BUS SCHEDULING IN URBAN TRANSPORTATION

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OVERVIEW

- Introduction
- Bus scheduling models
- Fueling time constraints
- Further questions

URBAN BUS TRANSPORTATION

- Provides:
  - Interesting, complex and hard problems for Operations Research

- Because:
  - Large savings can be realized
  - A large number of resources is involved

LARGE NUMBERS

Szeged

Number of trips per day	Number of buses per day	Number of bus types
2763	107	4

OPERATIONS PLANNING PROCESS

Lines

↓

Frequencies

↓

Timetables

↓

Bus schedules

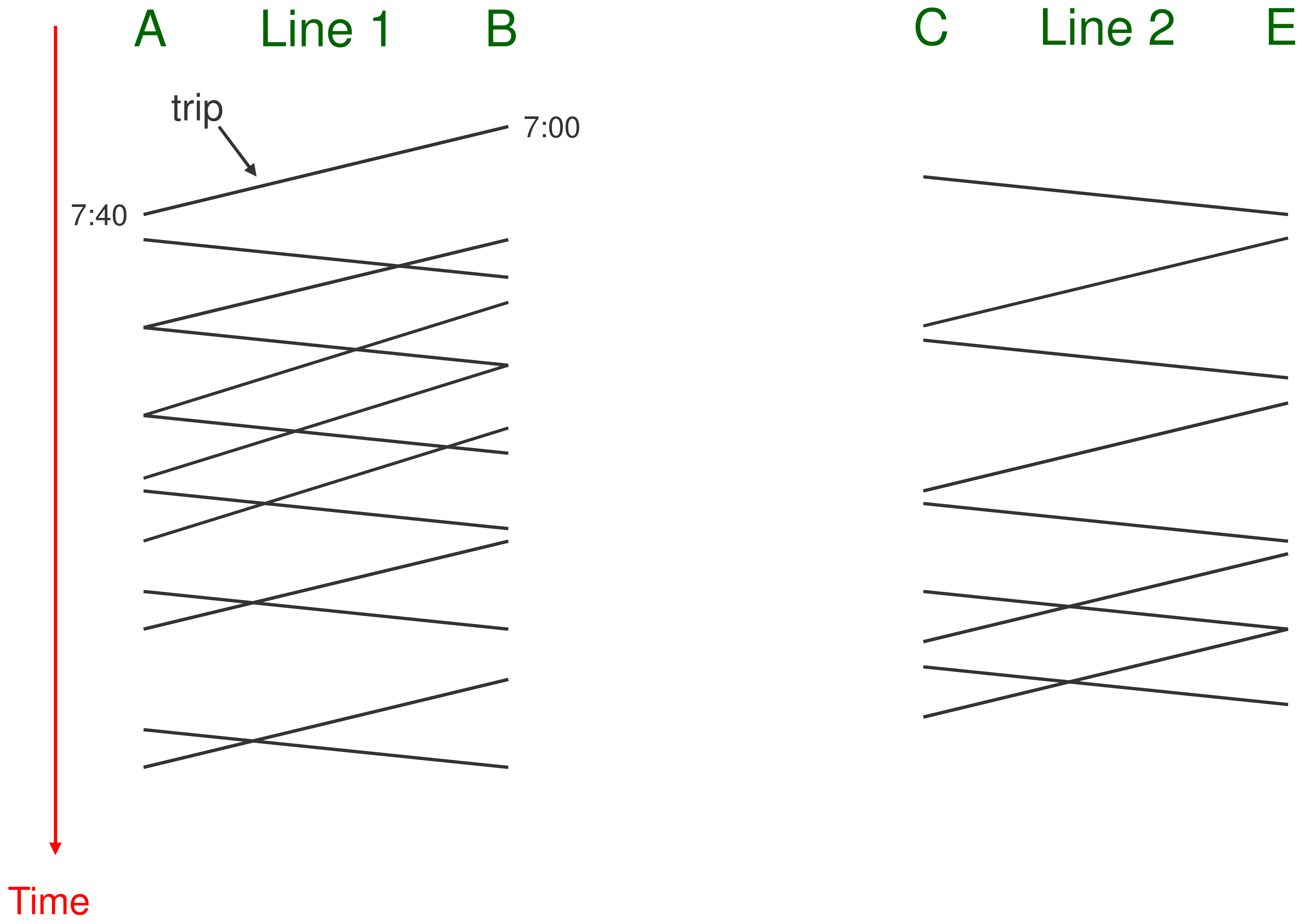
↓

Driver schedules
(Duties + Rosters)

