



**2nd Workshop on Railway Operation for Safety and Reliability**  
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**City University of Hong Kong**

# **Ex Post Heuristic Measures of Timetable Robustness**

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- **Evaluation of robustness**
  - **Delay propagation network from historical train traffic records**
  - **Numerical experiments**
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# Background

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- Trains are very punctual
- Passengers complain even for small delays
- Further improve punctuality
  - Avoid **delay propagation**
  - **Evaluate** railway systems from delay propagation

# Delay propagation

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## □ Why delays **propagate**?

### ■ Urban area

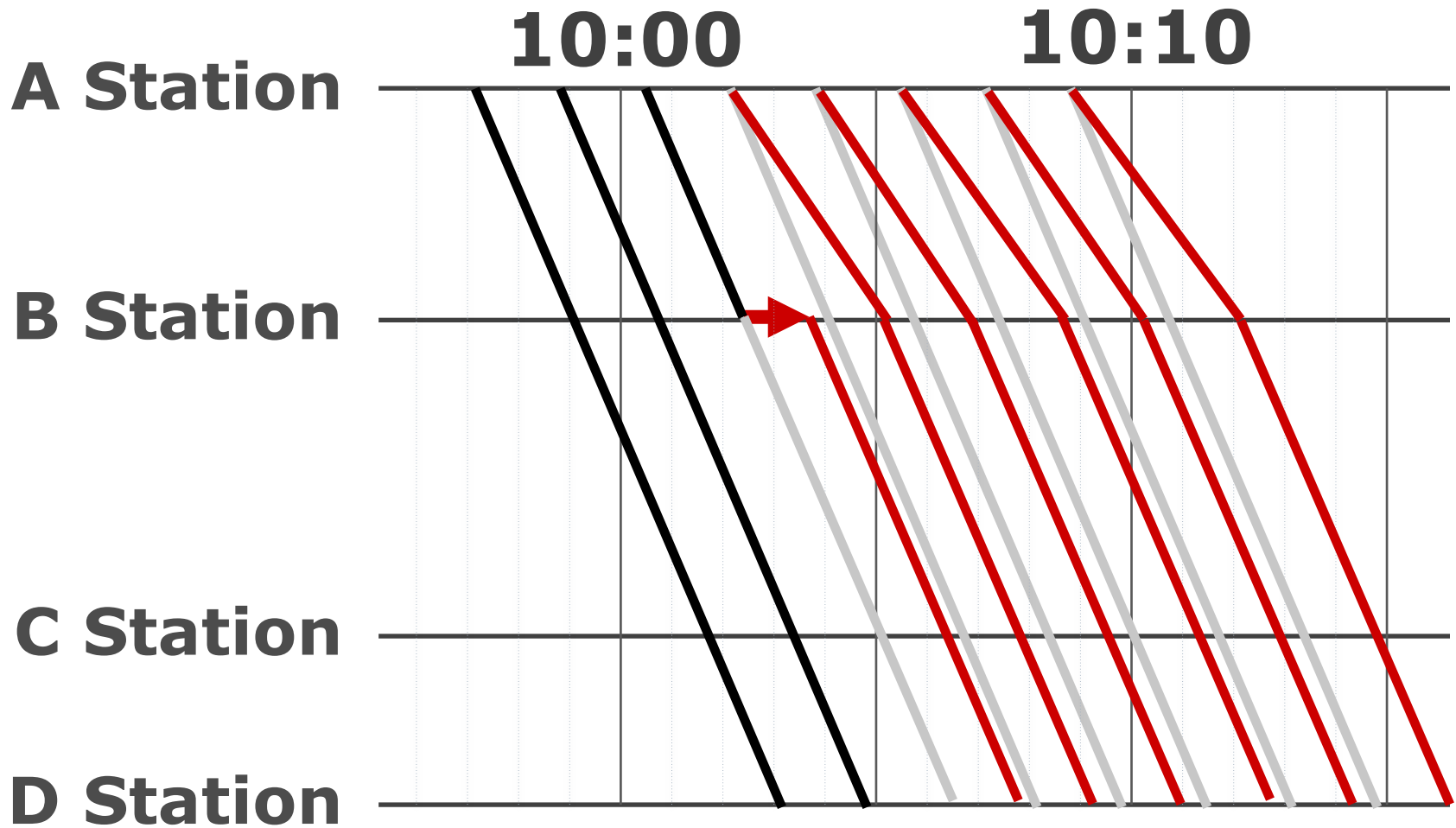
□ Trains are running densely

### ■ Intercity line

□ Single track

□ Long distance Express train

# Propagation



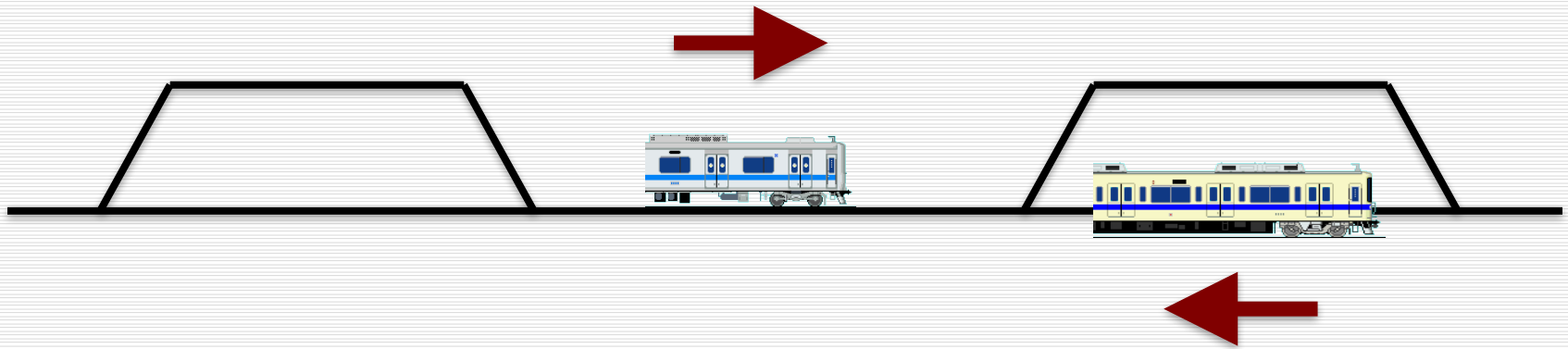
# Small delays

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- Why delays propagate?**
  - **Urban area**
    - Trains are running densely**
  - **Intercity line**
    - Single track**
    - Long distance Express train**

