Traffic flow – Seminar

Traffic signal timing

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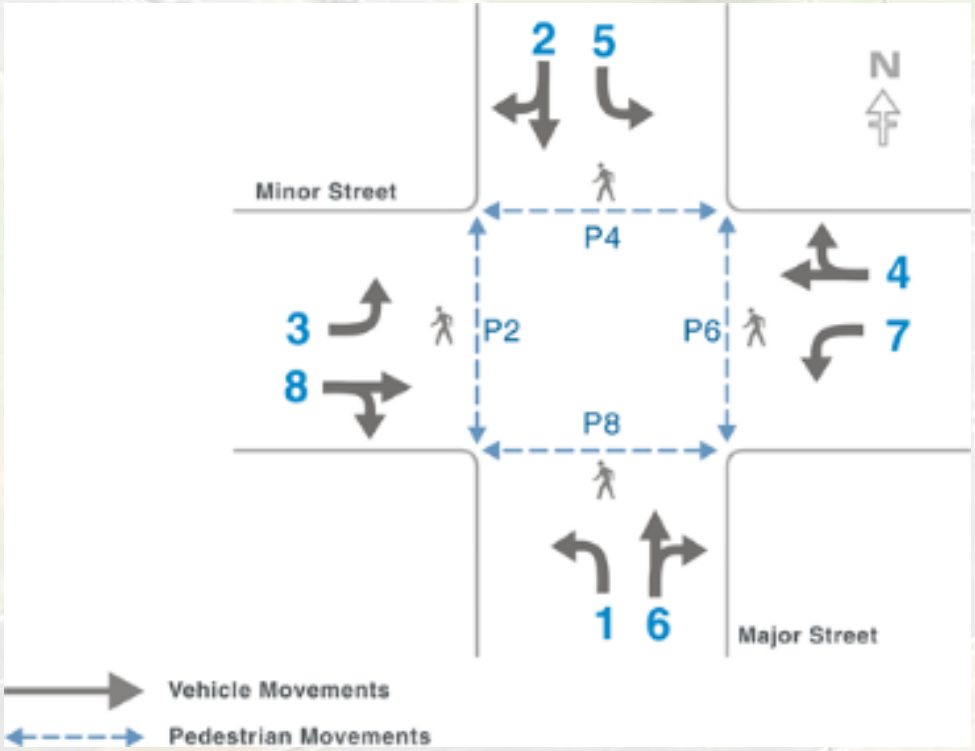
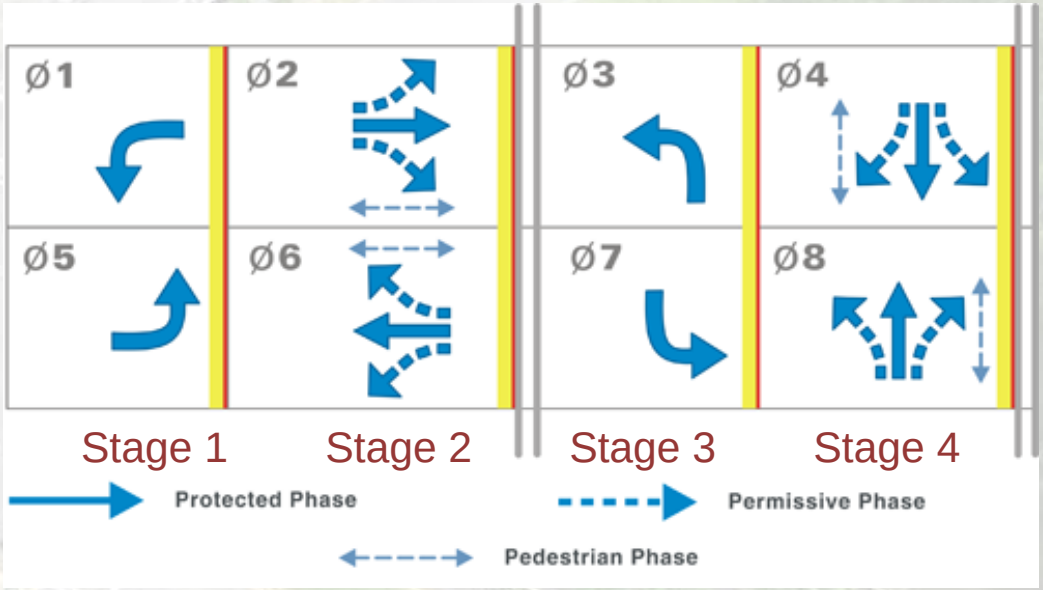
Terminology

- **Movement**: each separate queue leading to an inter-section, characterised by its direction and lane usage
- *Phase: a group of movements (or signal heads) that must have the same timing in all situations*
- **Stage**: a state of signals while the same movements are allowed *(if allowed movements change, a new state starts)*
- **Cycle time**: the minimum time while each stage appear once *(e.g. from the start of a green stage to the start of the next of green stage on a signal head)*

Terminology – Examples





Movements (12 arrows)

Phases (1-8)

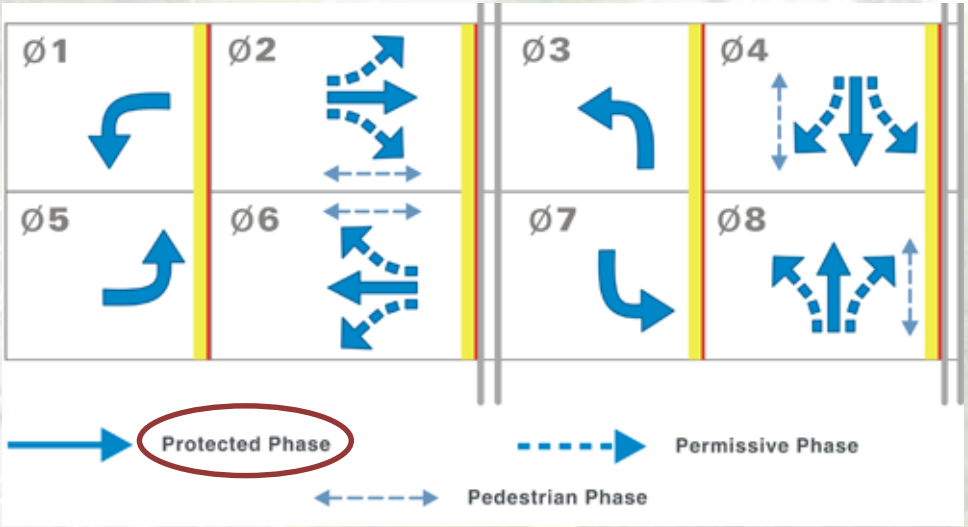
Stages (1-4)

Cycle: a total sequence of all stages (all movements)

About the assignment

- Signal timing of a separate intersection
  - 1:500 scale **layout**
    (same complexity, no easier or harder intersections)
  - peak hour **traffic volumes** (PCE/h) of each lane
- Consultation: on next seminar
- Objectives:
  - first: **safety** (‘intergreen’ times have to be guaranteed;
    we plan with clearance that ensures leaving the intersection)
  - second: **reducing delays** (optimized green times)

About the assignment



- Principles, limitations:
  - **protected left turns**
    (signals are covered with masks: no intersecting movements are allowed simultaneously)
    *the other type of staging use **permissive** left turns („full-green" signals: left turns are allowed simultaneously with the opposite straight movement)*
  - **no additional signal heads**
    (all movements from one lane has to be allowed together – but lanes can be separated)
  - pedestrians, cyclists and trams are not considered

