IISc-IBM Workshop on Operations Research and Data Analytics, March 4, 2008

Applied Operations Research in Japanese Industry

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Tokyo Research Laboratory (TRL)

- Director: Hiroshi Maruyama
  (**IBM Distinguished Engineer**)
  •Approximately 200 researchers

- History

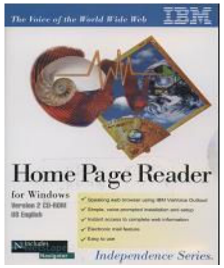
1970: Tokyo Scientific Center (TSC) was established
1982: Japan Science Institute (JSI) was established
1983: TSC was merged into JSI
1986: JSI was renamed to Tokyo Research Laboratory
1993: TRL was relocated to Yamato Site
2007: TRL celebrated 25th Anniversary
from establishment of JSI in 1982

Hiroshi Maruyama
Director of TRL

Yamato Laboratory

25 years of innovation: TRL has been a premium IT research laboratory

Speech Recognition & Synthesis

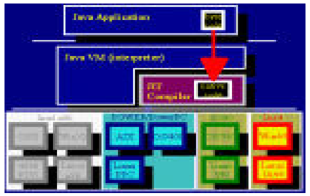


Home Page Reader

Web Services Security


Liquid Crystal Display (LCD)


aDesigner

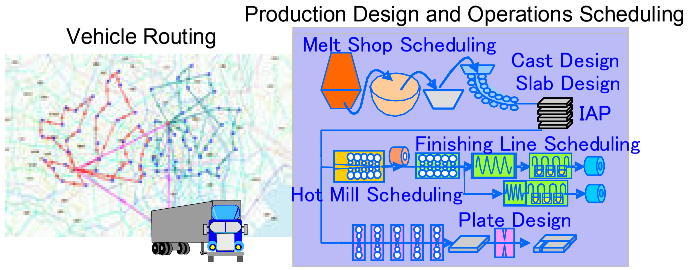


Java JIT Compiler

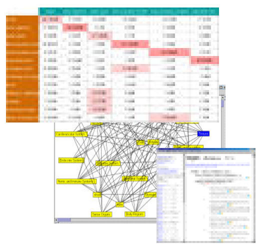
Data Hiding


Power-saving technology


HDD Active Protection



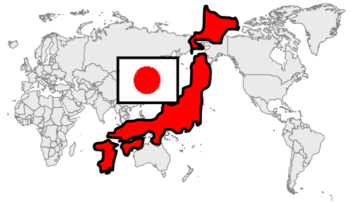
Optimization


Text Mining


WatchPad


HDD Control Unit

Know Japanese Clients

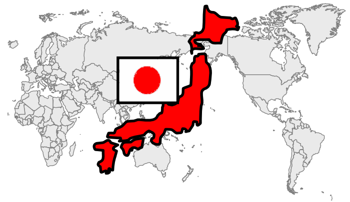


- Manufacturing and services are two major sectors in Japanese industry.
- Manufacturing companies in Japan are influencing globally by their practical approaches.
  - Kaizen (*Improvement* or *change for the better*), JIT (Kanban), TQC, …
  - Same spirit as OR (*science of better*) ?

2007 Nikkei Ranking of Excellent Companies in Japan

1. Nintendo	(Game)	15. Kyocera	(Electronics)
2. Fanuc	(FA/robot)	15. Nissan	(Automotive)
3. Takeda	(Pharma)	17. Denso	(Automotive parts)
4. HOYA	(Optics)	18. Daito	(Construction)
5. Canon	(Electronics)	19. JFE	(Steel)
6. Keyence	(Electronics)	20. TDK	(Electronics)
7. Toyota	(Automotive)	21. Yahoo!	(Internet/Comm.)
8. Rohm	(Electronics)	22. Matsushita	(Electronics)
9. Honda	(Automotive)	23. Murata	(Electronics)
10. Trend	(Internet Security)	24. JT	(Tabaco)
11. ShinEtsu	(Material)	25. NTT	(Communication)
12. Astellas	(Pharma)	26. Hirose	(Electronics)
13. Nippon Steel	(Steel)	27. Komatsu	(Machinery)
14. NTT DoCoMo	(Communication)	28. Sumitomo Metal	(Steel)

Know Japanese Clients



- **Issues in Automotive Manufacturers**
  - Create new products and brands
  - Shorten lead time from design to production start
  - Global SCM (procurement, manufacturing, **logistics**…)
  - After sales product **diagnosis** and traceability
  - Computer simulation-based experiments
  - …
- **Issues in Steel Manufacturers**
  - Skill transfer from near-retirement generation to younger generations
  - Automated and integrated planning and **scheduling**
  - Manage root causes of schedule disruptions and quality problems
  - …
- **Issues in Electronics Manufacturers**
  - Shorten lead time from design to production to the end of product life
  - Automated and integrated planning and scheduling
  - …

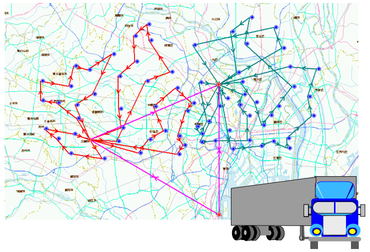
Operations Research Group in TRL

We apply OR in practice.