# Single track

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# Propagation

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**A Station**

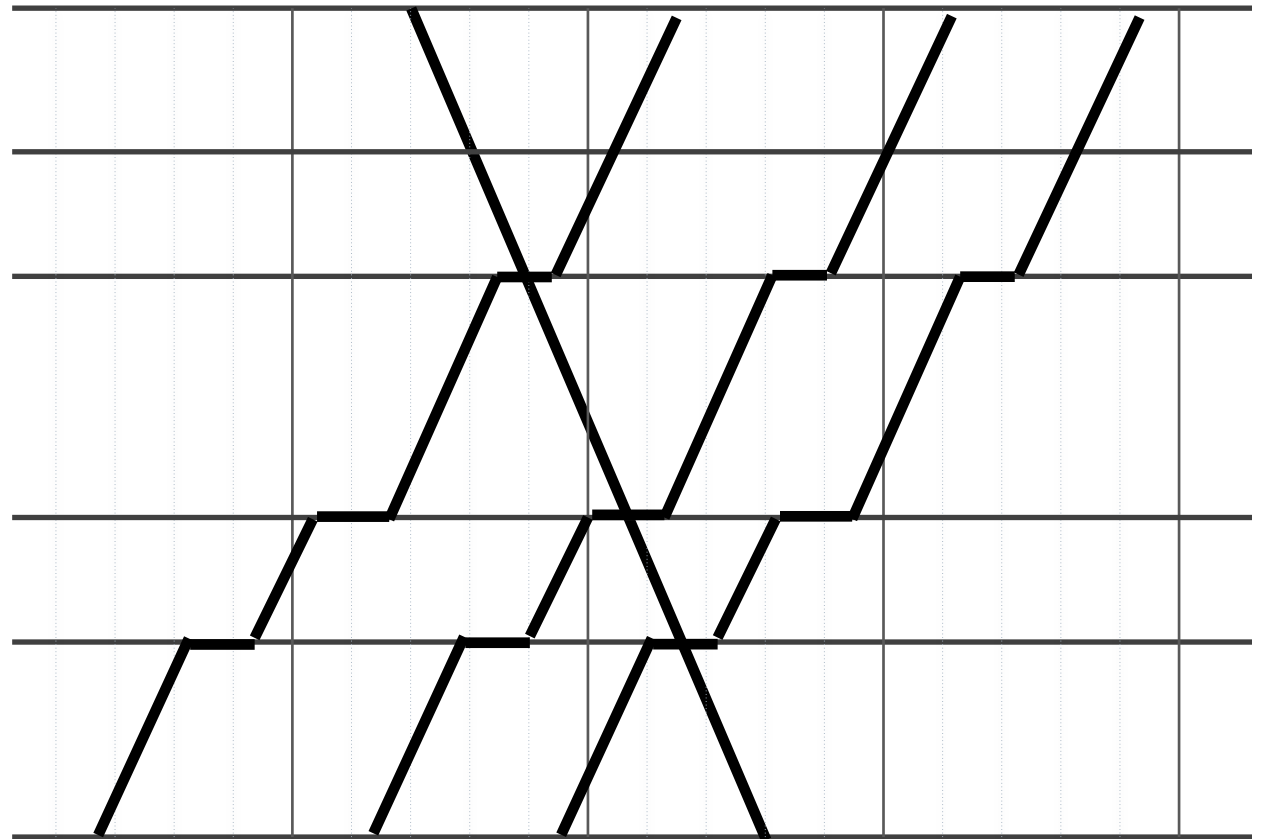
**B Station**

**C Station**

**D Station**

**E Station**

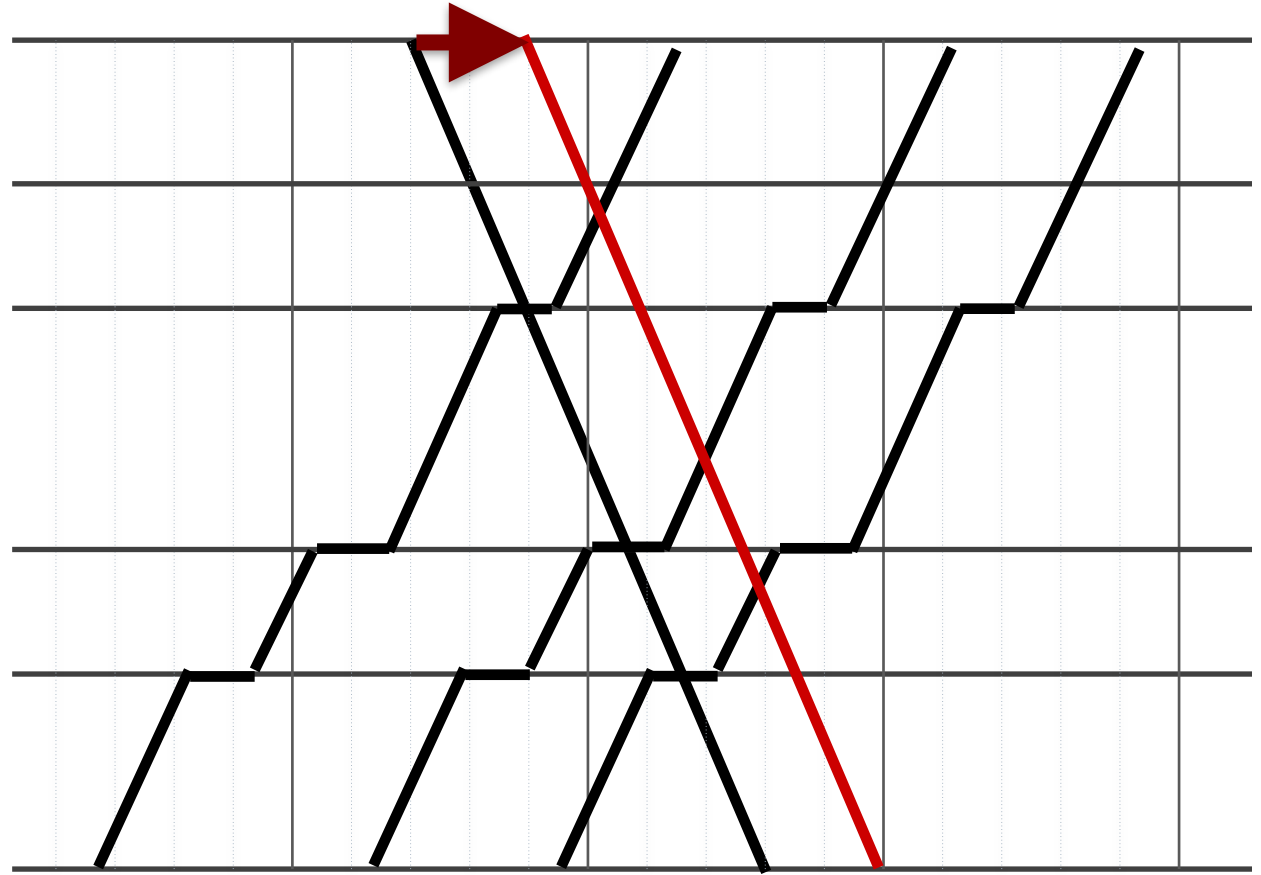
