Integrated Optimization of Timetable and Rolling Stock Rescheduling due to Temporary Maintenance Task

Jianrui Miao
State Key Laboratory of Rail Traffic Control and Safety
Beijing Jiaotong University
Associate Professor

Joint work with
Xin Hong, Lingyun Meng, Andrea D'Ariano, Luuk Veelenturf, and Francesco Corman

4 November, 2018

Outline

- Introduction
- Literature review
- Problem statement
- Mathematical formulation
- Numerical study

01

PART ONE

Introduction

Introduction

Operation

Unexpected perturbations
bad weather conditions, rolling stock break down, signal problems, infrastructure failures

↓

Negative effects on running time
dwelling, arriving and departing events

↓

Primary delays

↓ High interdependency between train services

Consecutive delays

Introduction

disturbance

disruptions

Timetable rescheduling

retiming, reordering, rerouting and reserviceing etc.

Feedback

Input

Rolling stock rescheduling

adjusting the original circulation plan and maintenance plan etc.

Introduction

disruptions

unavailability of railway track segments due to broken overhead wires or rolling stock breakdowns

Timetable rescheduling

retiming, reordering, rerouting and reserviceing etc.

Rolling stock rescheduling

adjusting the original circulation plan and maintenance plan etc.

02

PART TWO

Literature review

Literature review

- **Timetable rescheduling**

Publications	Perturbation type	Infrastructure details	Model structure	Objective(s)	Rescheduling measures	Solution method	Rolling stock issue
D'Ariano et al. (2007)	Disturbance	Micro	MILP based on TSDG, AG	Min the maximum secondary delay for all trains at all visited stations	Retiming and reordering	B&B, H	Ignored
D'Ariano et al. (2008)	Disturbance	Micro	MILP based on TSDG, AG	Min the maximum consecutive delay for all trains	Retiming, reordering and rerouting	B&B, LS, H	Considered (in constraints)
Pellegrini et al. (2012)	Disturbance/ disruption	Micro	MILP based on TSDG	Min the maximum secondary delay imposed to a train	Retiming, reordering and rerouting	EX	Considered (in constraints)
Corman et al. (2012)	Disturbance	Micro	MILP based on TSDG, AG	Min the consecutive delays between trains and max the total value of satisfied connections	Retiming and reordering	B&B, H (Pareto front based)	Ignored
Sato et al. (2013)	Disruption	Marco	MIP based on TSDG	Min further inconvenience to passengers	Retiming reordering and rerouting	EX, H	Considered (in constraints)
Louwerse and Huisman (2014)	Disruption	Marco	IP based on EADG	Min the number of canceled train sub series and the delays of the trains that are not canceled, balance the number of trains in both directions and distribute the operated trains evenly over time	Retiming and reservicing	EX	Considered (in objectives and constraints)
Meng and Zhou (2014)	Disturbance	Micro	IP based on TSDG, CF	Min the total delay time of all involved trains at the destination	Retiming, reordering and rerouting	EX, LR	Ignored
Veelenturf et al. (2016)	Disruption	Marco	ILP based on EADG	Min the number of cancelled and delayed train services	Retiming, rerouting and reservicing	EX	Considered (in constraints)
Binder et al. (2017)	Disruption	Marco	ILP based on TSDG	Min the passenger inconvenience, operational cost and deviation from undisrupted timetable	Retiming, rerouting and reservicing	EX	Considered (in constraints)
Corman et al. (2017)	Disturbance	Micro	MILP based on TSDG, AG	Min the total time spent in the system by all passengers	Retiming and reordering	EX, H	Ignored
Our research	Disruption	Macro	ILP based on SSTDG	Min the total cost of timetable rescheduling and rolling stock rescheduling	Retiming, reordering and reservicing	EX	Considered (in objectives and constraints)

Literature review

- **Rolling stock rescheduling**

publications	Model structure	Objective(s)	Solution method	Considered characteristics of rolling stock
Budai et al. (2010)	ILP, FB	Min the number of off-balances, carriage kilometers, shortage kilometers and the number of composition changes	H	Rolling stock balance
Nielsen et al. (2012)	ILP, FB	Min the difference from original assignments of compositions to trips, the carriage kilometer costs, seat shortage kilometer costs, deviations from the original shunting operation and deviations from end-of-day balance	EX, H	Type, inventory, coupling and uncoupling; end-off-day balance, capacity
Kroon et al. (2015)	MILP, FB	Minimize the system related cost of a rolling stock assignment and the service related cost of a passenger flow	EX, H	Type, inventory, coupling and uncoupling; end-off-day balance, capacity
Wagenaar et al. (2015)	MILP, FB	Min the number of cancelled trips, the capacity shortages, the number of carriage kilometers, modified shunting movements, and the total deviation from the end of day balance.	EX	Type, inventory, coupling and uncoupling, end-of-day balance, capacity
Lusby et al. (2017)	ILP, PB	Min the cost of cancellations and seat-shortage, end-of-day balance shortage cost, and the (de)coupling and mileage cost	CGA, B&B	Type, inventory, coupling and uncoupling, end-of-day balance, capacity, composition length
Haahr et al. (2016)	MILP, PB	Min the trip cancelation, seat shortage, operational costs, the shunting costs and the end-of-day shortage costs	EX, CRGA	Type, inventory, coupling and uncoupling, end-of-day balance, capacity
Our research	ILP, PB	Min the total cost of timetable rescheduling and rolling stock rescheduling	EX	Type, inventory, coupling and uncoupling, end-of-day balance, capacity

Literature review

- **Integrated rescheduling of timetable and rolling stock**

publications	Infrastructure details	Model structure	Objective(s)	Solution framework and method	Considered characteristics of timetable	Considered the characteristics of rolling stock	Considered timetabling rescheduling measures
Fekete et al. (2011)	Marco	IP	Max the number of recovered trips in a conflict-free new timetable, possibly with delay	EX	Headway times	No details	Retiming, reordering and reservicing
Cadarso et al. (2013)	Macro	MILP	Min the operating costs of planned and emergency services, operating costs of empty movement, composition changes, cancellation of services, denied passenger, deviation from the schedule of commercial services, and deviation from the schedule of the empty movements	Two-step algorithm in an iterative heuristic framework, EX	Headway times	Type, inventory, coupling and uncoupling, end-of-day balance, capacity	Reservicing
Cadarso et al. (2015)	Marco	ILP	Min the operating costs of planned, empty and emergency services, composition changes, cancellation of services, denied passenger, deviation from the planned schedule, and the penalty cost of every time period during which the recovery is active	EX	Headway times	Type, inventory, coupling and uncoupling, end-of-day balance, capacity	Reservicing
Dollevoet et al. (2017)	Marco	MILP	Min the total duration of cancelled train services.	An iterative framework, EX and GA for timetable rescheduling, EX for rolling stock rescheduling, CGA and LRA for crew rescheduling	Headway times	Type, inventory, coupling and uncoupling, end-of-day balance, capacity	Retiming and reservicing
Veelenturf et al. (2017)	Macro	ILP	Min the total costs of the rolling stock rescheduling, the passenger flows (sum of delays) and the timetable rescheduling	An iterative heuristic framework, EX	No details	Type, inventory, coupling and uncoupling, end-of-day balance, capacity	Retiming and reservicing which is limited to the adaptations of stopping patterns
Our research	Marco	ILP	Min the total cost of timetable rescheduling and rolling stock rescheduling	EX	Headway times	Type, inventory, coupling and uncoupling, end-of-day balance, capacity	Retiming, reordering and reservicing