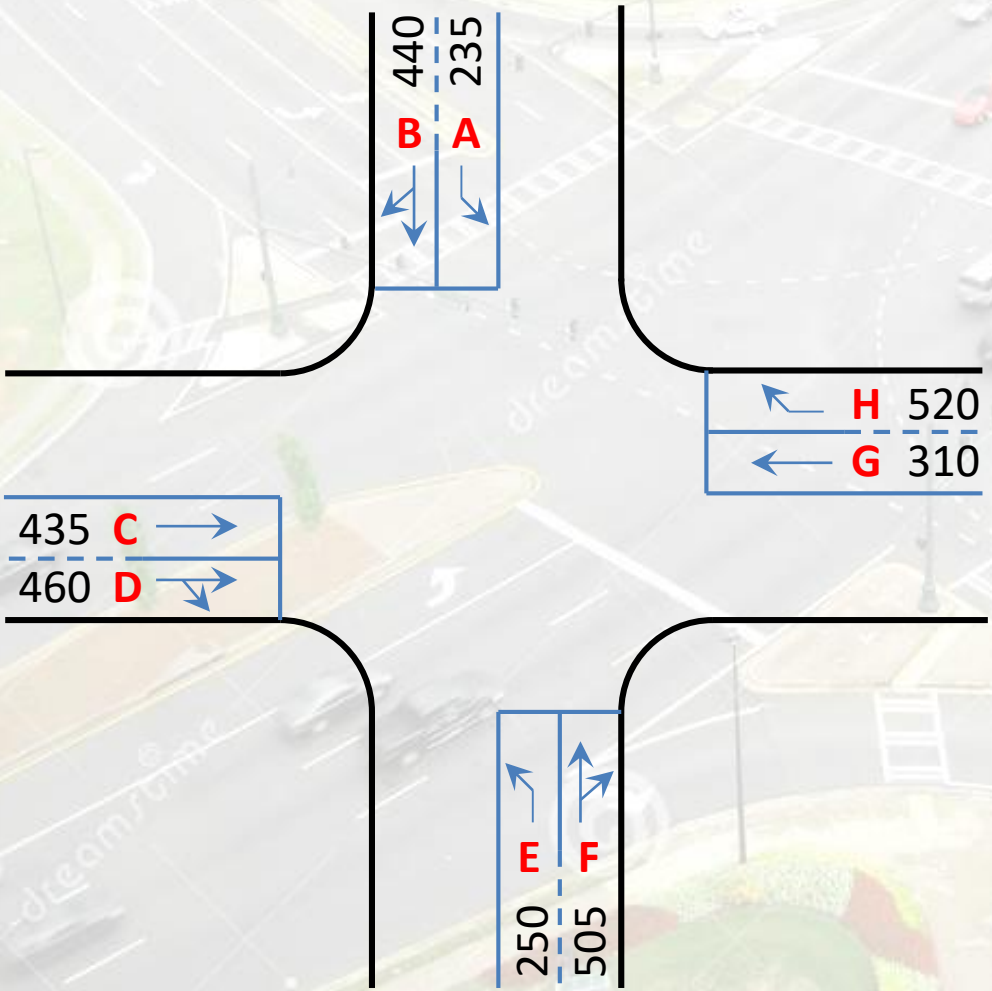
Step 1: **Staging**

- *Before this: step 0 is the **revision** of current traffic order – which directions can be prohibited*
  (not needed in this assignment)
- Basic principles of **staging**:
  - number of stages has to be minimized
  - no. of movements in each stage have to be maximized
  - movements with similar traffic volumes should be in one stage, if possible (the sum of peak traffic volumes should be minimal)

Step 1: **Staging**

- **<u>Rules</u>**:
  1) **Intersecting** (or even merging!) **movements cannot be allowed simultaneously**
  2) **If a movement can be allowed** together with the others in a stage, **it has to be allowed** (no. movements in the stage is maximized this way)
  3) **Lanes** next to each other **has to be allowed simultaneously if they have a common direction** (as there are no additional signals)
- There can be lanes which are allowed in multiple stages
  - In this case traffic volume will be considered as $Q/2$

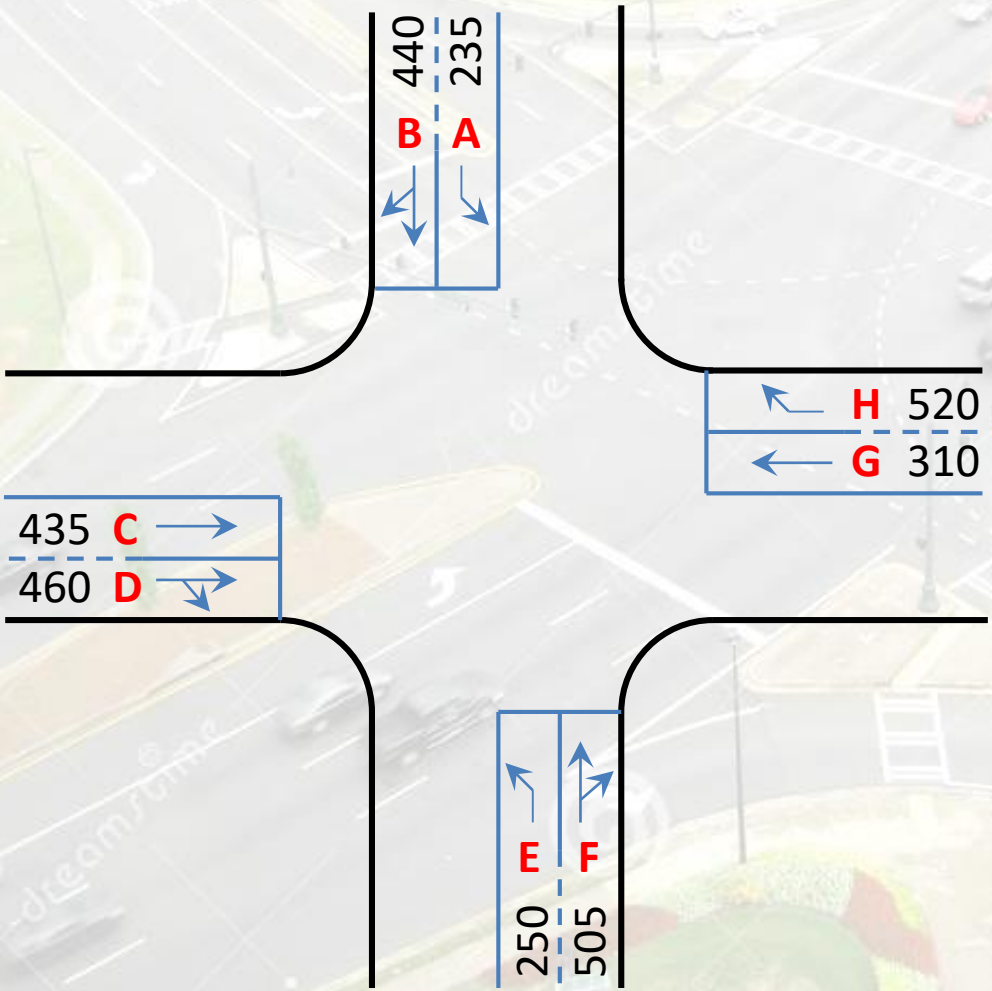
Example



1. <u>Staging</u>

- Examples for rules:
  1) Cannot go together:
     e.g. H-F, G-E, …
  2) Has to be allowed:
     H with both G and A
  3) Only together:
     C és D
- There are 2 options:
  I. ABH – CDGH – EF
  II. AEH – CDGH – BF