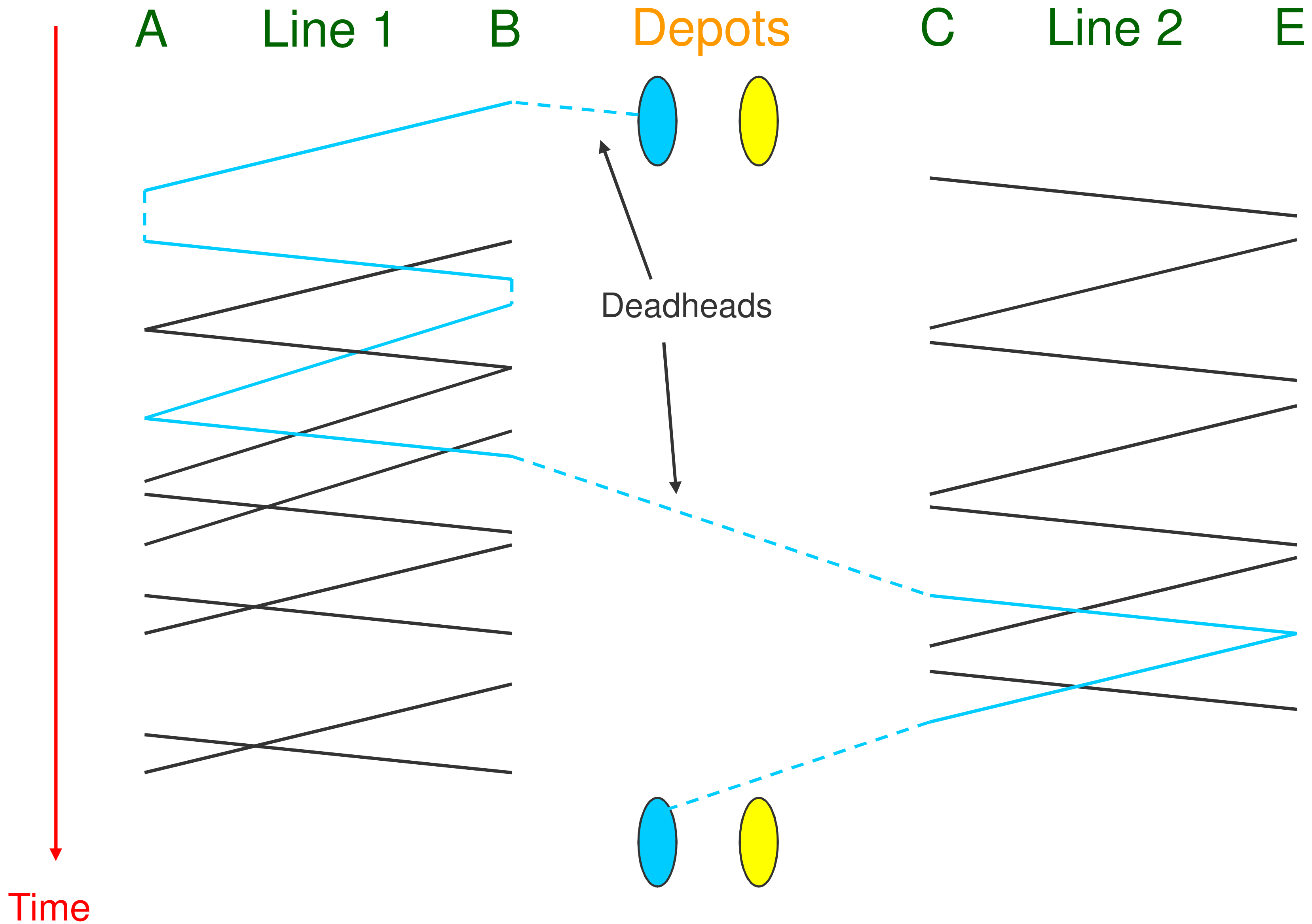
BUS SCHEDULING PROBLEM DEFINITION

- One-day horizon
- Several depots
  - Different locations
  - Different bus types (standard, low floor, long, short, …)

