The New Dutch Timetable: The OR Revolution

Netherlands Railways

Winner 2008

Franz Edelman Award 2008

- Last timetable changed before 2007 was in 1970
- Number of passengers doubled
- Significant increase in freight transport
- Infrastructure remained nearly the same

How can we transport many more passengers, and at the same time offer a more reliable service?

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and at the same time offer a more reliable service?

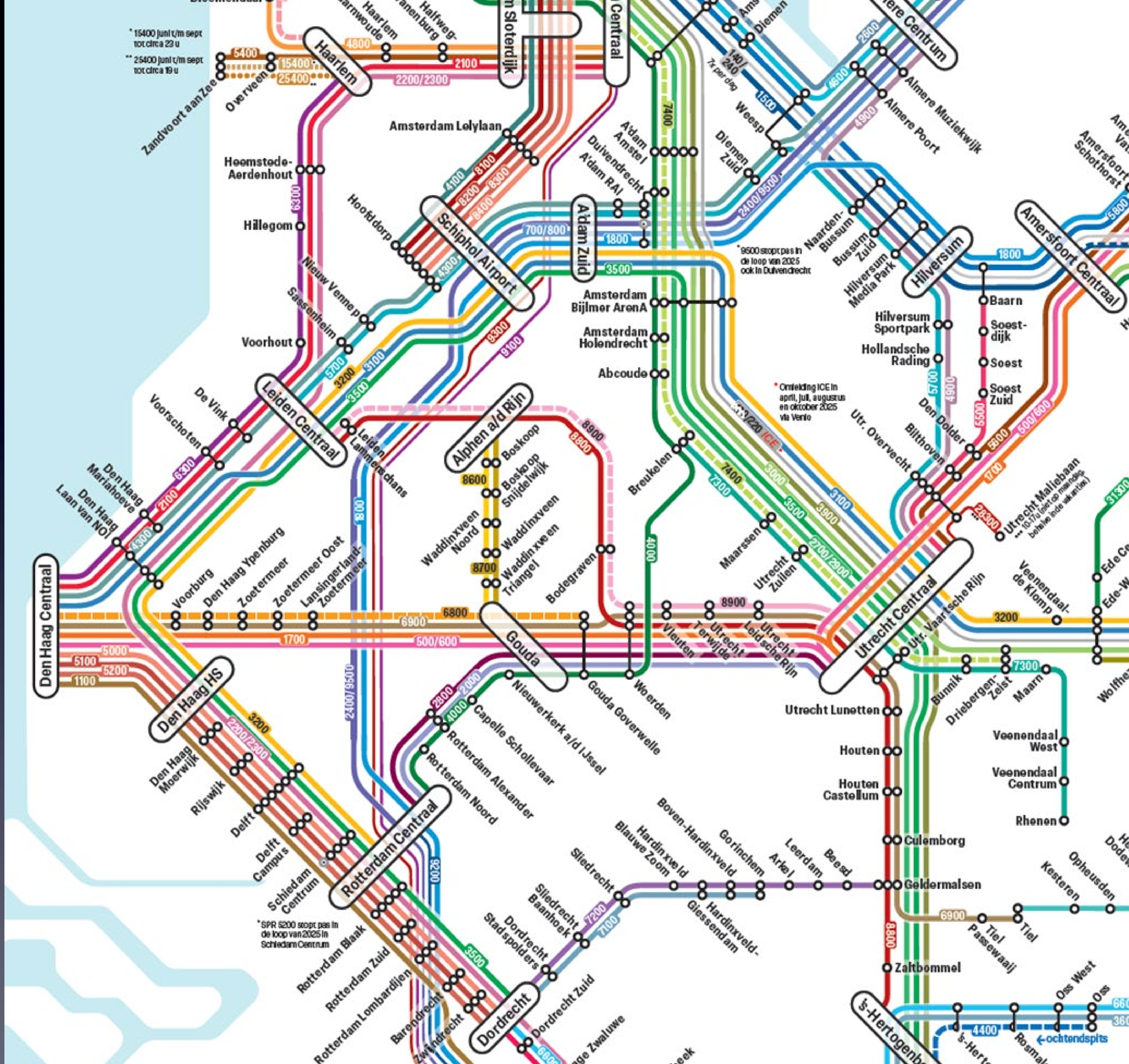
Solution:

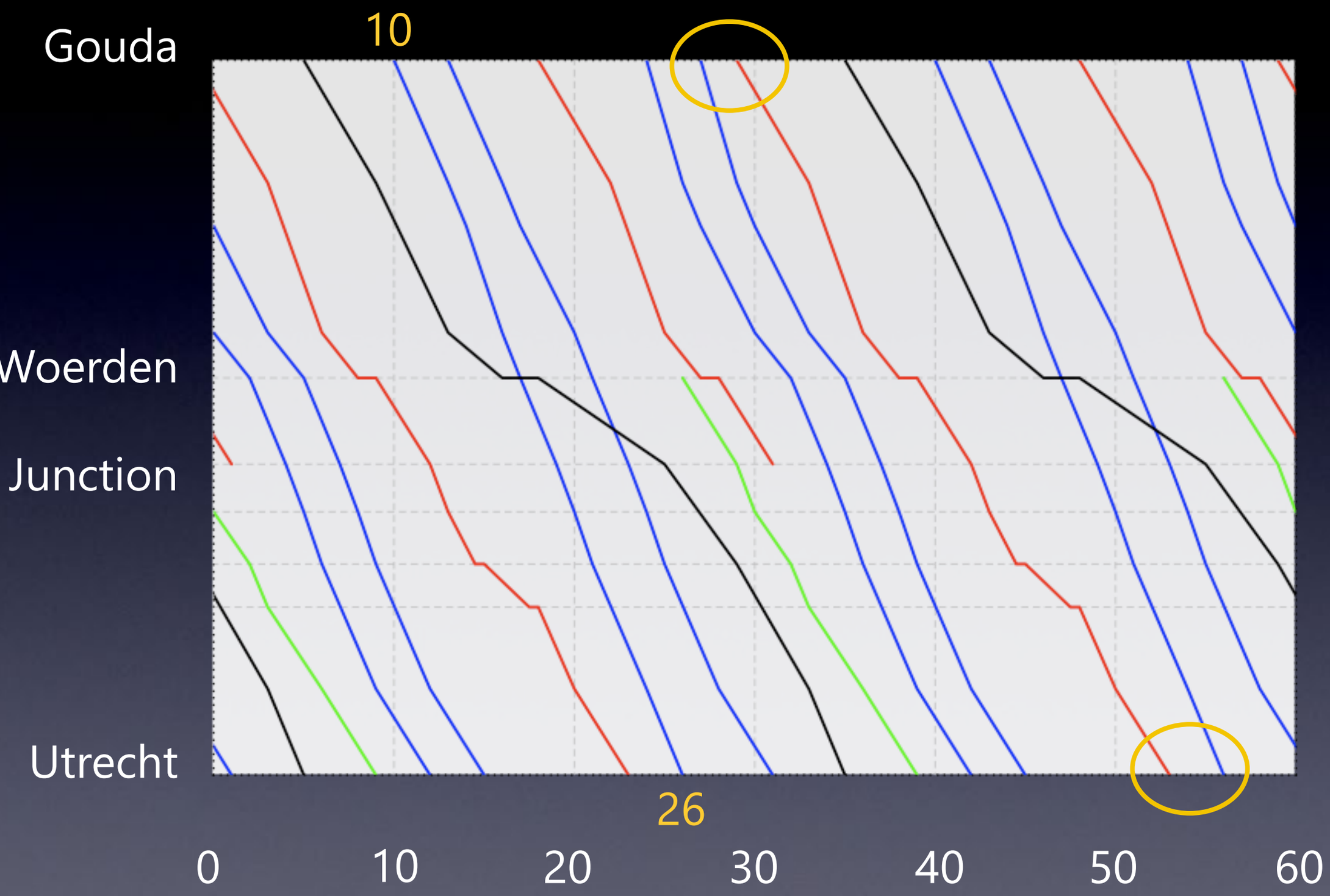
Develop a new timetable from scratch
based on Operations Research