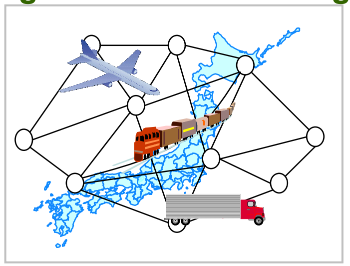
- Optimization
  - logistics
  - scheduling
- Data Analytics
  - time series analysis
  - machine learning
- Business Service Research
  - process modeling
  - simulation

Total about 15 people

Vehicle Routing

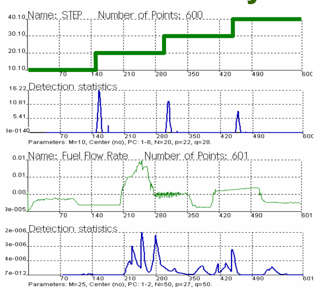


Logistics Network Design

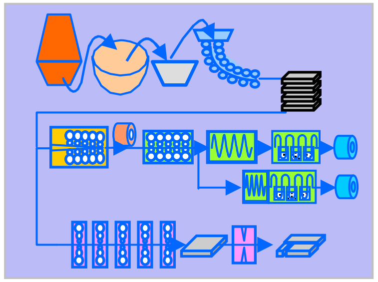


Warehouse Location

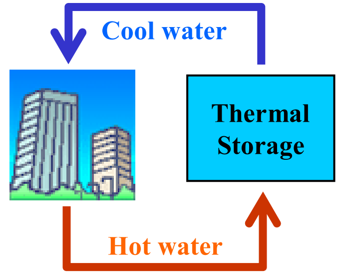
Time-Series Analysis



Production Scheduling



Peak-shift Optimization

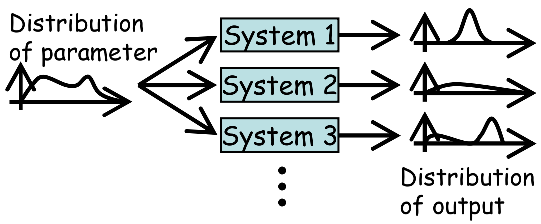


Process Maturity Modeling

rework needed / if done later	process1	process2	process3	process4	process5
process1		0	20	20	100
process2	0		0	50	0
process3	0	0		0	80
process4	20	0	0		50
process5	0	0	0	0	

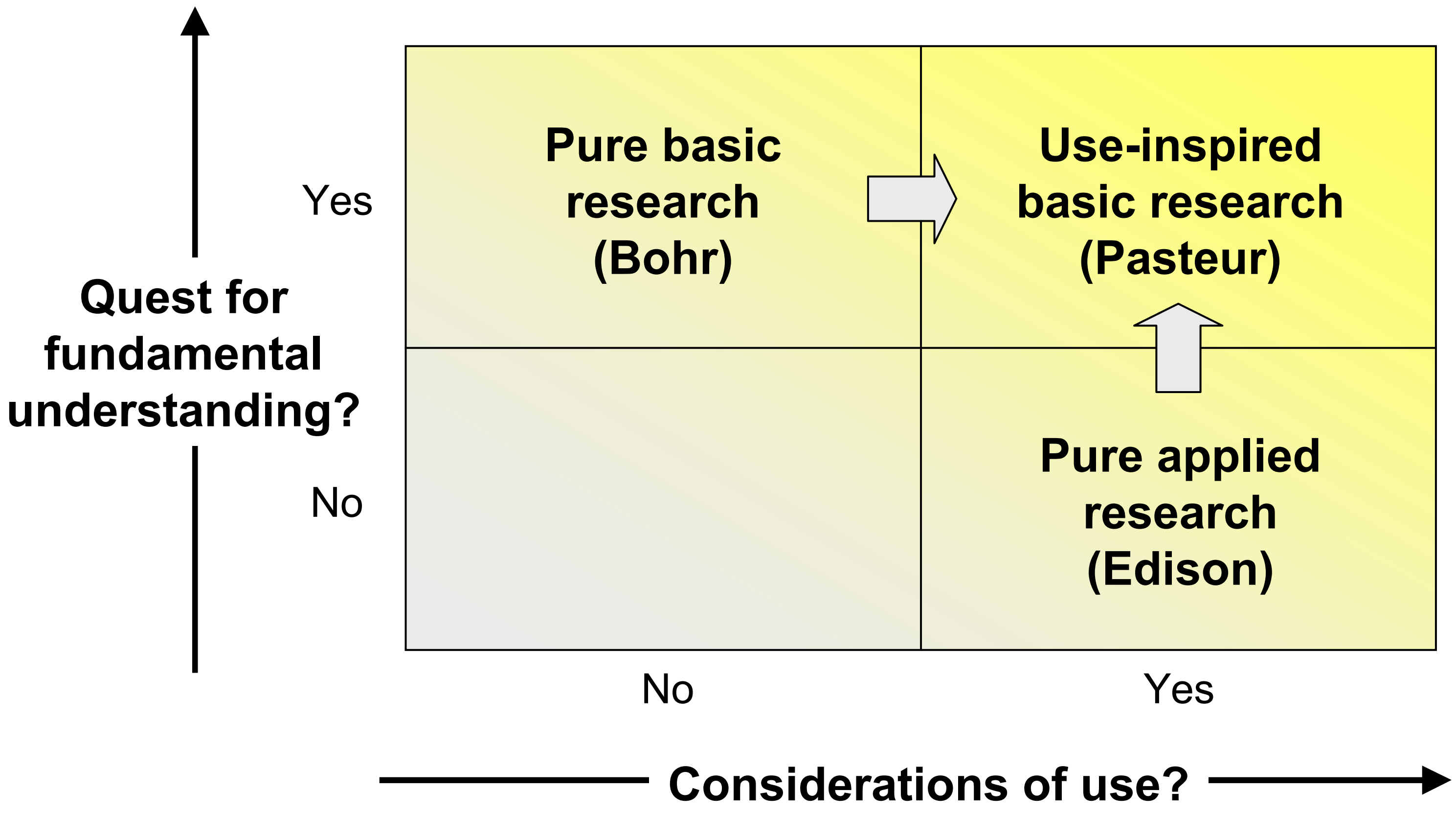
Process	WL	Skill
process 1	8	High
process 2	4	High
process 3	8	Low
process 4	16	High
process 5	8	High