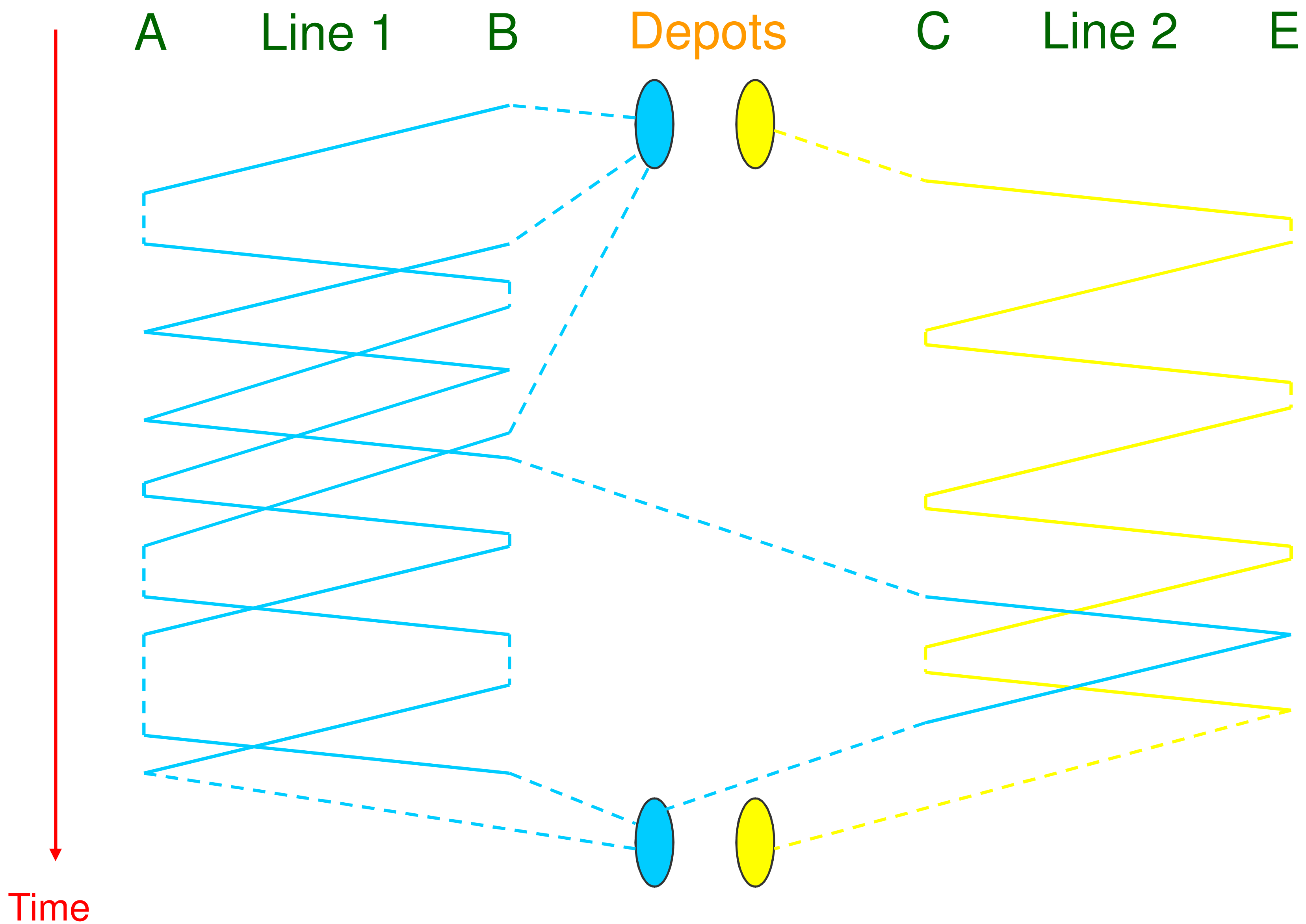
PROBLEM DEFINITION



PROBLEM DEFINITION



PROBLEM DEFINITION



PROBLEM DEFINITION

- Constraints
  - Cover all trips
  - Feasible bus routes
    - Schedule starts and ends at the same depot
    - No overlaps in time
  - Bus availability per depot
  - Depot-trip compatibility
  - Deadhead restrictions