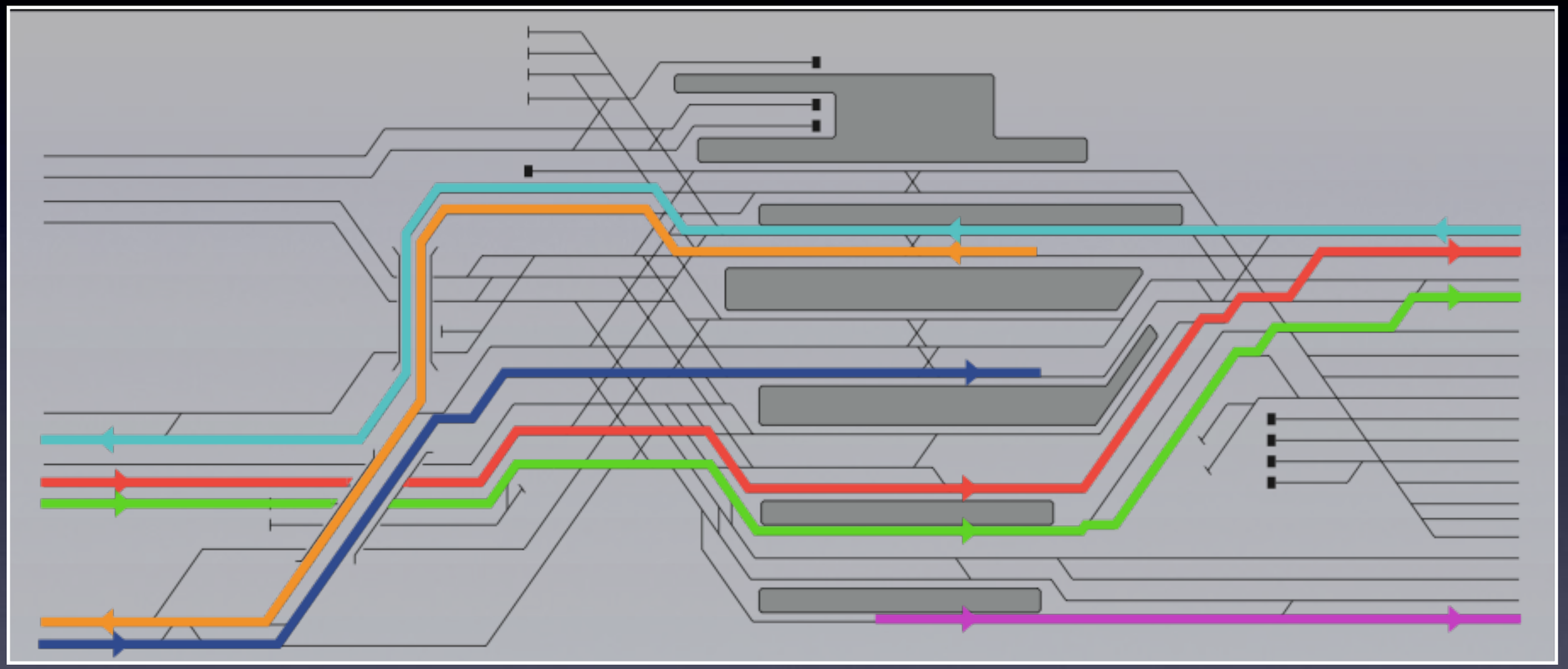
- One timetable for all operators
- New timetable in operation December 2006
  Reason: Infrastructure projects finished
- Given amount of rolling stock and crew
- Cyclic property of the timetable must stay intact

