Presented at ILOG User Meeting 2002

Railway Rescheduling System Based on Constraint Programming

Naotugu Nozue

Math-Model Research Inc.,Japan

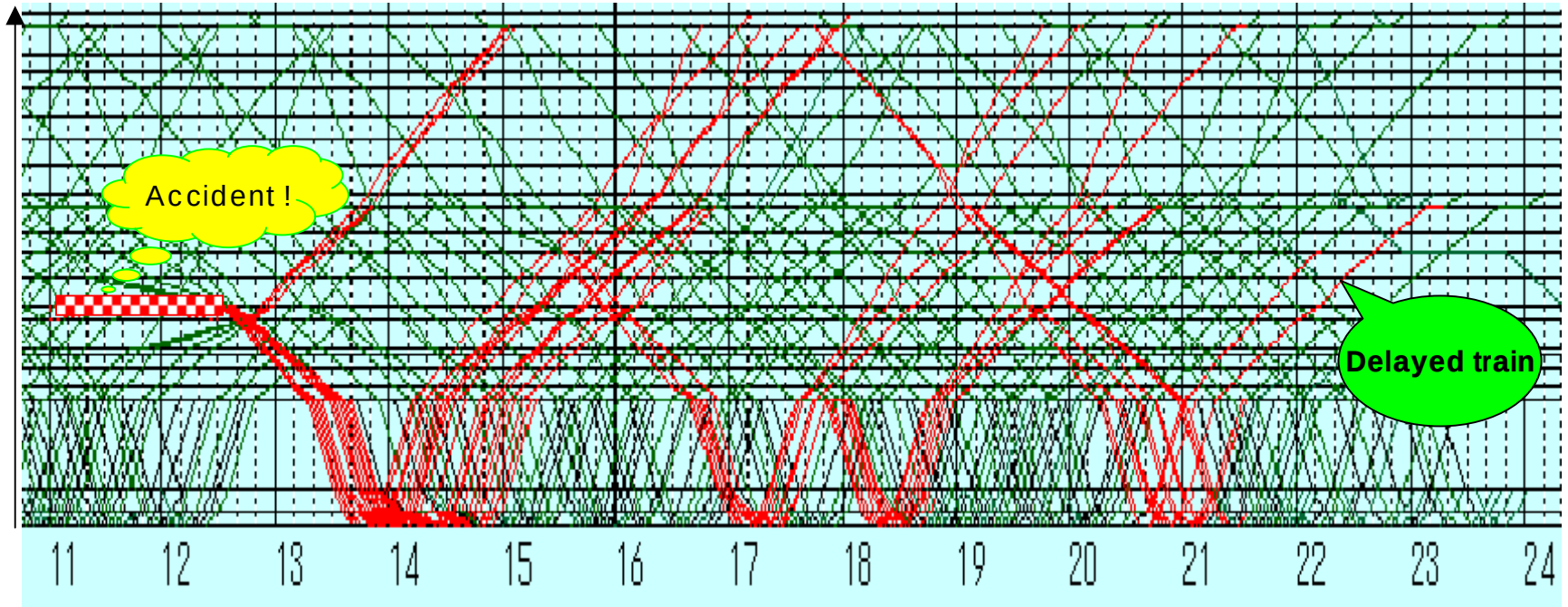
URL: www.Math-Model.Co.JP

Math-Model Research Inc.

- Foundation: 2000.4.1
- Main Field
  - **Consultation: General**
    - Architecture design of decision support systems
    - Optimization of scheduling and planning
      - Constraint base: ILOG optimization suit, CHIP
      - LP base : CPLEX, SOPT
  - **Consultation: Transportation**
    - Railway operation planning
    - Demand forecasting of transportation
  - **Software Development**
    - Algorithms mainly based on network architecture

What is the rescheduling in railway?

A small accident causes a large disorder throughout the network, if an appropriate **reschedule** isn't made.