**F Station**





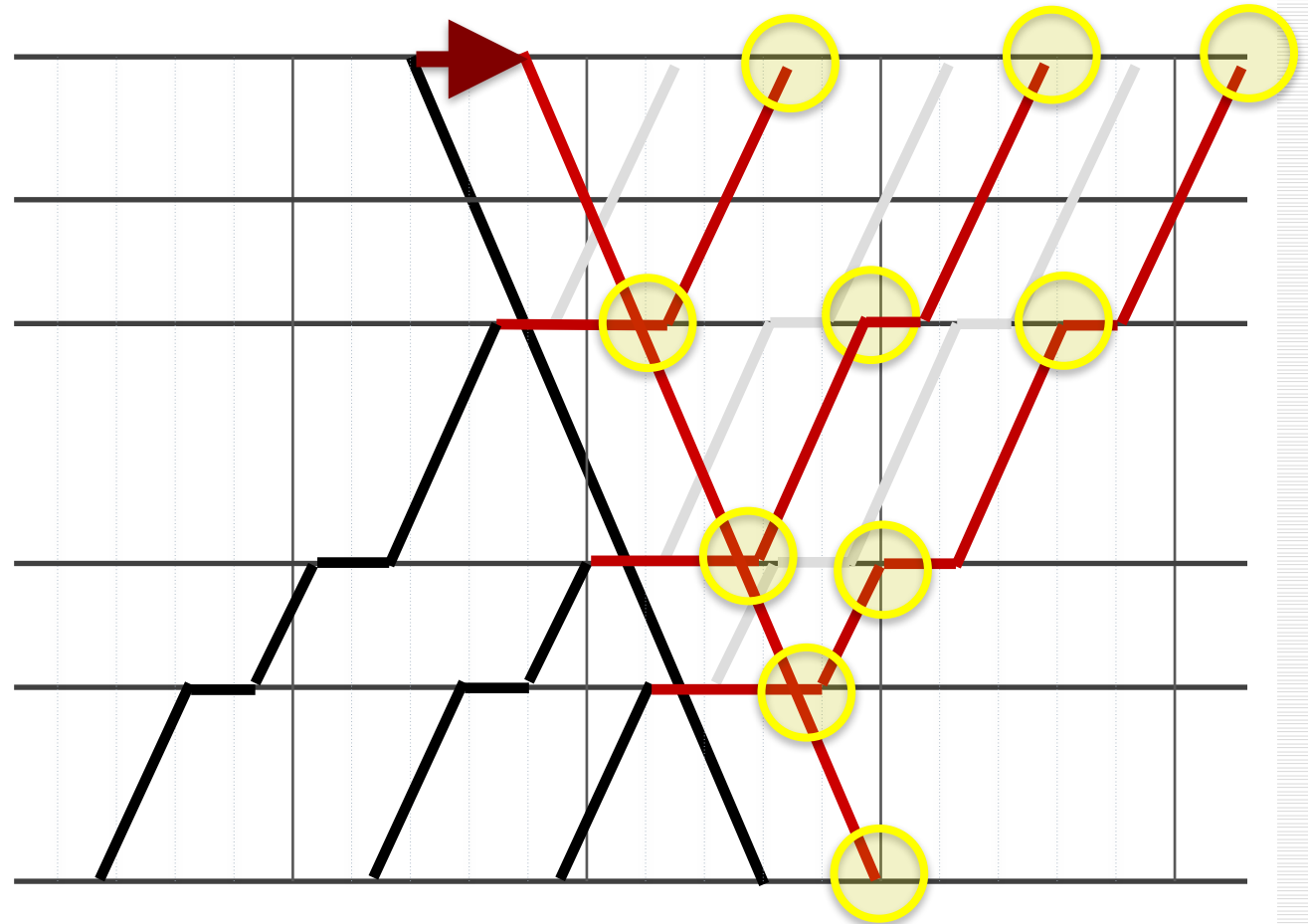
# Propagation

**A Station**  
**B Station**  
**C Station**  
**D Station**  
**E Station**  
**F Station**



# Propagation

**A Station**  
**B Station**  
**C Station**  
**D Station**  
**E Station**  
**F Station**



# Delay propagation

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- Propagation occurs following **physical rules**
  - running times, headway, conflict of routes, conflict of tracks,...