Literature review

- **Summary**

Timetable rescheduling

Constraint

Considering *rolling stock compositions* as a type of *resource*

Pellegrini et al. (2012)
Louwerse and Huisman (2014)
Veelenturf et al. (2016)

Timetable rescheduling

updated rolling stock assignment

updated timetable

Rolling stock rescheduling

Cadarso et al. (2013) (2015)
Veelenturf et al. (2017)
Dollevoet et al. (2017)

In our research

We consider a high dimension decision variable.

03

PART THREE

Problem statement

In this research

disruptions

a ***temporary maintenance task*** due to ***infrastructure break-down***, resulting in unavailability of railway track segments

Timetable rescheduling

retiming, reordering and reserviceing

Rolling stock rescheduling

adjusting the original circulation plan

Input

- Railway network
- Timetable
- Rolling stock and circulation schedule
- A set of candidate shunting operations
- A set of disruptions

Key decisions

- For ***each train service***, we need to determine whether it is ***canceled***, if not, the ***detailed arrival and departure times*** at relevant stations in the railway network will be obtained.

- For each train service operated in the adjusted timetable, we need to determine which ***rolling stock composition available*** to operate it, and the specific ***order*** of above rolling stock units in the composition. That is to say, the adjusted rolling stock circulation schedule will be obtained.

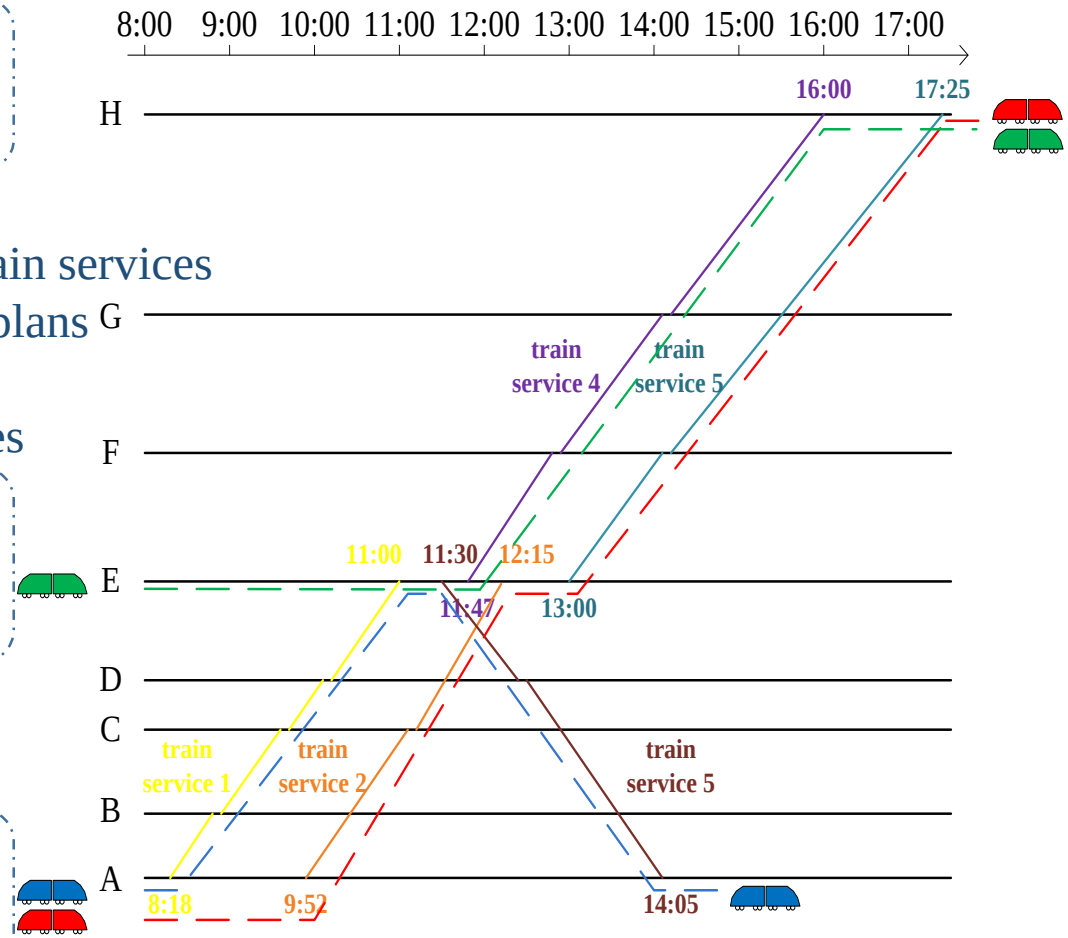
Output

Feasible ***timetable*** and ***rolling stock circulation plan***

Total delay times
Number of canceled train services
Deviation of shunting plans
Seat shortage
End-of-day off-balances

Minimize the total ***cost of timetable rescheduling*** and ***rolling stock rescheduling***

A number of ***operational constraints***, like capacity constraint



Assumptions

- The ***capacity of every station*** depends on ***the number of tracks*** in the station
- The ***preferred terminal stations and intermediate stations*** of train services cannot be changed.
- We don’t consider ***passenger demand changing*** due to disruptions.

State-space-time Network

- ***SST* = (*Φ*, *A*)** with a set of vertices ***Φ*** and a set of arcs ***A***