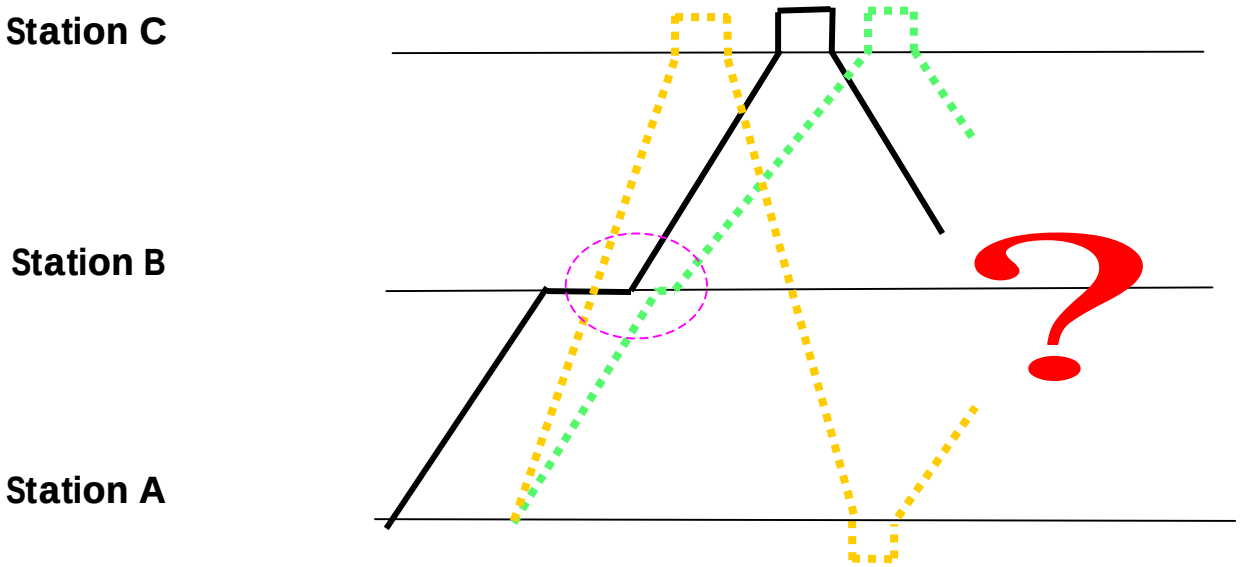


Rescheduling of train dispatching order,usage of resources,etc

==> very difficult combinatorial problem

Chaotic nature of decisions

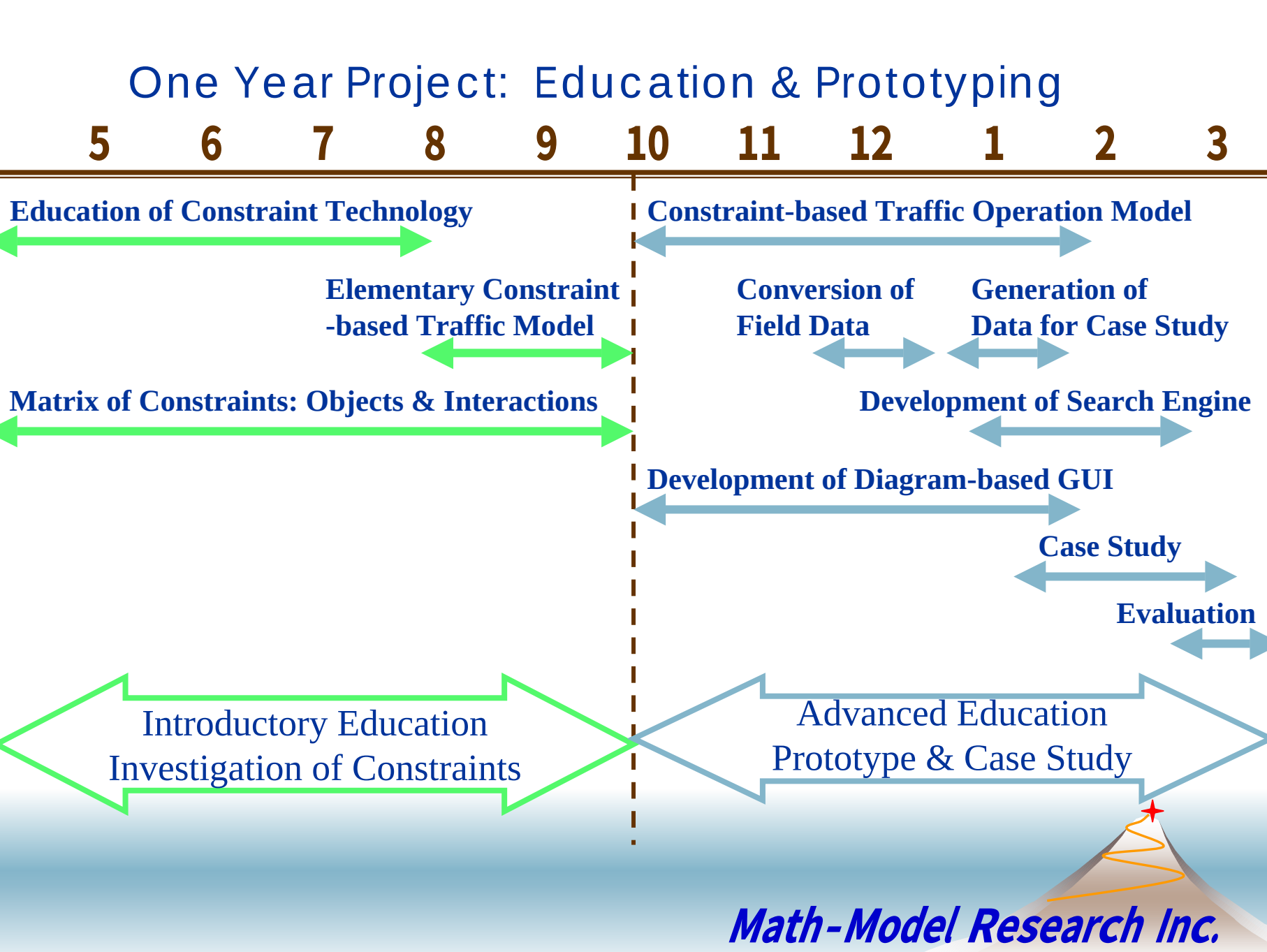
- Overtaking or not overtaking



Outline of This Project

- **Joint Project**
  - JR East Japan Information Systems Co., Ltd. (JEIS)
  - New media Research Co., Ltd. (NMS)
  - Math-Model Research Inc. (MMRI)
- **Objective**
  - **Feasibility study** of a constraint based approach to railway traffic control problems -- especially **rescheduling** problem.
  - **Education of fresh SE's** on constraint based skills through prototyping.
  - Establishment of a constraint based **design methodology.**
- **Period**
  - **1 year**
- **Member**
  - **1 consultant** (MMRI)
  - **2 fresh SE's** for constraint based development (JEIS)
  - **1 fresh SE** for graphical user interface (NMS)

One Year Project: Education & Prototyping



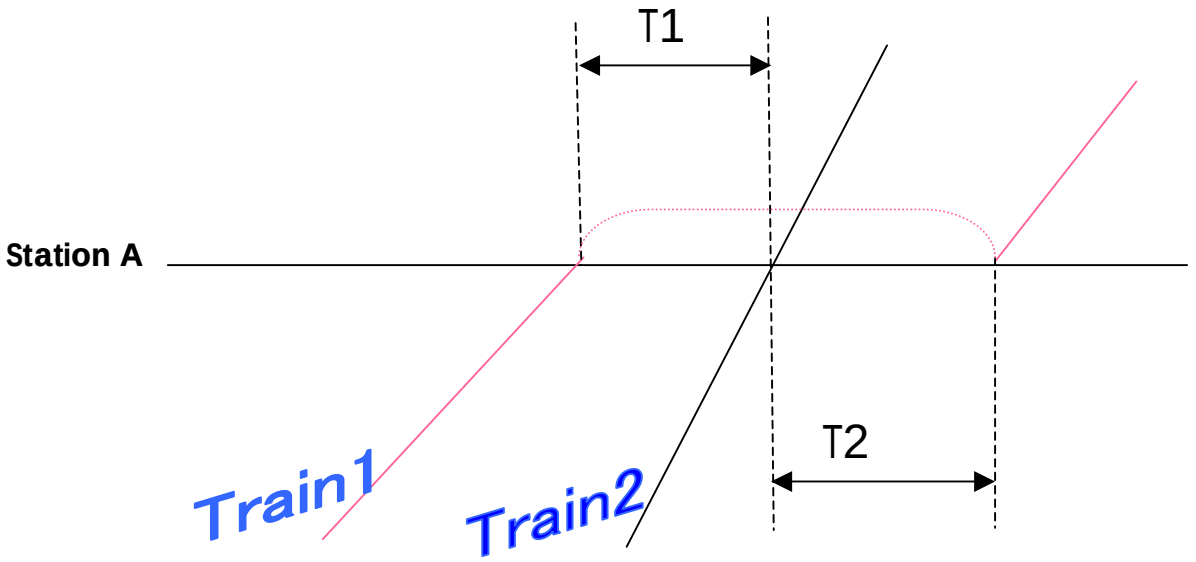
Math-Model Research Inc.

Why is the rescheduling in railway difficult ?