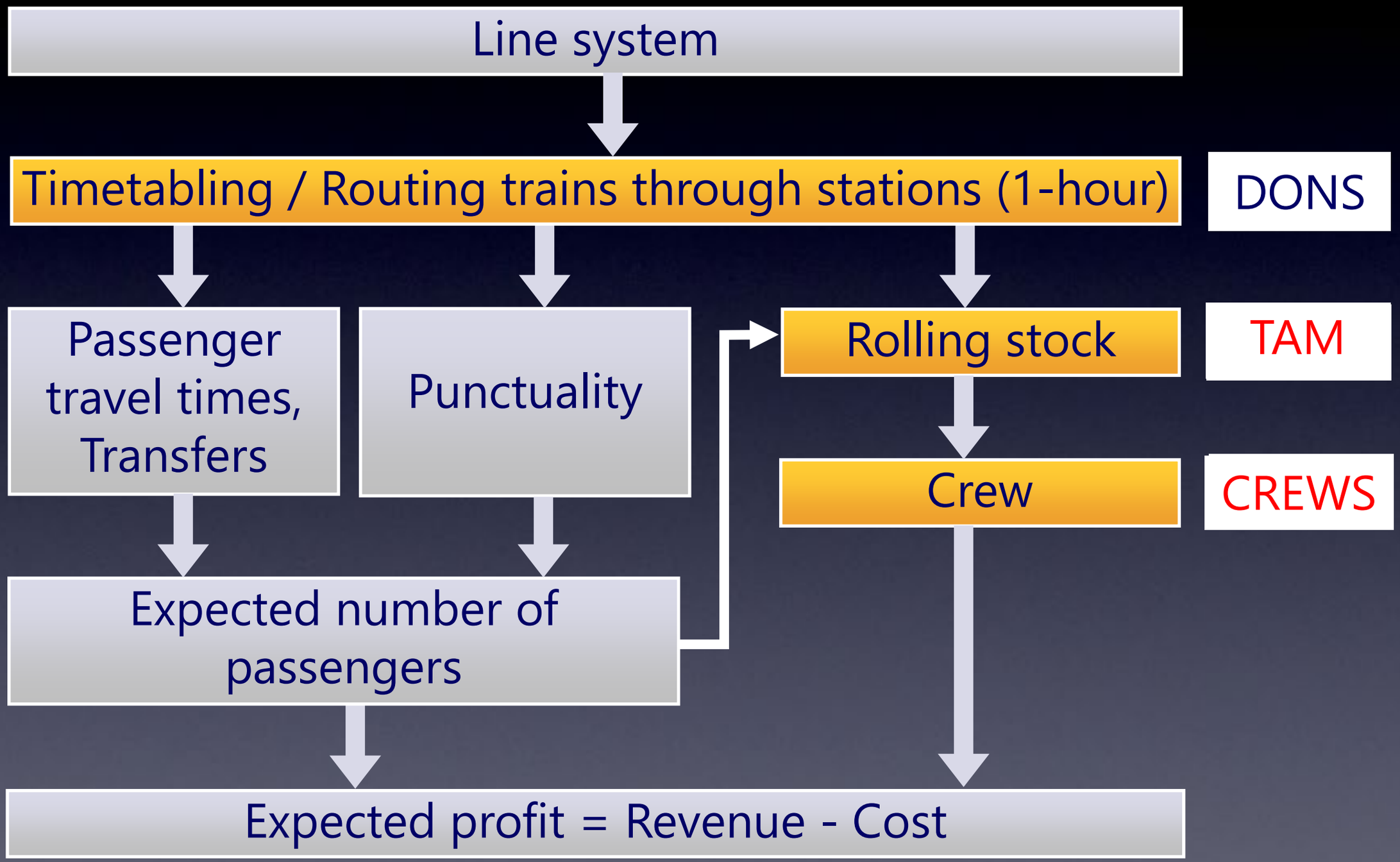
Cyclic timetables

- Common in many European countries
- Cycle time in the Netherlands: 1 hour

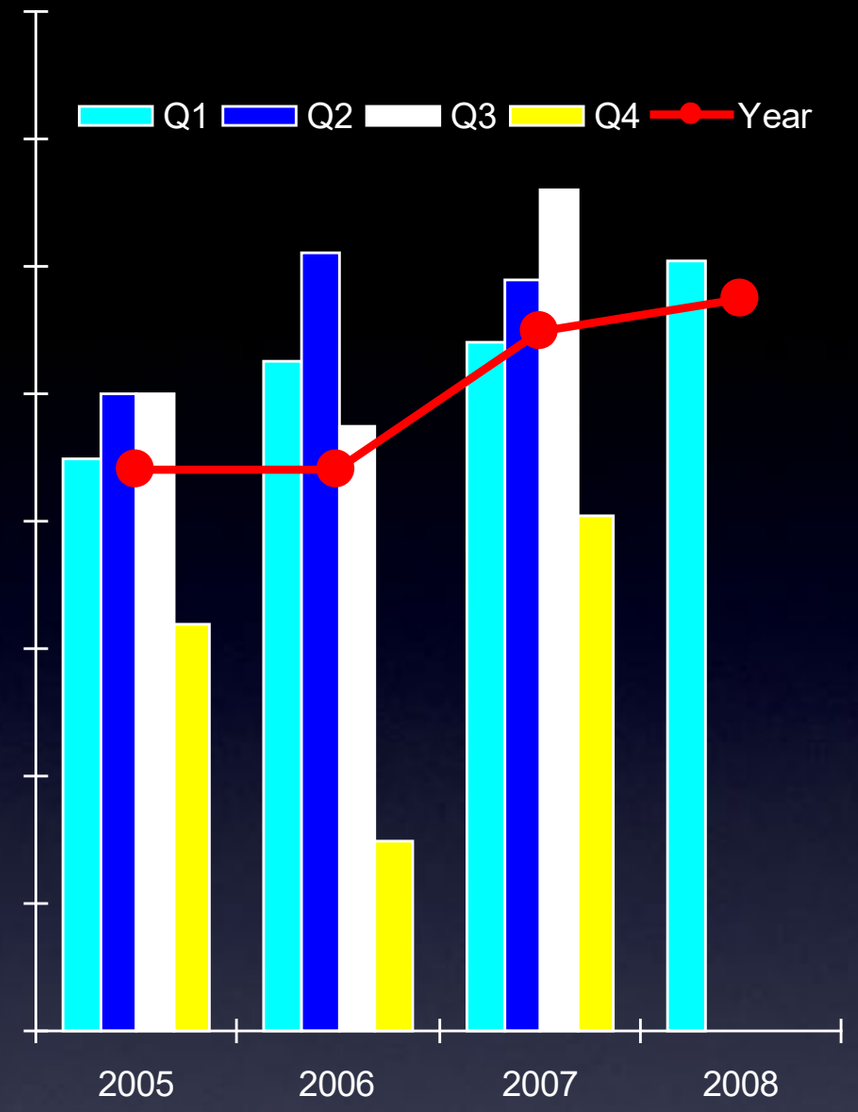

* 15400 juni t/m sept tot circa 23 u
** 25400 juni t/m sept tot circa 19 u
5400
15400
25400
4800
2100
2200/2300
Haarlem
Overveen
Zandvoort aan Zee
Halfweg-Zwanenburg
Amsterdam Lelylaan
Heemstede-Aerdenhout
6300
Hillegom
Hoofddorp
Schiphol Airport
Nieuw Vennep
Sassenheim
Voorhout
4100
8100
8200
8300
8400
4300
700/800
1800
A'dam Zuid
A'dam RAI
Duivendrecht
A'dam Amstel
Diemen Zuid
Weesp
Diemen
140/240
7x per dag
1500
7400
3500
Amsterdam Bijlmer ArenA
Amsterdam Holendrecht
Abcoude
* 9500 stopt pas in de loop van 2025 ook in Duivendrecht
2600
4600
4900
Almere Centrum
Almere Muziekwijk
Almere Poort
2400/9500
Naarden-Bussum
Bussum Zuid
Hilversum Media Park
Hilversum
Hilversum Sportpark
Hollandsche Rading
Baarn
Soestdijk
Soest
Soest Zuid
5700
4900
5500
Amersfoort Schothorst
Amersfoort Centraal
5800
Den Dolder
Bilthoven
Utr. Overvecht
5600
500/600
1700
28300
Utrecht Maliebaan
** 10-17u (niet op maandag en in de vakanties)
* Omleiding ICE in april, juli, augustus en oktober 2025 via Venlo
ICE
3000
3900
3100
2700/2900
7300
Breukelen
Maarssen
Utrecht Zuilen
4000
Leiden Centraal
De Vink
Voorschoten
Den Haag Mariahoeve
Den Haag Laan van NOI
2100
6300
4300
5700
3200
3100
3500
9300
9100
Leiden Lammenschans
Alphen a/d Rijn
Boskoop
Boskoop Snijdelwijk
8600
Waddinxveen Noord
Waddinxveen
Waddinxveen Triangel
8700
8900
8800
Bodegraven
Den Haag Centraal
Voorburg
Den Haag Ypenburg
Zoetermeer
Zoetermeer Oost
Lansingerland-Zoetermeer
6800
6900
1700
500/600
5000
5100
5200
1100
Gouda
Woerden
Vleuten
Utrecht Terwijde
Utrecht Leidsche Rijn
Utrecht Centraal
Utr. Vaartsche Rijn
Veenendaal-de Klomp
3200
Ede-Wageningen
Ede Centrum
Bunnik
Driebergen-Zeist
Maarn
7300
Wolfheze
Veenendaal West
Veenendaal Centrum
Rhenen
Utrecht Lunetten
Houten
Houten Castellum
Culemborg
Geldermalsen
Zaltbommel
8800
6900
Tiel Passewaaij
Tiel
Kesteren
Opheusden
Den Haag HS
Den Haag Moerwijk
Rijswijk
Delft
Delft Campus
Schiedam Centrum
2200/2300
3200
1800
2400/9500
2800
2000
4000
Nieuwerkerk a/d IJssel
Gouda Goverwelle
Capelle Schollevaar
Rotterdam Alexander
Rotterdam Noord
Rotterdam Centraal
9200
* SPR 5200 stopt pas in de loop van 2025 in Schiedam Centrum
Rotterdam Blaak
Rotterdam Zuid
Rotterdam Lombardijen
Barendrecht
Zwijndrecht
Dordrecht
Dordrecht Zuid
Dordrecht Stadspolders
Sliedrecht Baanhoek
Sliedrecht
7200
7100
3500
Hardinxveld Blauwe Zoom
Hardinxveld-Giessendam
Boven-Hardinxveld
Gorinchem
Arkel
Leerdam
Beesd
's-Hertogenbosch
Oss West
Oss
Rosmalen
6600
3600
4400
← ochtendspits






Line system
Timetabling / Routing trains through stations (1-hour)
DONS
Passenger travel times, Transfers
Punctuality
Rolling stock
TAM
Crew
CREWS
Expected number of passengers
Expected profit = Revenue - Cost

Results



- More passengers than ever before
- All-time high punctuality
- OR led to more efficient resource schedules
  - 4% in crew duties
  - 6% in rolling stock kilometers
- Annual benefit for NS: $ 105 Million
- Future: More growth with limited infrastructure extensions
- Crucial for Dutch economy and environment

