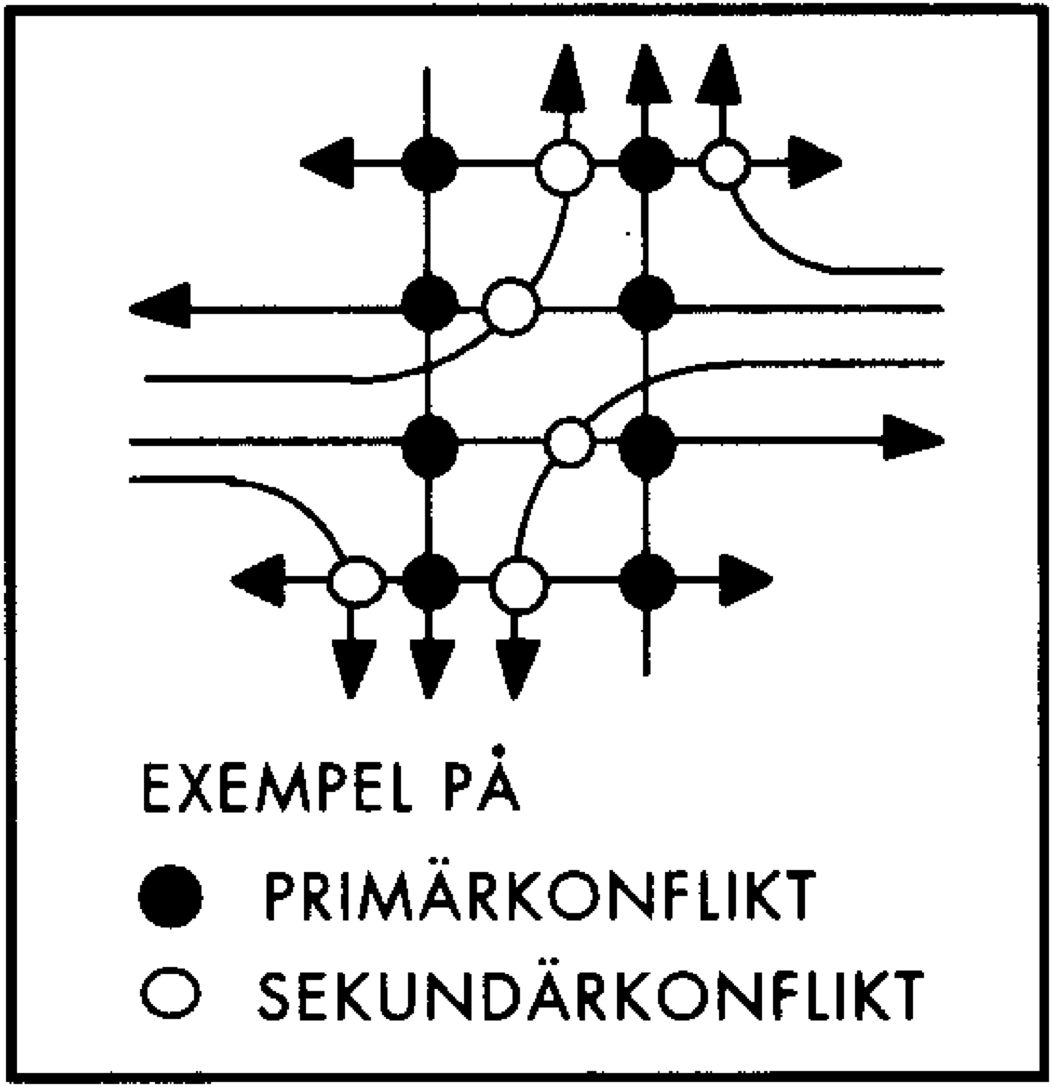


Terminology

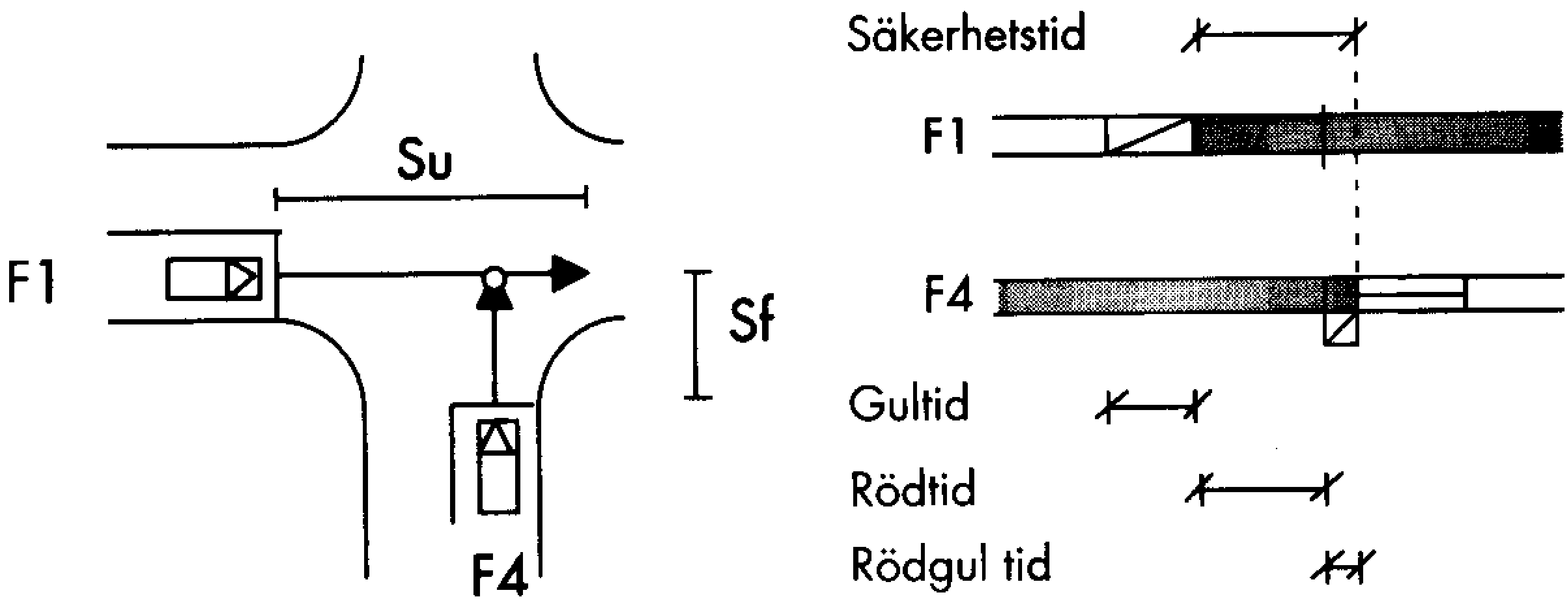
- Intergreen, Intergreen Matrix
  - The length of time (in seconds) that is the minimum time between the end of one conflicting phase and the start of another
  - Defined mainly for safety reasons.
  - The Intergreen Matrix specifies the intergreen between each conflicting pair of phases.


Intergreen Matrix

From	To: A	B	C	D	E	F	G	H	I	J	K	L	M
A		6	5		5	5	10	5			5		
B	8				5	5	8		9				
C	5				5				5				
D										5			
E	9	5	6			6			9	9		5	
F	5	6			5		9		5				
G	9	9				9							
H	10												
I		9	10		8	10							
J				10	7								
K	8												
L					8								
M													