- **Railway network is very large**.
  - **3 lines**(Tohoku, Joetsu, Hokuriku): total length is **800km**.
  - **400 trains** a day: a variety of missions(destination, service)
- **Many resources and related constraints**
  - **cars**(many types),**drivers**(licensee),
  - **line section** between stations, home **tracks**
- **Many safety-related constraints of train operations**
  - between consecutive **trains**
  - **line capacity** constraint (**Railway specific constraint**)
- **Chaotic nature of the problem**
  - **trajectory** of each **train consists** forms a pattern of folded lines

Constraint between consecutive trains (1)

- Train2 **overtakes** Train1 at station A

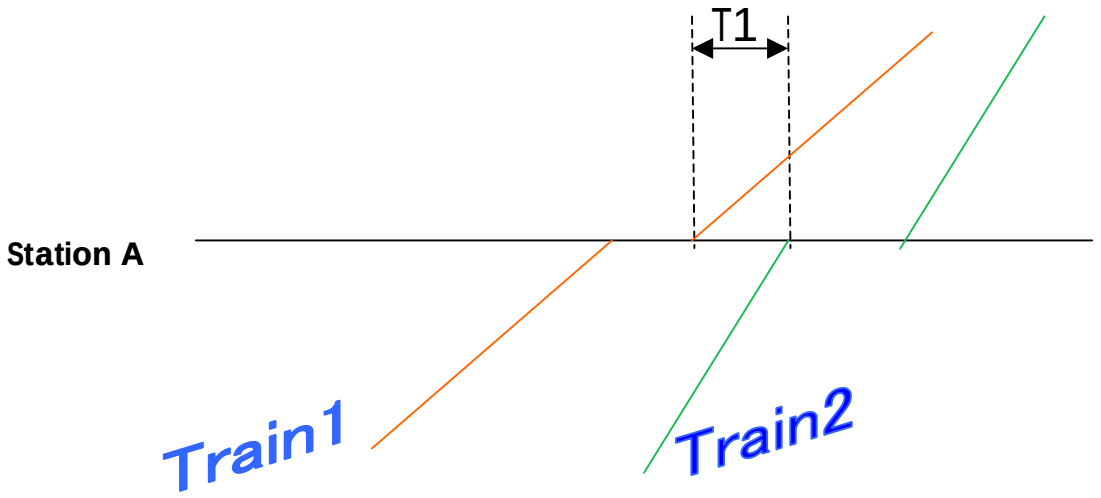


T1: Minimum time spacing of consecutive arrival
T2: Minimum time spacing of consecutive departure

Constraint: Arrival time of train1 + T1 <= Arrival time of train2
Starting time of train2 + T2 <= Starting time of train1

Constraint between consecutive trains (2)

- Train1 and Train2 use **the same home track** at station A

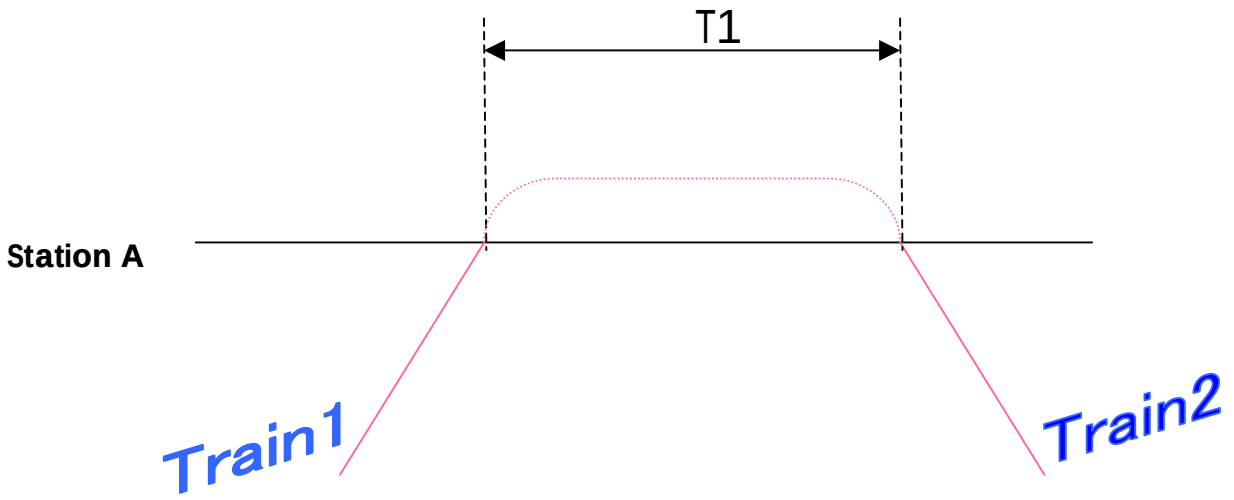


T1: Minimum time spacing of consecutive use of same track

Constraint: Staring time of Train1 + T1 <= Arrival time of train 2

Constraint between consecutive trains (3)

- Train1 and Train2 are operated by **the same train consists**

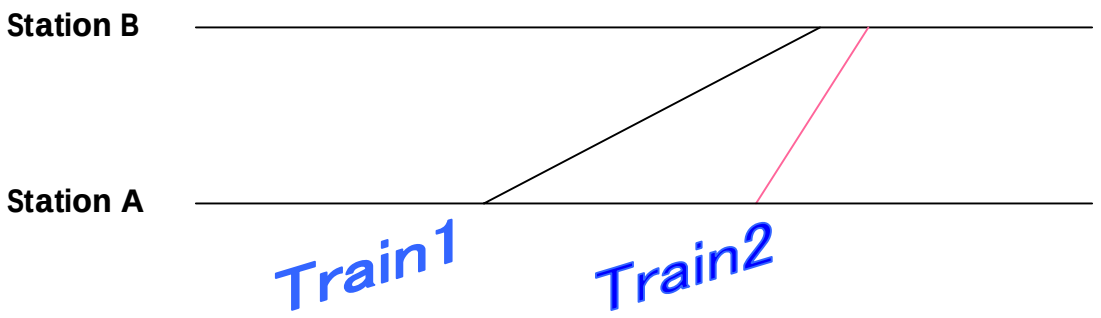


T1: Minimum time spacing of turn-back operation

Constraint: Arrival time of Train1 + T1 <= Starting time of train2

Constraint between stations: **FIFO QUEUE**

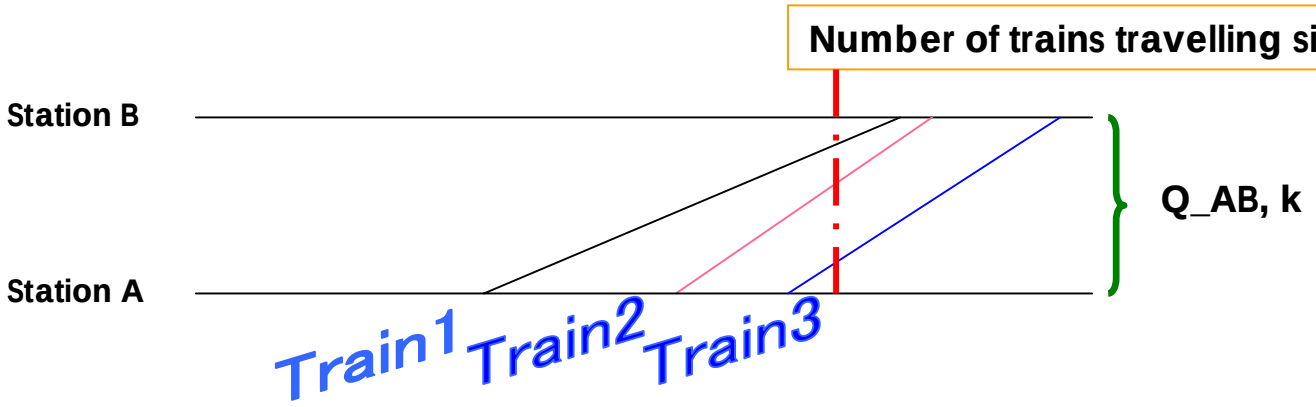
- Train2 **starts after** train1, then train2 **arrives after** train1, and vice versa