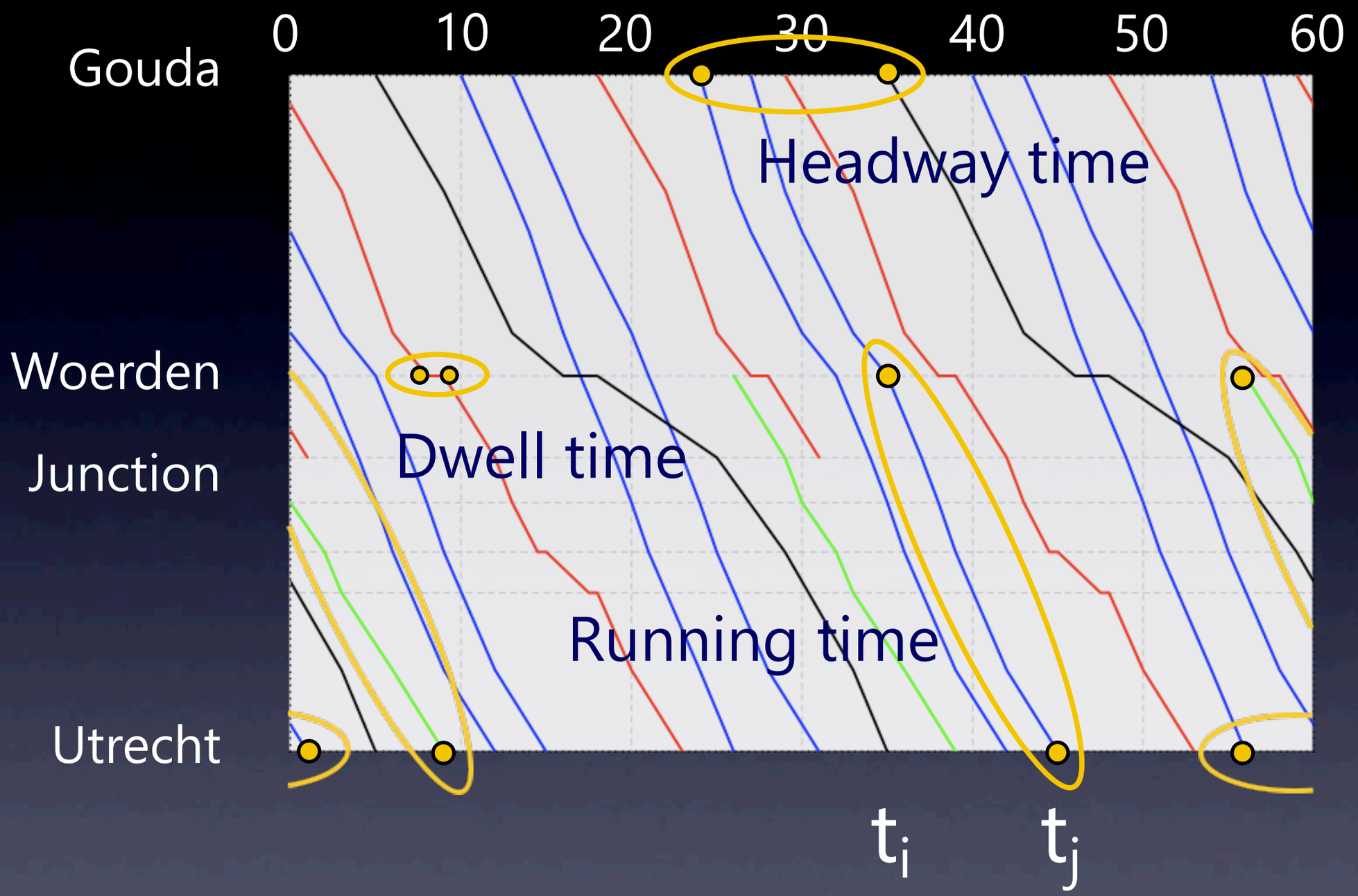
Netherlands Railways

Operations Research Applied

Determine departure and arrival times

- Running times
- Dwell times
- Headway times
- Transfer times

Cyclic timetable

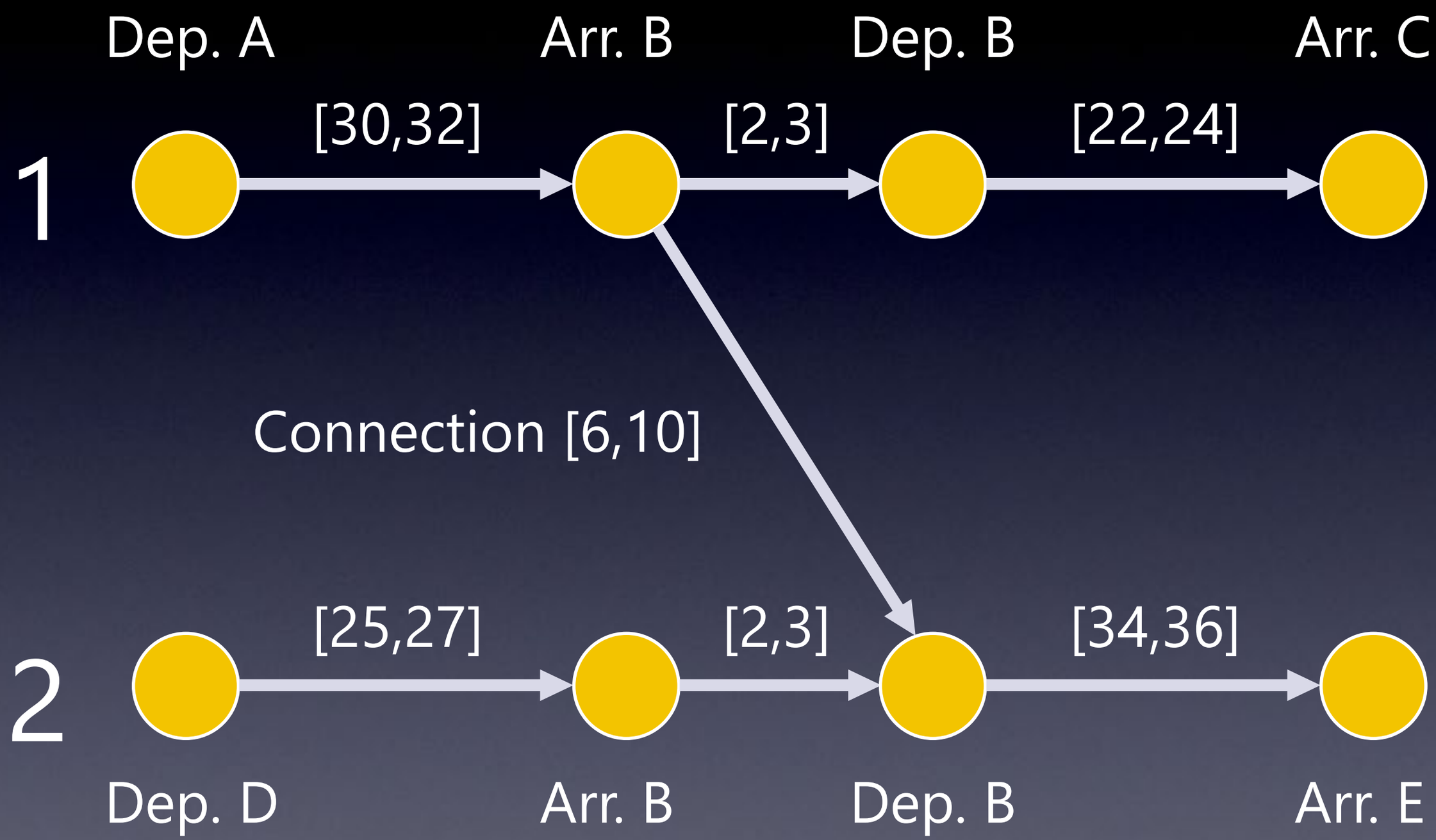


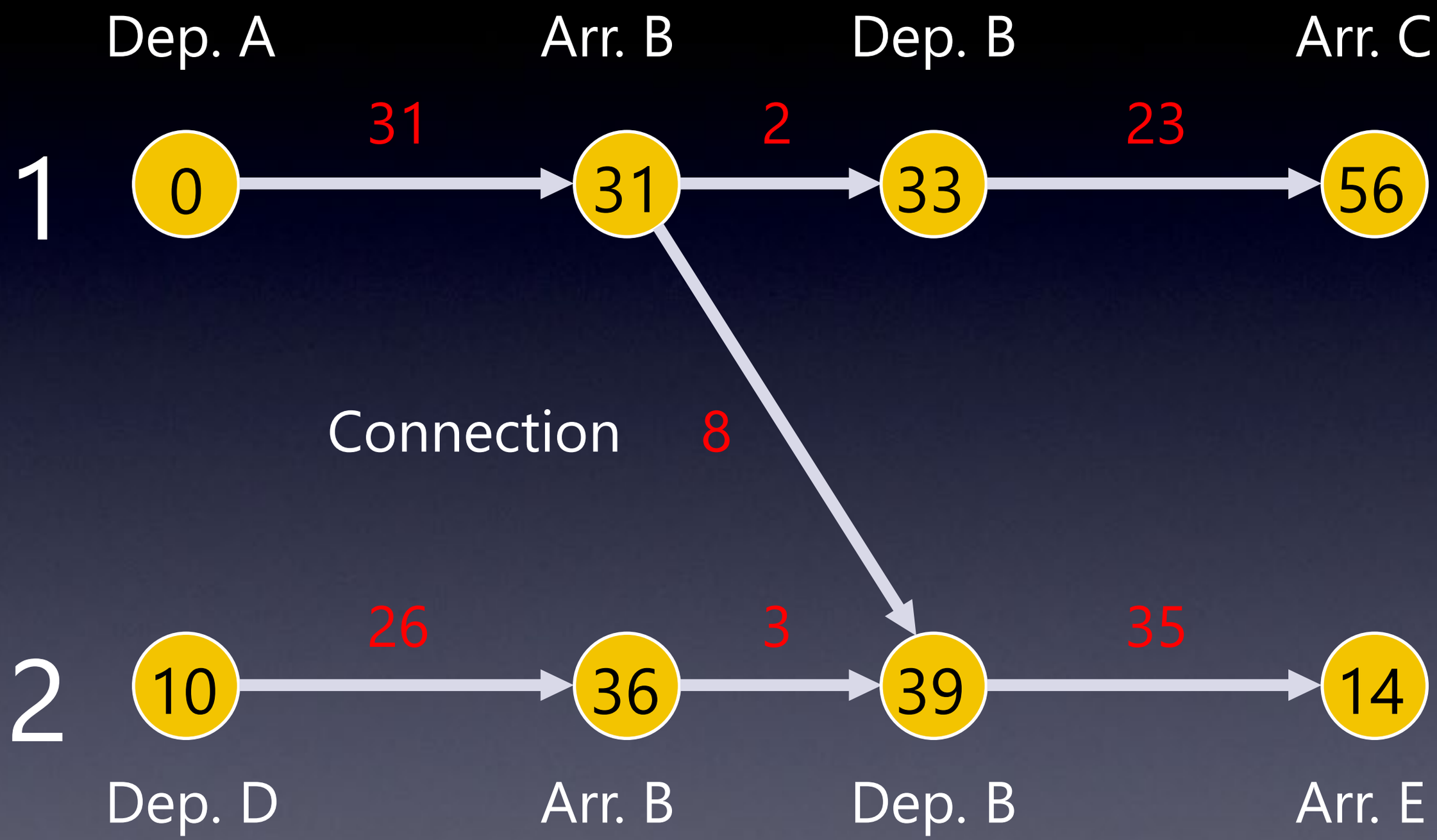
$$10_{ij} \leqslant t_j - t_i \leqslant 60_{ij} \leqslant U_{ij}$$