Stochastic Optimization



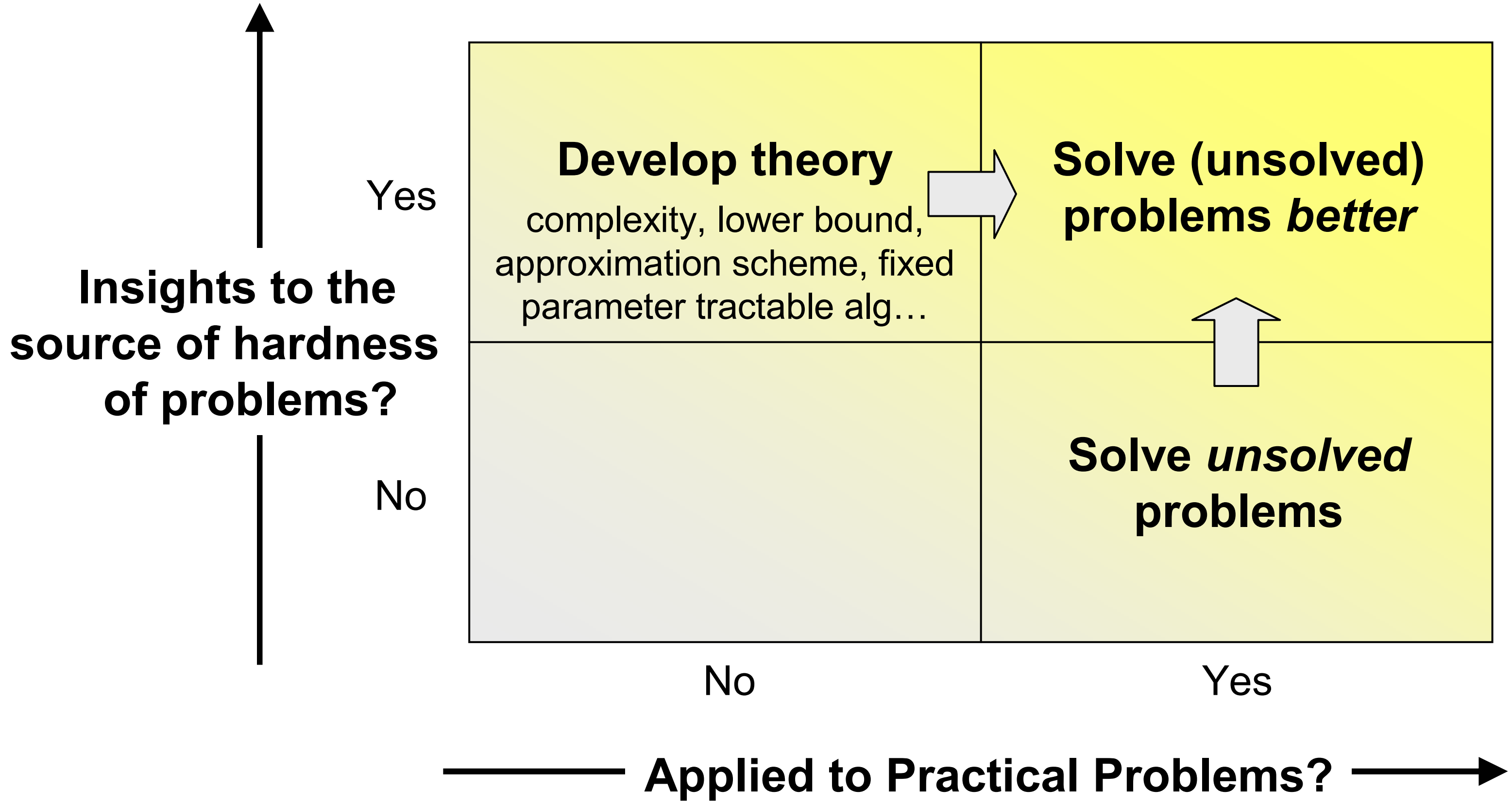
Does Operations Research *Matter* to Clients?