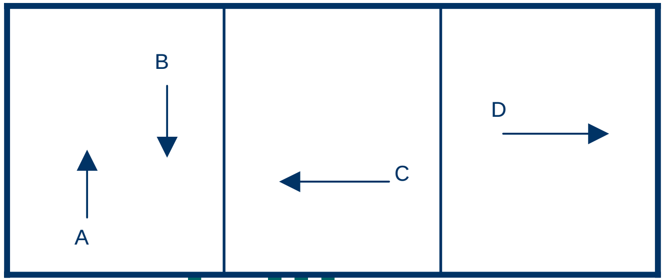


Example of primary and secondary conflicts

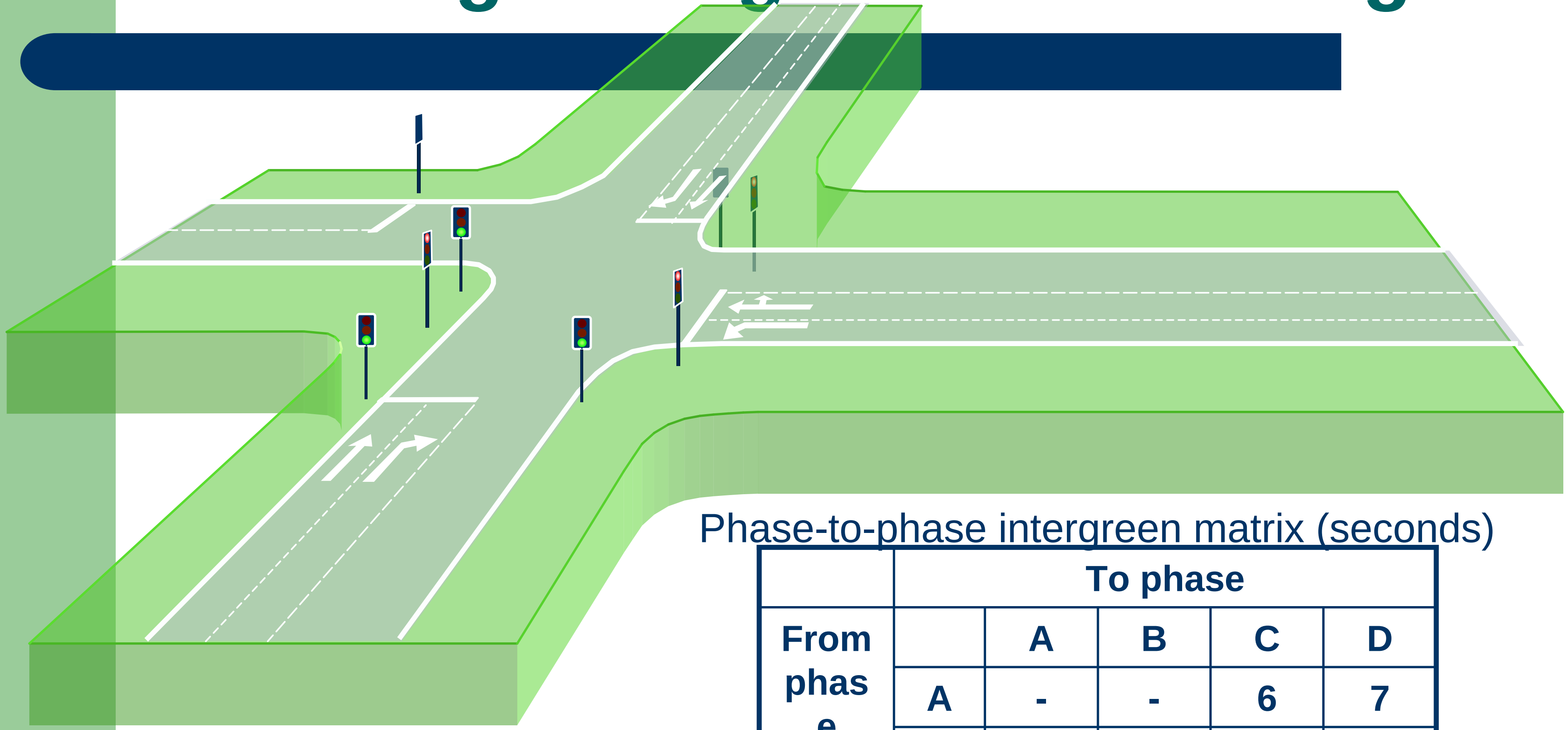


Säkerhetstid

Stage diagram



Interstage design and modelling

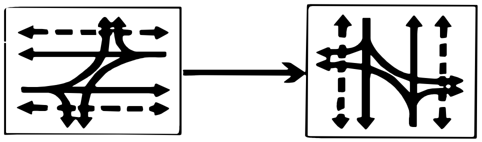


Phase-to-phase intergreen matrix (seconds)

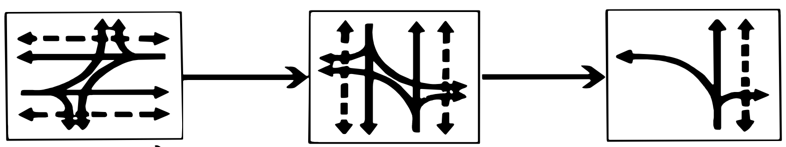
	To phase				
From phase		A	B	C	D
	A	-	-	6	7
	B	-	-	6	5
	C	6	5	-	7
	D	5	8	7	-

Different forms of separating the secondary conflicts

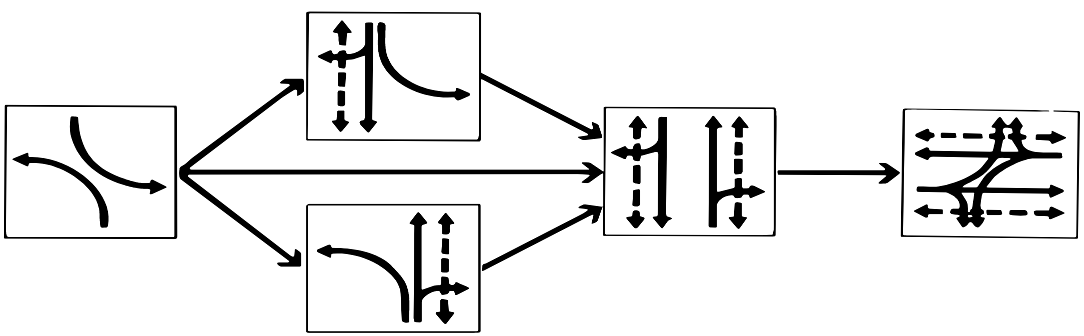
A Ingen separatreglering av sekundärkonflikter