Example



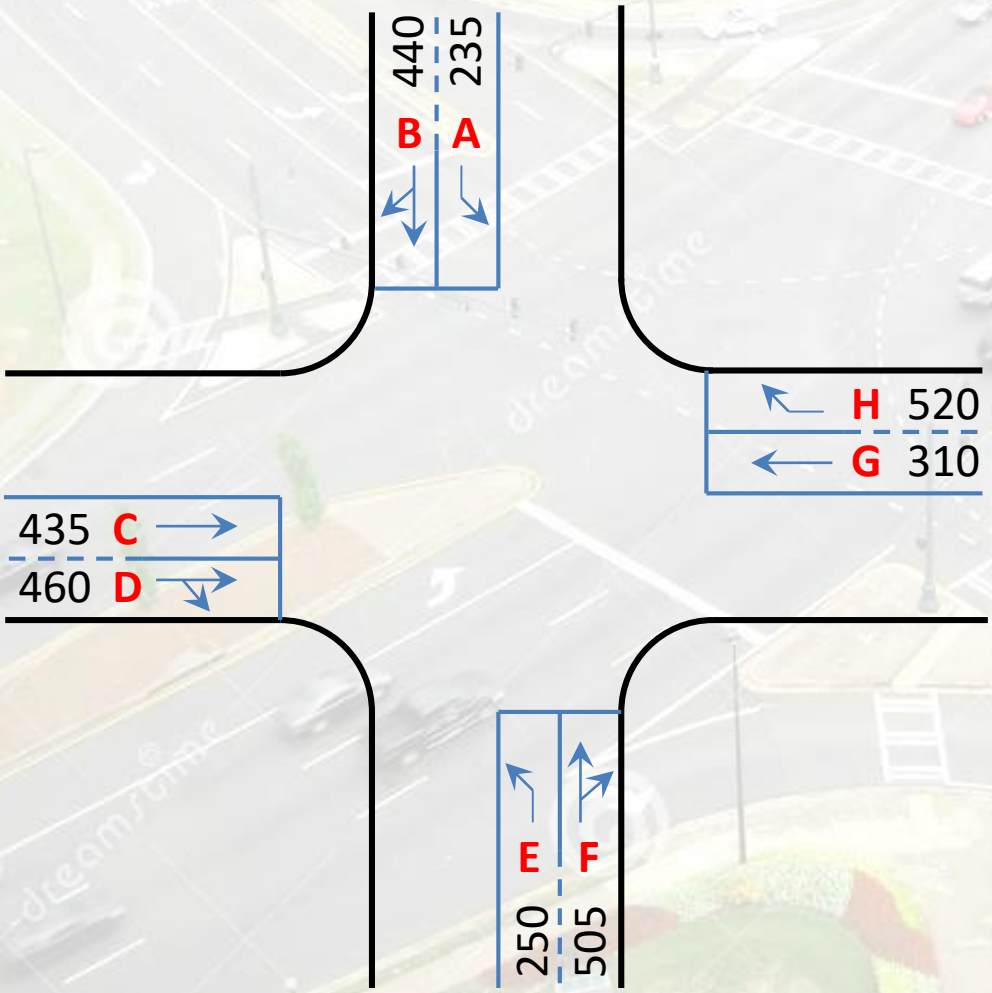
1. Staging

- The option should be chosen in which similar volumes are in the groups (← better usage)
- Lanes in two stages are calculated with half volume:

  H → 520/2 = 260
- Better option can be chosen easily in many cases:

  here ABH-EF and AEH-BF groups compete, the latter is obviously better

Example



1. Staging

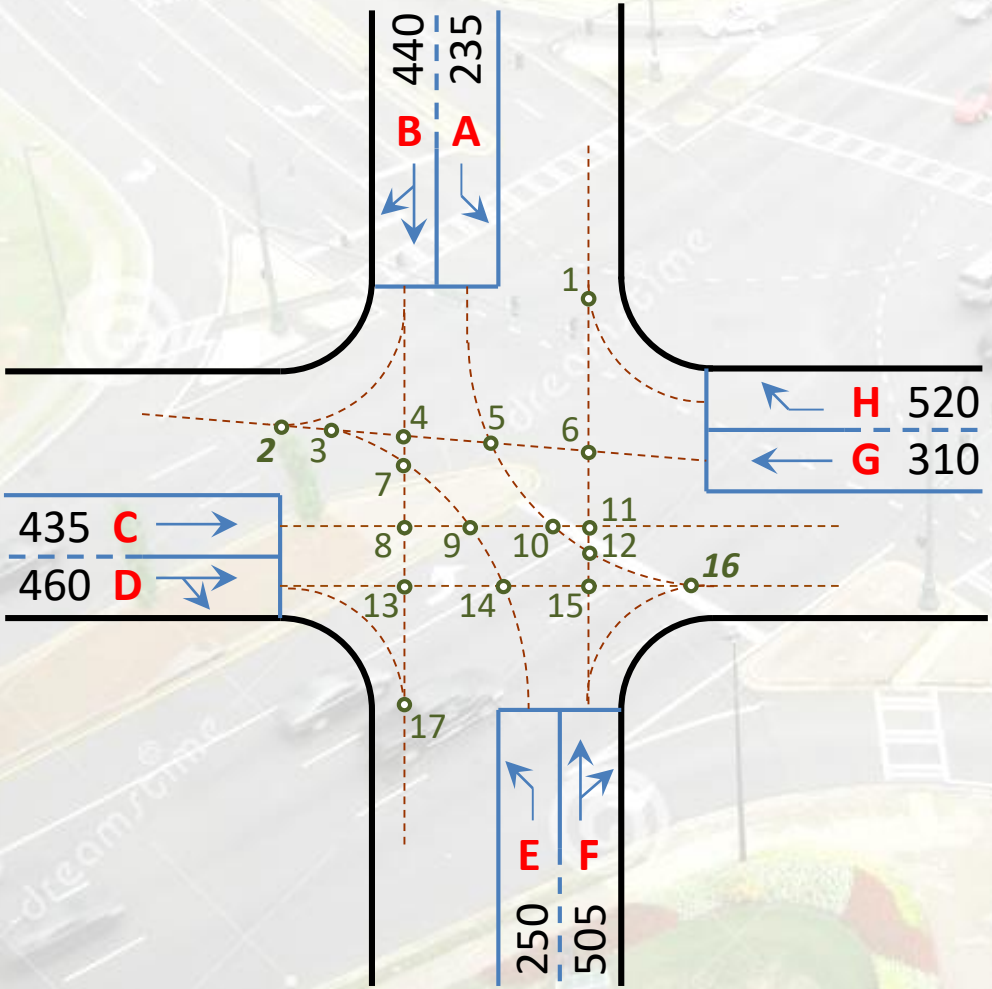
- Decision also can be made by calculating peak volumes ($Q_{p,m}$) of stages (also needed for step 4):

	Stage	Peak vol. lane	$Q_{p,m}$
I.	ABH	B	440
	CDGH	D	460
	EF	F	505
		Σ	1405
II.	AEH	H/2	260
	CDGH	D	460
	BF	F	505
		Σ	1225

Step 2: Determining **stage order**

- At 2 stages: order does not make sense
  At 3 stages: two possible orders, with 3 stage changes: A → B, B → C, C → A; or A→C→B(→A)
  At 4 stages: 6 orders (not in our assignment)
- **Conflict map**
  - Finding and numbering all possible conflict points (where movements can cross each other or merge)
  - Measuring the distances of conflict points from stop lines (along vehicle paths)