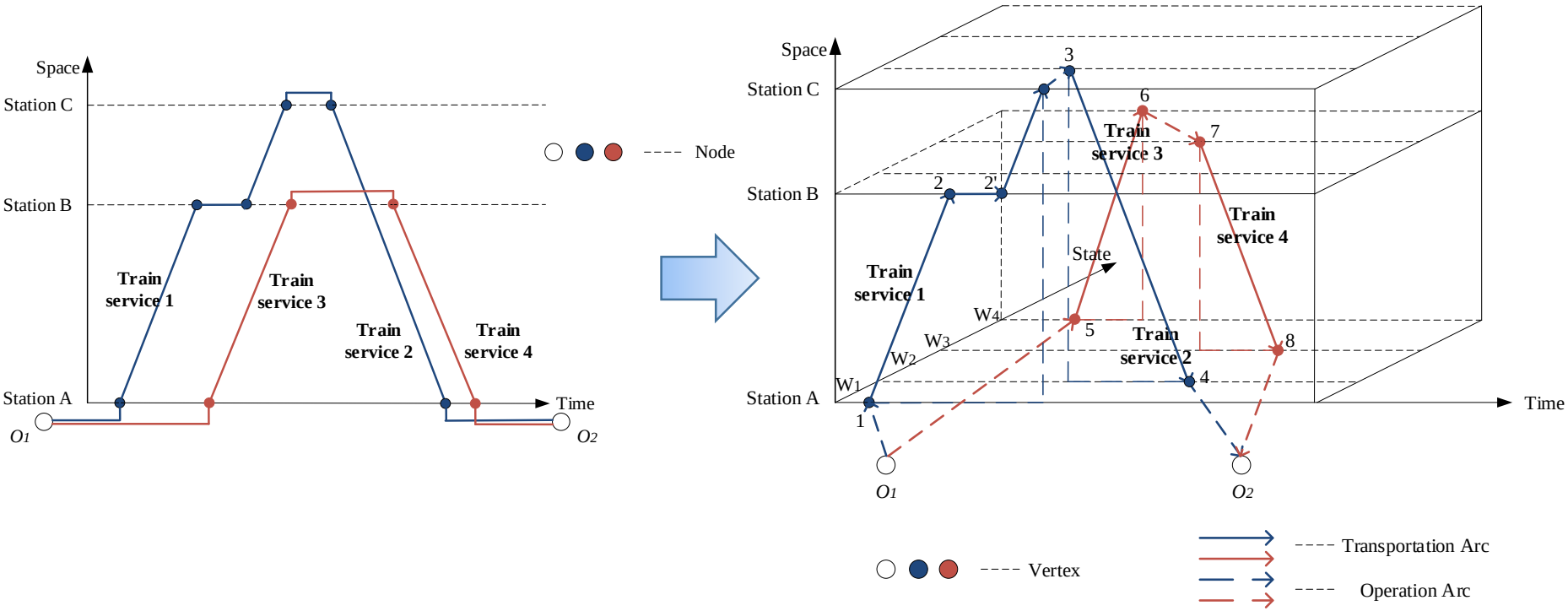


Figure: An illustration of a state-space-time network

State-space-time Network

- **State dimension**

  a vector with four elements [ts_{rol}, td_{rol}, $task_{rol}$, com_{rol}]

State-space-time Network

- **State dimension**

  a vector with four elements [ts_{rol}, td_{rol}, com_{rol}, $task_{rol}$]

  Train service ID operated by the rolling stock unit *rol*

State-space-time Network

- **State dimension**

  a vector with four elements [ts_{rol}, td_{rol}, com_{rol}, $task_{rol}$]

  Total travel distance until rolling stock unit *rol* finishes operating train service *ts*

State-space-time Network

- **State dimension**

  a vector with four elements [ts_{rol}, td_{rol}, com_{rol}, $task_{rol}$]

  Rolling stock composition *com* which operates train service *ts*

State-space-time Network

- **State dimension**

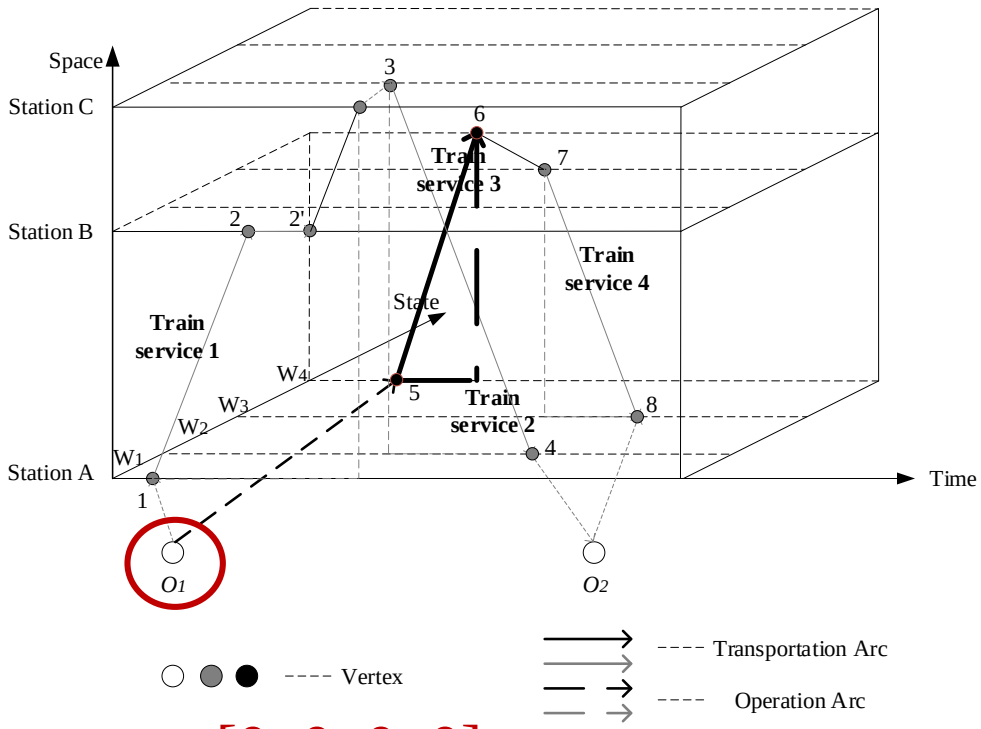
  a vector with four elements $[ts_{rol}, td_{rol}, com_{rol}, task_{rol}]$