B Delvis separatreglering
Eftergrönt



C Helt separatreglerade vänstersvängar i huvudgatan

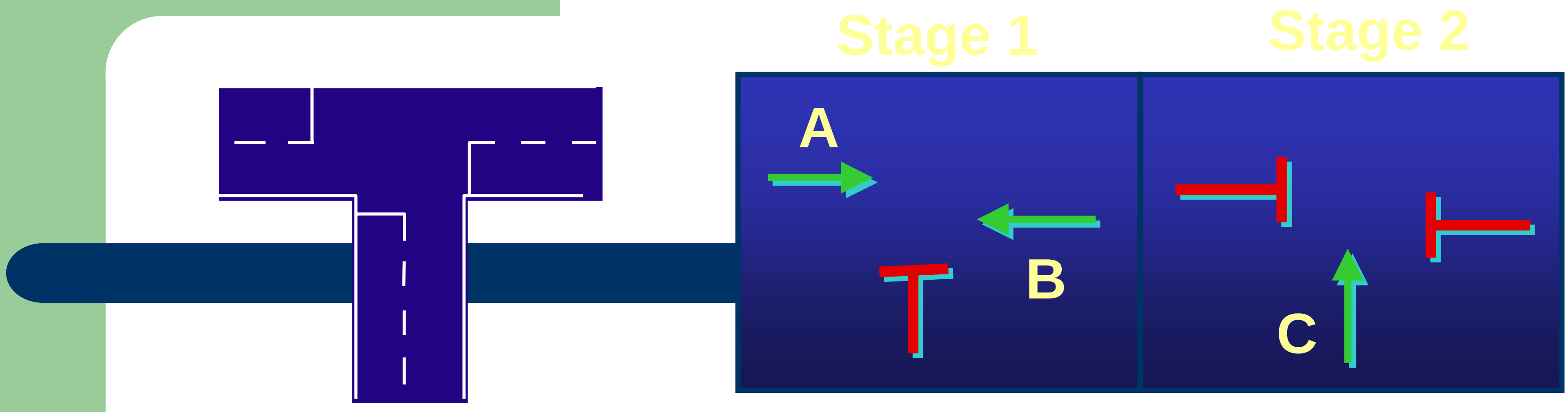


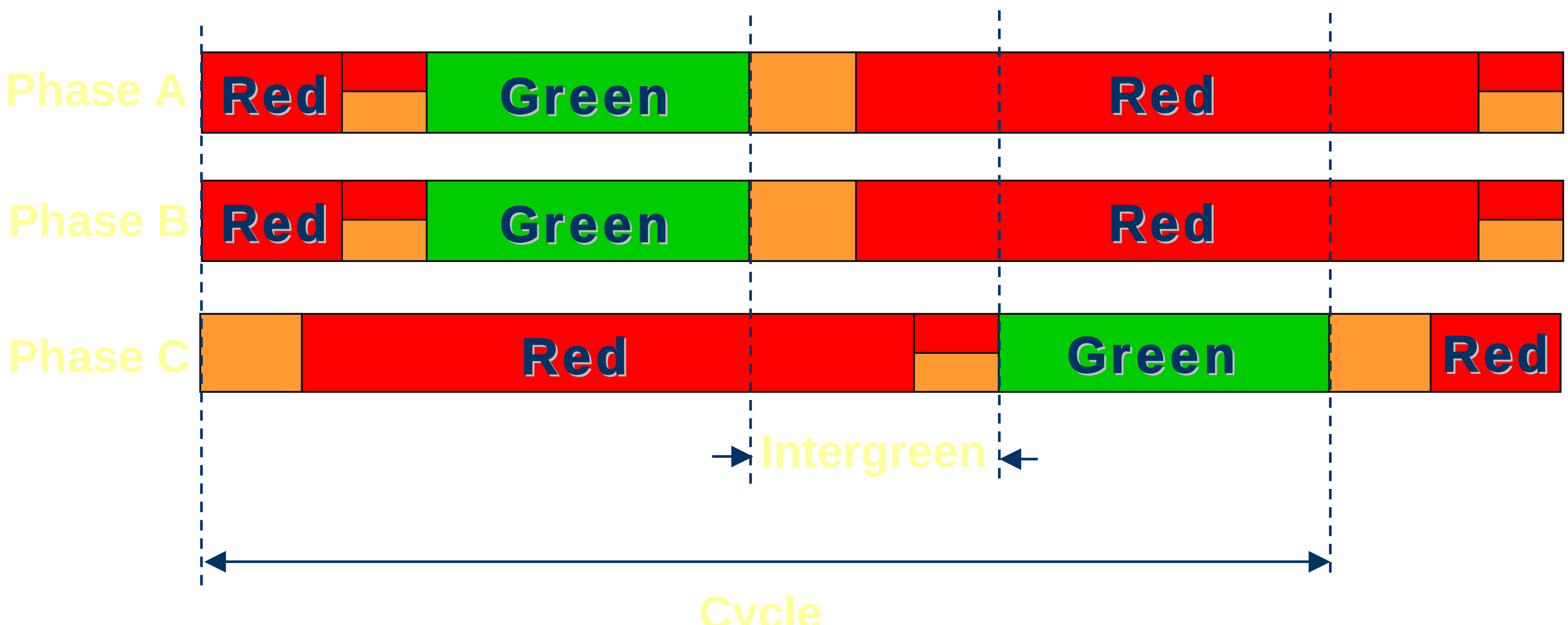
Teckenförklaring

fordon, grönt ljus

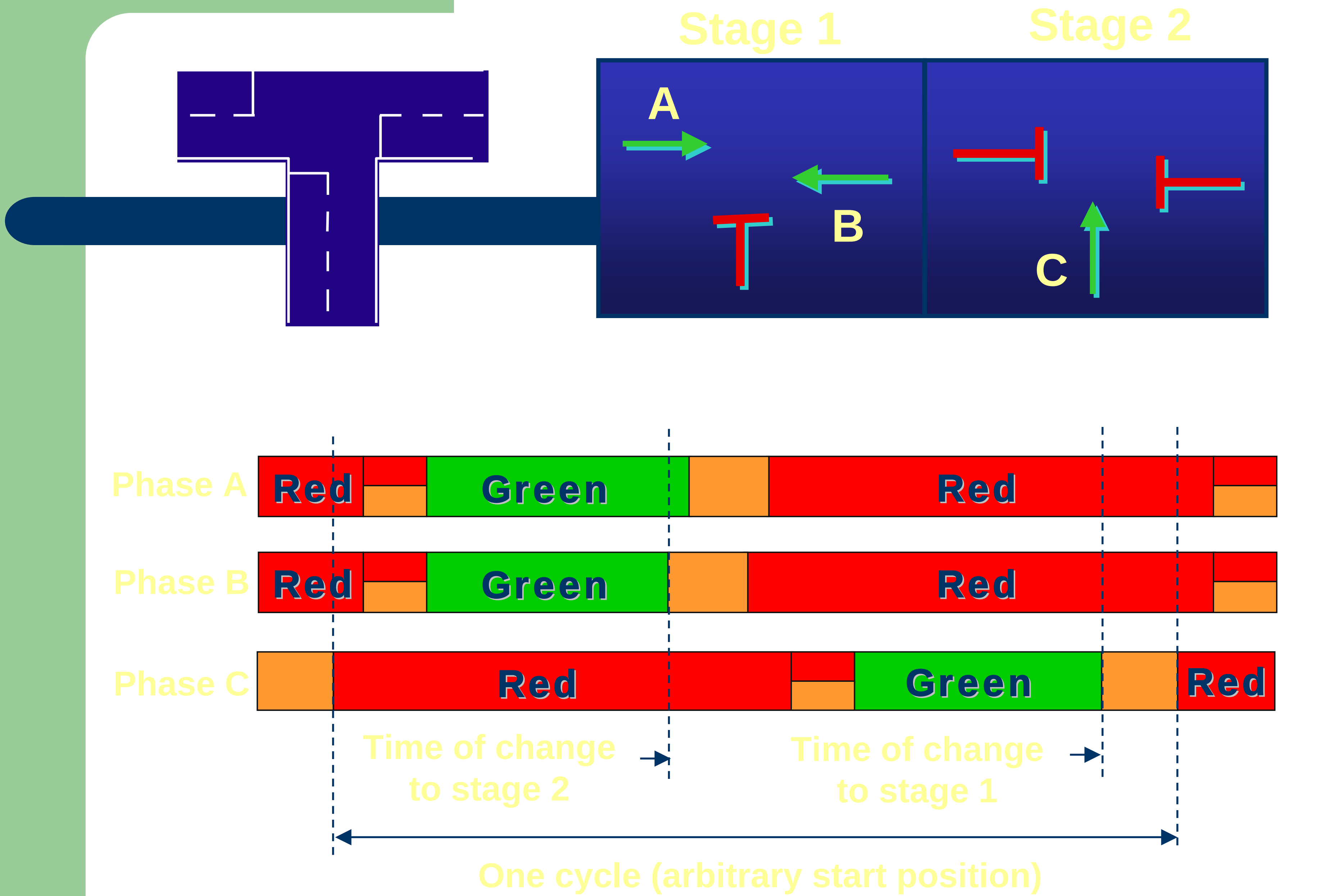
fotgängare, grönt ljus

Traffic signal stages and phases

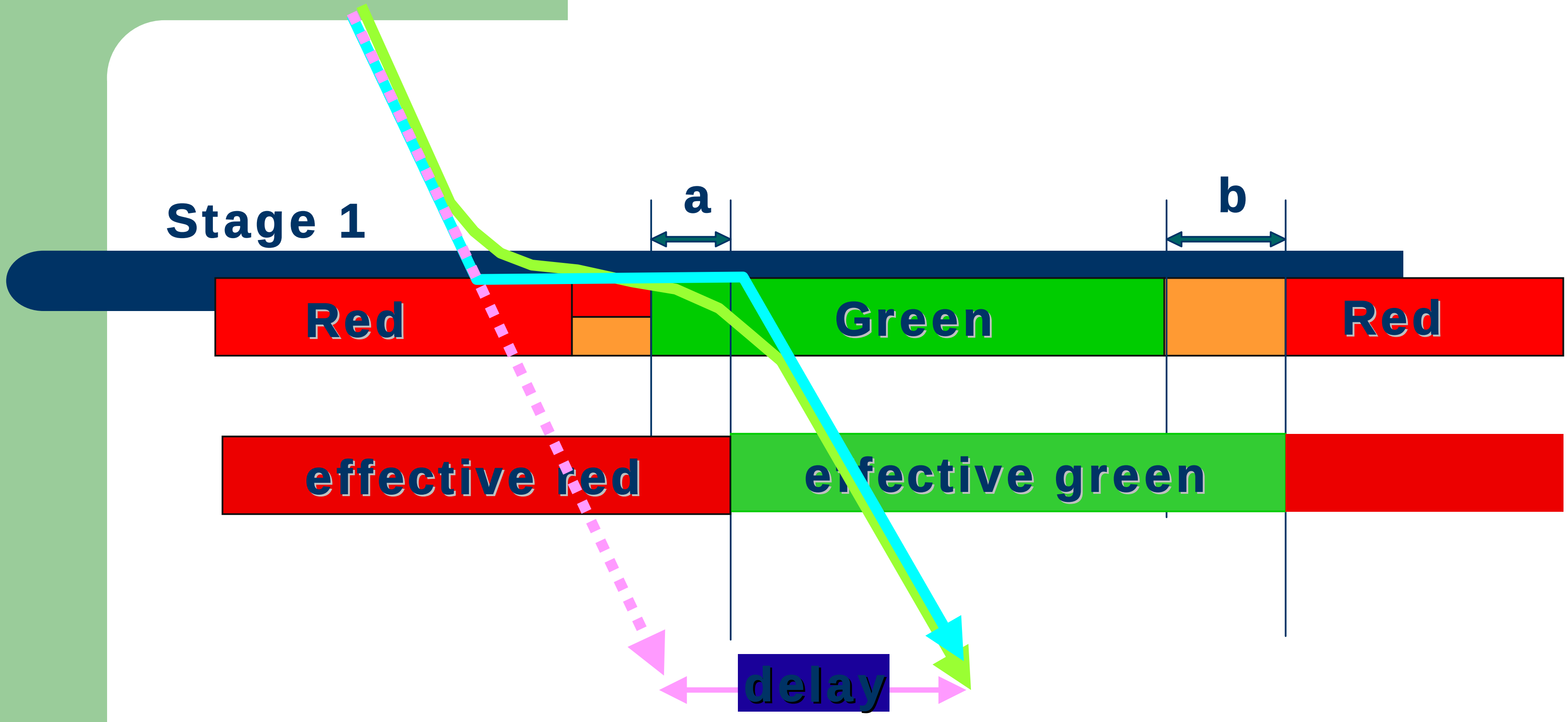




Time of change to stage



Effective green

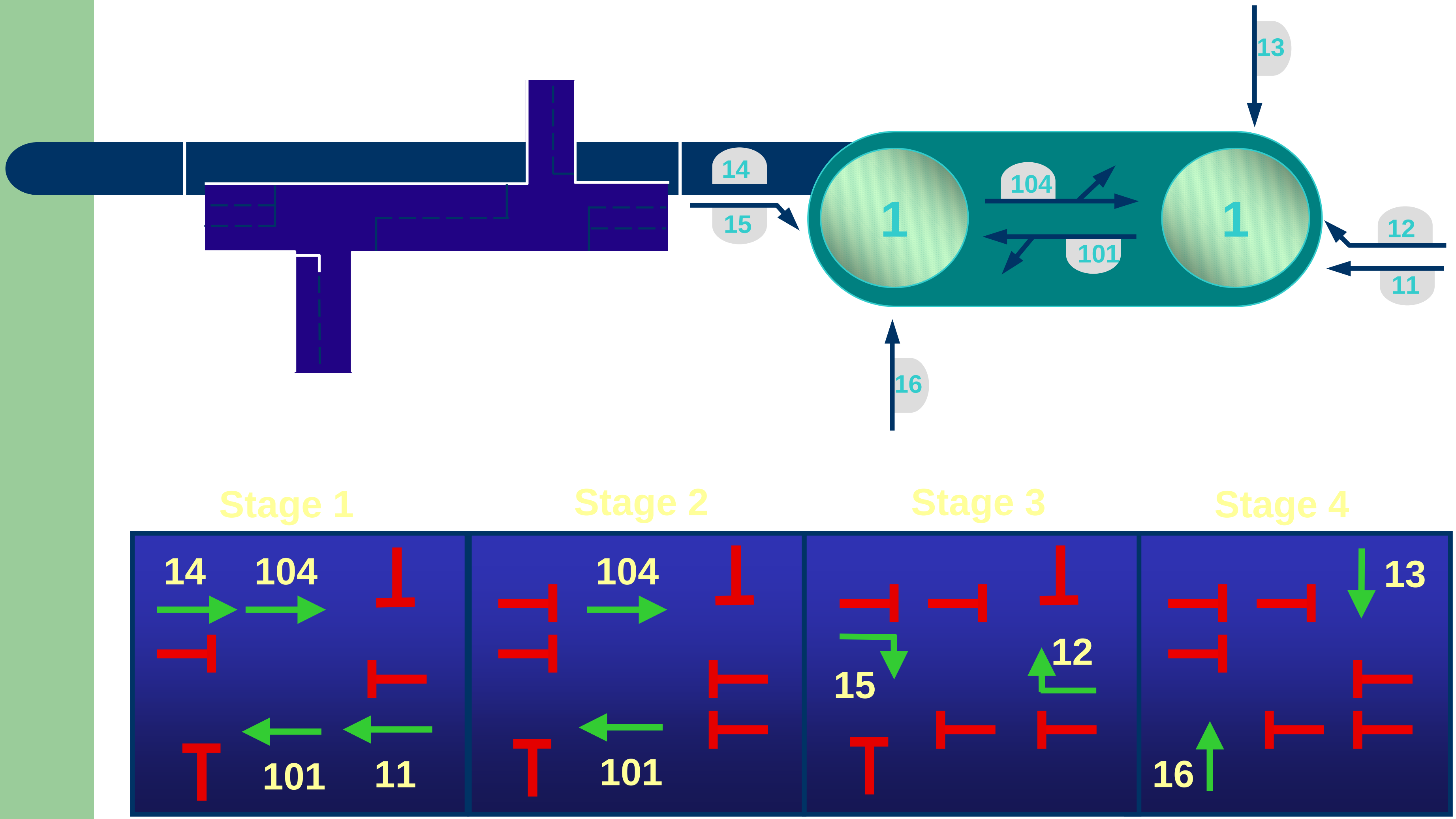


a start displacement (normally 2s in TRANSYT)

b end displacement (normally 3s)