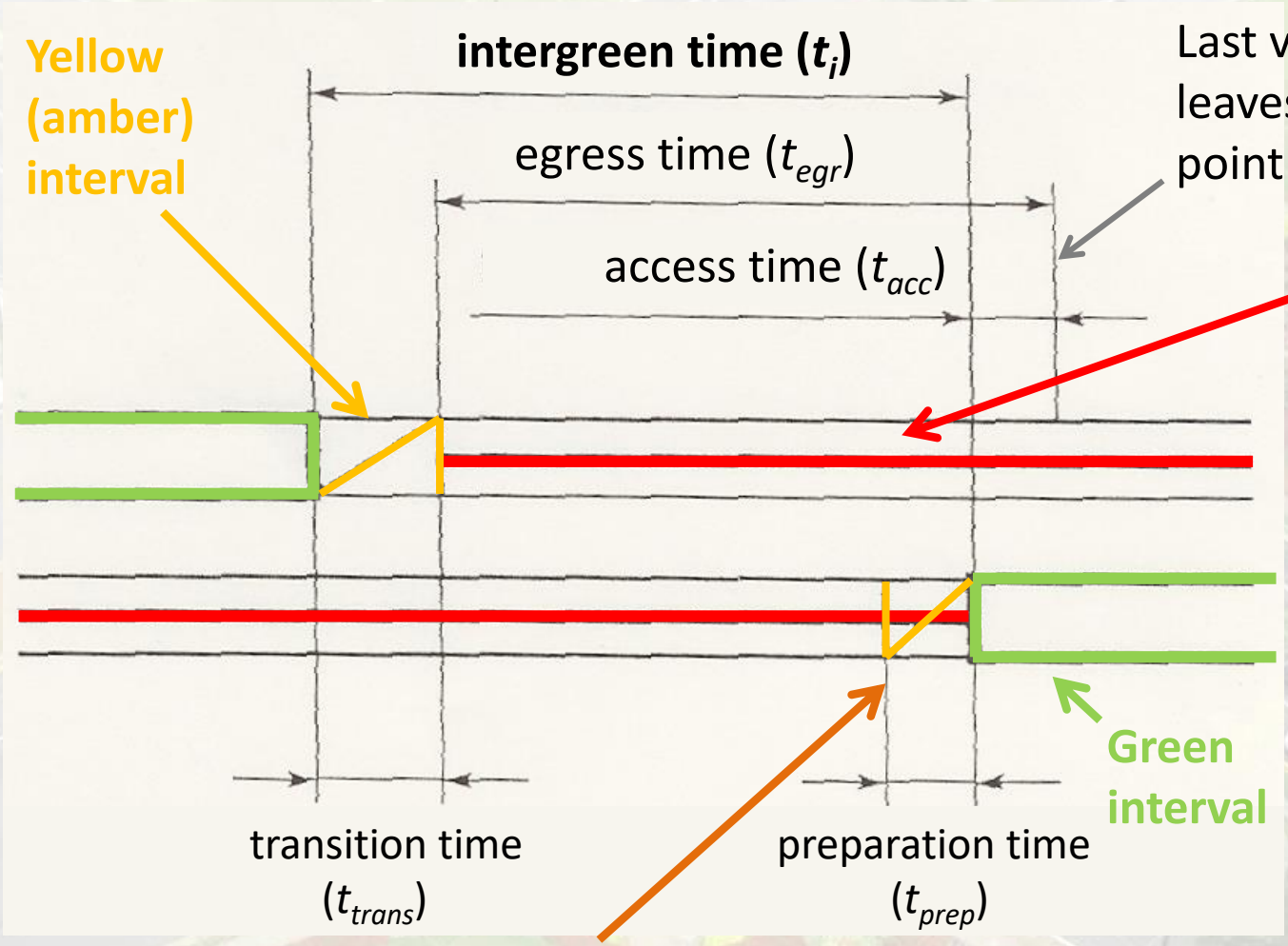
Example



2. <u>Stage order</u>

- AEH-CDGH-BF or AEH-BF-CDGH
- Decision: based on intergreen times
- For this, the conflict map is needed
  - Left turns can arrive to all egress lanes, we calculate with the outer (right) one(s)

Step 3: Calculating **intergreen times**



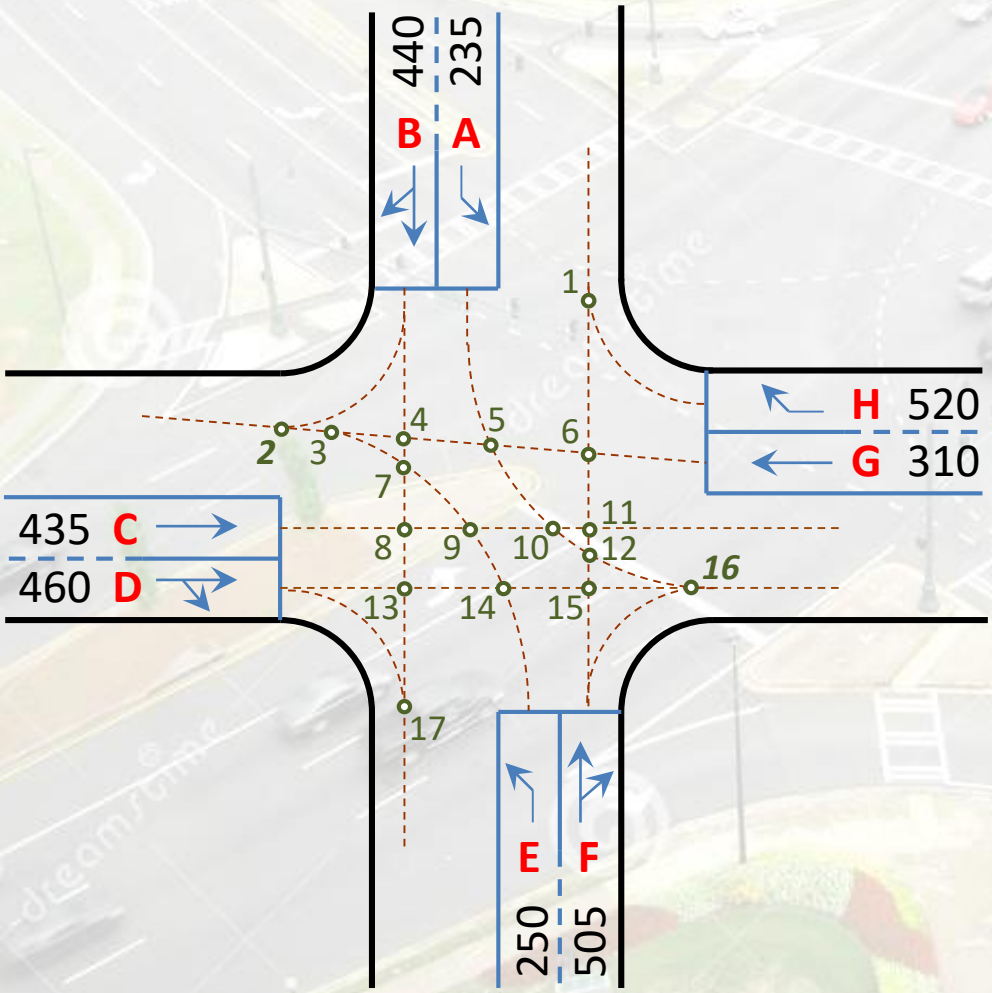
Step 3: Calculating **intergreen times**

- For all stage changes (3-3) in all possible stage orders (2)
- For each conflict point (*i*) in a stage change:

$$t_{ig} = t_{yellow} + \frac{l_{egr} + l_{veh}}{v_{egr}} - \frac{l_{acc}}{v_{acc}}$$

- Choosing maximum t_{ig} in each stage change (safety)
- Summarize these peak t_{ig} values for the two stage orders and choose the order with the lower $\sum t_{ig}$
- *Results are usually given in the intergreen time matrix*