Pasteur's Quadrant

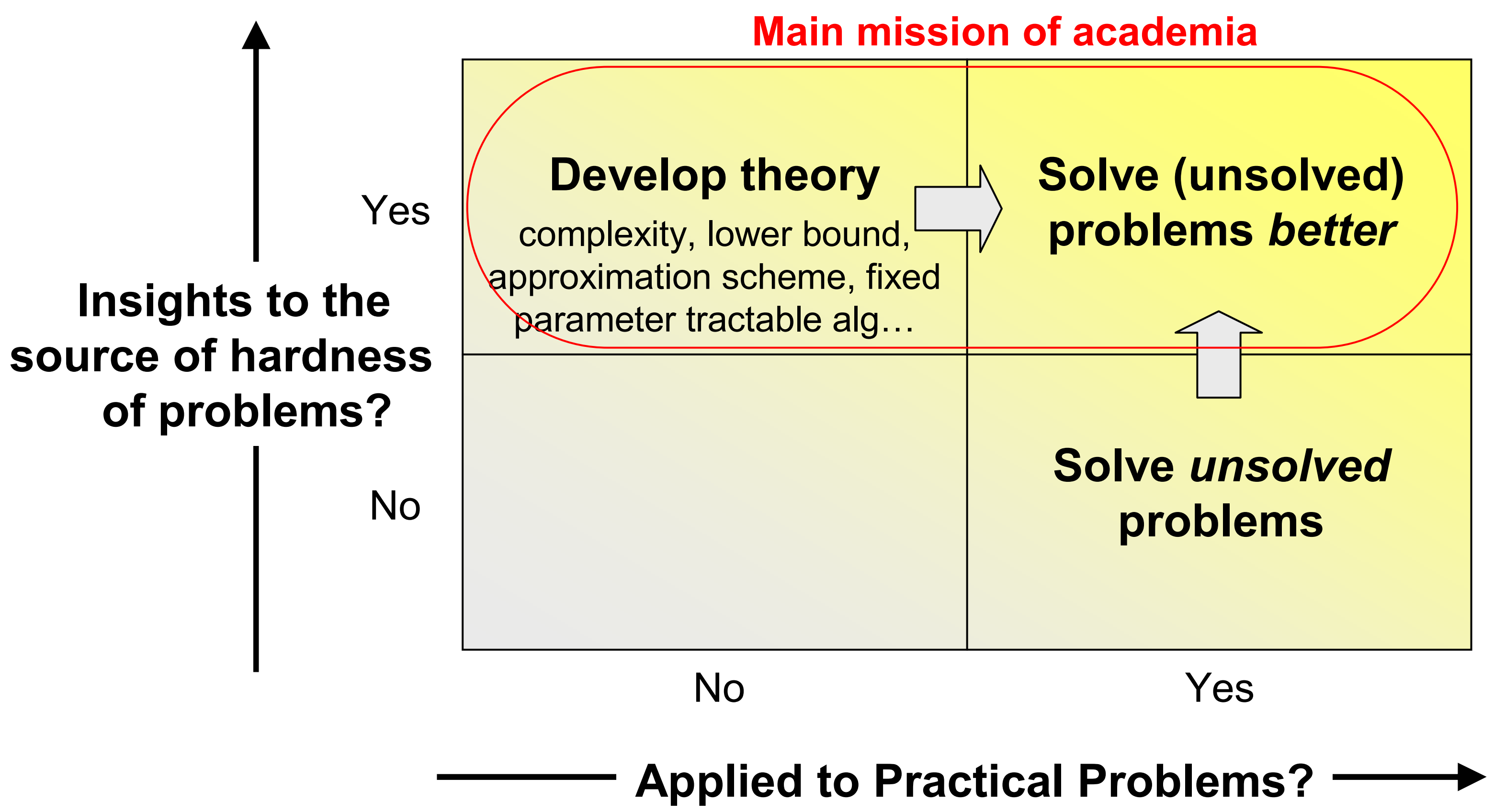


Source: Donald E. Stokes, Brookings Institution Press 1997
* Two arrows are augmented for this presentation.