NB - (a) and (b) are modelling parameters

Junction with internal stoplines

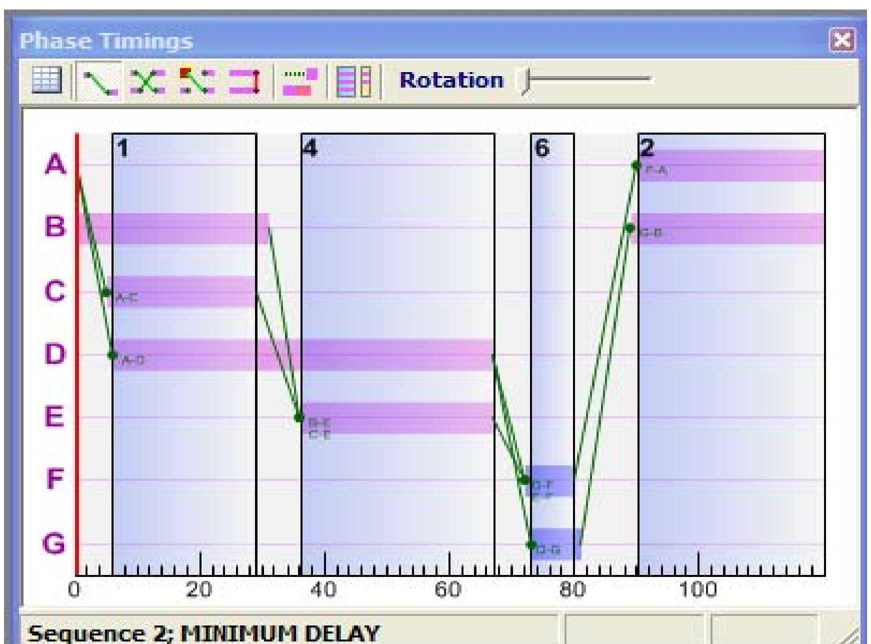


Stage and Sequence Generation

E.g., this Intergreen Matrix leads to these optimised phase timings:

Intergreen Matrix

From	To A	To B	To C	To D	To E	To F	To G
A			5	6	5	6	7
B					5		5
C	7				7	7	5
D	5					5	6
E	6	7	6			5	
F	10		9	8	8		
G	8	8	8	9			



Headway distribution

- In isolated signal control it is normally assumed that the arrival of vehicles in the approaches to the intersection is random with a negative exponential time headway distribution.

q

- $$f(h) = qe^{-qh}$$

where:

h = Headway

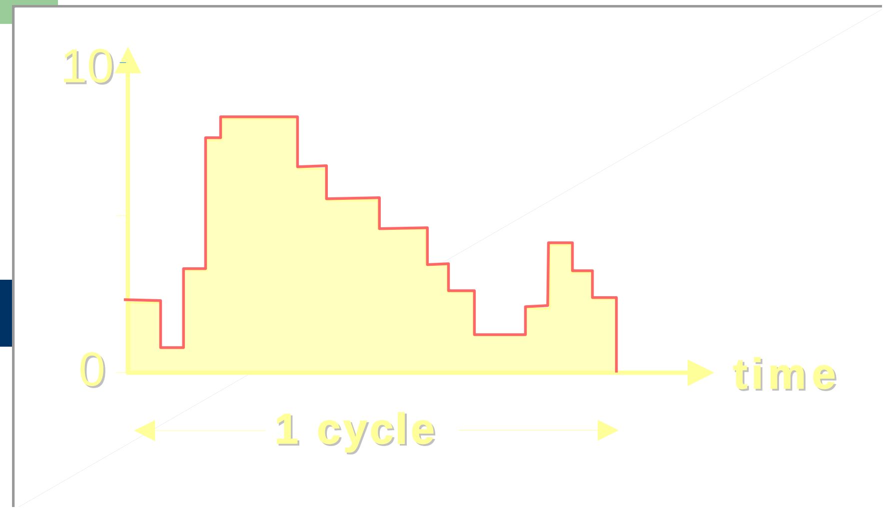
q = Traffic flow = $\frac{1}{\bar{h}}$

Queueing

Arrival (IN) pattern

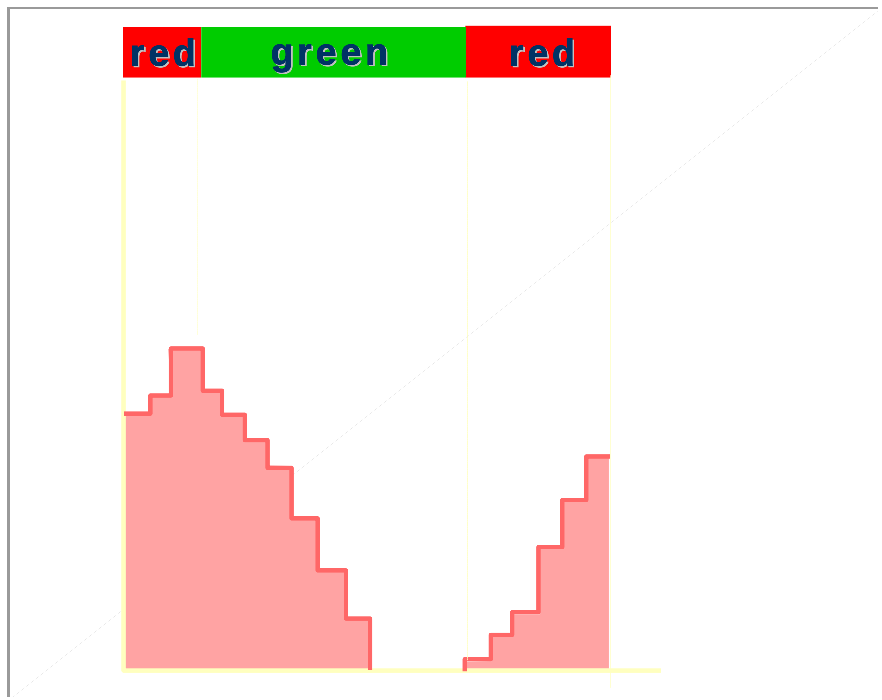
Average flow

(vehicles per 4 seconds)



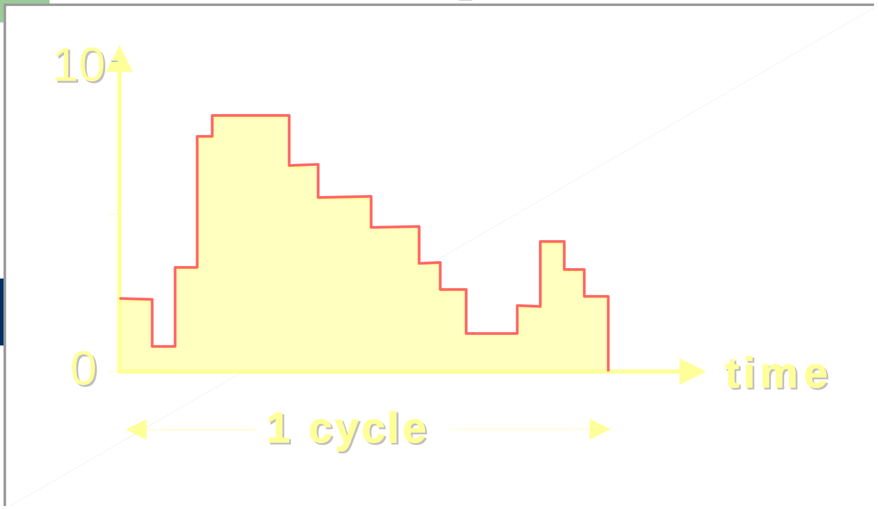
vehicles

in queue



Queue profile

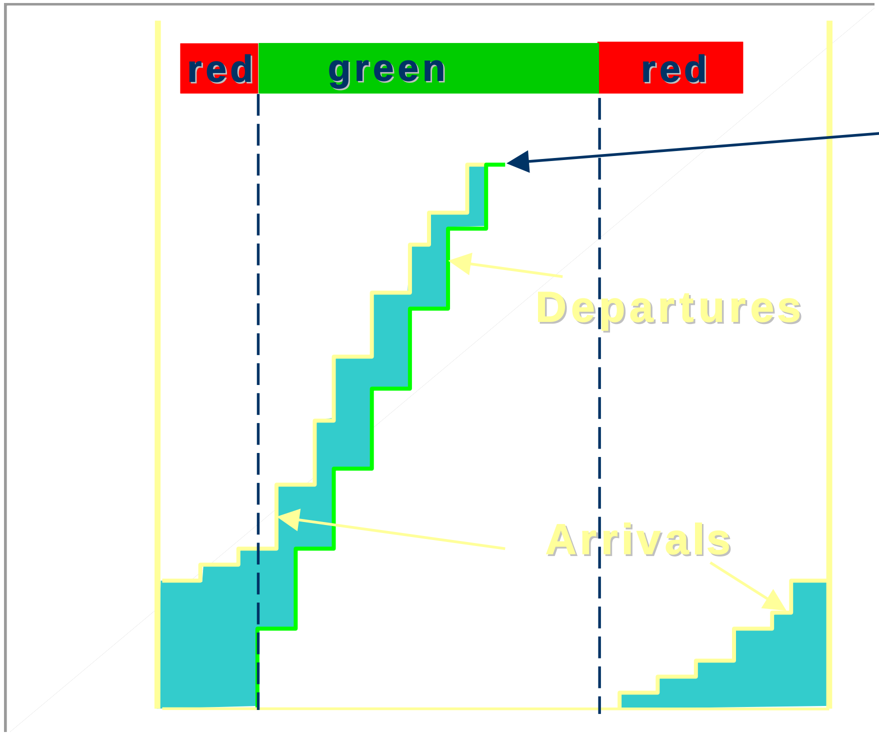
average flow
(vehicles per 4 seconds)