Constraint: Iff Starting time of train1 <= Starting time of train2,
Arrival Time of train1 <= Arrival time of train2

Constraint between stations: **Queue with capacity**

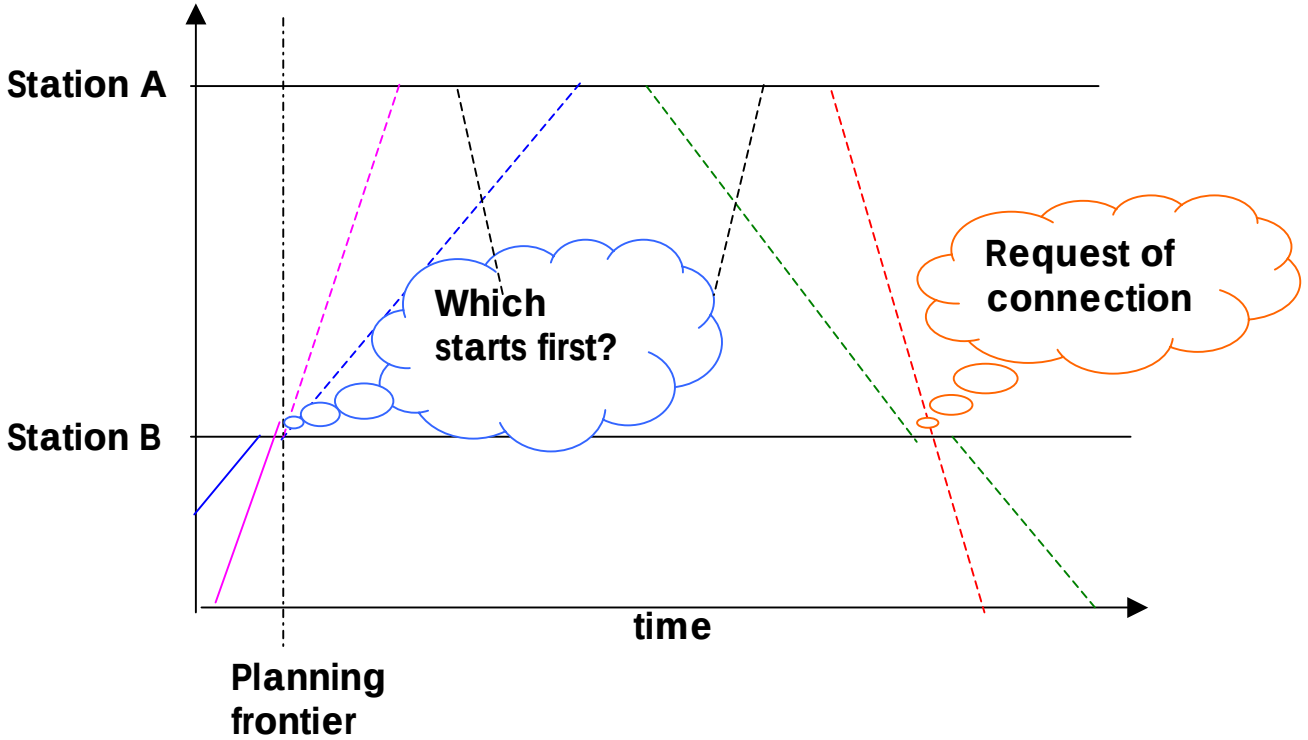
- No more than k trains can travel between station A and B simultaneously (**line capacity**)



k: Line Capacity between Station A and Station B

Constraint: Queue_constraint({...., train1,train2,train3,....},Q_AB,k)

Current Approach and Constraints in the Future



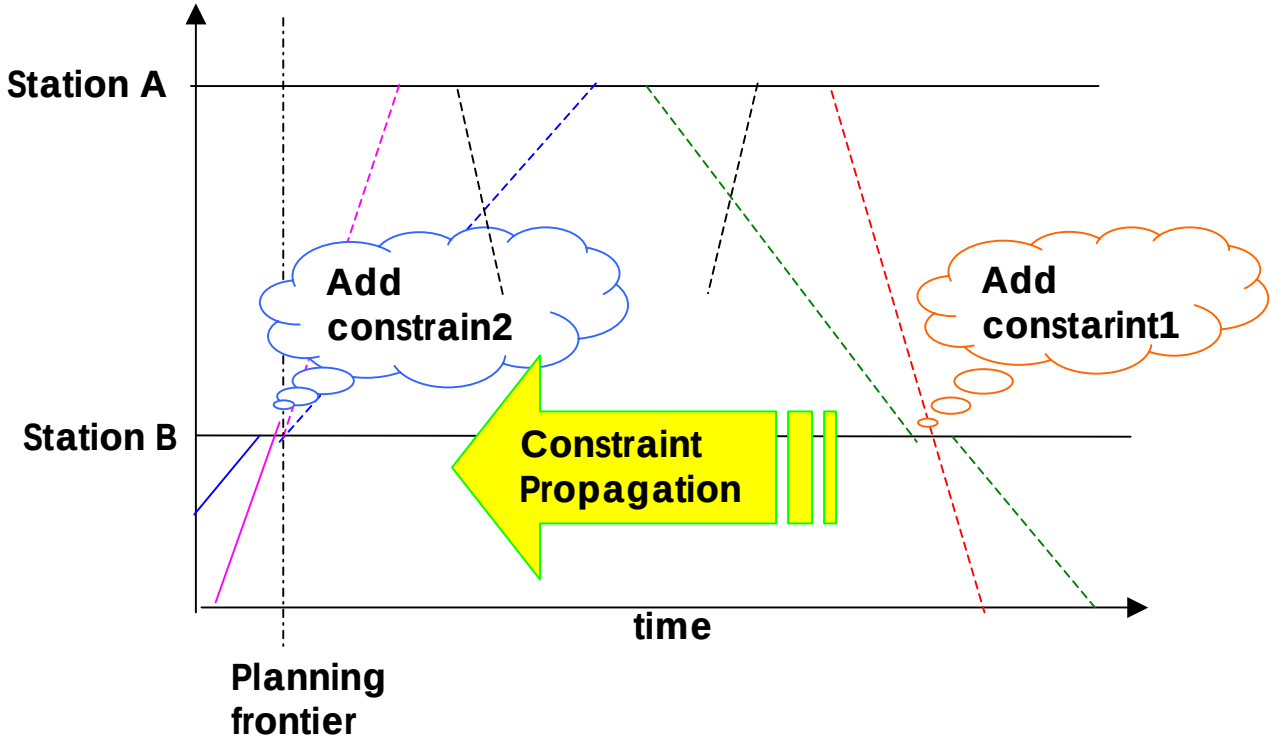
1) Set temporal starting times of red and blue trains and continue the calculation

2) If connection is missed or green train wait for long period, back to 1)

How is the current simulation based approach?