PROBLEM DEFINITION

- Objectives:
  - Minimize the number of buses
  - Minimize deadhead costs
    - Proportional to travel distance or time
  - No trip costs

SOLUTION METHODOLOGIES

- Multi-commodity flow minimization models
  - Connection based network model (Andreas Löbel, TU Berlin, 1997)
  - Time space network model (Natalie Kliewer et al., University of Paderborn, 2006)

CONNECTION BASED MODEL

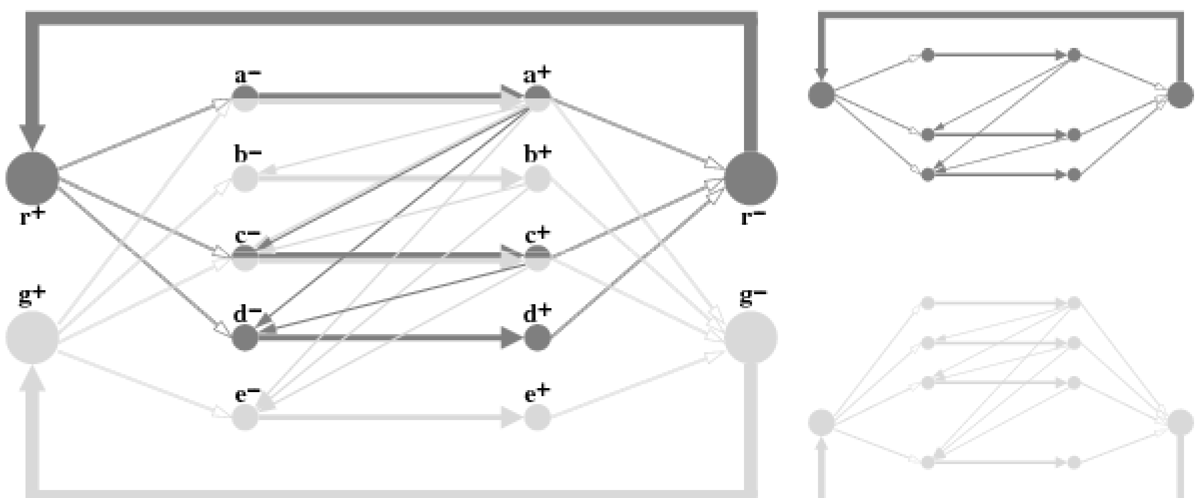


Figure 2.6: Digraphs (V', A') and (V'_d, A'_d), $d \in \mathcal{D}$, with $\mathcal{D} = \{\text{r,g}\}$ and $\mathcal{T} = \{\text{a,b,c,d,e}\}$.

CONNECTION BASED MODEL

To describe a feasible vehicle schedule (and multicommodity flow vector, respectively), an integer vector $x \in \mathbb{R}^{A'}$ must satisfy the conditions from (1.23):

1. The common lower and upper capacities (1.23b), both together define the equations

$$\sum_{d \in G(t)} x^d_{(t^-,t^+)} = 1, \qquad \forall\, t \in \mathcal{T}. \tag{2.2}$$

2. The flow conservation constraints (1.23c) defining

$$x^d\big(\delta^+_{D'}(v)\big) - x^d\big(\delta^-_{D'}(v)\big) = 0, \qquad \forall\, v \in V'_d \;\; \forall\, d \in \mathcal{D}, \tag{2.3}$$