IN profile

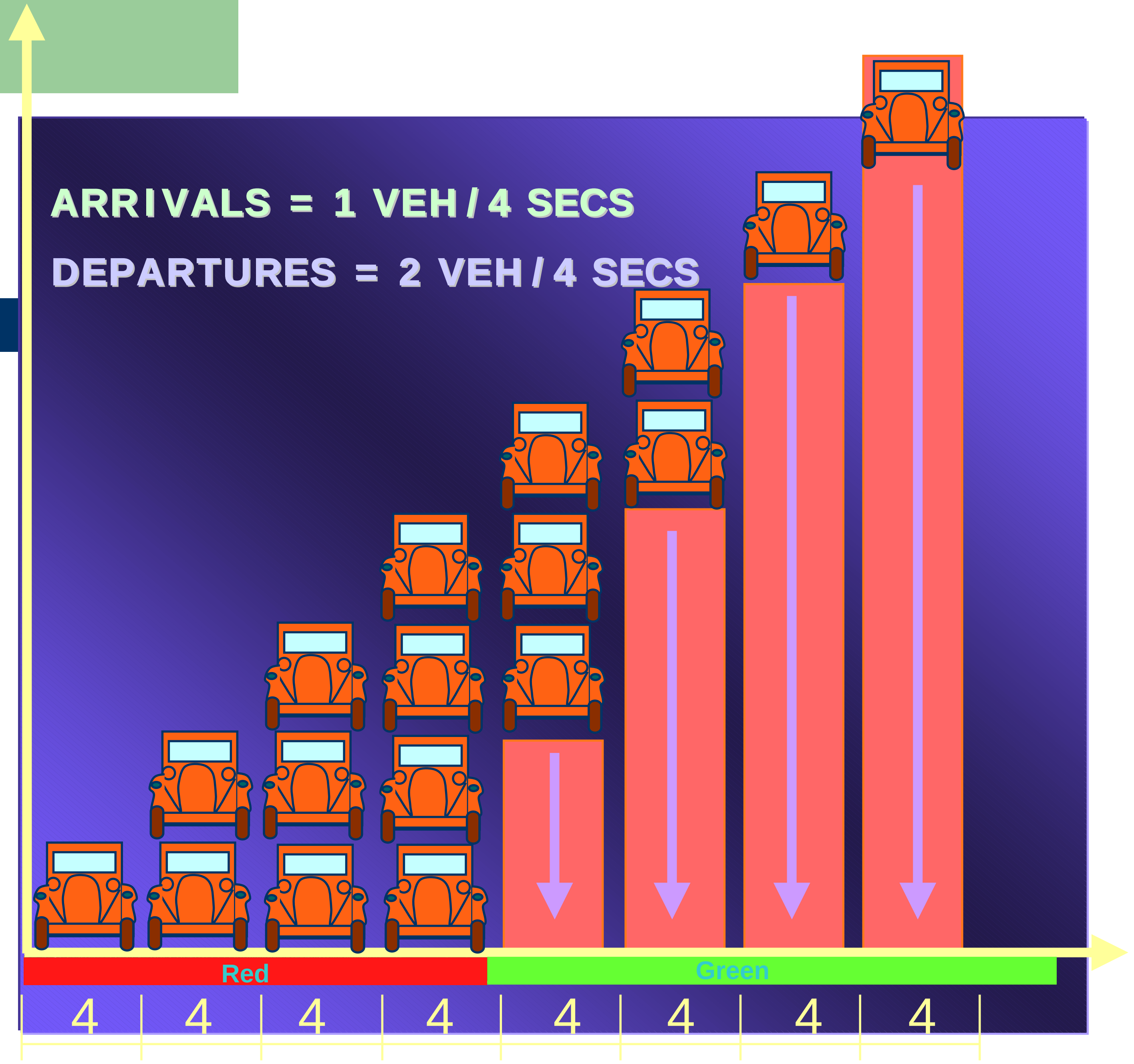
Vehicles in queue

cumulative inflow
and outflow

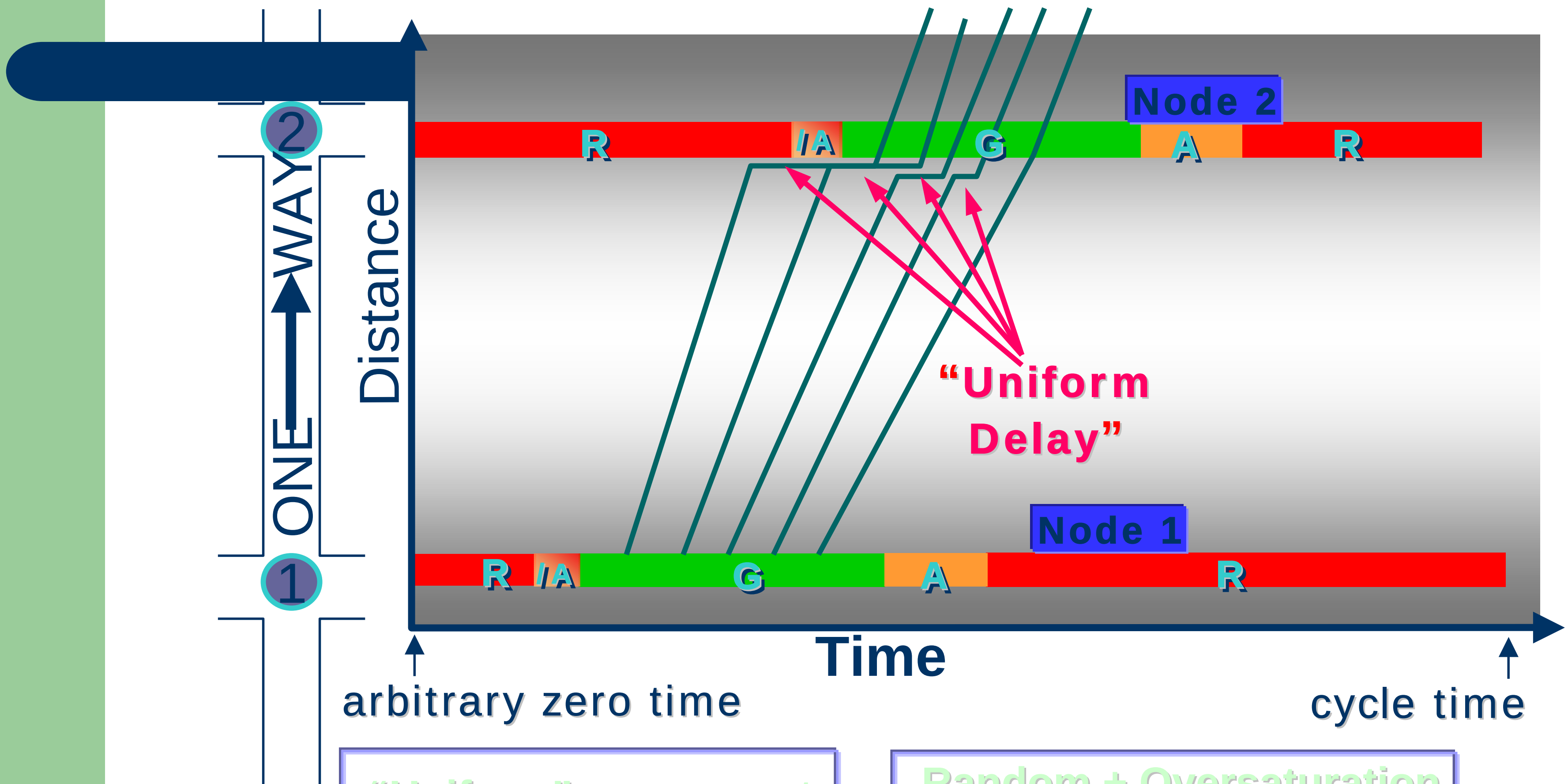


Max back of queue:
Queue-clears time

Queue profile


ARRIVALS = 1 VEH / 4 SECS
DEPARTURES = 2 VEH / 4 SECS
Red
Green
4
4
4
4
4
4
4
4

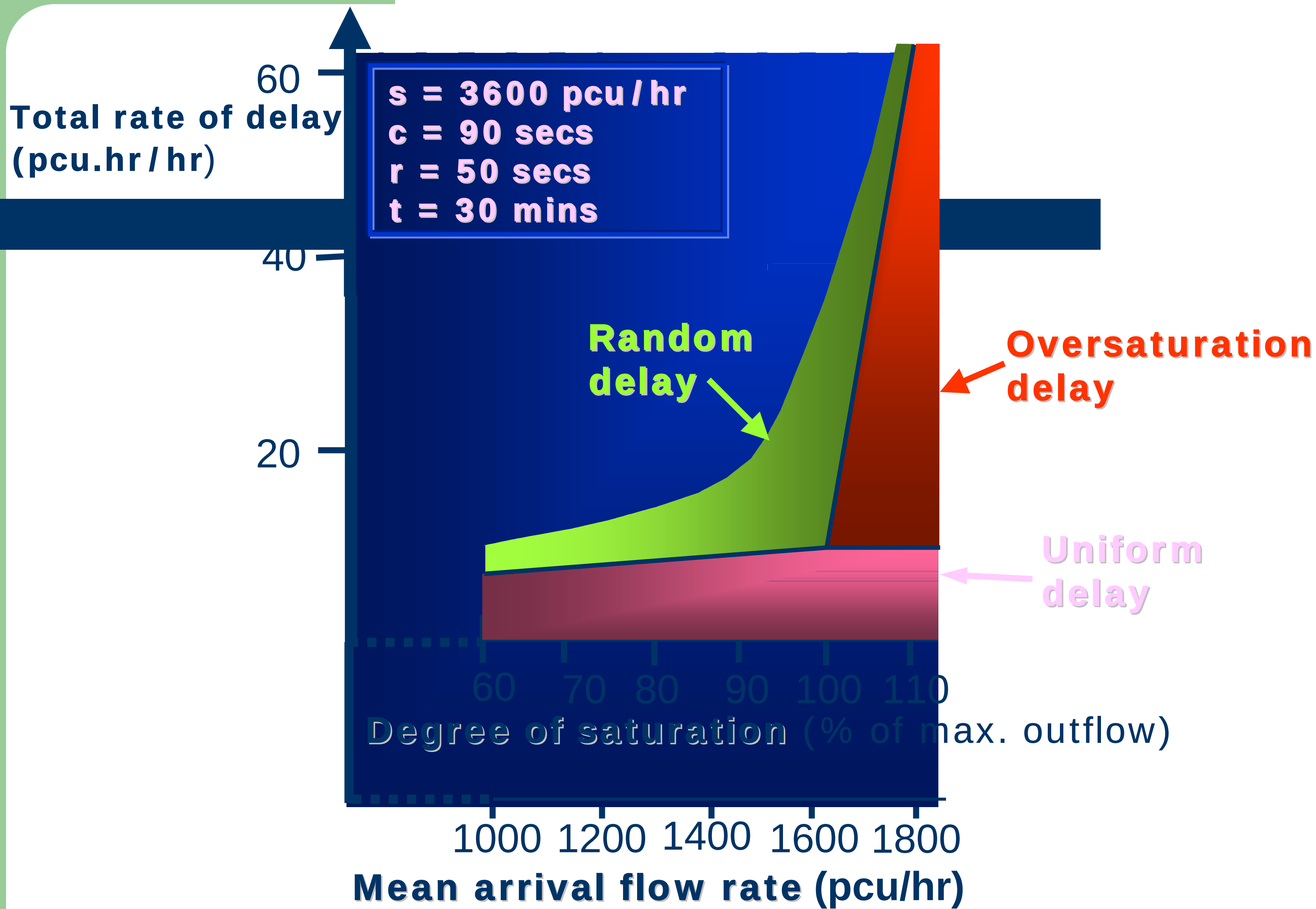
Derivation of uniform delay



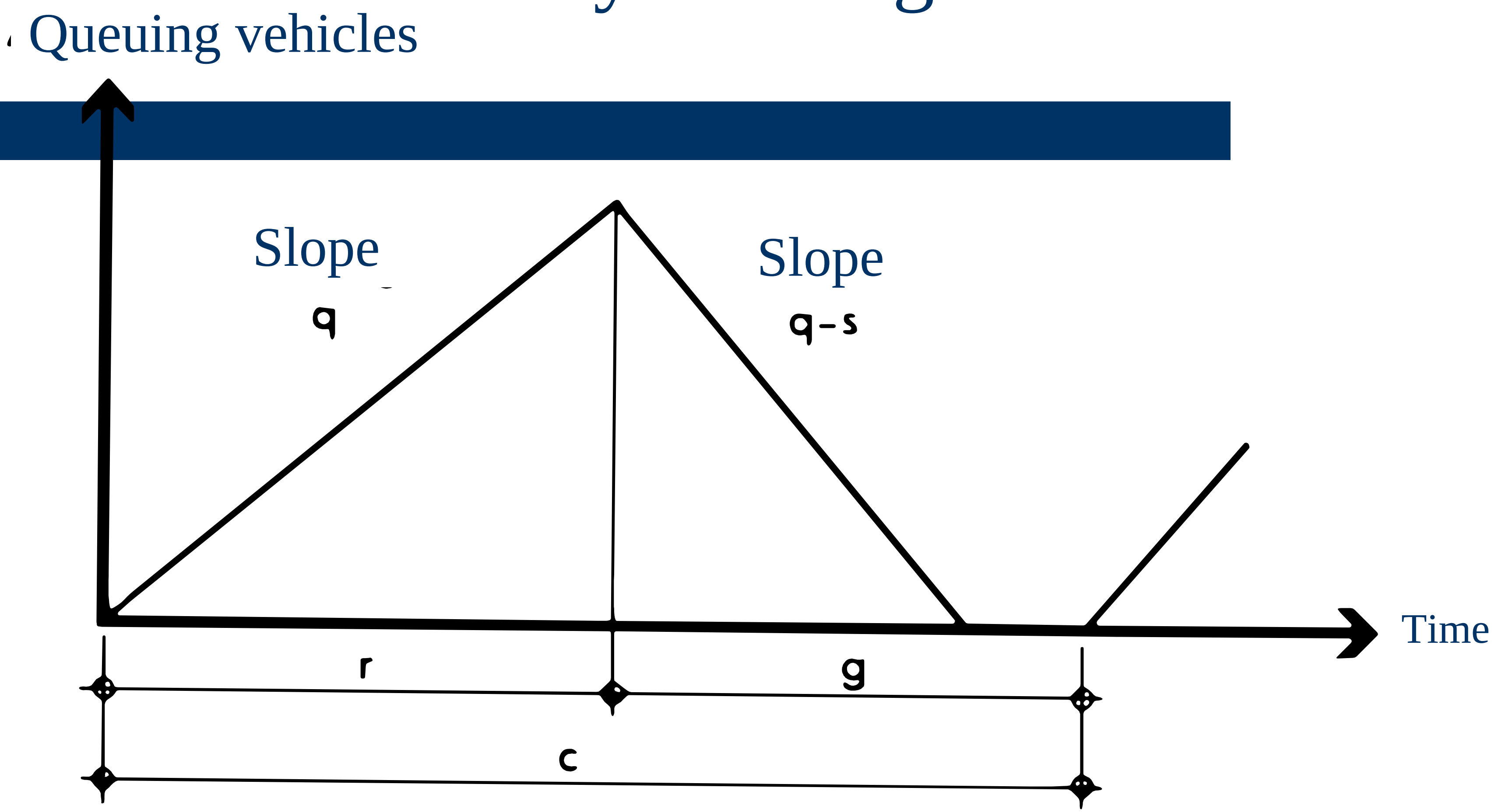
"Uniform" component of total delays shown

Random + Oversaturation delays are calculated separately

Junction delay



Delay with regular income



Representation of discharging vehicles in one lane.

Delay

Webster (1966) found that

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0{,}65\left(\frac{c}{q^2}\right)^{1/3} * x^{(2+5\lambda)}$$

where:

d = Average delay per vehicle on the particular arm

q = Traffic flow

c = Cycle time

g = Effective green time