  Task of rolling stock unit *rol*

State-space-time Network

- **State dimension**

  a vector with four elements $[ts_{rol}, td_{rol}, com_{rol}, task_{rol}]$



$w_0 = [0, 0, 0, 0]$

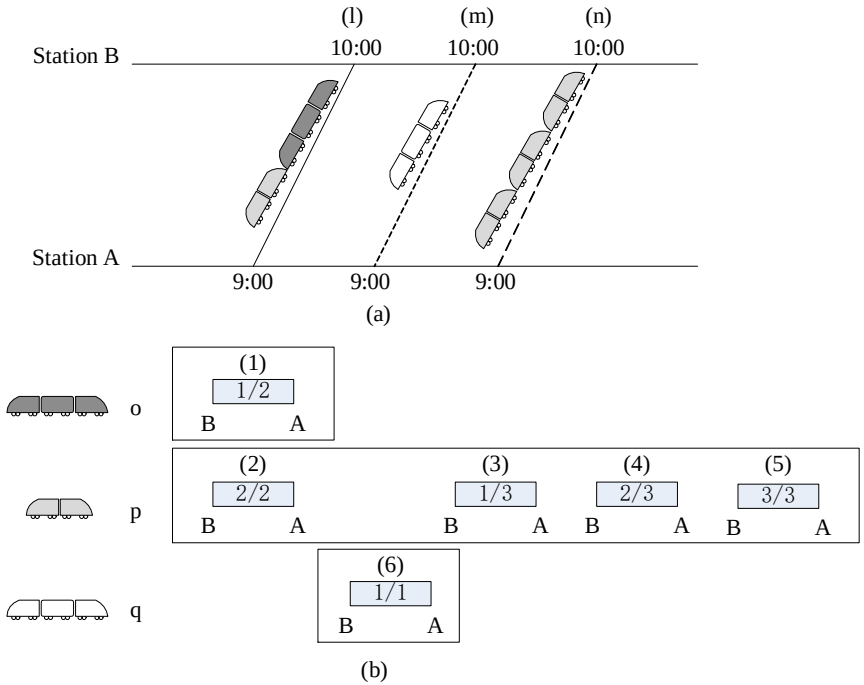
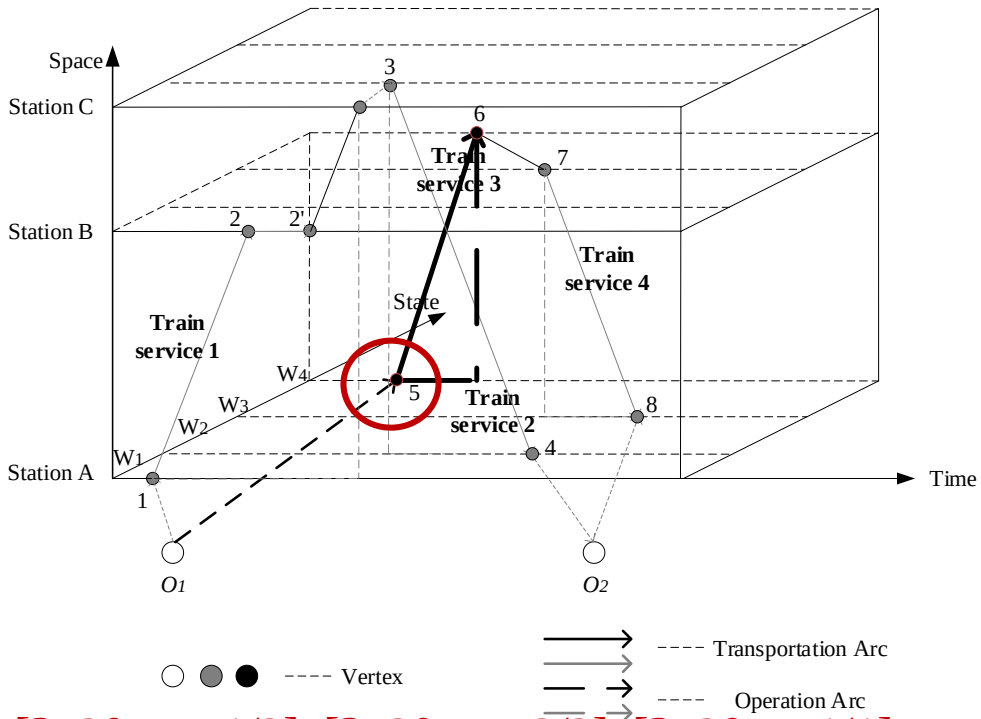


Figure: (a) Three possible compositions (l), (m) and (n) for Train Service 3 (b) Possible tasks (1)-(6) for three different types of rolling stock units (o), (p) and (q)

State-space-time Network

- **State dimension**

  a vector with four elements $[ts_{rol}, td_{rol}, com_{rol}, task_{rol}]$



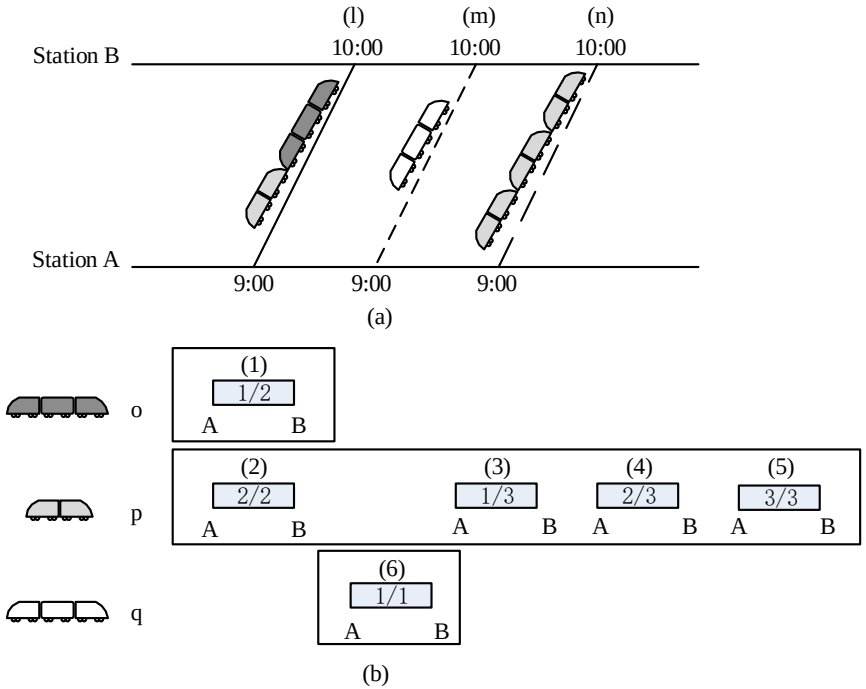


Figure: (a) Three possible compositions (l), (m) and (n) for Train Service 3 (b) Possible tasks (1)-(6) for three different types of rolling stock units (o), (p) and (q)

[3, 20, op, 1/2], [3, 20, op, 2/2], [3, 20, q, 1/1], [3, 20, ppp, 1/3], [3, 20, ppp, 2/3], [3, 20, ppp, 3/3]