TIME SPACE NETWORK MODEL

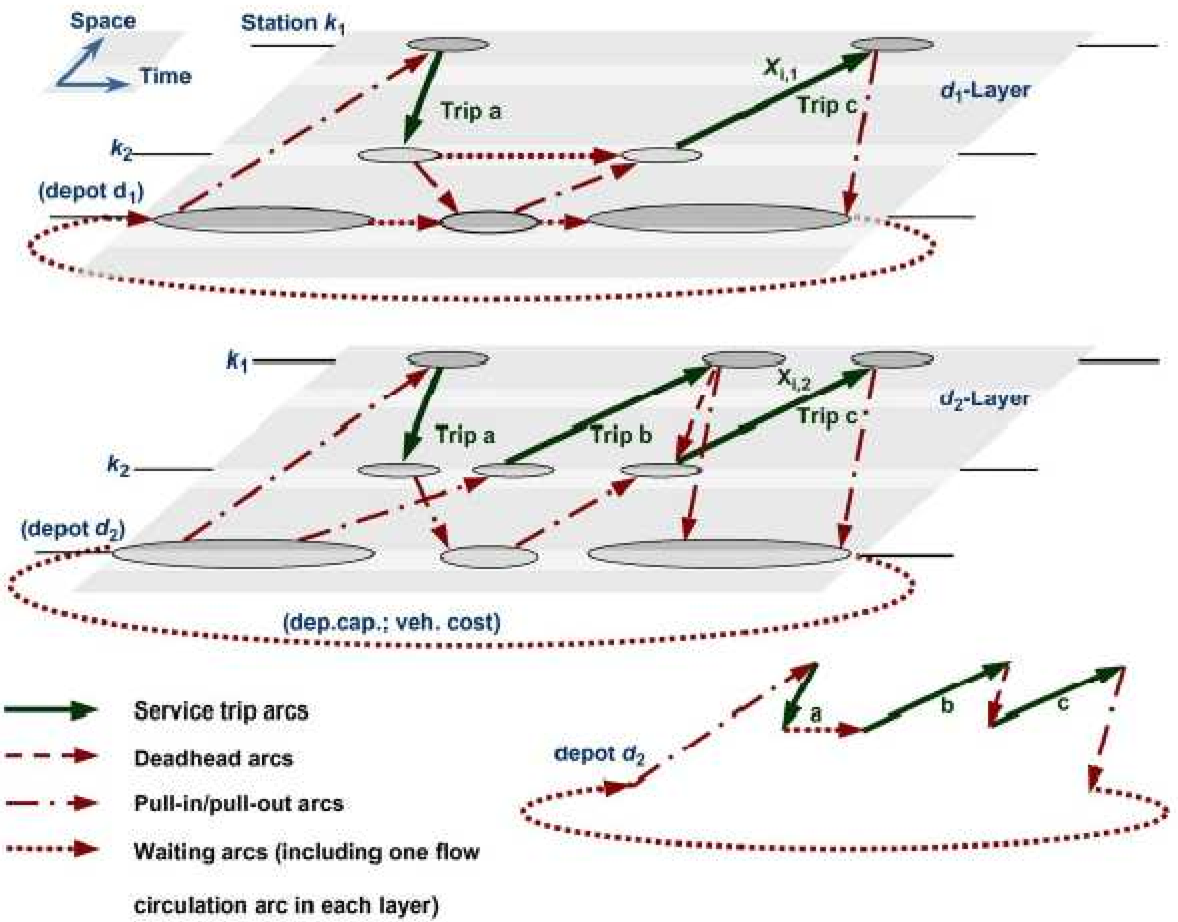


Fig. 3. The example from Fig. 1 modeled with new time–space network approach.