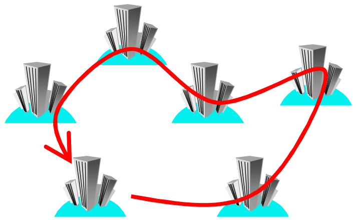
OR *Matters* If…



OR *Matters* If…

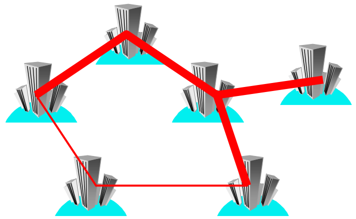


An Example of the Traveling Salesman Problem (TSP)



$$\begin{array}{lll} \min_x & \sum_{i<j} c_{ij}x_{ij} & \\ \text{subject to} & \sum_{i<j} x_{ij} + \sum_{i>k} x_{ki} = 2 & \text{for all } i \in V \\ \text{such that} & x \text{ is a connected graph.} & \end{array}$$

- Source of hardness
  - Degree 2 constraint



Held-Karp lower bound (1970)

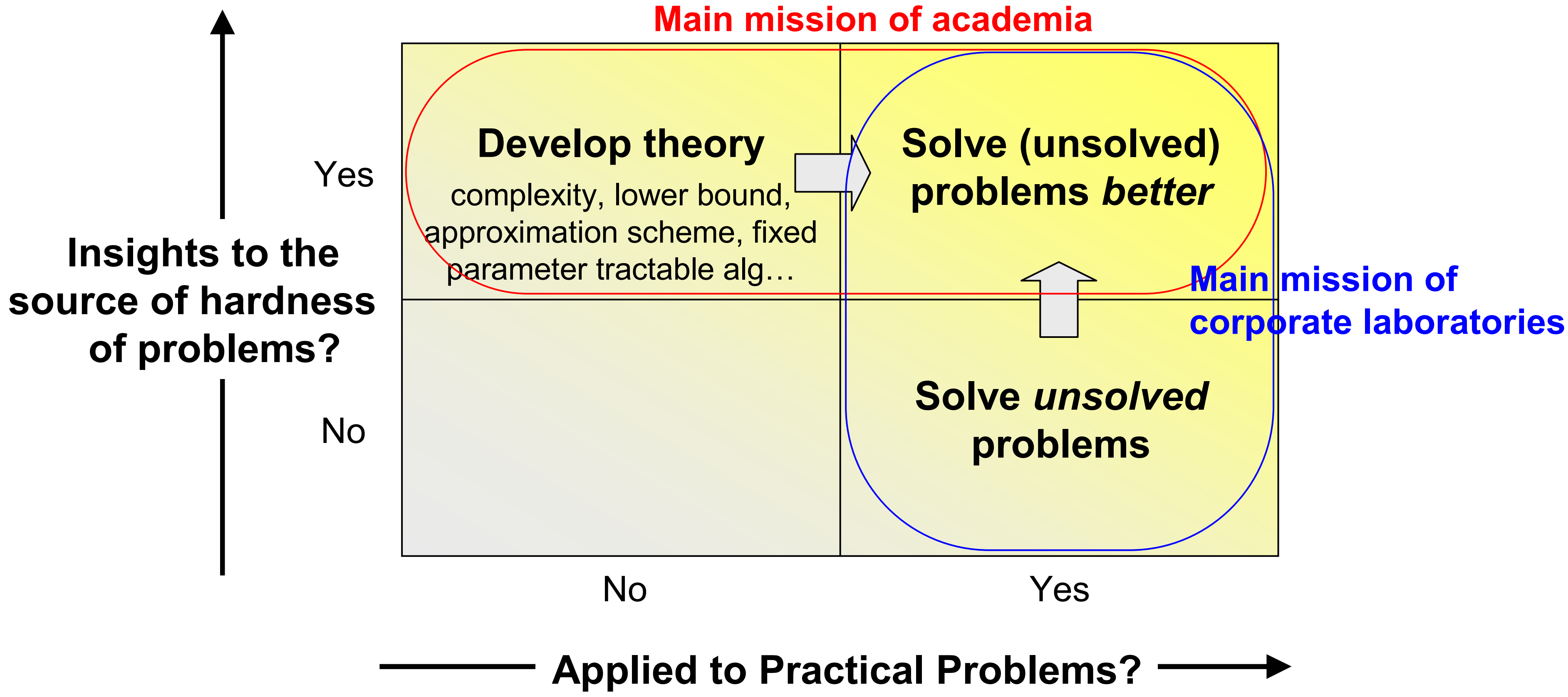
$$\begin{array}{ll} \max_\lambda & \sum_{i<j} c_{ij}x_{ij} + \\ & \sum_i \lambda_i (\sum_{i<j} x_{ij} + \sum_{i>k} x_{ki} - 2) \\ \text{such that} & x \text{ is the minimum spanning 1-tree.} \end{array}$$

- How to solve better
  - Limit the candidate *edges* examined by k-opt algorithm using the Held-Karp lower bound as measure of *nearness* to optimal (Helsgaun 1998*)

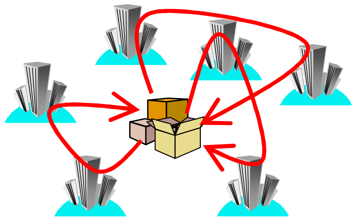
$$nearness(s,t) = (\max_\lambda \text{1-tree}(\lambda) \text{ subject to } x_{st} = 1) - \max_\lambda \text{1-tree}(\lambda).$$

* example from academia, not an IBM work.