λ = Proportion of the cycle which is effectively green (i.e. g/c)

x = The degree of saturation (i.e. $q/\lambda s$) (s = saturation flow)

Optimal cycle time

- Webster (1966) found that minimization of the overall delay at an intersection with respect to the cycle time could be represented by

$$c_o = \frac{aL+b}{1-y_1-y_2-....y_n} = \frac{aL+b}{1-Y}\,\text{sec}$$

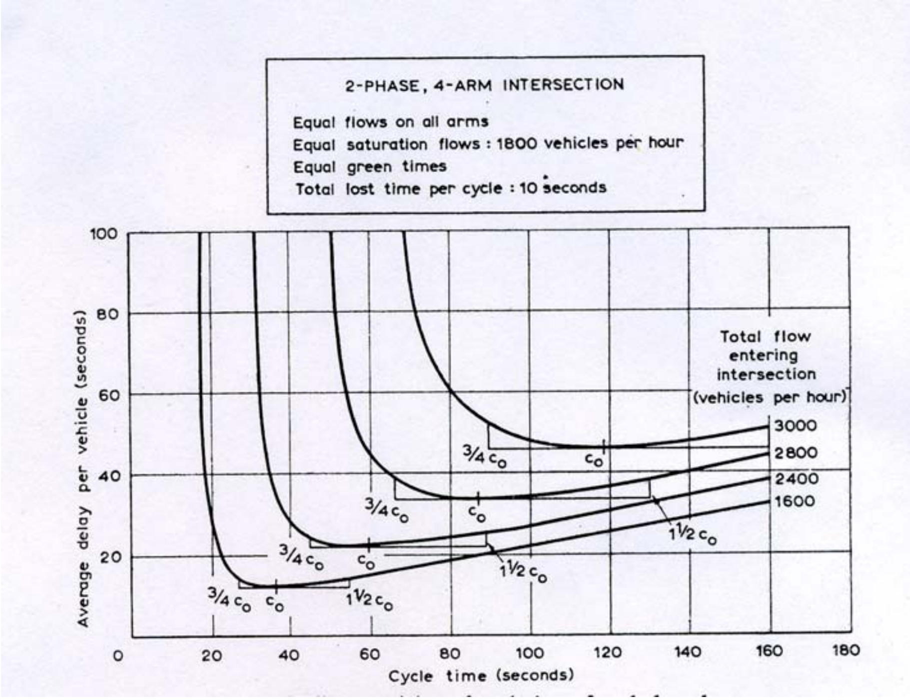
where:

- $y_1, y_2 .... y_n$ = The maximum ratios of flow to saturation flow for phases 1,2….*n*,
- *Y* = Σy
- *L* = The total lost time per cycle.
- *a* & *b* are constants.

- For a certain balance of flows the values of *a* & *b* are 1.5 & 5 respectively:

$$c_o = \frac{1.5L + 5}{1 - Y} \text{sec}$$

- From a practical point of view, including safety considerations, it may be desirable to consider it as lying between 25 and 120 seconds.