State-space-time Network

- **Two types of arcs**

Transportation arcs

Traveling arcs

Waiting arcs

Operation arcs

Take-over operation arcs

Accomplishment operation arcs

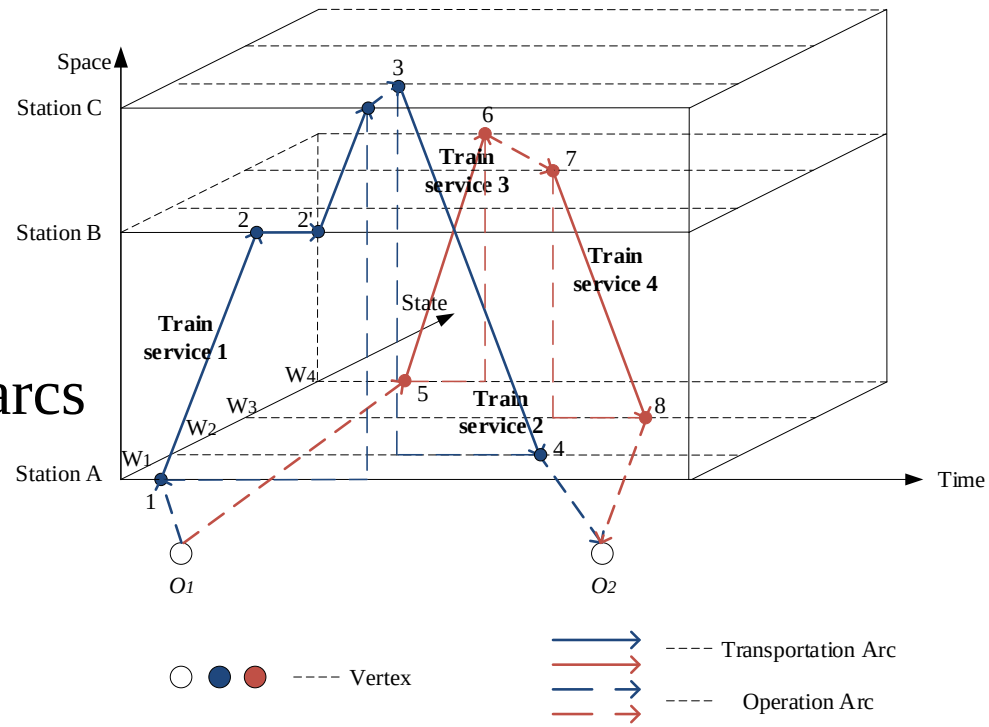


Figure: An illustration of a state-space-time network

Strategies for generating state-space-time network

Firstly. Searching all **feasible states** for every rolling stock unit

Secondly. Searching all **feasible arcs** for every train service **in space-time network**

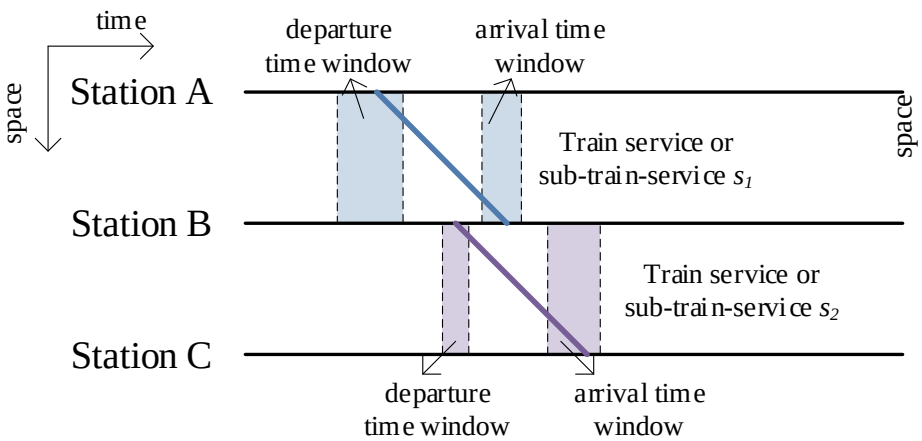
Thirdly. Searching **feasible arcs** in **state-space-time network** by combining feasible states and feasible arcs in space-time network

Reduce the scale of state-space-time network

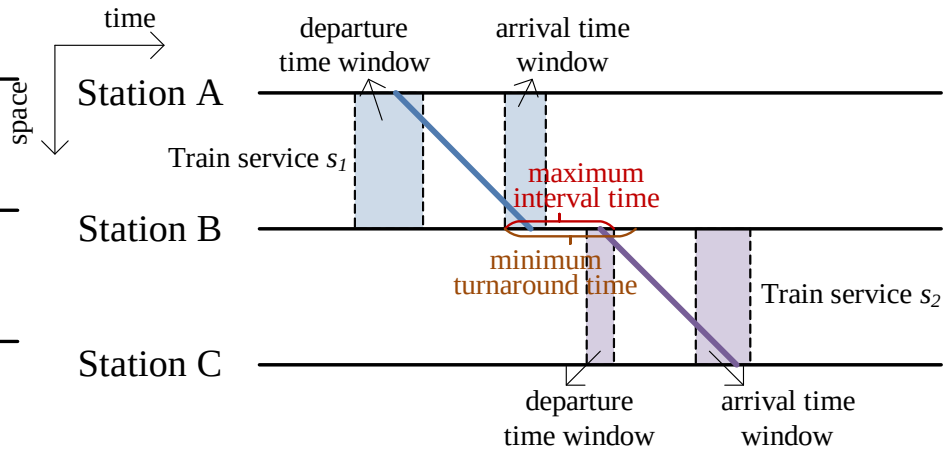
Strategies for generating state-space-time network

- **Searching feasible arcs in space-time network**

Rule 1: Overlapping time windows



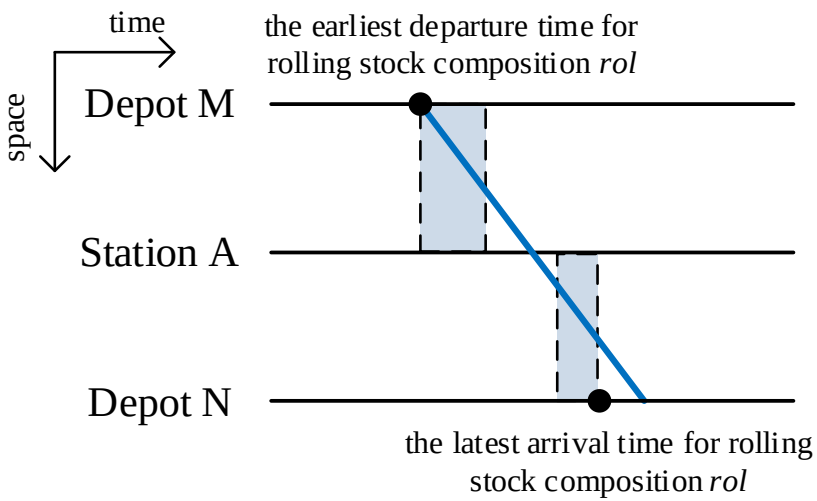
Rule 2: Turnaround time is sufficient



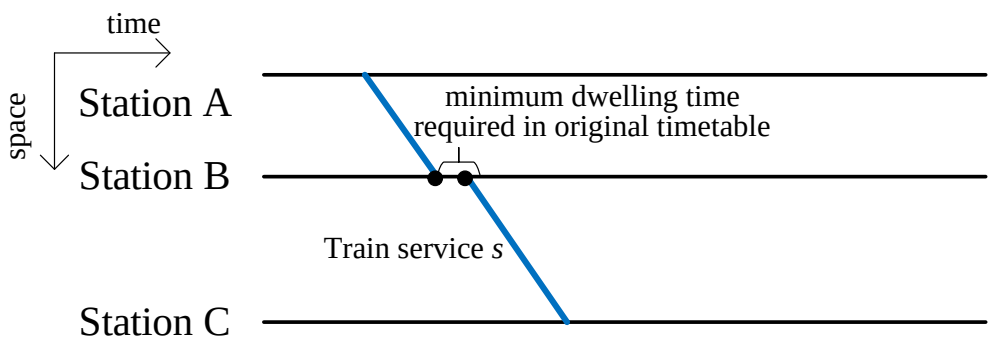
Strategies for generating state-space-time network