OR *Matters* If…



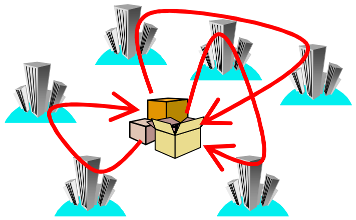
The Vehicle Routing Problem (VRP)



$$\begin{array}{ll} \min & (|\boldsymbol{\sigma}|, \sum_{i \in \boldsymbol{\sigma}} d_i) \text{ in the lexicographic order,} \\ \text{subject to} & \text{constraints on time windows of customers,} \\ & \text{and vehicle capacities, } \boldsymbol{\sigma} = \text{set of vehicles} \\ & \text{used, } d_i = \text{travel distance of } i\text{-th vehicle.} \end{array}$$

- Minimize the number of vehicles used.
  - if the number of vehicles is the same, minimize the total travel distance.
- Many other side constraints need to be considered.
  - assignable depots/vehicles for each customer, rest times of drivers, etc.
- Local search-based solutions are the best choice in practice.
  - $s \leftarrow \arg\min_{s' \in N(s)} f(s') \mid f(s') < f(s)$
  - *But* normal local search is easily trapped by bad local opt. *Why?*

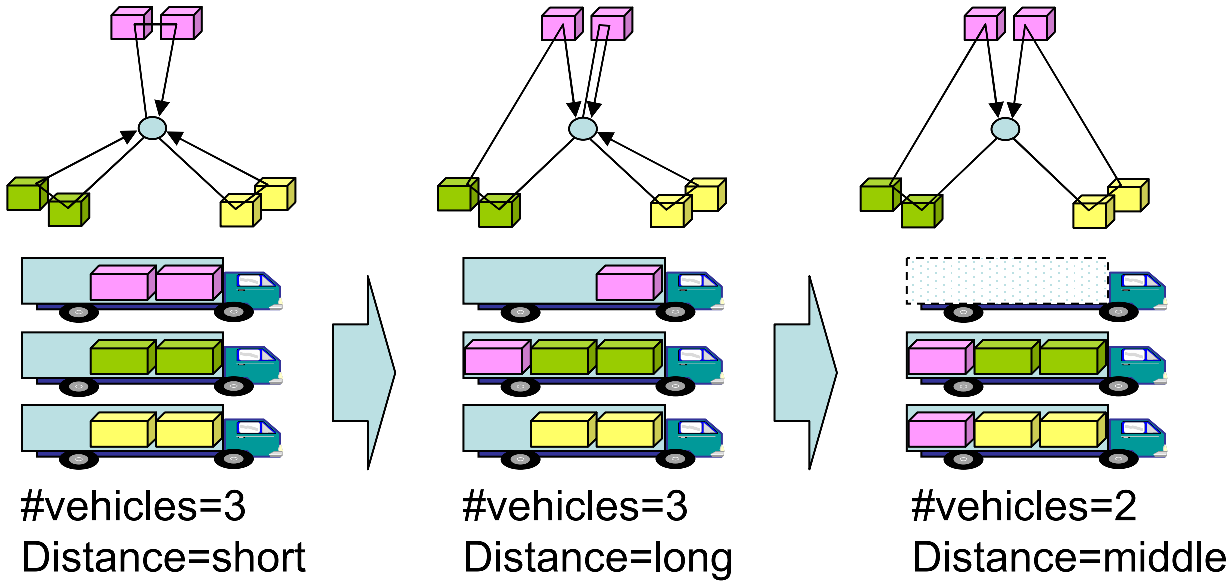
The Vehicle Routing Problem (VRP)



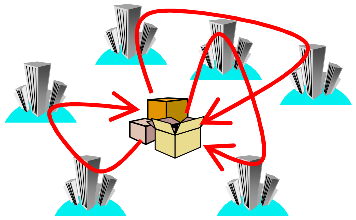
min $\left(|\boldsymbol{\sigma}|, \sum_{i \in \boldsymbol{\sigma}} d_i\right)$ in the lexicographic order,

subject to constraints on time windows of customers, and vehicle capacities, $\boldsymbol{\sigma}$ = set of vehicles used, d_i = travel distance of i-th vehicle.

- Source of hardness
  - Need to increase travel distance in order to decrease #vehicles.



The Vehicle Routing Problem (VRP)



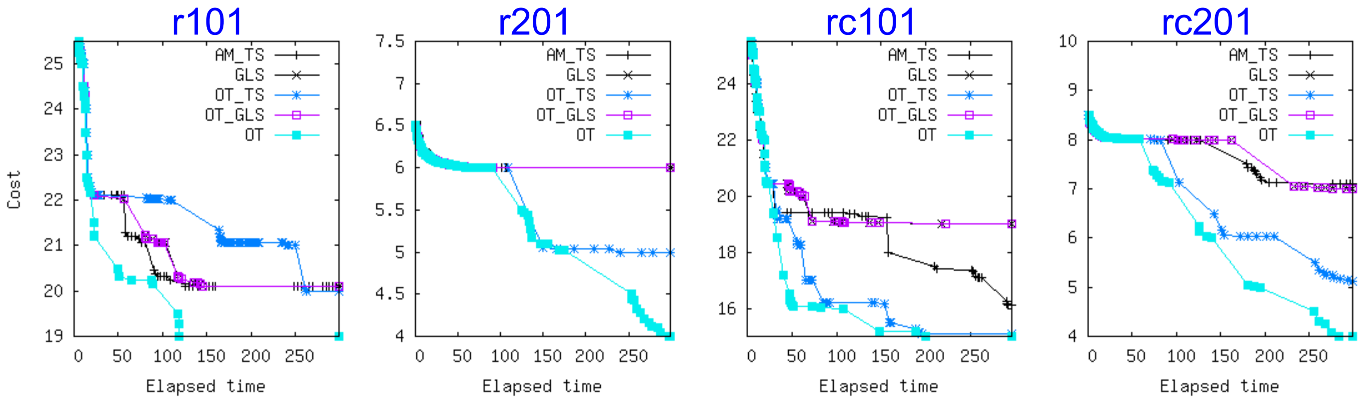
$$\min \quad (|\boldsymbol{\sigma}|, \textstyle\sum_{i\in\boldsymbol{\sigma}} d_i) \text{ in the lexicographic order,}$$