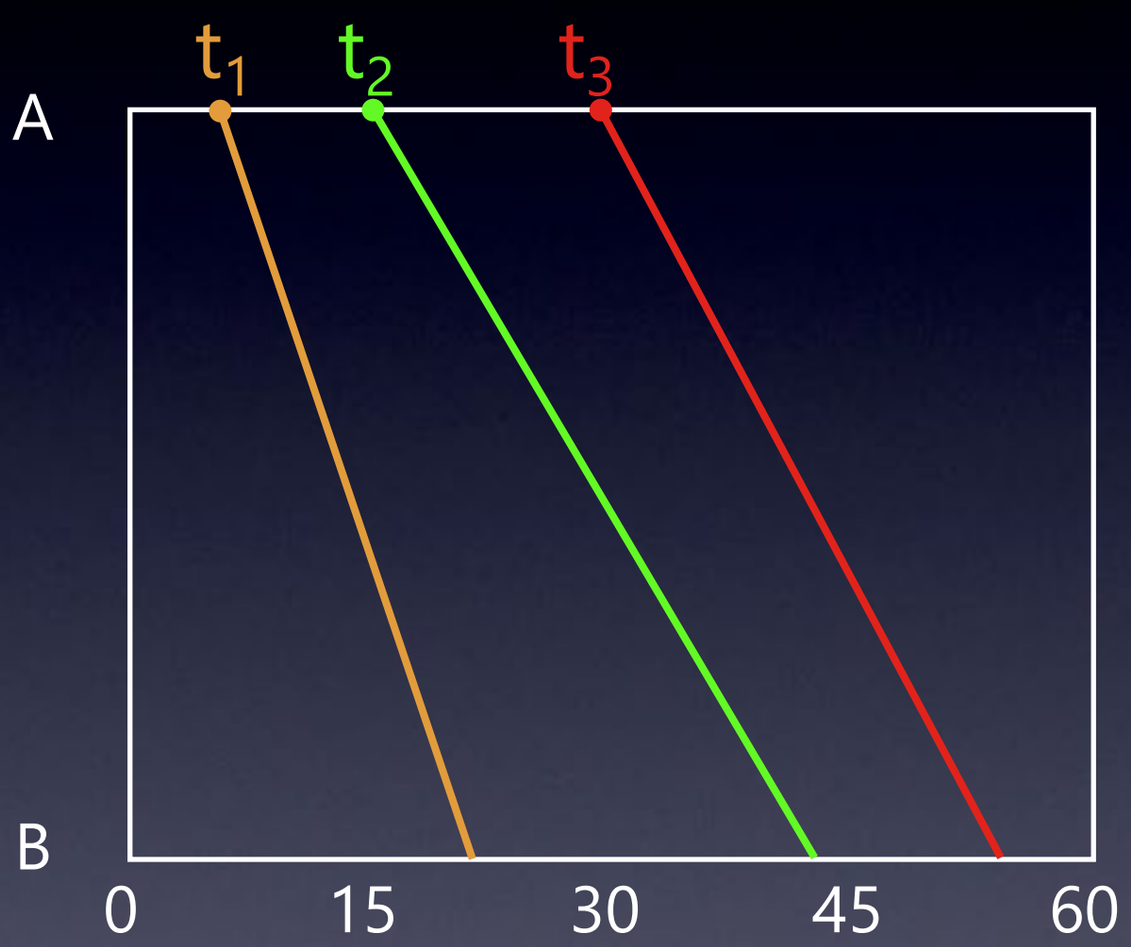
Periodic Event Scheduling Problem (PESP)

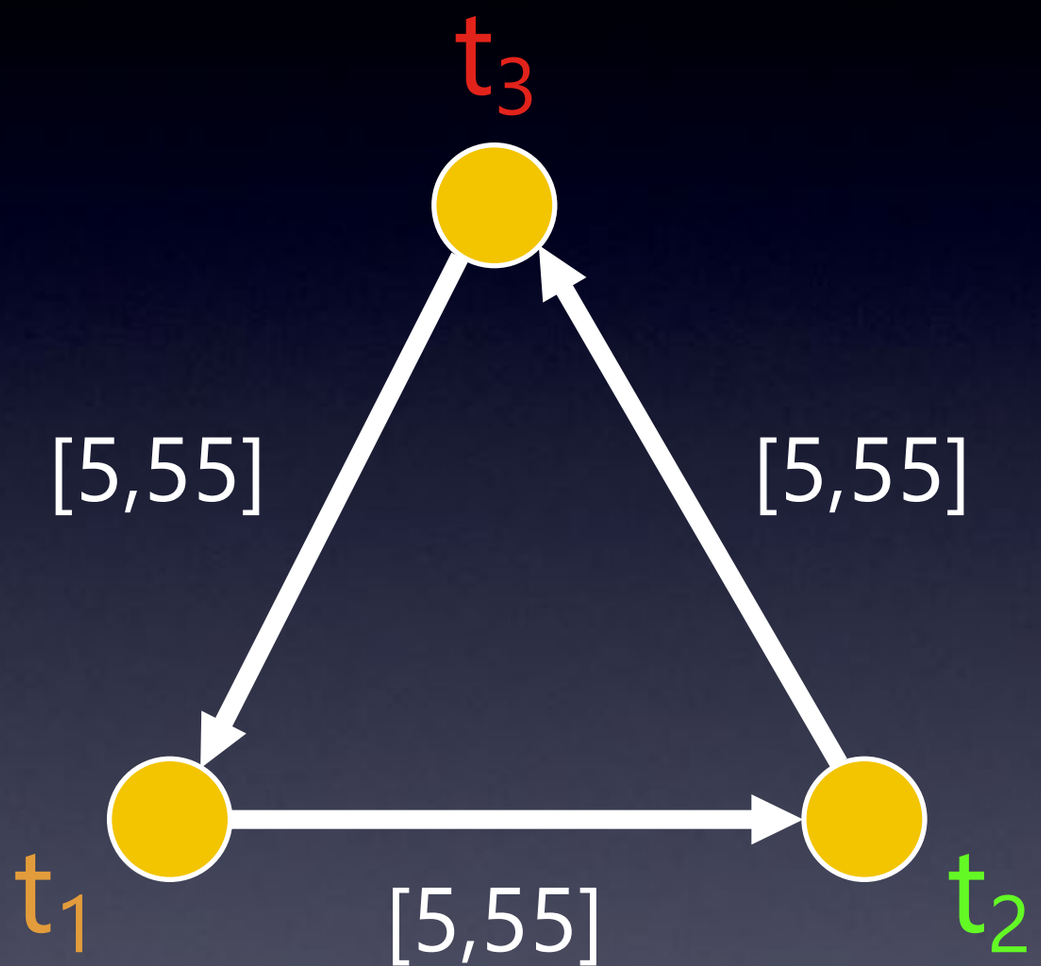
$$L_{i,j} \leqslant t_j - t_i + 60 \times Q_{i,j} \leqslant U_{i,j}$$