Example

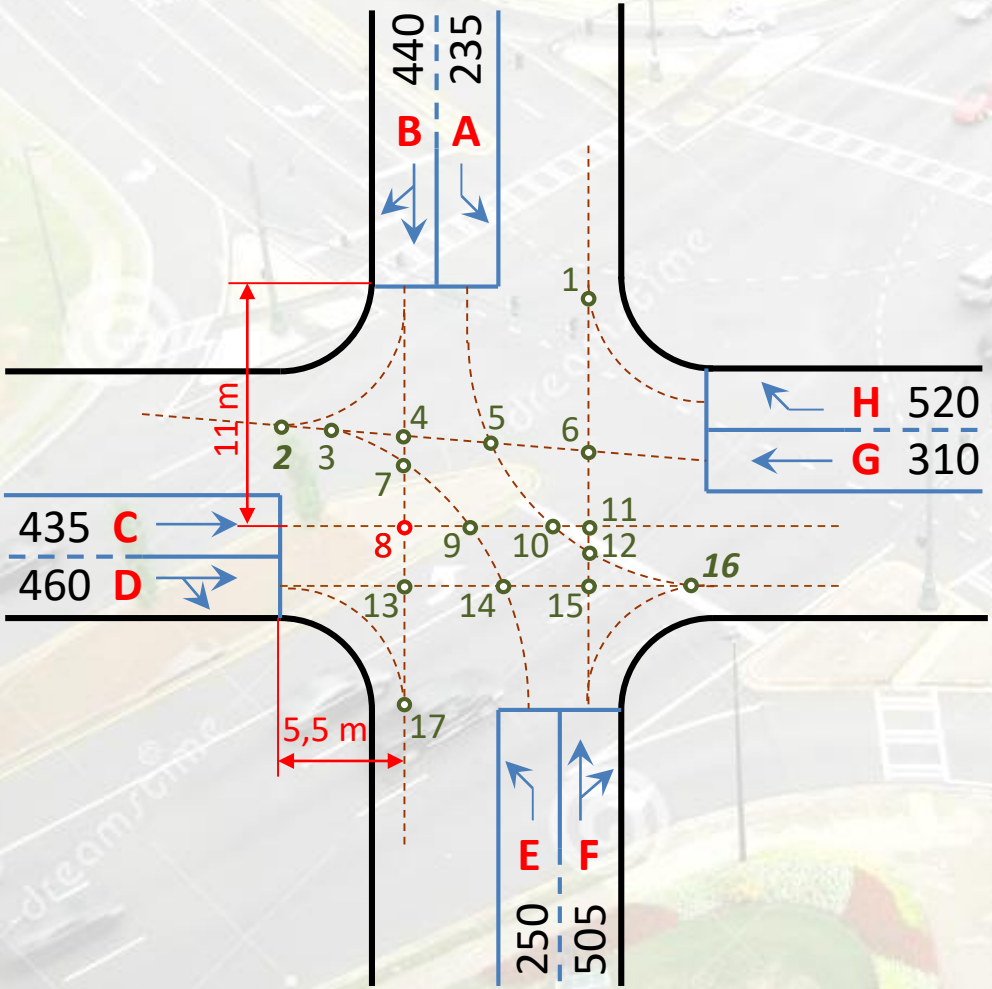


3. Intergreen times

- For both orders, all stage changes, all conflict points
- Conflict: between movements (not lanes!)
- E.g. CDGH → BF change:
  C → B_s (8), F_s (11)
  D_s → B_s (13), F_s (15), F_r (16)
  D_r → B_s (17)
  G → F_s (6), B_s (4), B_r (2)
  H → F_s (1)

(s: straight, r: right, l: left)

Example



3. Intergreen times

$$t_{ig} = t_y + t_{egress} - t_{access} =$$

$$= t_y + \frac{l_{egr} + l_{veh}}{v_{egr}} - \frac{l_{acc}}{v_{acc}}$$

E.g. $t_{ig\ C \to B_s} =$

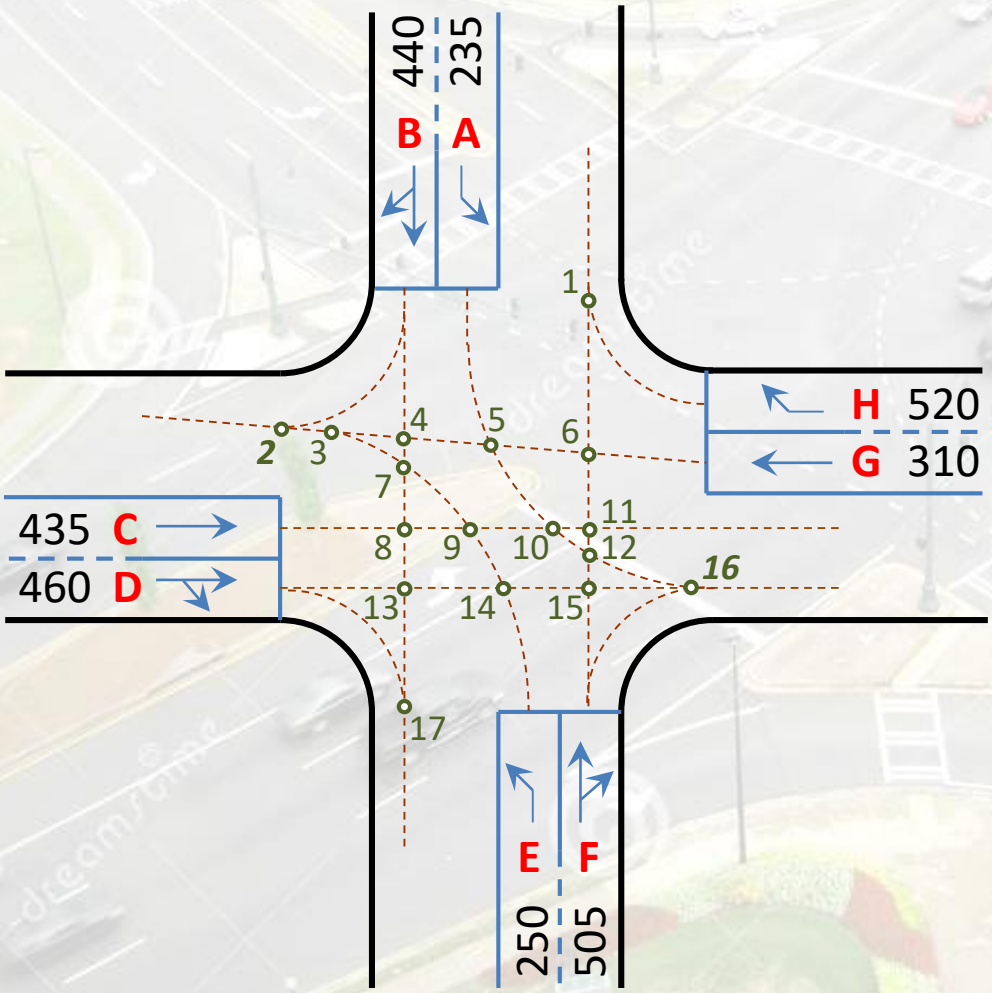
$$= 3 + \frac{l_{C-8} + l_{veh}}{v_{egr}} - \frac{l_{B-8}}{v_{acc}} =$$