# Delay propagation

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- Propagation occurs following physical rules
  - running times, headway, conflict of routes, conflict of tracks,...
- **Non physical** rules
  - connection, crew

# Robustness

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□ Timetables are **Robust**

■ Primary delays do not  
**propagate**

# We would like to

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- Evaluate robustness of timetable
  - Evaluate timetable from the viewpoints of delay propagation
  - Evaluate
    - Timetable revision
  
- Is it enough to evaluate only **timetables?**

# Target of evaluation

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- **Railway system consists of**
  - **Schedule** – timetable, rolling stock, crew,...
  - **Facilities** – track layout, rolling stock, signaling system,..
  - **Operation** – rescheduling, drivers operation, ...
  - **Troubles** - primary delays

# Target of evaluation

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## □ Railway system consists of

- **Schedule** – timetable, rolling stock, crew,...
- **Facilities** – track layout, rolling stock, signaling system,..
- **Operation** – rescheduling, drivers operation, ...
- **Troubles** - primary delays

## □ We have to evaluate the **whole!**



# When ?

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- **Ex post** evaluation is needed
  - Timetable was revised
  - Signaling system was improved
  - ....
  
- **Historical train traffic records**
  - Actual departure/arrival times of all the trains at all the stations everyday
  - Contain whole information!

# How ?

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- **How we should use historical train traffic records?**
  
- **At present**
  - **Average delays**
  - **Percentage of delays larger than threshold**
  
- **do not suffice**
  - **Just the outcome**
  - **Not useful for analysis: more information!**

# What we would like to do?

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## How robust?

- Delays which occur frequently
- Evaluate quantitatively
- Delay propagation
  - both Physical and non physical

# Our key ideas

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- 1. Delay Propagation Network**  
from historical train traffic records
  
- 2. Evaluate robustness from**  
attributes of Delay Propagation  
Network

# Image

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## □ Delay Propagation Network

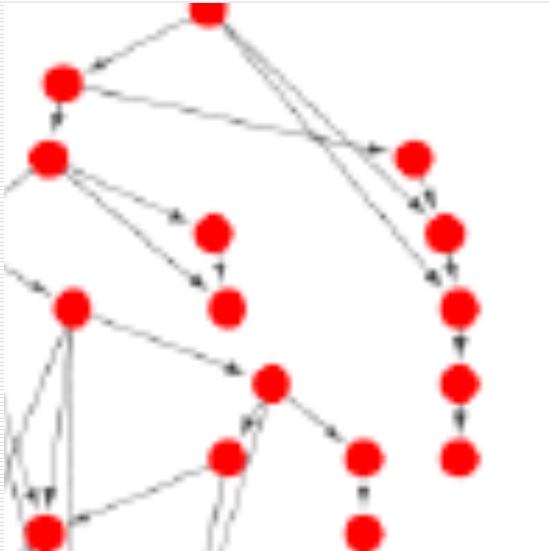


**If (Train X arrival Station A)  
then  
(Train Y departure Station A)**

# Image

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## □ Delay Propagation Network

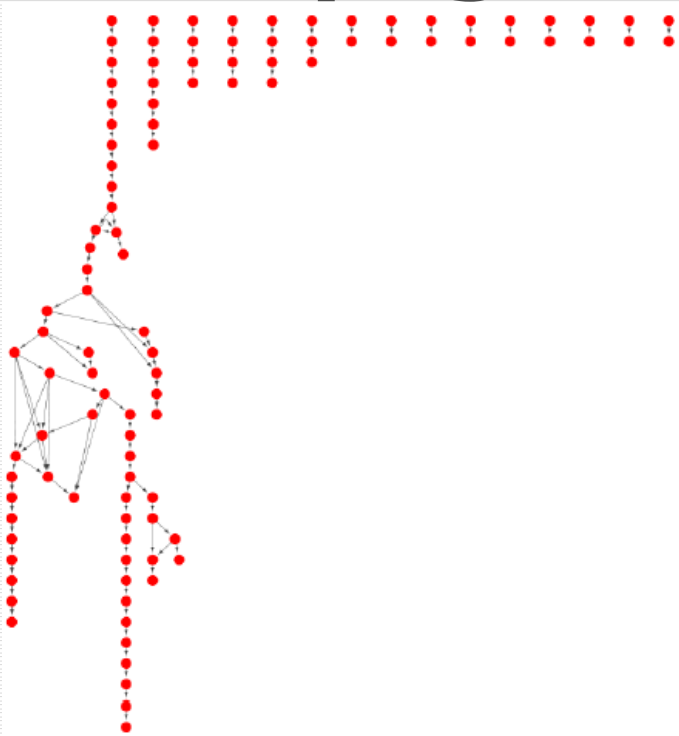


**If (Train X arrival Station A)  
then  
(Train Y departure Station A)**

# Image

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## □ Attributes of Delay Propagation Network