TIME SPACE NETWORK MODEL

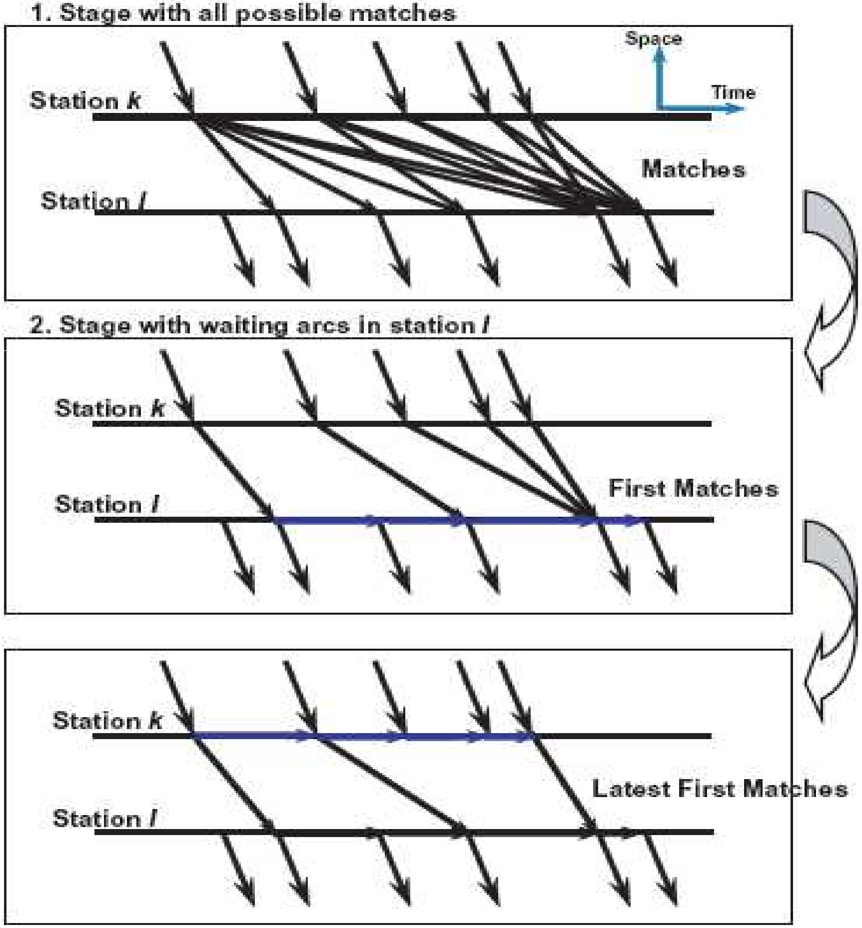
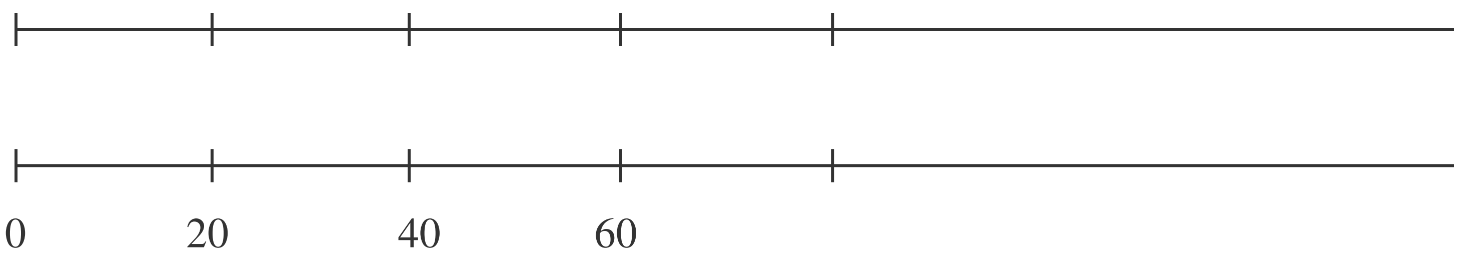


Fig. 4. Two-stage aggregation of possible connections.

FUELING TIME CONSTRAINTS



$$X_{ij} = \begin{cases} 1 \text{ if schedule i is refueled in time j} \\ 0 \text{ otherwise} \end{cases}$$

We consider only those variables, where schedule i can be refueled in time j.

FUELING TIME CONSTRAINTS

$$\min \sum C_{ij} X_{ij}$$

$$s.t.$$

$$\sum_{j=1}^{t} X_{ij} \leq 1, \text{ for all schedule } i$$

$$\sum_{i=1}^{s} X_{ij} \leq f, \text{ for all time } j$$

where

C_{ij} : cost of fueling schedule i at time j

t : number of time periods

s : number of schedules

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