$$= 3 + \frac{5{,}5 + 6}{10} - \frac{11}{13{,}9} =$$

$$= 3 + 1{,}15 - 0{,}791 =$$

$$= 3{,}359\ (\mathrm{s})$$

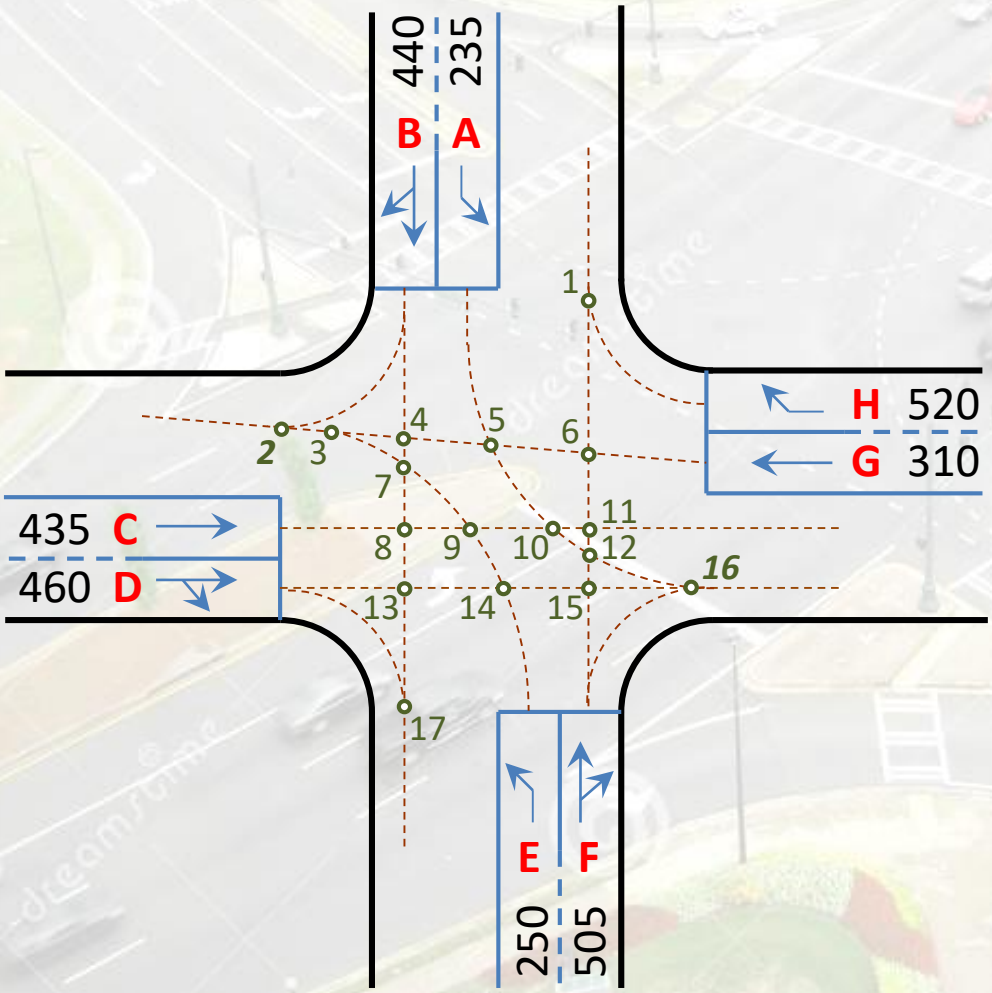
Example



3. Intergreen times

- Going through all conflicts, change by change
- Check: all points are calculated at least once in both stage orders
- Points can occur multiple times in a stage order if:
  - more than 2 movements match: in all combinations
    e.g. ***2***: B_r-G & B_r-E; ***16*** (3x)
  - it is reached by a movement in two stages: both lane orders
    e.g. 1: both F_s-H and H-F_s

Example



3. Intergreen times

- There are 21 conflicts here for both orders
  (17 points, but **1-2** 2x, **16** 3x)
- Aggregating:
  - $t_{ig,max}$ for each stage change
    AEH→ CDGH→ BF→ AEH
    e.g. 4,2 5,8 5,5 [s]
    in reverse: 6,2; 4,8; 5,8 s
  - $\Sigma t_{ig,max}$ for both orders
    in this case: 15,5 s & 16,8 s
  - the lower value is better from the two sums
    (first order in this case)

Step 4: Calculating **cycle time**

- Choosing **peak volumes** (Q_p) of each stage (if a lane is allowed in two stages, calculate with $Q/2$ in both), then summarize them
  - *If $\sum Q_p > 1250$ PCE/h, C would be large and delays would increase*

$$C = \sqrt{120 \cdot C_{min}} = \sqrt{120 \cdot \frac{\sum t_{ig}}{1 - Y}}; \quad Y = \frac{\sum Q_p}{Q_{max}}$$

- *In practice there are standard cycle times: 45, 60, 75, 90 or 120 seconds (with respect for coordination); but in this assignment we plan an individual intersection*
- Cycle time is integer in seconds (round at the end)

Step 5: Calculating **green times**

- For each *m* stage:

$$t_{g,m} = \left(C - \sum t_{ig}\right) * \frac{Q_{p,m}}{\sum Q_p}$$

- *Minimum green time is 10 s (5 s for pedestrians)*
- First calculate with exact *C* and t_{ig}
- Then round t_g (mathematically) and t_{ig} (up!) values
- Summarize all rounded t_g and t_{ig} values to get the rounded (working) *C*

Example

4-5. Cycle and green times

$$Y = \frac{\sum Q_p}{Q_{max}} = \frac{1225}{1800} = 0{,}68056$$ ($\sum Q_p$: see at step 1)

$$C = \sqrt{120 \cdot \frac{\sum t_{ig}}{1 - Y}} = \sqrt{120 \cdot \frac{15{,}5}{1 - 0{,}68056}} = \mathbf{76{,}306\ (s)}$$

$$t_{g,1} = \left(C - \sum t_{ig}\right) \cdot \frac{Q_1}{\sum Q_p} = (76{,}306 - 15{,}5) \cdot \frac{260}{1225} = 12{,}91\ (s)$$

Stage	$Q_{p,m}\left(\frac{\text{PCE}}{\text{h}}\right)$	$t_{g,m}$ (s)	$t_{g,rnd,m}$ (s)
AEH	260	**12,91**	13
CDGH	460	**22,83**	23
BF	505	**25,07**	25
Σ	1225	60,81	61

Rounding up intergreen times:

4,2 → 5 ; 5,8 → 6 ; 5,5 → 6 (Σ 17)

$$C_{work} = \sum t_{g,rnd} + \sum t_{ig,rnd} =$$
$$= 61 + 17 = \mathbf{78\ (s)}$$

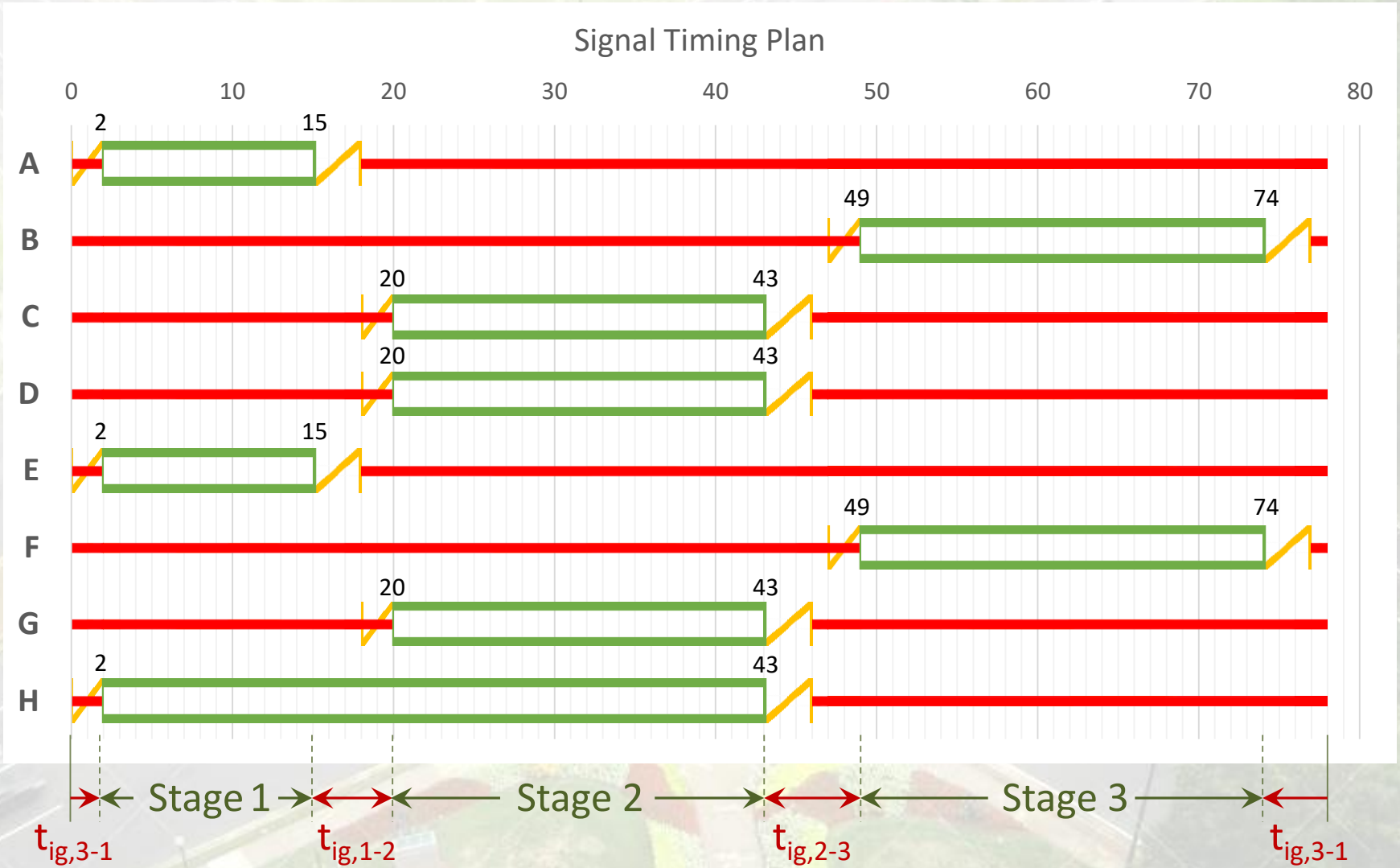
Step 6: Drawing **signal timing plan**

- Diagram shows <u>one cycle</u> and starts at a relevant moment (at the start of an interval)
- Plot all lanes (or phases) separately
- Standard signs for signal intervals:
  - Red
  - Green
  - Yellow