- Number of nodes
- Number of clusters
- Length of longest path
- Average length of paths
- Number of nodes which have only outgoing arcs

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# Algorithm

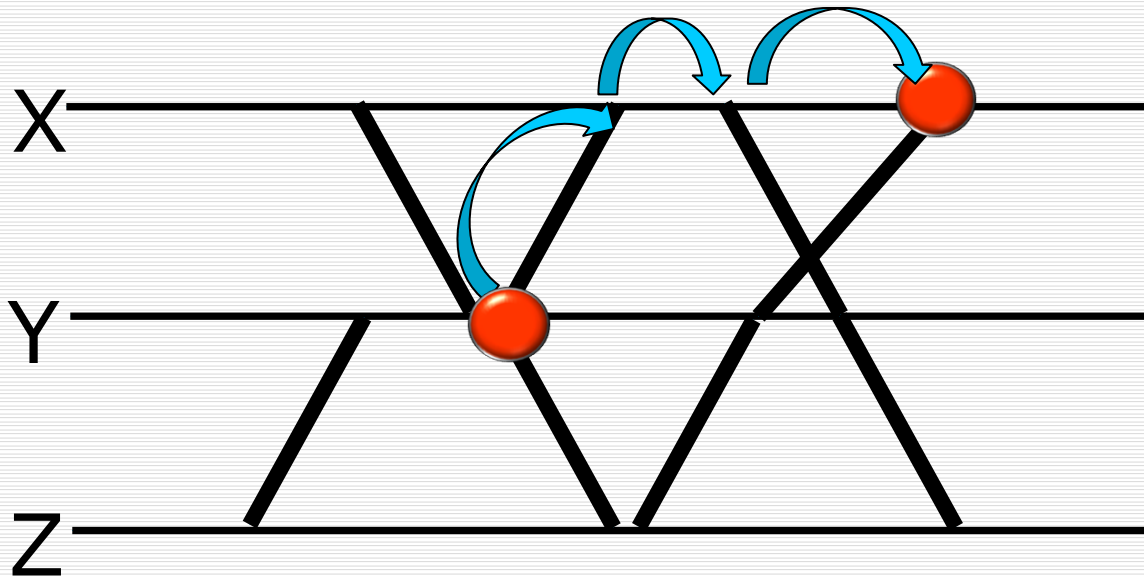
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- **How we can construct Delay Propagation Network?**

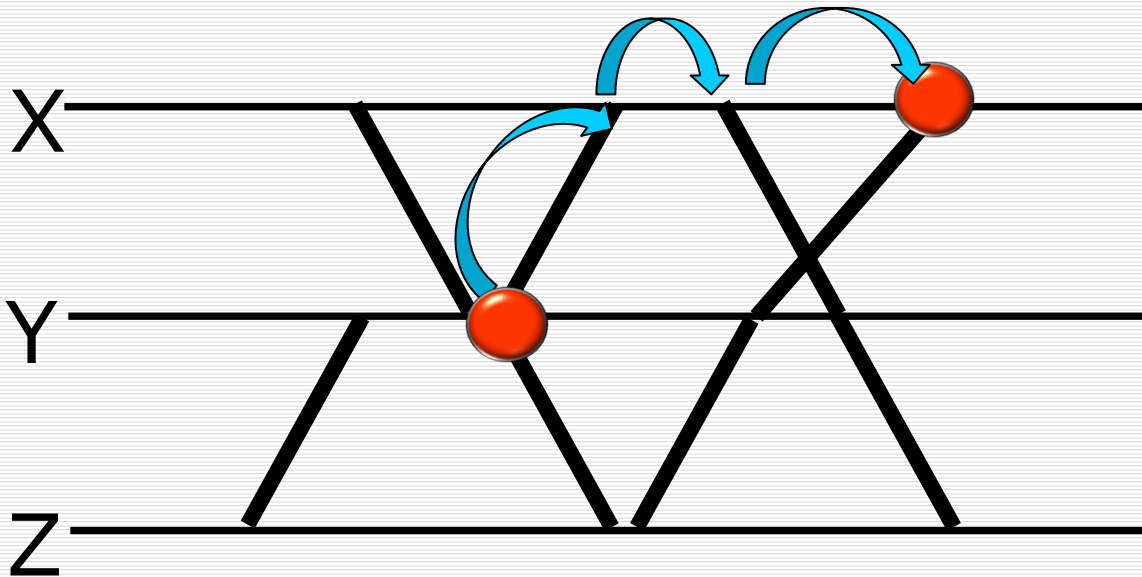


# Find delay propagation

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# Find delay propagation



if (Train **A** Delay) then (Train **B** Delay)