- **Searching feasible arcs in space-time network**

Rule 3: A node is not too far away from the starting or ending depots of rolling stock units



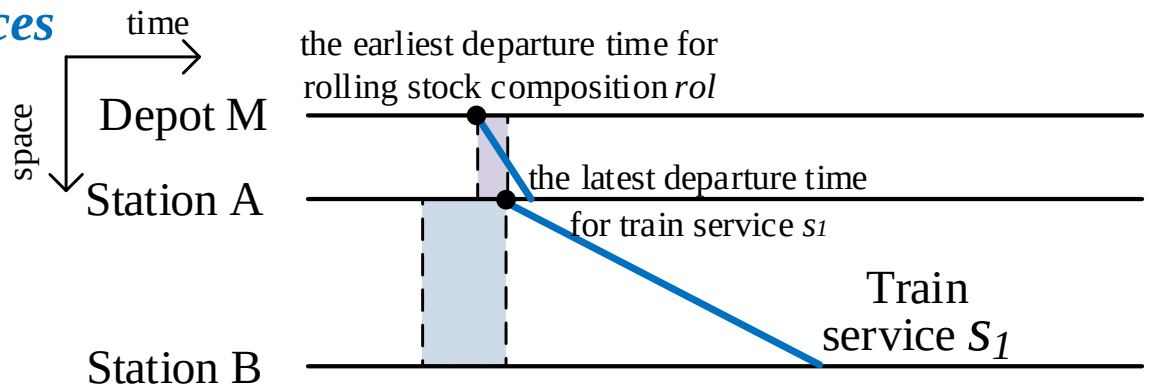
Rule 4: Minimum dwelling time of train services is sufficient

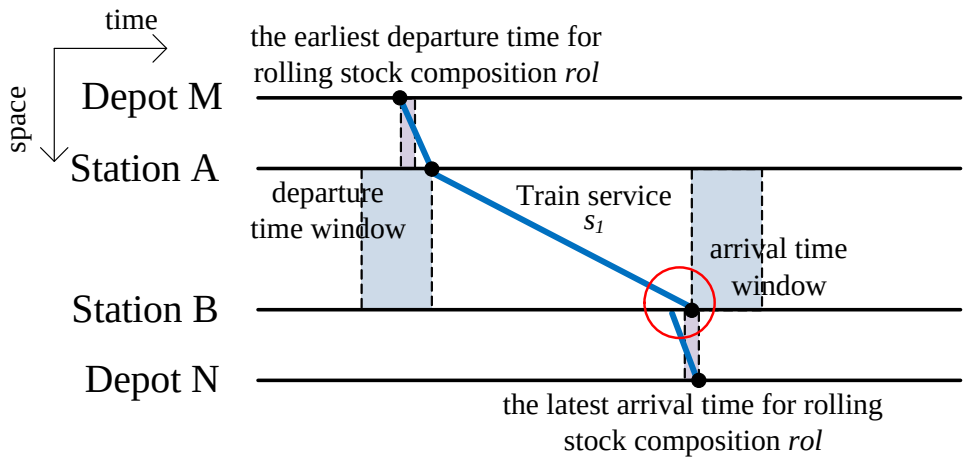


Strategies for generating state-space-time network

- **Searching feasible arcs in space-time network**

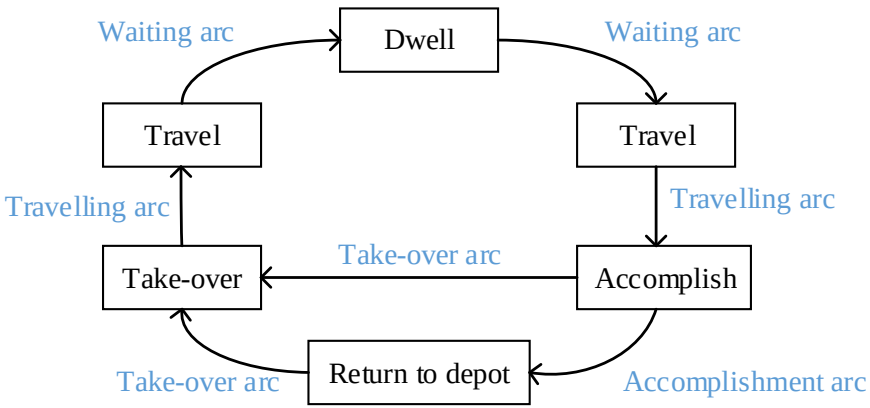
Rule 5: Time window of rolling stock units is sufficient for time window of train services