Some examples of the variation of delay with cycle time

Green times

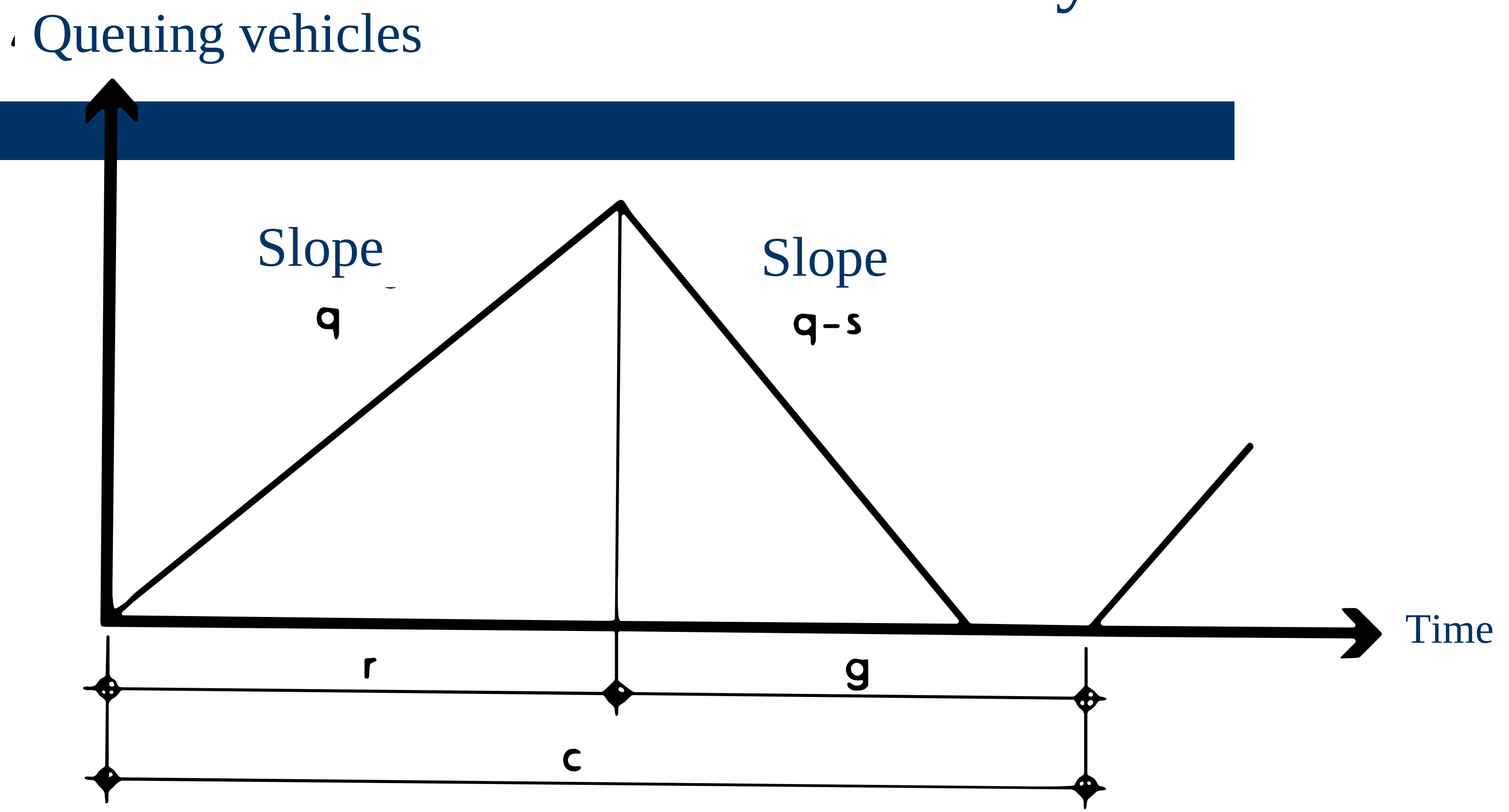
- For setting the green times, it was found that the ratio of the effective green times should equal the ratio of the *y* values, i.e.

$$\frac{g_1}{g_2} = \frac{y_1}{y_2} \ldots\ldots\ldots$$

- where g_1 and g_2 are the effective green times of phases 1 and 2 respectively.
- If $c_o - L$ is the total effective green time in the cycle, the above rule gives

$$g_1 = \frac{y_1}{Y}(c_o - L) \qquad g_2 = \frac{y_2}{Y}(c_o - L)$$

Estimation of delay in details



Representation of discharging vehicles in one lane.

1) $qr < (s\text{-}q)g$

2) $q < sg/c$

3) $q_1/s_1+q_2/s_2<(c\text{-}F)/c=1\text{-}F/c$

4) $$d_{tot} = 0{,}5qr * \left(r + \frac{qr}{s-q} \right) \frac{sqr^2}{2(s-q)}$$

5) $$\bar{d} = \frac{sr^2}{2c(s-q)}$$ which can be written as

$$\bar{d} = \frac{c(1-\lambda)^2}{2(1-\lambda z)}$$

where $z = \dfrac{qc}{gs} =$ degree of saturation, and

$\lambda = \dfrac{g}{c} =$ proportion of green time.

6) $$\bar{d} = \frac{c(1-\lambda)^{2}}{2(1\lambda z)} + \frac{z^{2}}{2q(1-z)} - 0,65\left(\frac{c}{q^{2}}\right)^{1/3} * z^{(2+5\lambda)}$$

7) $$c_{0} = \frac{a * F + b}{1 - \frac{q_{1}}{s_{1}} - \frac{q_{2}}{s_{2}}}$$

8) $$g_1 / g_2 = \left(\frac{q_1}{s_1}\right) \Big/ \left(\frac{q_2}{s_2}\right)$$

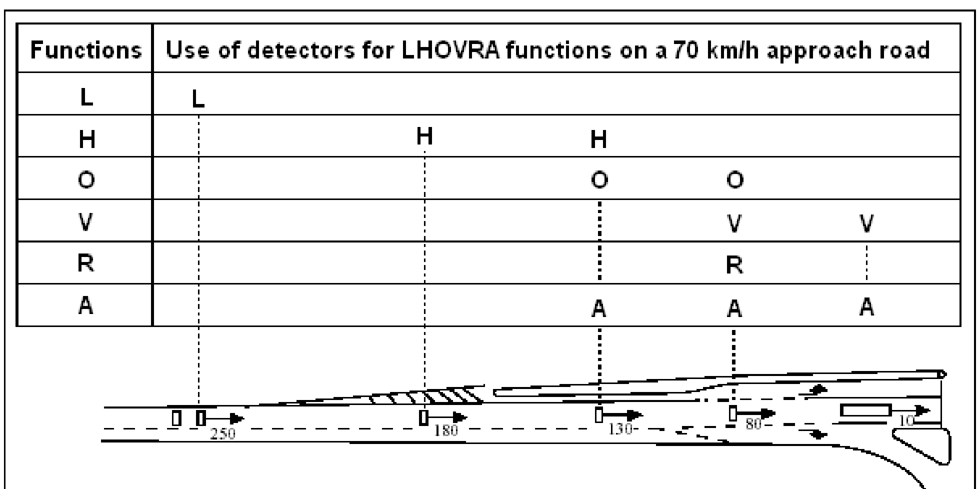
9) $$g_i = \frac{\dfrac{q_i}{s_i}}{\sum_i \dfrac{q_i}{s_i}} * (C - F)$$

Part II: Isolated signal control with the LHOVRA technique

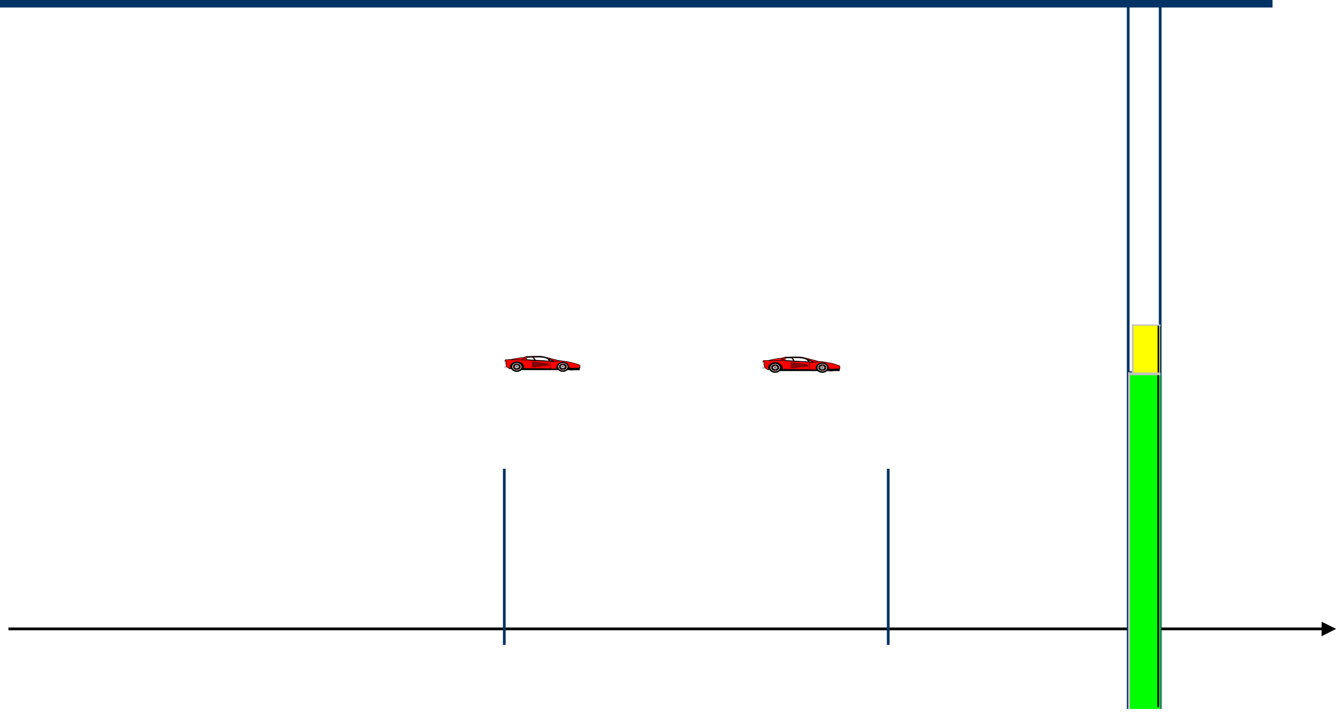
- LHOVRA was originally developed in order to increase safety and to reduce lost time and the number of stopped vehicles at signalized intersections along high-speed roads;
- Past-end green was originally incorporated as part of LHOVRA (the “O” function) and was intended for reducing the number of vehicles in the dilemma zone and thereby reducing the number of red light drivers and rear-end collisions.