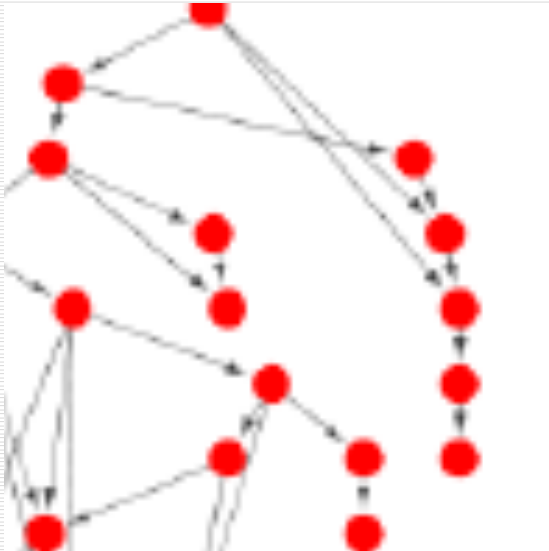
if (Train **B** Delay) then (Train **C** Delay)

if (Train **C** Delay) then (Train **D** Delay)

# Image

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## □ Delay Propagation Network



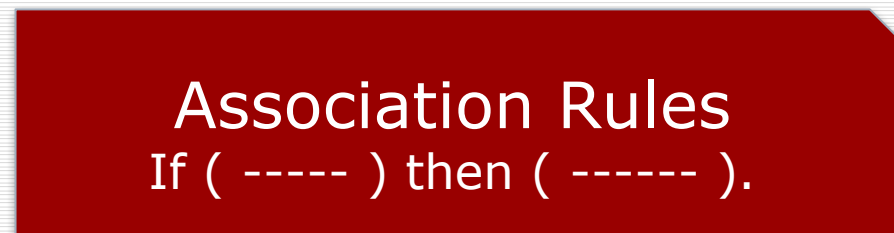
**If (Train X arrival Station A)  
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(Train Y departure Station A)**

# Delay propagation network

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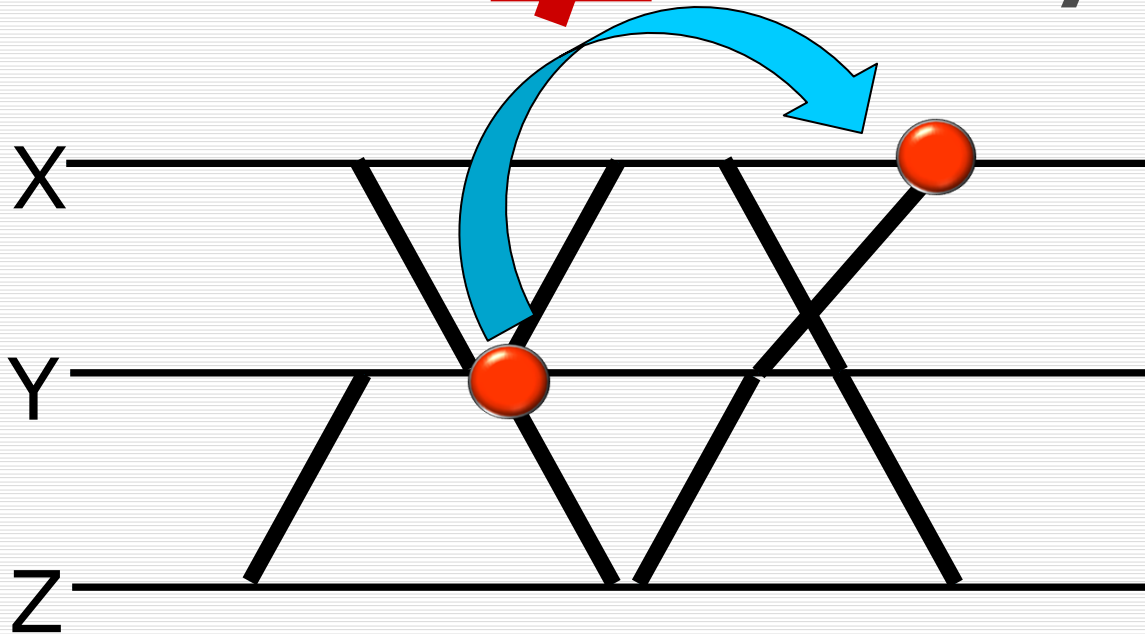
**a priori algorithm**