- **Current simulation based approach can't solve our problem.**
  - **Decision variables** are starting and arriving **times** of each train,
    => **too many alternatives** and difficult to search better solutions.
  - **Unable to predict** effects in the future owing to the **current overtaking decision**.
  - **No information** available to decide an appropriate overtaking to meet **constraints in the future**.

Constraint based Approach



Constraint1: Starting time of red train at station B <= Starting time of green train at station B

Starting time of green train at station B - Arrival time of green train at station B <= TS

Constraint2: Staring time of magenta train at station B <= Starting time of blue train at station B

Refinement of constraints: **Constraint-Matrix**

Objective:

- Database entity is not always an **appropriate object for constraints**.
- Distinction of **original constraints** and **derived constraints**.
- Most **simplified representation** of constraint.
- Mapping to the **global constraints** provided by ILOG

Abstract Object Model and Constraint

- Selection of **essential objects** in railway traffic model
- Selection of **fundamental constraints** upon abstract objects
- Use of the **Constraint-Matrix**

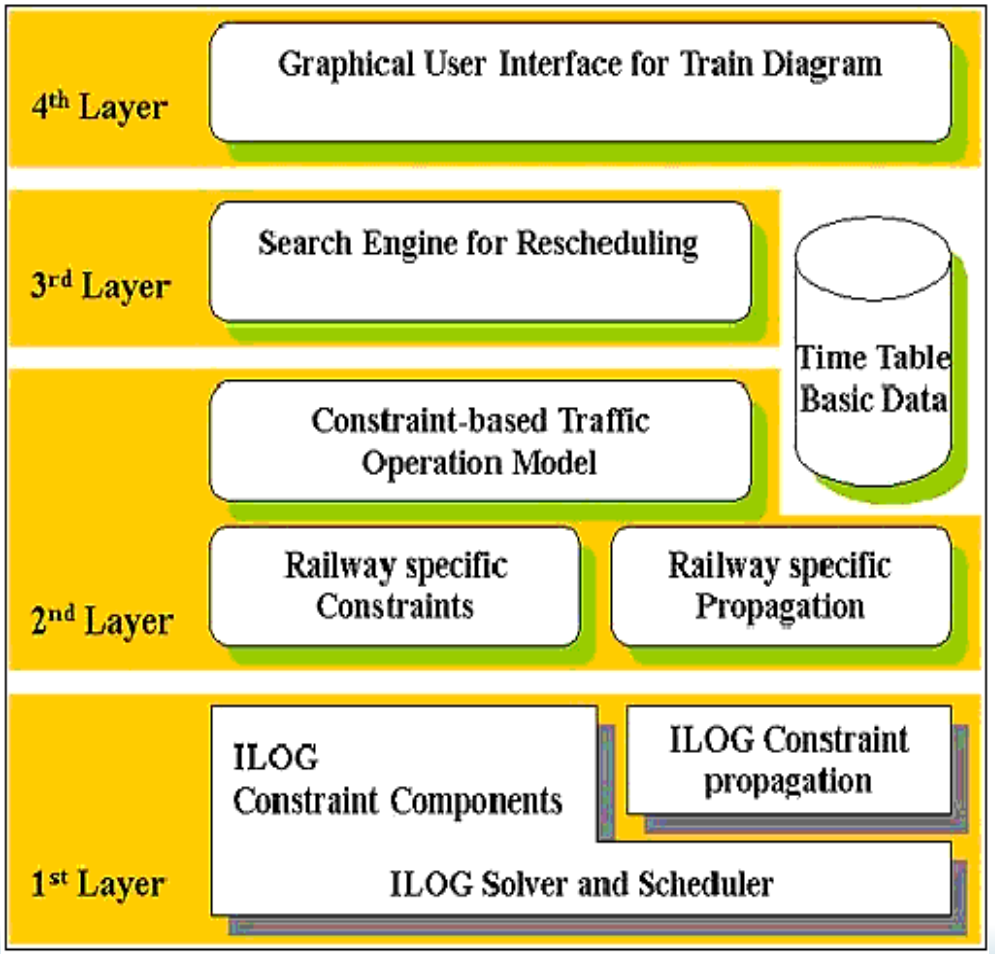
Constraint Matrix

	a1	a2	a3	b1	
a1					
a2					
a3					

Soft Constraint

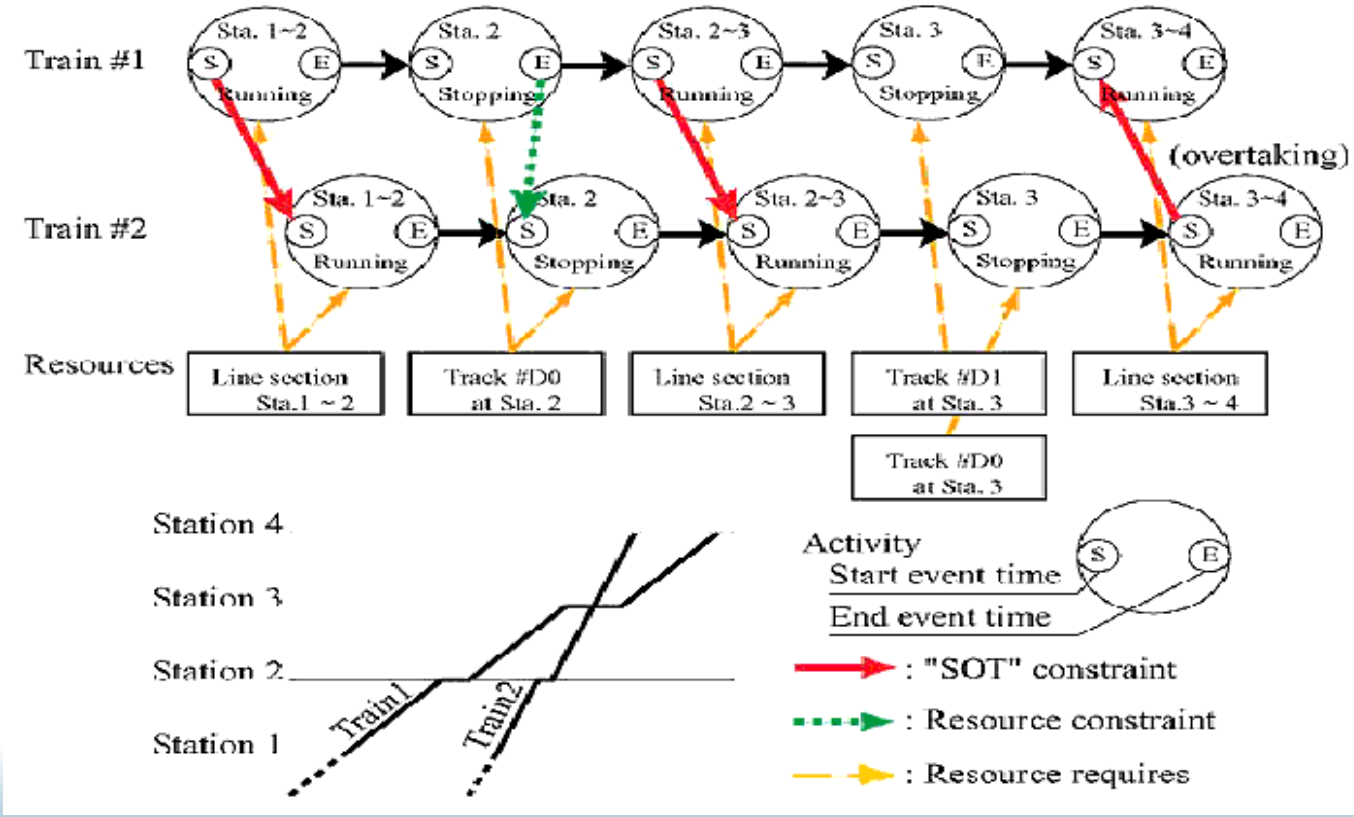
Hard Constraint

Architecture of CIBERS



Network of Activities and Constraints

- **Activity Type**