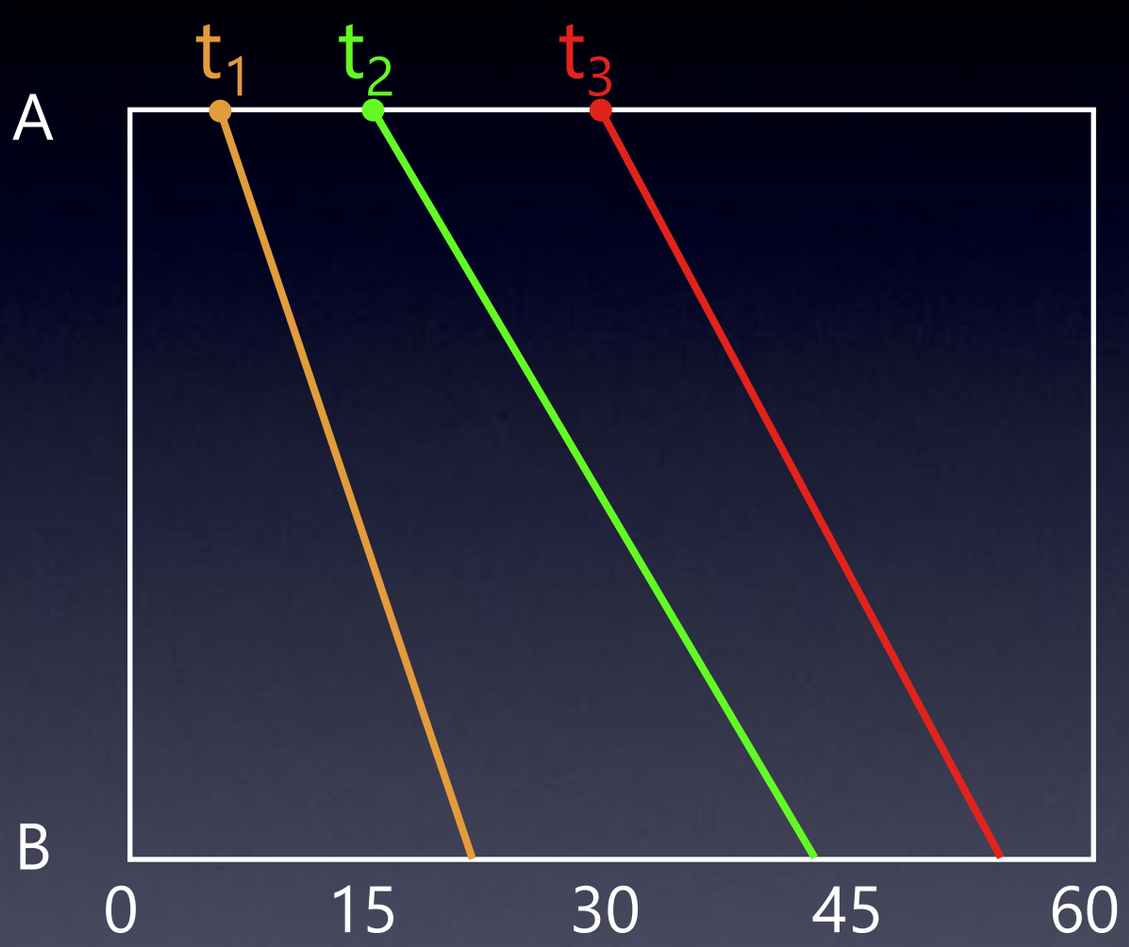
Constraint Graph

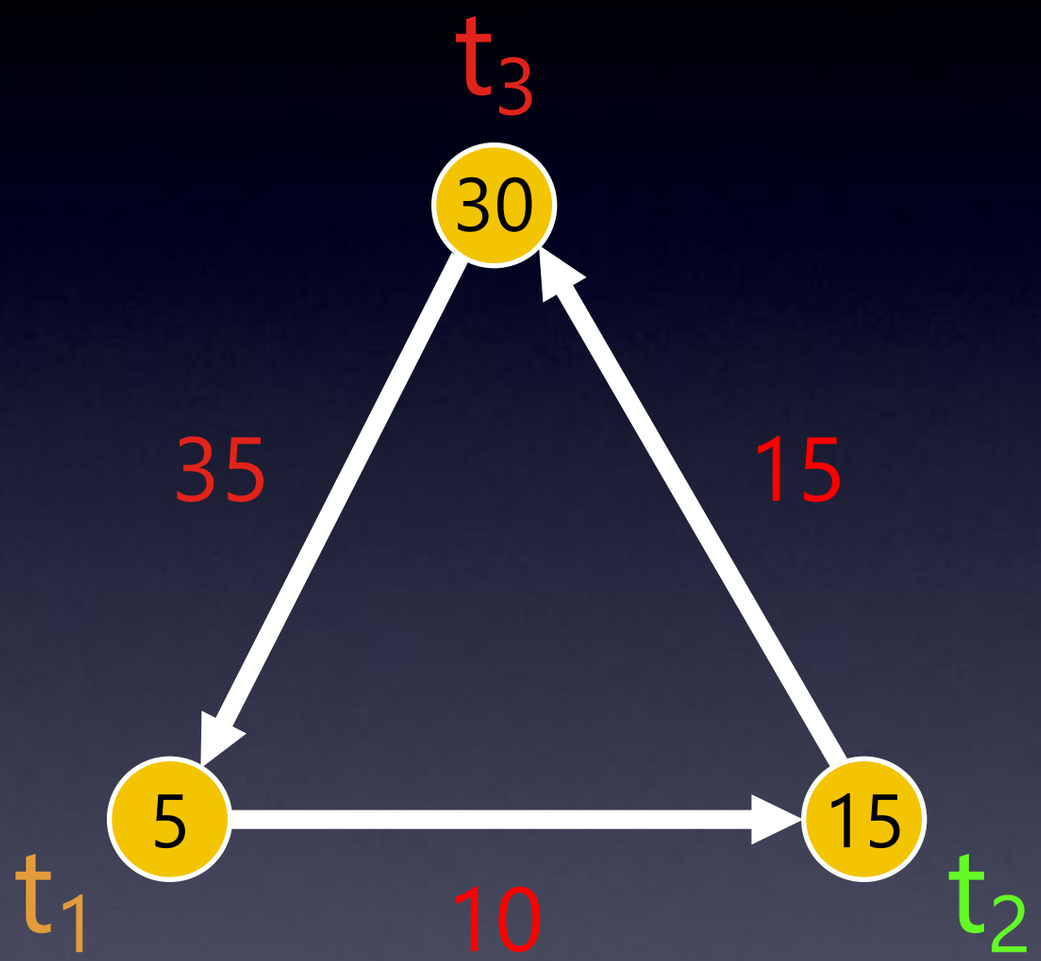

Dep. A
Arr. B
Dep. B
Arr. C
1
[30,32]
[2,3]
[22,24]
Connection [6,10]
2
[25,27]
[2,3]
[34,36]
Dep. D
Arr. B
Dep. B
Arr. E


Dep. A
Arr. B
Dep. B
Arr. C
1
0
31
2
23
31
33
56
Connection
8
2
10
26
36
3
39
35
14
Dep. D
Arr. B
Dep. B
Arr. E