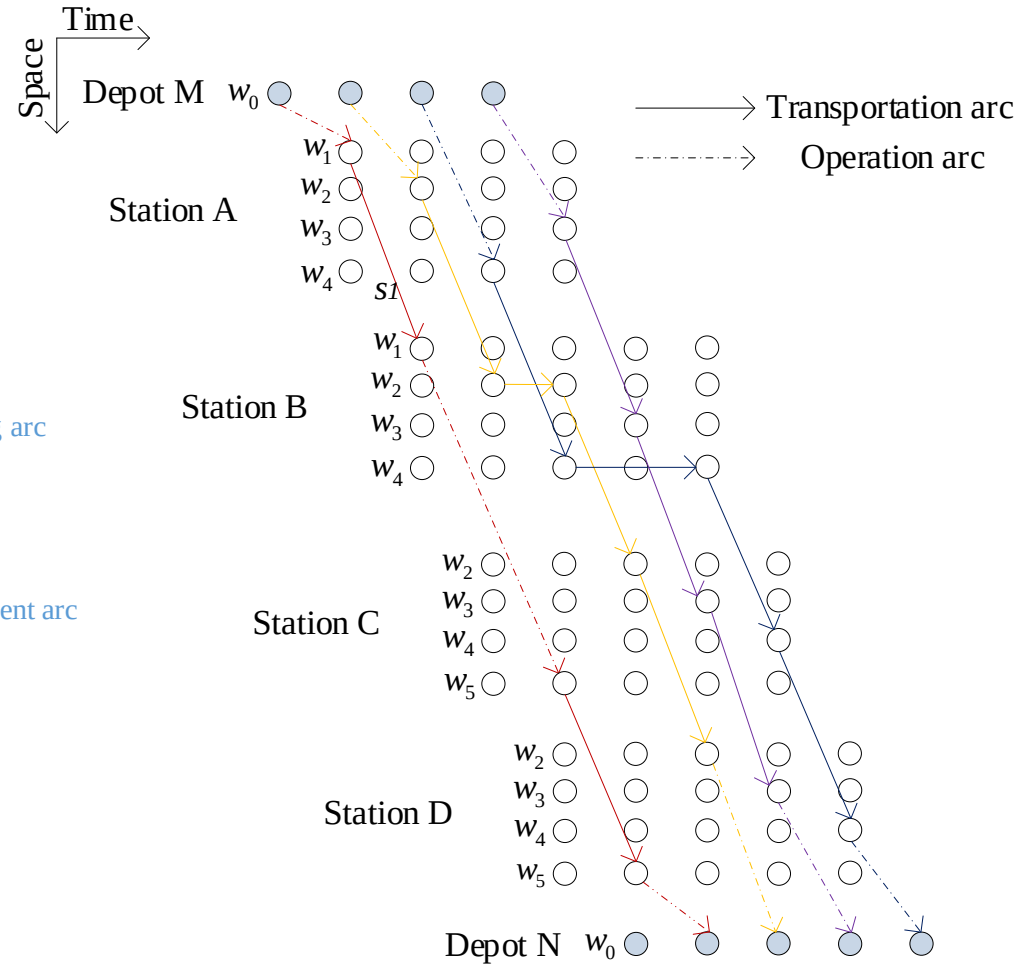




Strategies for generating state-space-time network

- **Searching feasible arcs in state-space-time network**





04

PART FOUR

Mathematical formulation

Mathematical Formulation

- **Decision variable**

$$x(rol,i,j,t,s,w,w') \begin{cases} \textbf{=1, arc } (i,j,t,s,w,w') \textbf{ is used by } \textbf{\textit{rolling stock unit}} \textit{ rol} \\ \textbf{=0, otherwise} \end{cases}$$

$$y(com,i,j,t,s,w,w') \begin{cases} \textbf{=1,} \text{ arc } (i,j,t,s,w,w') \text{ is used by } \textbf{\textit{rolling stock composition}} \textit{ com} \\ \textbf{=0,} \text{ otherwise} \end{cases}$$

Mathematical Formulation

- **Objective function**

$$Min\ Z = \sum_{rol \in (ROL \cup ROL^*)} \sum_{(i,j,t,t',w,w') \in A_{rol}} c(rol,i,j,t,t',w,w')x(rol,i,j,t,t',w,w')$$

Mathematical Formulation

- **Objective function**

$$Min\ Z = \sum_{rol \in (ROL \cup ROL^*)} \sum_{(i,j,t,t',w,w') \in A_{rol}} c(rol,i,j,t,t',w,w')x(rol,i,j,t,t',w,w')$$

- **Constraints**

Flow balance constraints

Train services operated constraints

Capacity constraints ***(section and station)***

Matching constraint between arcs for ***rolling stock unit*** and arcs for ***corresponding rolling stock composition***