  - **Stopping Activity**: represents dueling of a train at a station.
  - **Running Activity** : represents running of a train between stations



Constraint based model of CIBERS

- **Constraint based traffic operation model of CIBERS:**
  - ILOG components: Activity and Resource
  - Railway specific constraints(**Queue with capacity**)
  - Safety constraints among trains
  - **Network of activities** with constraints related to resources
- **Decision Variables:**
  - **SOT**: the order of trains starting at each station
  - **ROT**: the order of trains using the same resource
- **Objective Function:**
  - Minimization of **the weighted sum of delays** of each train at each station.
- **Searching Heuristics**

Railway Specific Implementation

- **Maximum freedom and minimum choice points**

  main principle:
  - Start time and arrival **time** are **never enumerated**.
  - **Enumerate SOT** and **add inequalities** between trains **dynamically**.
  - Make **constraint propagation** as far as possible

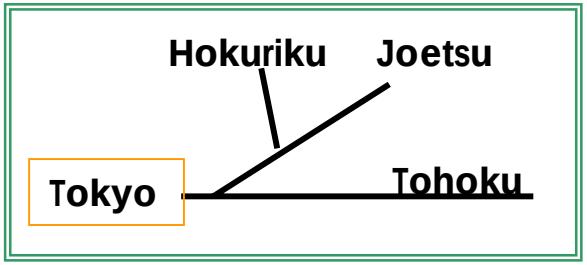
- **Constraint propagation of discrete resource is not enough**

  => **Lower bound** of the objective function is **not tight**.
  => Development of "**Queue with capacity**" and its propagation

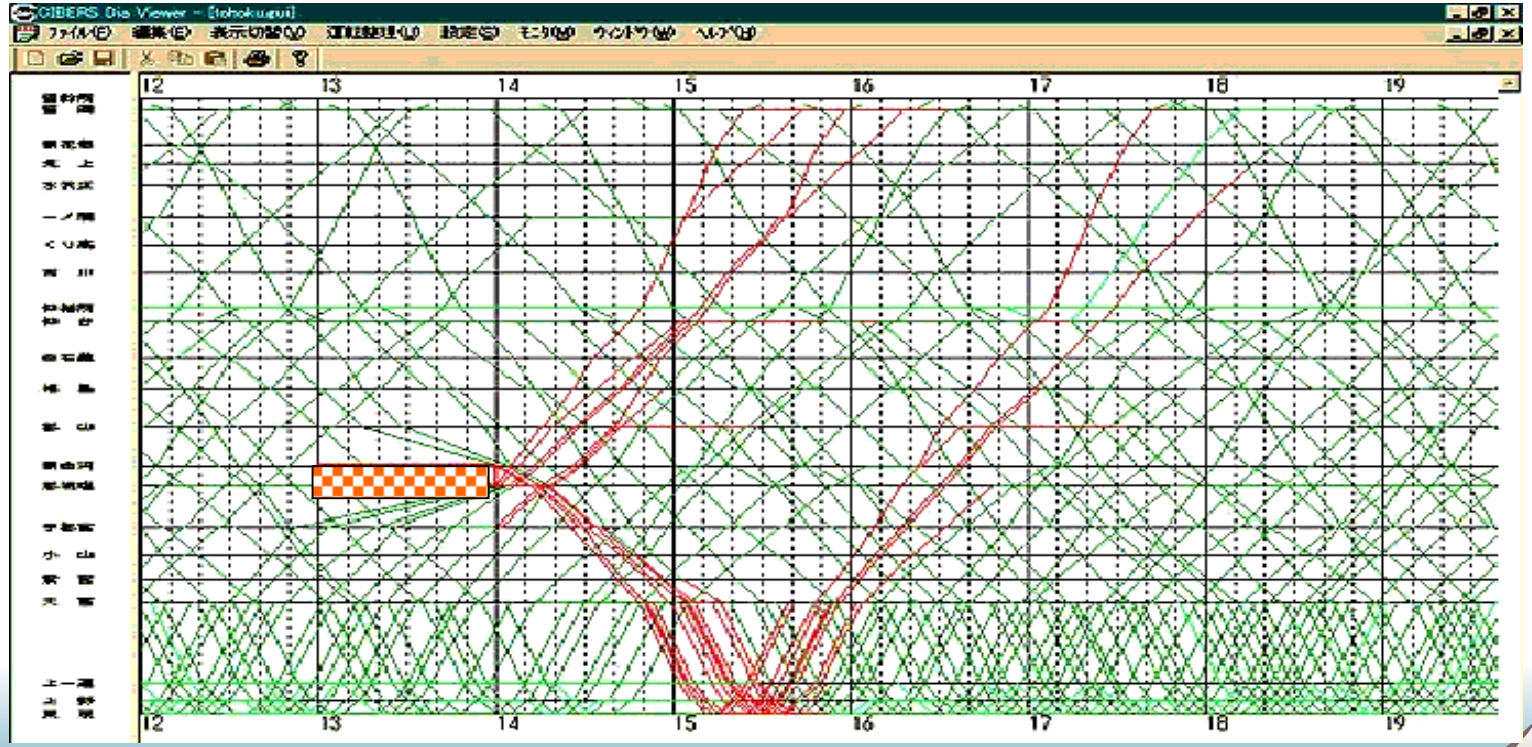
- **Constraint propagation of SOT using railway network knowledge**
  - **Maximum** number of trains that a fast train overtakes slow trains by terminal is **Min**(number of **side tracks** ahead, number of related **slow trains** ahead).