- Indicate the start and end times of each green stage (in seconds)

Example

6. Signal timing plan



Step 7: **Evaluation** of signal timing plan

- **Delay per vehicle**
  - average delay per vehicle in a line by Webster (calculate only for peak volume lanes):

$$d = \frac{(C - G_E)^2}{2C\left(1 - \frac{q}{s}\right)} + \frac{x^2}{2(1 - x)q} - 0{,}65\left(\frac{C}{q^2}\right)^{\frac{1}{3}} \cdot x^{2+5\frac{G_E}{C}}$$

  - G_E : effective green time = $t_y + t_g$ [s]
    C : cycle time [s]
    q : traffic volume [PCE/s]; $q = Q/3600$
    s : saturation flow (0,5 PCE/s)
    x = $(C/G_E) \cdot (q/s) = (q/s) / (G_E/C) < 1$

Example

7. Evaluation

$$G_{E,1} = t_y + t_{g,1} = 3 + 13 = 16\ (\mathrm{s});\ q_1 = \frac{Q_1}{3600} = \frac{260}{3600} = 0{,}07222\ \left(\frac{\mathrm{PCE}}{\mathrm{s}}\right)$$

$$x_1 = \frac{q_1/s}{G_{E,1}/C} = \frac{0{,}07222/0{,}5}{16/78} = \frac{0{,}1444}{0{,}2051} = 0{,}7042$$

$$d_1 = \frac{\left(C - G_{E,1}\right)^2}{2C(1 - q_1/s)} + \frac{x_1^2}{2(1 - x_1)q_1} - 0{,}65\left(\frac{C}{q_1^2}\right)^{\frac{1}{3}} \cdot x_1^{2+5\cdot\frac{G_{E,1}}{C}} =$$

$$= \frac{(78 - 16)^2}{2 \cdot 78(1 - 0{,}1444)} + \frac{0{,}7042^2}{2(1 - 0{,}7042)0{,}07222} -$$

$$- 0{,}65\left(\frac{78}{0{,}07222^2}\right)^{\frac{1}{3}} \cdot 0{,}7042^{2+5\cdot\frac{16}{78}} =$$

$$= \frac{3844}{133{,}47} + \frac{0{,}4959}{0{,}04273} - 16{,}014 \cdot 0{,}7042^{3{,}026} =$$

$$= 28{,}801 + 11{,}604 - 5{,}541 = \mathbf{34{,}86\ (s)}$$

Step 7: **Evaluation** of signal timing plan

- **Average queue length**
  - number of stopped vehicles in a lane during a cycle (calculate only for peak volume lanes)
  - average queue length (the higher of these two):

$$n = q \cdot t_r \quad \text{or} \quad n = q \cdot \left(\frac{t_r}{2} + d\right)$$

  - where t_r : red time = $C - G_E$ [s]

Example

7. Evaluation

$$t_{r,1} = C - G_{E,1} = 78 - 16 = 62\ (\mathrm{s})$$

$$n_1 = \max\left(q_1 \cdot t_{r,1}\,;\, q_1 \cdot \left(\frac{t_{r,1}}{2} + d_1\right)\right) = q_1 \cdot \max\left(t_{r,1}\,;\, \frac{t_{r,1}}{2} + d_1\right) =$$

$$= 0{,}07222 \cdot \max\left(62\,;\, \frac{62}{2} + 34{,}86\right) = 0{,}07222 \cdot \max(62\,;\, 65{,}86) =$$

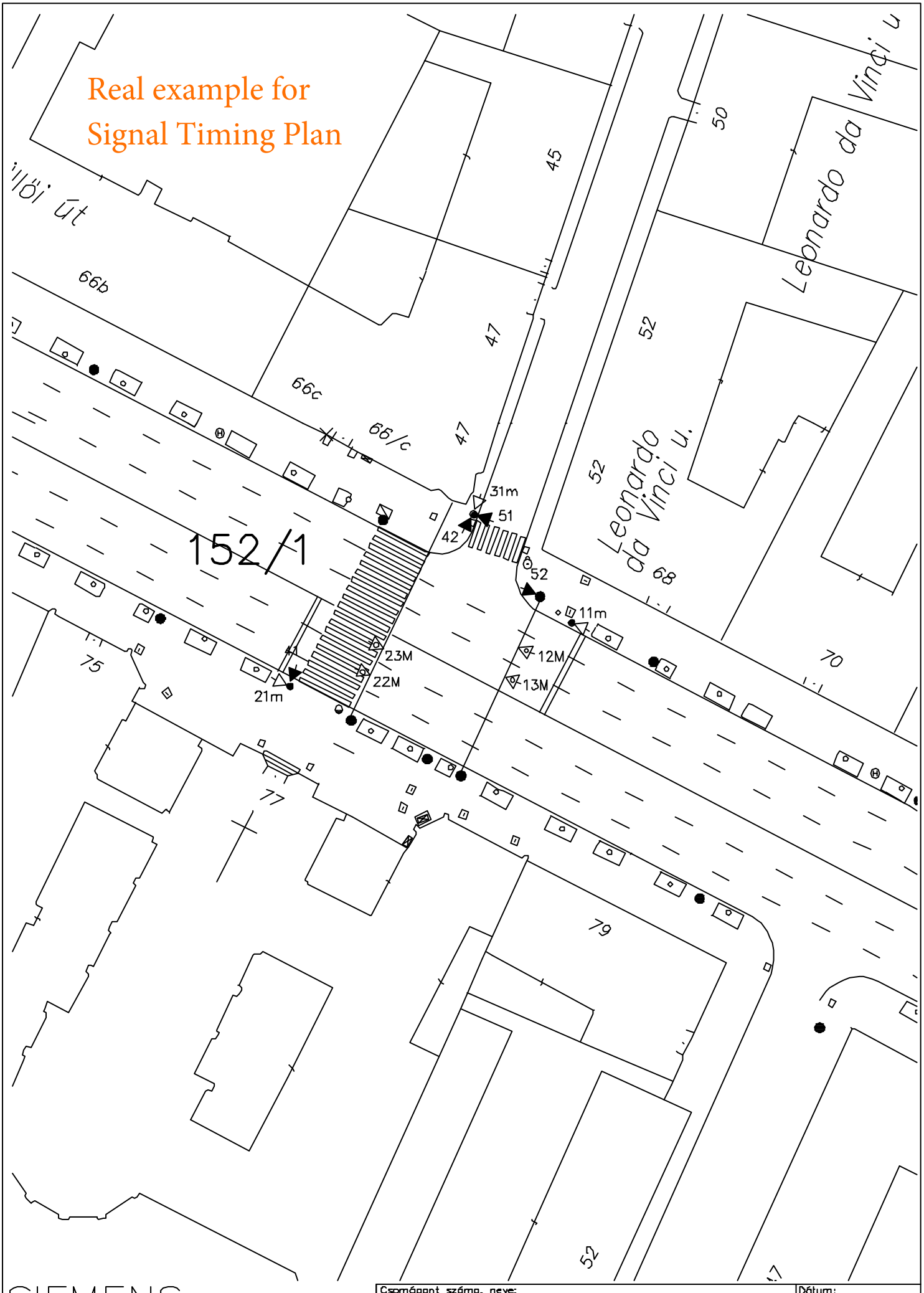
$$= \mathbf{4{,}757\ (PCE)}$$

stage	q_m $\left(\frac{\text{PCE}}{\text{s}}\right)$	$G_{E,m}$ (s)	x_m	$\boldsymbol{d_m}$ (s)	$t_{p,m}$ (s)	$\boldsymbol{n_{1,m}}$ (PCE)		$\boldsymbol{n_{2,m}}$ (PCE)
AEH	0,07222	16	0,7142	**34,86**	62	4,478	<	**4,757**
CDGH	0,12778	26	0,7667	**29,01**	52	6,645	<	**7,029**
BF	0,14028	28	0,7815	**28,20**	50	7,014	<	**7,464**