The LHOVRA acronym and detector positions

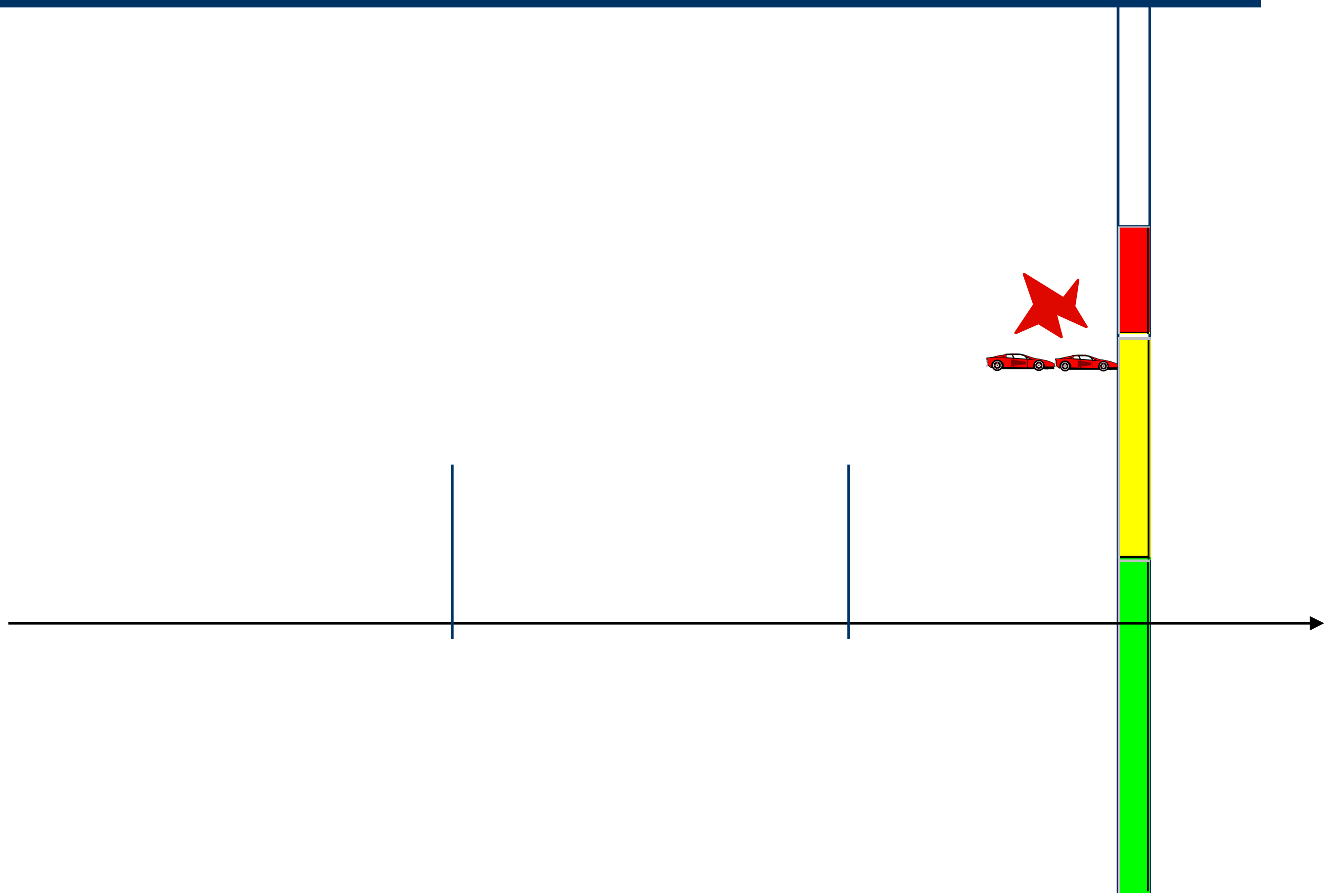
Acronym	Swedish Name	English Translation
L	Lastbil prioritering	Truck, bus and platoon priority
H	Huvudväg prioritering	Main road priority
O	Olycka reduktion funktion	Incident reduction
V	Variabel gul	Variable amber time
R	Rödkörning control	Red driving control (variable red time)
A	Allrödvänding	All red turning



DILEMMA ZONE



DILEMMA ZONE



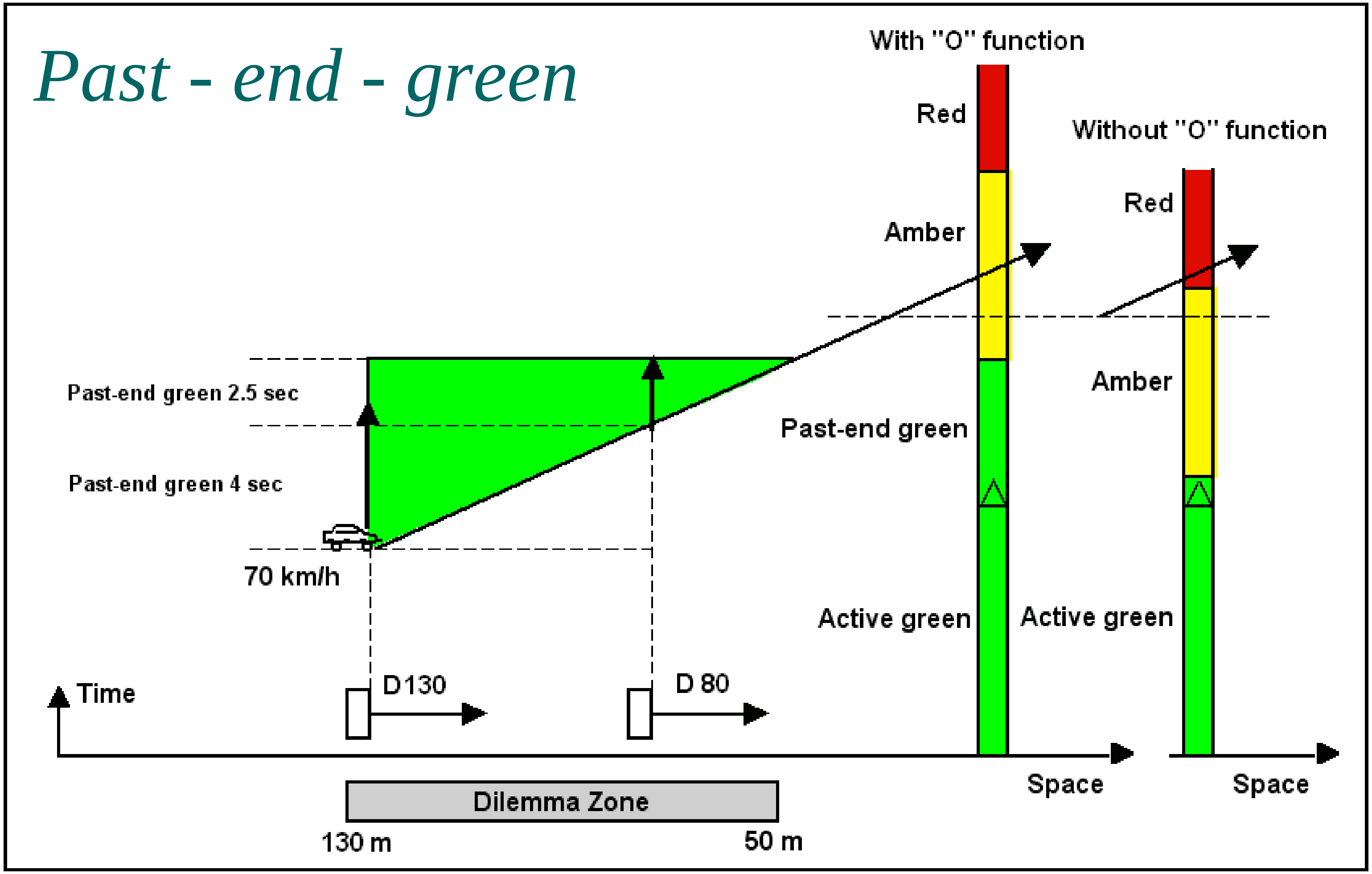


Diagram illustrating the utility of the “O” function in preventing red light violations

Self optimised Strategies

- **TOL:** Developed theory by K-L Bång 1976. This system, was tested in field trials with good results compared with traditional Swedish vehicle actuated control.
- **MOVA:** Developed by TRL 1982 with Miller algorithm . In the optimisation, MOVA uses a microscopic traffic model. Every half second MOVA makes a calculation whether the total delay will minimised if the current stage continues to be green.
- **SOS:** It combines the signal group control with mathematical optimisation,developed in Sweden 1997. SOS seeks optimal moment to change to yellow.

References

- Transport Planning and Traffic Engineering (C.A. 0'Flaherty et al; 2005),
- Highway Capacity Manuel, (HCM, 2000)
- Traffic signals (Webster, 1966)
- Impacts of Traffic Signal Control Strategies, Part I (A. Al-Mudhaffar; 2006)
- TRANSYT 11 workshop (TRL, 2002),
- OSCADY PRO user guide (TRL, 2006),
- Other references included in Swedish lectures by prof. Bång.