Case Study

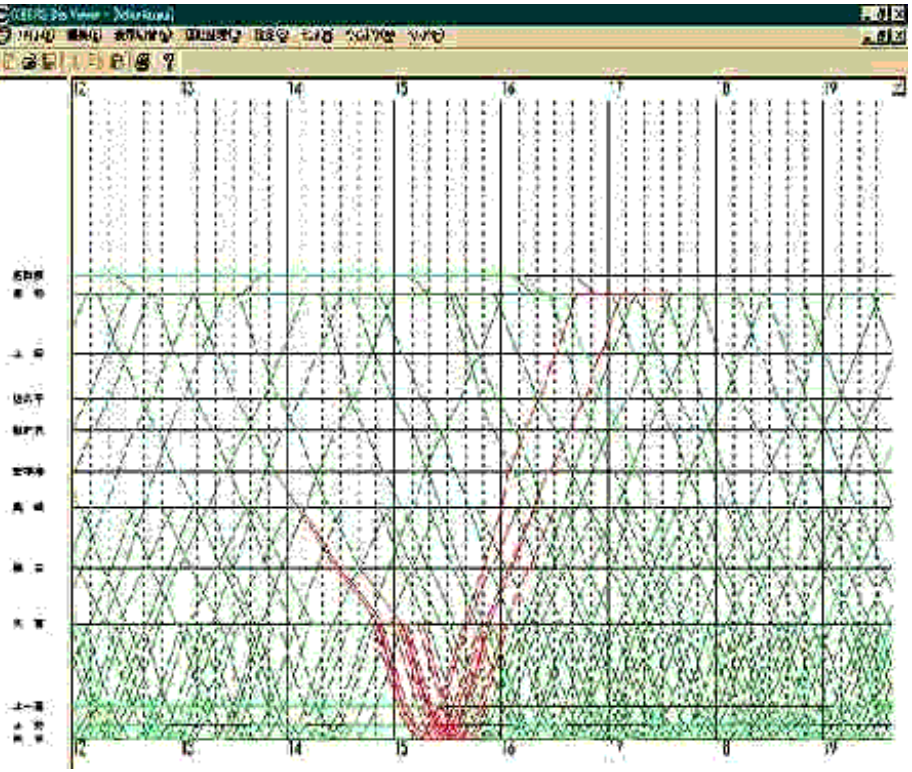
- JR-East Shinkansen Network
- 60 minutes suspension