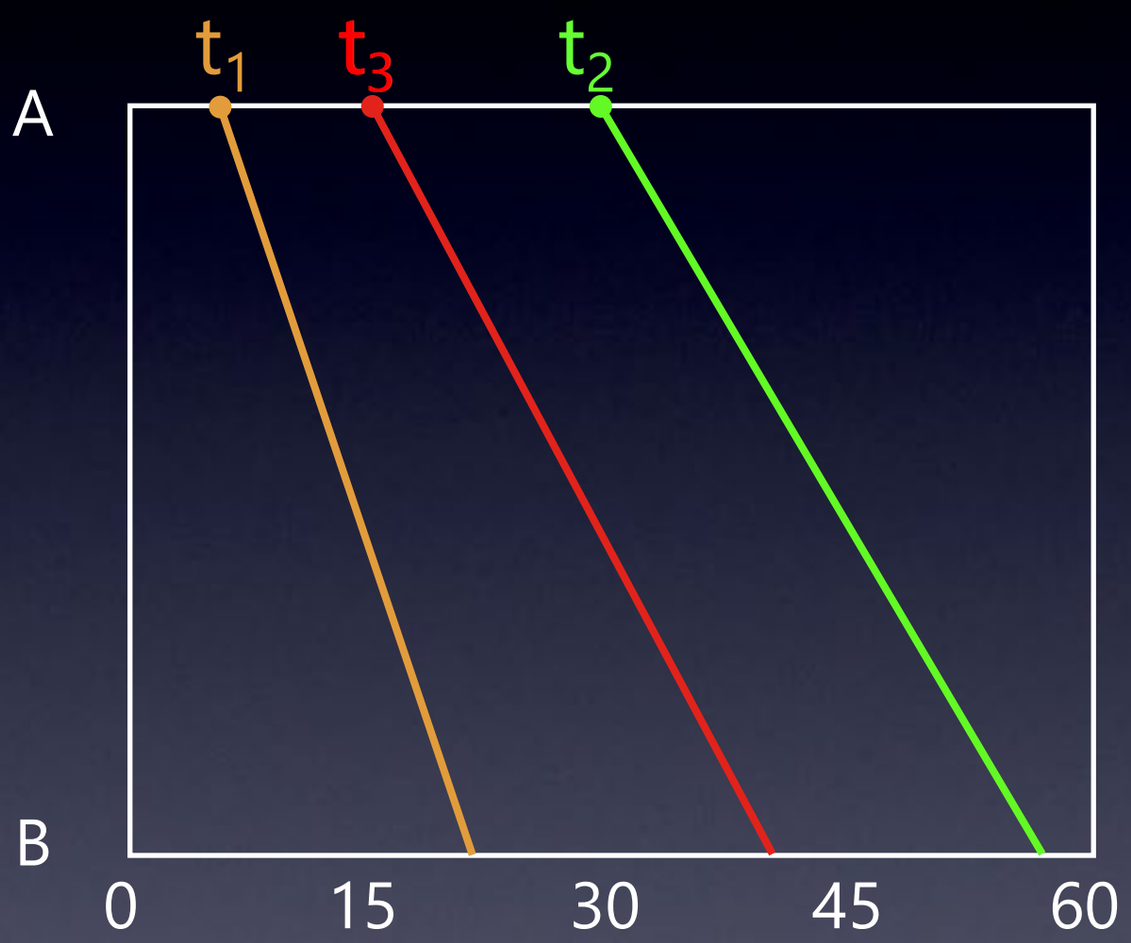


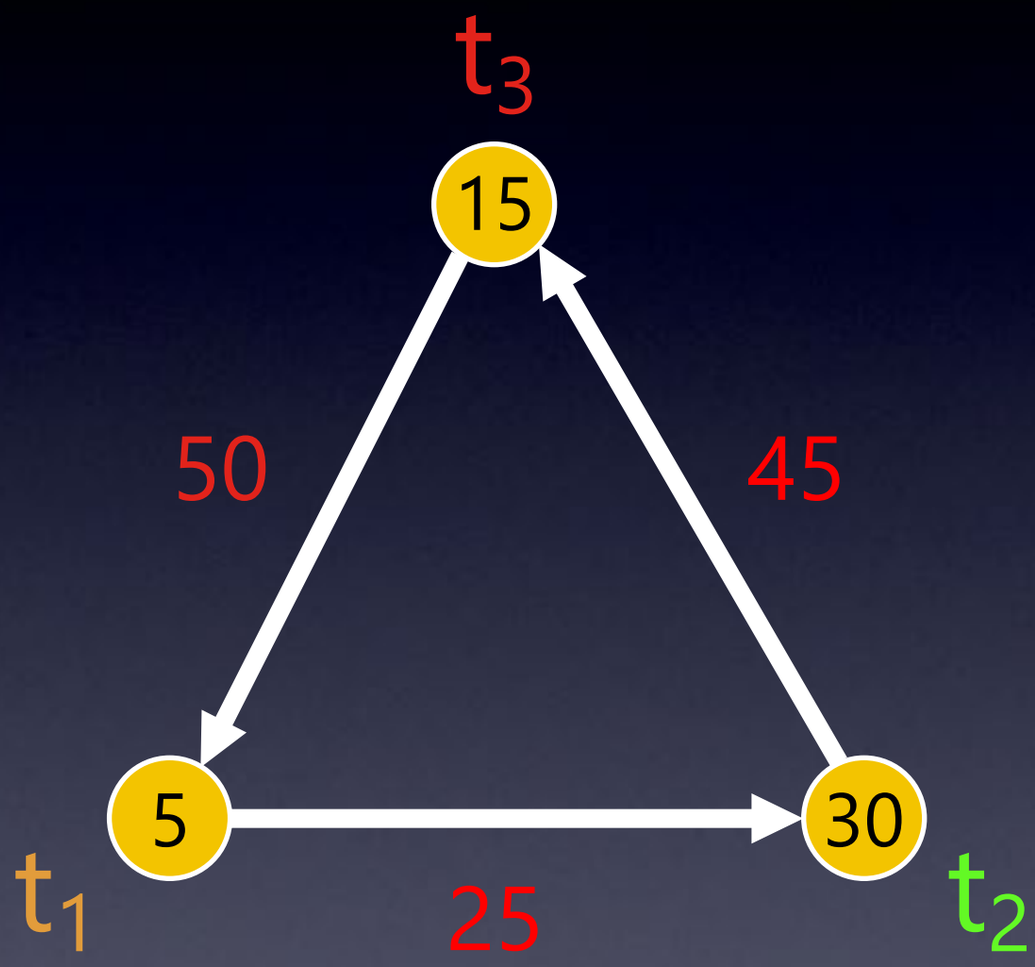






Sum of the headway times = 60





Sum of the headway times = 120

Sum of the process times along any directed cycle is a multiple of 60

Many passenger connections

300+ trains per hour

8400+ event times t_i

70000+ PESP constraints

70000+ binary variables $Q_{i,j}$

Huge number of directed cycles

- Mixed Integer Programming failed
- Constraint Programming successful:
  - Feasible solution, if one exists
  - Indication of infeasibility, otherwise
- Post-optimization model

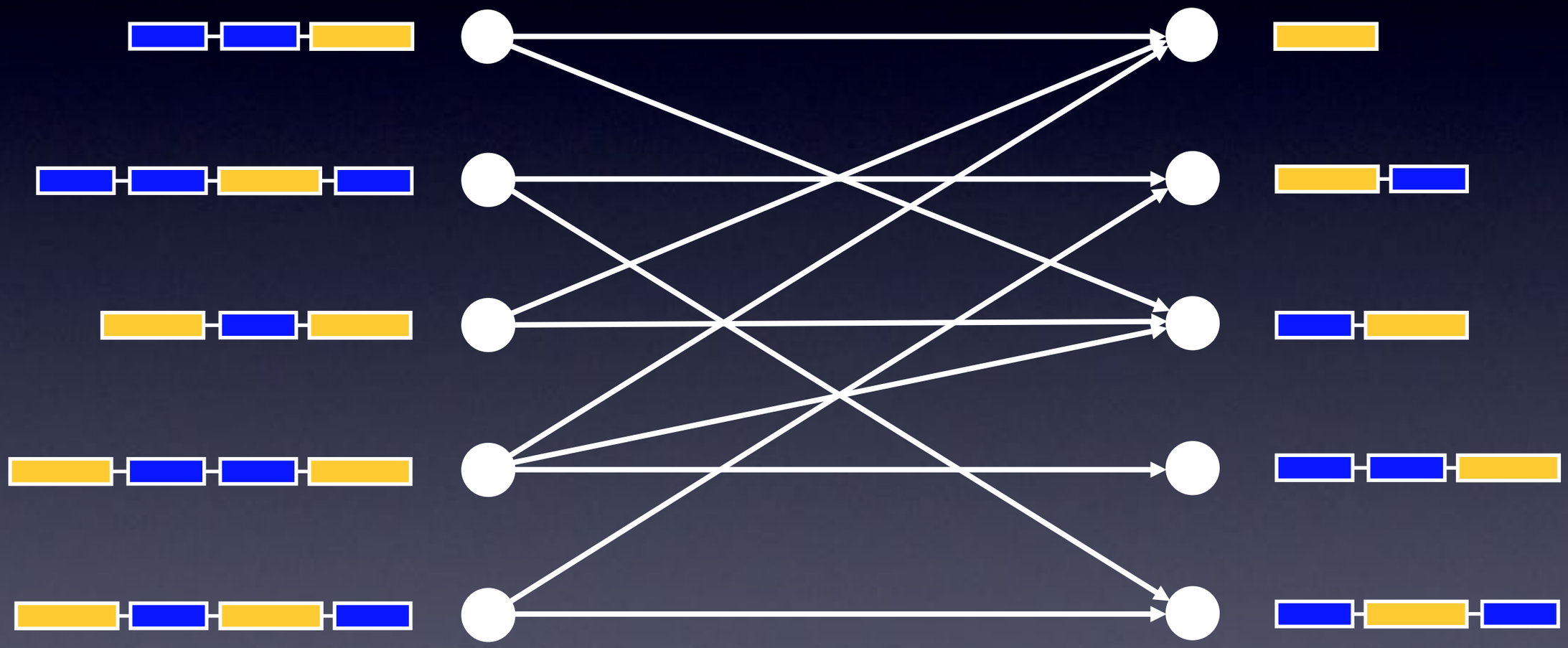
Determine for each train an appropriate composition