As lane H has special green time (which lasts for two stages), values should been calculated for it separately (so that the peak volume of AEH stage would also change), but here we simplify the calculation for the three stages.

Documentation

- Calculation can be made in Excel, but the calculation method has to be descripted
- Documentation contains:
  - Assignment sheet
  - Layout with conflict map (making a copy is advised)
  - Description of calculation steps, results
  - Signal timing plan diagram (constructed!)



SIEMENS

Csomópont száma, neve:
152,1 VIII. Üllői út – Leonardo da Vinci u.
Jelzőszámozási helyszínrajz

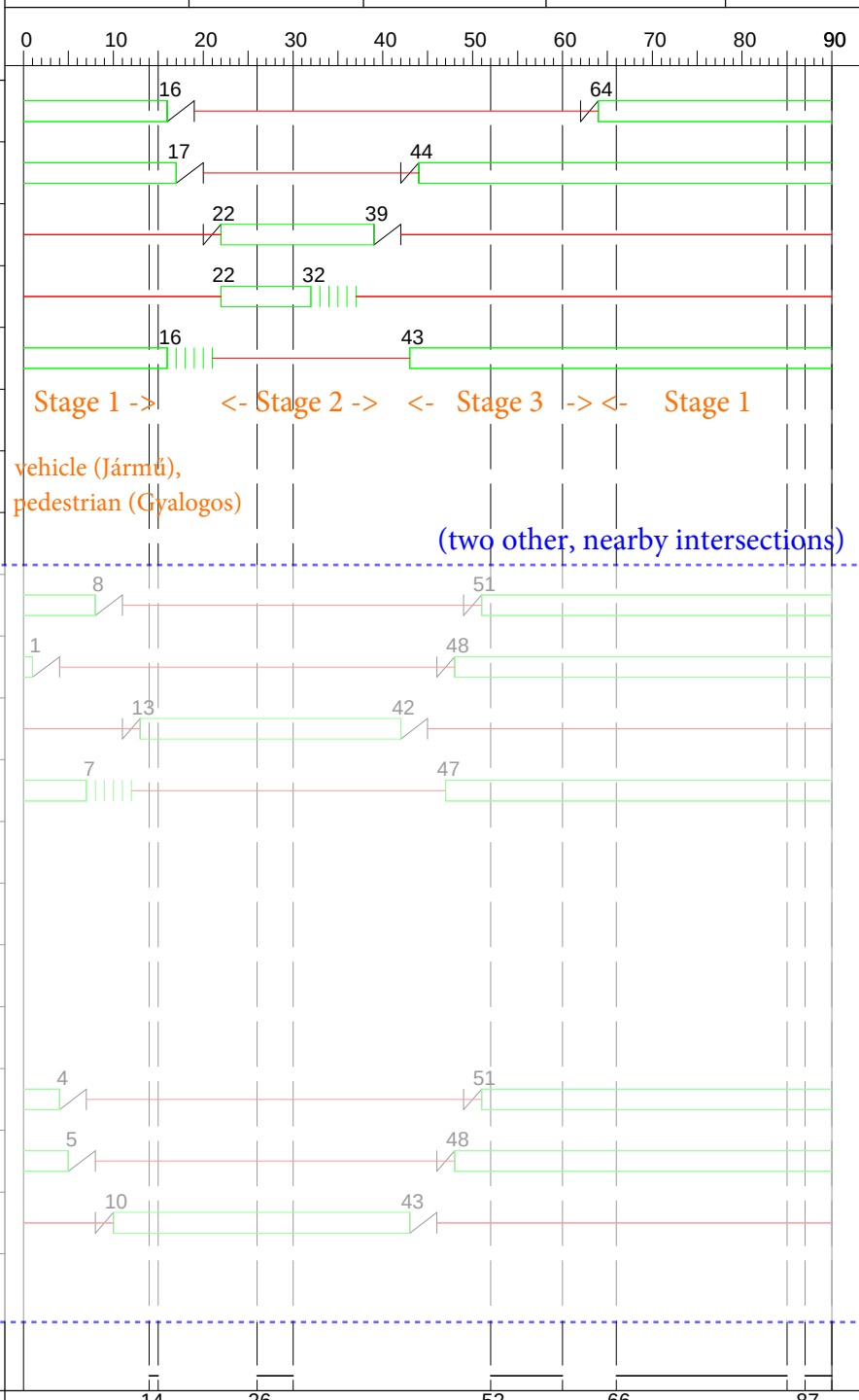
Dátum: 2008.09.24.

Készítette: Cseh Zoltán

JELZŐ Signal	Tervező	Tervezés dátuma	Jóváhagyó	Jóváhagyás dátuma	Megjegyzés
	Kupcsik	2007.05.07			

Periódusidő	Programváltási pont	Bekapcsolási pont	Általános tilos	Eltolás
C= 90	85	80	12	

srsz	Száma no.	tip type	Zöld idő green time	Kapacitás capacity
1 (Phase 1)	11,21, 31	J	42	2520
2	21,22,23	J	63	3780
3	31	J	17	340
Pedestrian crossings	41-42	GY	10	
	51-52	GY	63	
6				
7				
8				
9	11,12,13	J	47	2820
10	21,22,23	J	43	2580
11	31	J	29	580
12	41-42	GY	50	
13				
14				
15				
16				
17	11,12,13	J	43	2580
18	21,22,23	J	47	2820
19	31	J	33	660



Futtatási szakaszok

Str. száma

Várakozási idők

Siemens	Csomópont neve	Érvényesség
152.1	Üllői út - Leonardo, Thaly, Szigony u.	-tól
Vilati 219	2. Struktúra	-ig

———	Tervező	Tervezés dátuma	Jóváhagyó	Jóváhagyás dátuma	Megjegyzés

Egressing at the end of green

Accessing at the start of green

SZABAD JELZÉS VÉGÉN KIHALADÓ			SZABAD JELZÉS ELEJÉN BEHALADÓ																							
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21			
ssz	száma	jele																								
1	11,21, 31	J			6	6																				
2	21,22,23	J			5	5																				
3	31	J	6	5			4																			
4	41-42	GY	10	12																						
5	51-52	GY			6																					
6																										
7																										
8																										
9	11,12,13	J											5													
10	21,22,23	J											6													
11	31	J									5	6		5												
12	41-42	GY											6													
13																										
14																										
15																										
16																										
17	11,12,13	J																			5	6				
18	21,22,23	J																			5	5				
19	31	J																	6	5			5			
20	41.42	GY																	11	12						
21	51-52	GY																			6					

Siemens	Csomópont neve	Érvényesség
152.1	Üllői út - Leonardo, Thaly, Szigony u.	-tól
Vilati	Tiltás ill. közbenső idő mátrix	-ig
219		

Intergreen time matrix