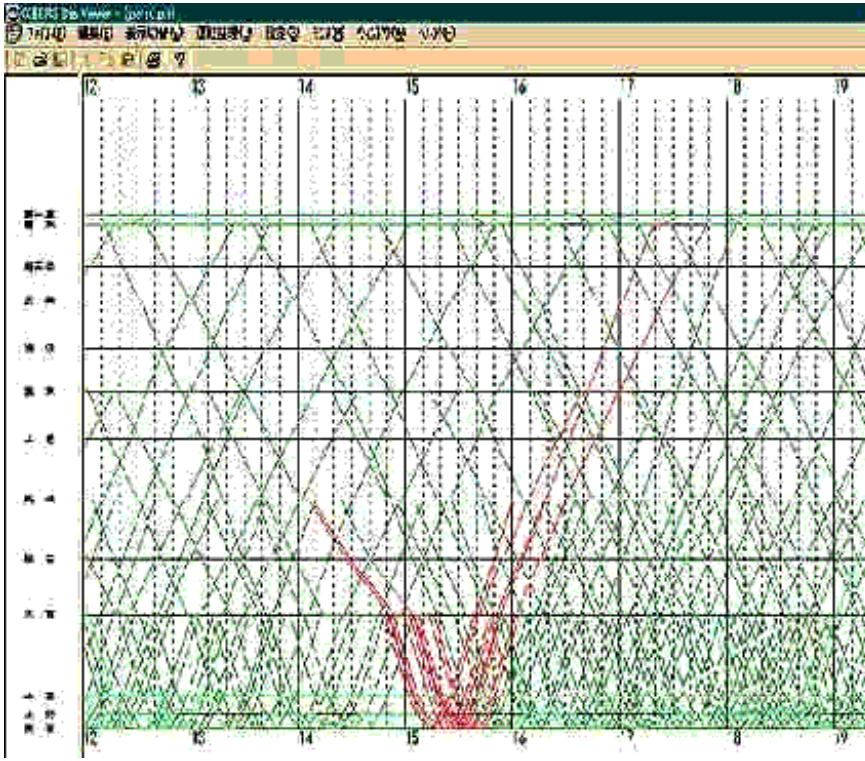
Tohoku line: Original SOT



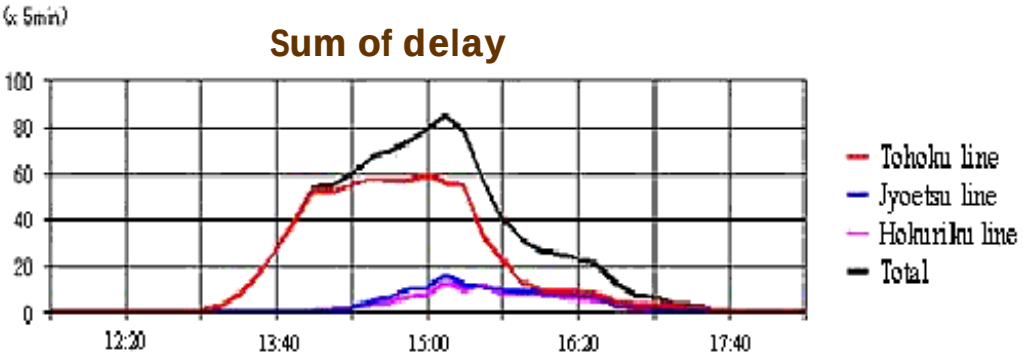
Hokuriku Line: original SOT



Joetsu Line: original SOT

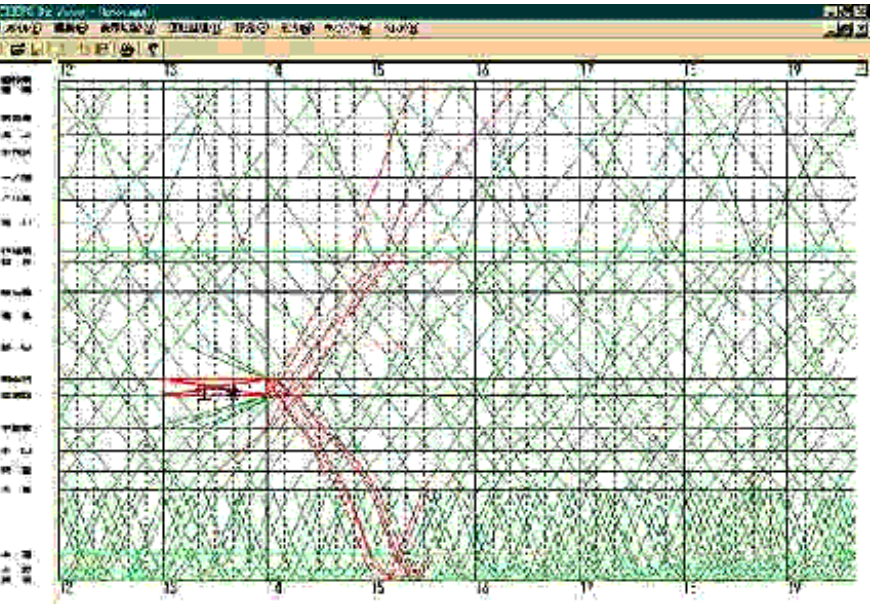


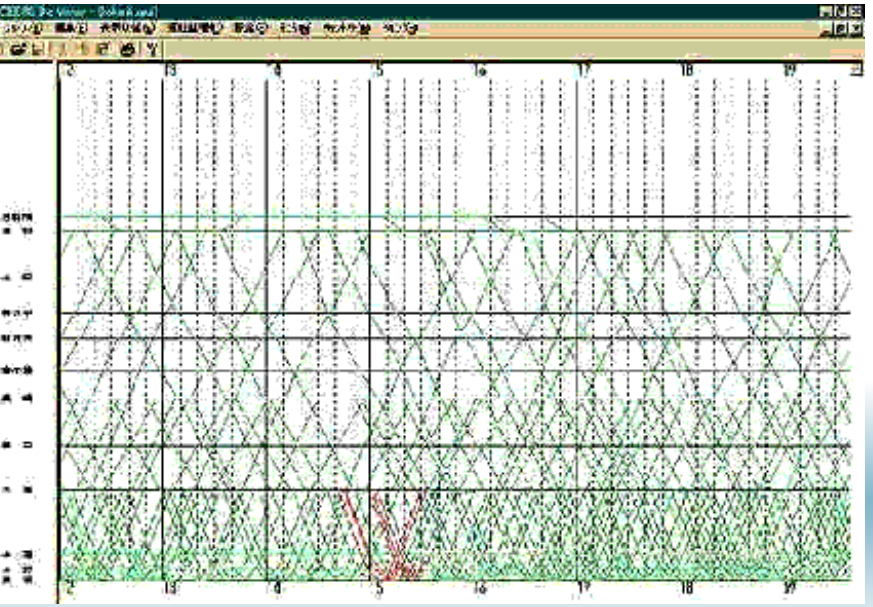
Sum of delay

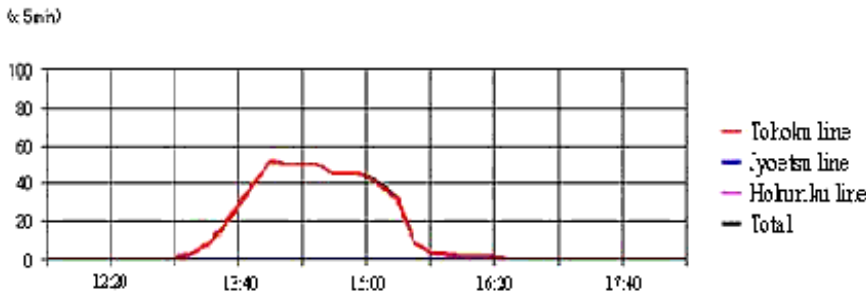


Math-Model Research Inc.

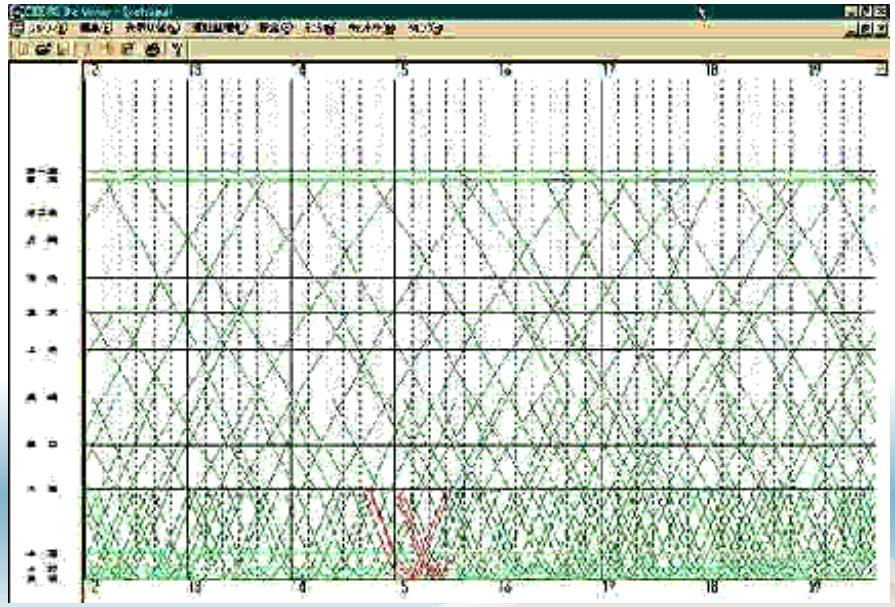
Result of Reschedule







	Change of "SOT" [sections]		Total Delay [minutes]
	Down	Up	
Before Rescheduling	0	0	4496
After Rescheduling	35	32	2219



Conclusion & Current situation

Constraint based Rescheduling System(CIBERS) is practical.

- **Optimized Solutions** fulfilled not only the **constraints** but also the **preferences** requested by **the experts** in train dispatching.

CIBERS is computationally feasible.

- Computation takes less than **1 minute using a personal computer**(1 GHz).

Constraint based approach is effective

- Applicability of **design methodology** based on **Constraint- Matrix**.
- Development needed only **1.5 man-years**
- Reusable **common model** of railway traffic problems

Current Situation

- CIBERS can be applicable to **large disorder** lasting more than **10 hours**.
- **Extend to several planing problems** in JR-East Shinkansen using **Constraint- Matrix approach** by **other SE's .**

発表：ILOG社ユーザ・ミーティング　2002

制約プログラミングによる鉄道運転整理システム

(Railway Rescheduling System Based on Constraint Programming)

(株) 数理モデリング研究所

野末 尚次

URL: www.Math-Model.Co.JP

Mail: nozue@bk9.so-net.ne.jp

Math-Model Research Inc.