subject to constraints on time windows of customers, and vehicle capacities, $\boldsymbol{\sigma}$ = set of vehicles used, d_i = travel distance of i-th vehicle.

- How to solve better
  - Raise the travel distance of vehicles, one by one. (Okano 1998*)

    While terminal criteria are not met do:

    1. Randomly select vehicle $p \in \boldsymbol{\sigma}$.
    2. Apply local search to $\min\left(d_p, |\boldsymbol{\sigma}|, \sum_{i\in\boldsymbol{\sigma}} d_i\right)$.



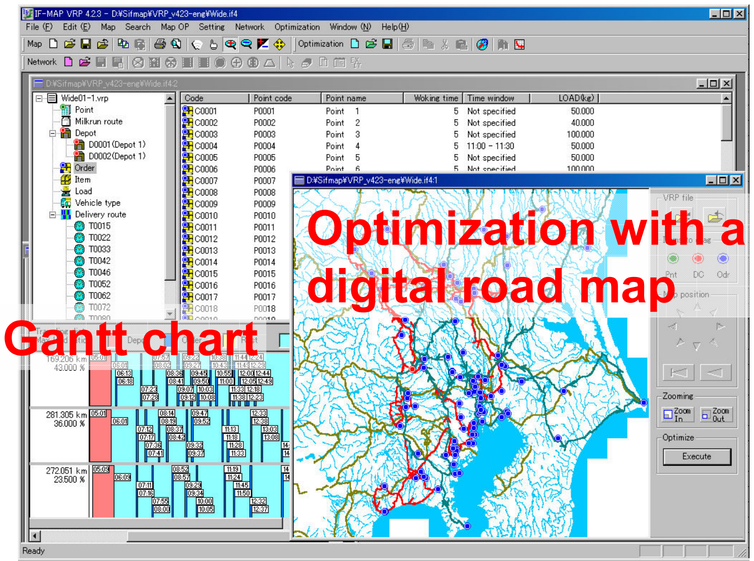
Proposed method has better tradeoff.

AM_TS=Adaptive memory and tabu search
GLS =Guided local search
OT =Proposed method (Objective Tuning)

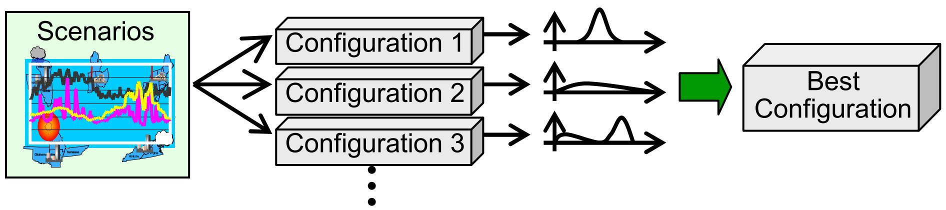
* in Japanese

The Vehicle Routing Problem (VRP)

- IBM Vehicle Routing Planner (1999~)
  - TRL's core algorithm is used.
  - Applicable to various practical problems without parameter tuning.
  - Used by 30+ customers
    - Automotive, utility, office appliance, airlines, food, …
  - Models and constraints supported by VRP
    - The multiple types of vehicles (2t, 4t, etc.)
    - The working times of drivers (ex: 9:00--17:00)
    - The rest times of drivers (ex: one hour after 12:00)
    - The visit time windows (ex: between 10:00--12:00)
    - The assignable depots/vehicles for each customer
    - The service time for each item and each customer
    - The multiple trips of vehicles in a day
    - Pick-up and delivery
    - etc.