Rolling stock unit ***inventory*** constraint

Rolling stock unit ***end-of-day balance*** constraint

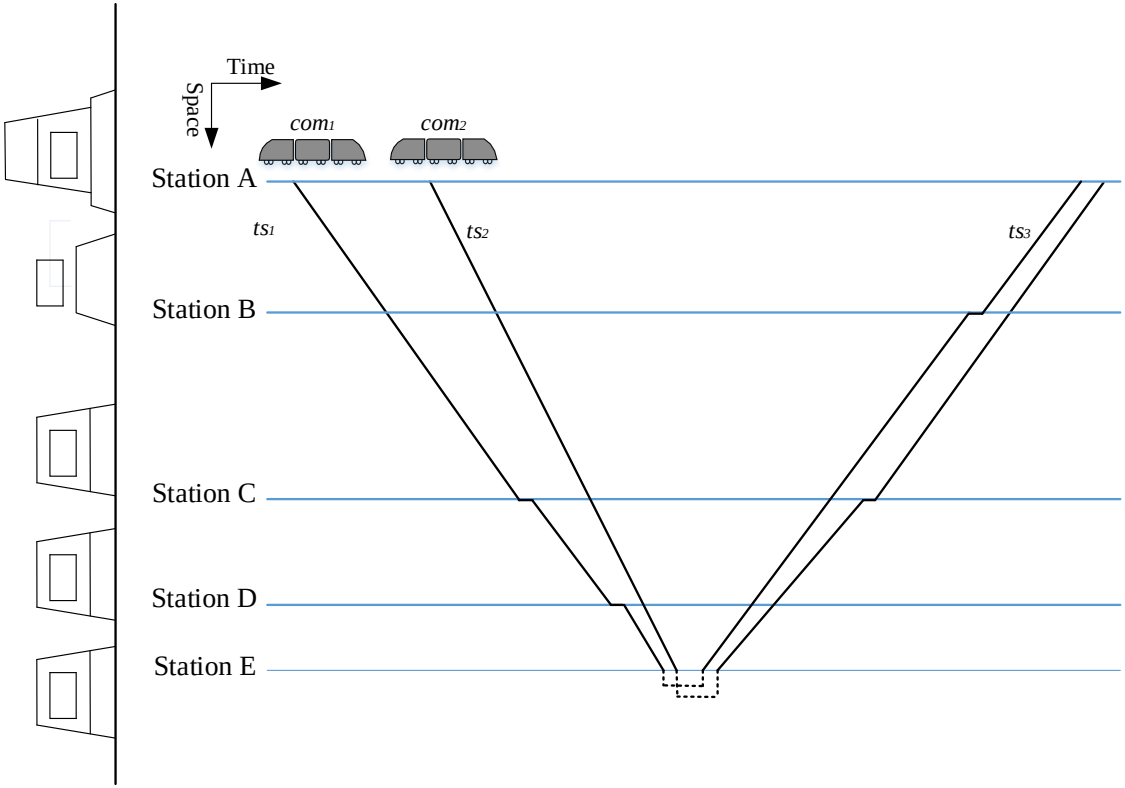
05

PART FIVE

Numerical study

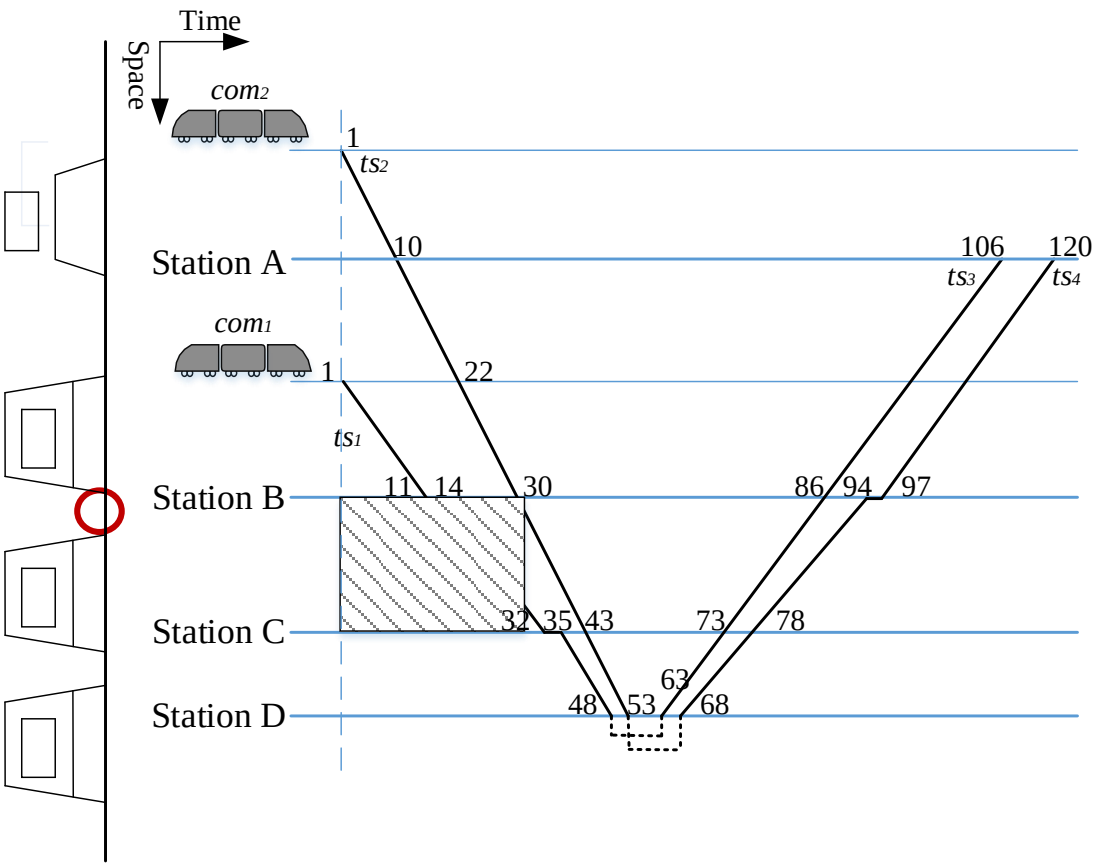
Numerical Study

- Original timetable and rolling stock circulation plan



Numerical Study

Track failure in the section between station B and Station C, a temporary maintenance task executed with the duration from time point 1 to time point 31



Numerical Study

- Cost Setting

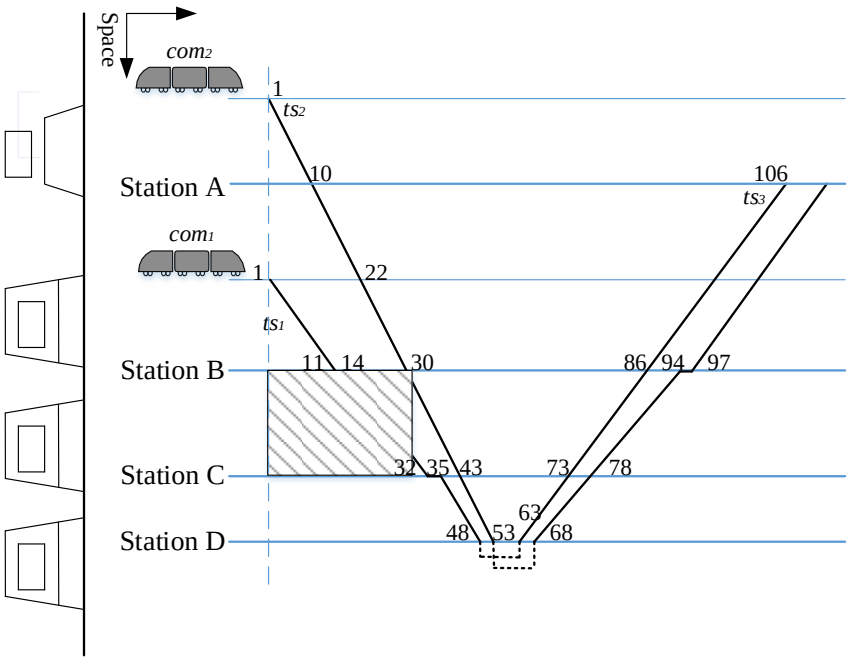
Cost for the timetable rescheduling

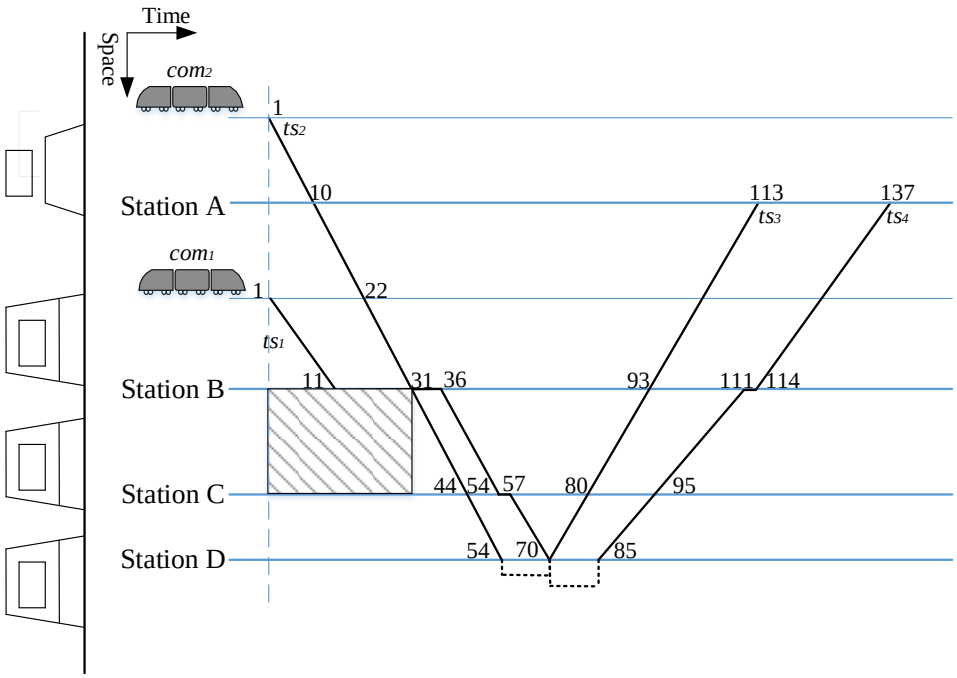
Description	Cost
Cancelled trip	100,000 + 1000 * running time of the train service
Per arrival delay minute	1

Cost for the rolling stock rescheduling

Description	Cost
Per positive seat capacity deviation	travel distance of the train service
Per cancelled shunting movement	100
Per new shunting movement	1000
Per exceeding turnaround minute	1

Numerical Study





solution time: 0.55 sec

Future Research

- Consider **more detailed information** about **infrastructure**, like a microscopic network
- Consider the **uncertainty** for the duration of **disruption**
- **Design algorithm** to solve large scale problems with efficiency
- Do **more contrast experiments** to examine the effectiveness and applicability of our model and solution method

Thanks for your attention!
Any questions?

Jianrui Miao
State Key Laboratory of Rail Traffic Control and Safety
Beijing Jiaotong University