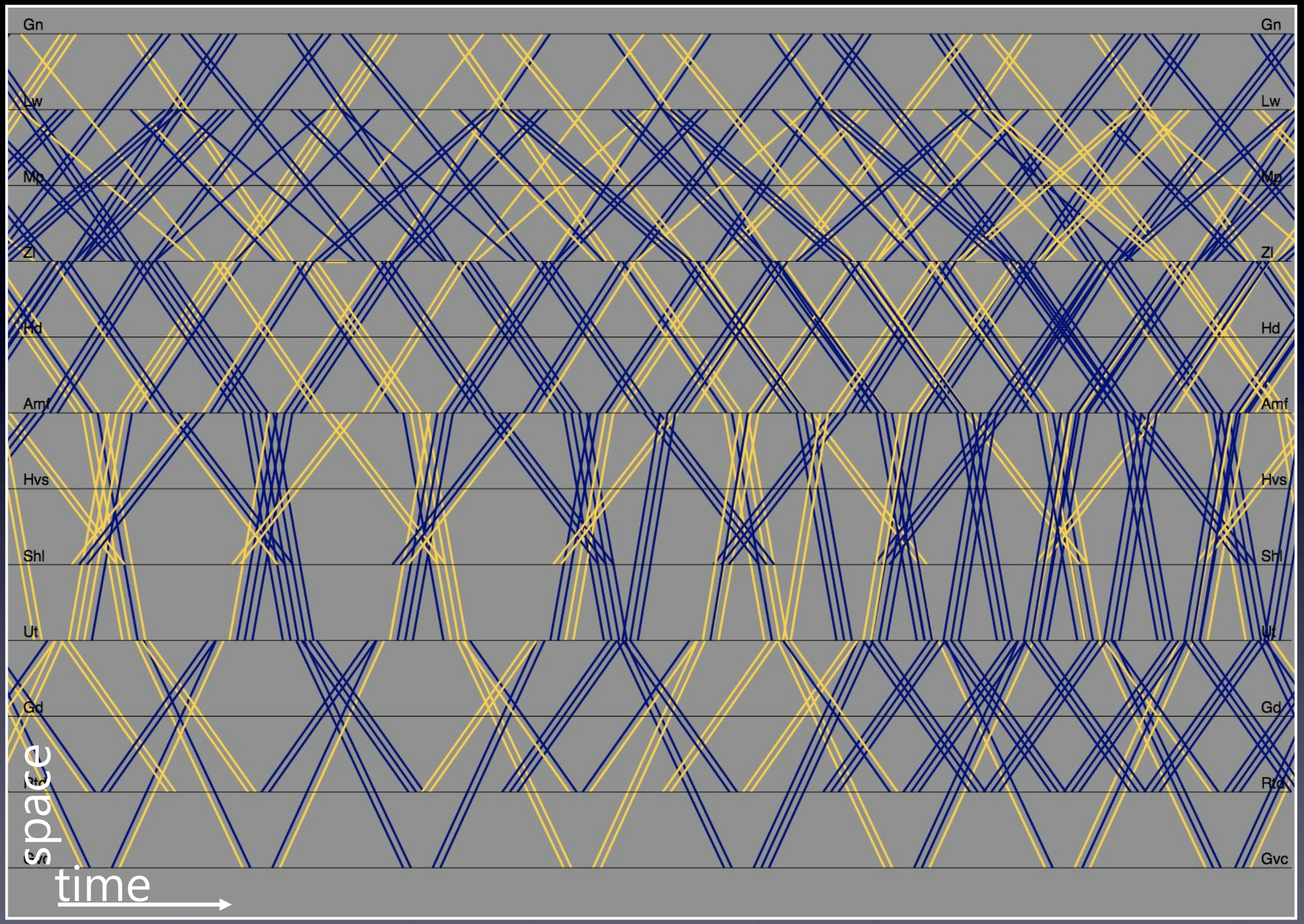
- Passenger demand
- Operational costs
- Total amount of rolling stock

Objectives: efficiency

Utrecht - Zwolle

Zwolle - Groningen




Gn
Lw
Mp
Zl
Hd
Amf
Hvs
Shl
Ut
Gd
Rtd
Gvc
space
time

Netherlands Railways

Developments since 2008

- New OR algorithms in operation for rolling stock scheduling (TAM), crew scheduling and dispatching (CREWS)
- We are now able to reschedule the timetable, rolling stock and crew within 24 hours in case of heavy disruptions (weather, strike)
- Most of these methods were developed in joint PhD projects with universities, e.g.:

- John van de Broek (2009), Daniel Potthoff (2010), Lars Nielsen (2011), Twan Dollevoet (2013), Luuk Veelenturf (2014), Erwin Abbink (2014), Evelien van der Hurk (2015), Joris Wagenaar (2016), Paul Bouman (2017), Denise Toenissen (2018), Thomas Breugem (2020), Gert-Jaap Polinder (2020), Johann Hartleb (2021), Rowan Hoogervorst (2021), Gerben Scheepmaker (2022), Rolf van Lieshout (2022), Roel van den Broek (2022)

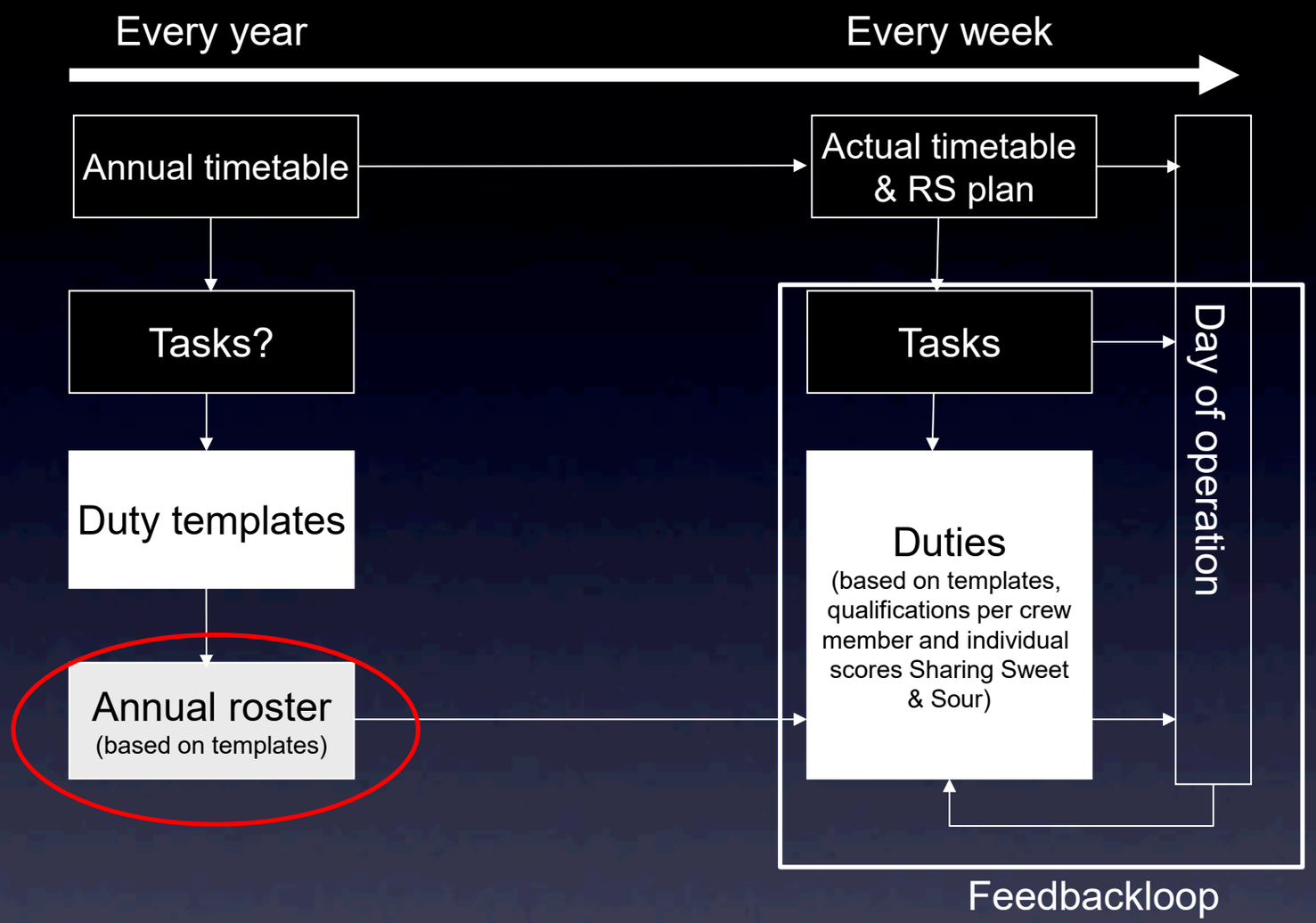
Current research projects

- In house research
- EU Rail Motional
- 13 PhD projects (Erasmus Univ. Rotterdam, TU Delft, Univ. Utrecht)

PhD projects:

- Strategic Timetabling / Short-Term Timetabling
- Rolling Stock Dispatching
- Shunting
- New Concepts in Crew Planning

Example PhD project Bart van Rossum



Project Veerle van den Hurk

Our goal is to iteratively construct a feasible crew plan that covers the timetable, matches the rosters, and satisfies individual SS&S rules at the end of the planning period.

Solution techniques: column generation, Bender's decomposition

Netherlands Railways

Operations Research Impact

Impact since 2008

- New timetable in 2017

  (updated in 2025 with more services than ever)

- Successful mid-term review in 2019 with all-time high punctuality and more efficient rolling stock and crew plan (30 Million/year)

- Quicker response to unforeseen events and disruptions

  (e.g. within 1 week a new timetable during the first months of the pandemic in 2020)

“When you just missed your train,
you are always in time for the next one”.

Johan Cruijff