# Issue

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□ Correlation  $\neq$  Causality

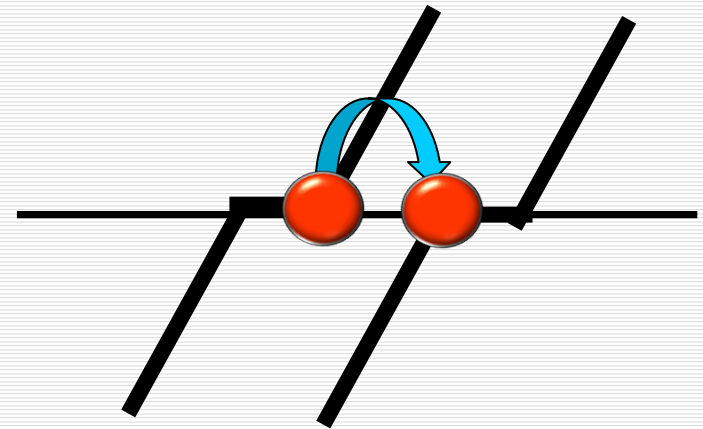
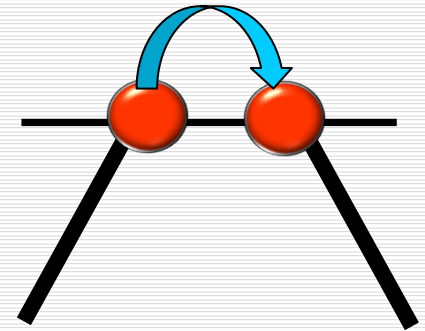
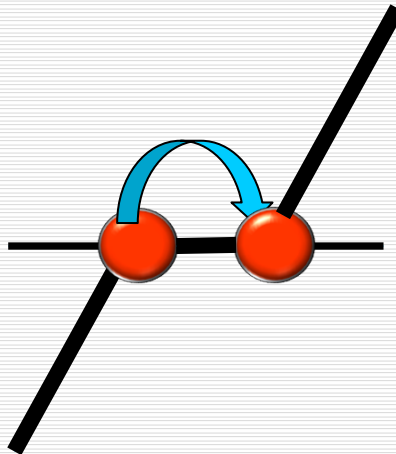
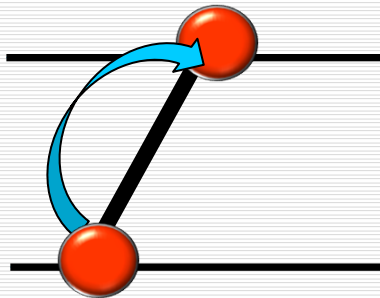


□ Coincidence?

# Our ideas

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- To find only “local” rules



# Numerical experiments

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Branch main line

# 2016

# 2015

**2016 is less robust!**

	2015	2016
Cluster		11
Diameter		1
Ave. path length	10.0	
Primary delays	15	
Secondary delays	88	326
Total delays	103	342



# Discussions

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## □ Ex Post heuristics

### ■ Isn't it unfair to compare

□ 2015: less big troubles

□ 2016: more big troubles

## □ Two ways of thinkings

**1.** We should be prepared for all possible troubles.

**2.** It is not reasonable to prepare for all (big) troubles.

# Discussions

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## □ Ex Post heuristics

### ■ Isn't it unfair to compare

□ 2015: less big troubles

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## □ Two ways of thinkings

**1.** We should be prepared for all possible troubles.

**2.** It is not reasonable to prepare for all (big) troubles.

# Future works

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- From **Ex Post** to **Ex Ante**
- Apply our algorithm to results of simulation.
- What kind of simulation algorithm should be used?

# Future works

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- **How to identify causes to make railway systems less robust?**
- **How to improve robustness?**
  - **structure of delay propagation network**

# Conclusions

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- Evaluation of robustness of railway systems
  - based on “**facts**”
  - Datamining: association rules
  
- Key idea
  - **Delay propagation network**
  
- From numerical experiments
  - very promising

# Reference

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- **Kono, A., TOMII, N. (2017), Identifying the Cause and the Propagation Route of Delays of Trains using Association Rules, *International Railway Symposium Aachen, Aachen, Germany, Nov.2017.***
- **Kono, A., TOMII, N. (2017) Ex-Post heuristic measures of timetable robustness, EASTS Conference 2017 – *The 12<sup>th</sup> International Conference of Eastern Asia Society for Transportation Studies, Ho Chi Minh City, Vietnam, Sep. 2017.***



**Thank you for your attention!**