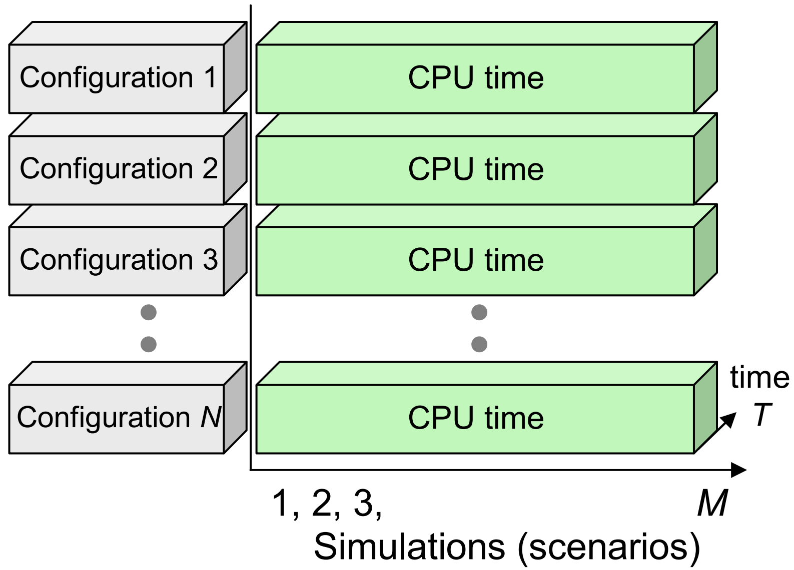


Stochastic Optimization via Simulations

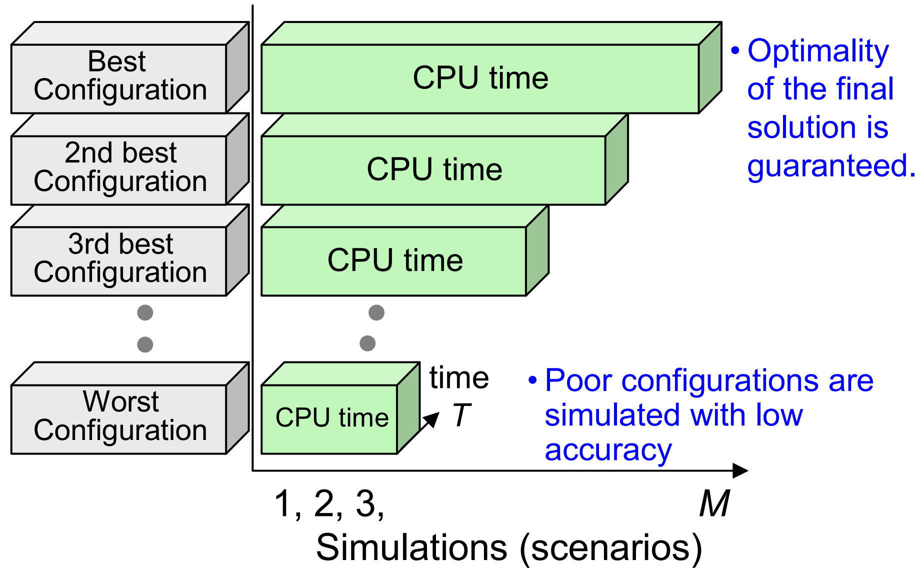


- Find the best configuration among many candidate configurations, when each configuration is evaluated via simulations.

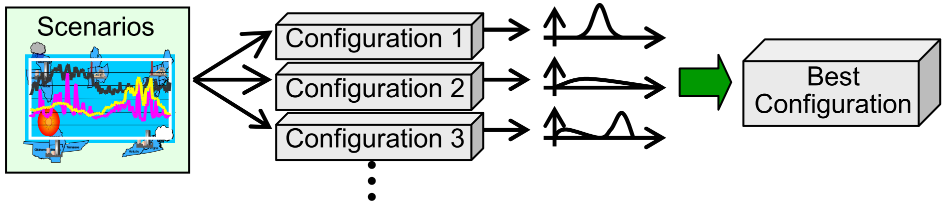
• Naïve simulations require $N \times M \times T$ time.



• Clever simulations require much shorter time.



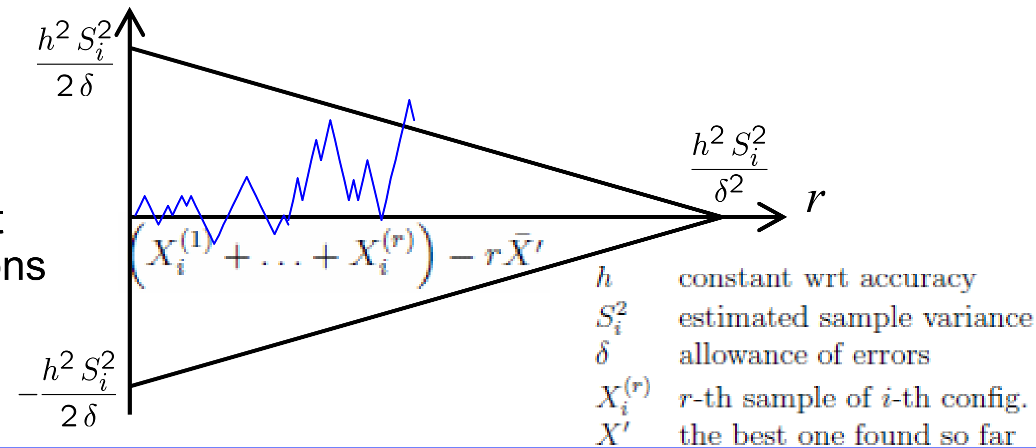
Stochastic Optimization via Simulations



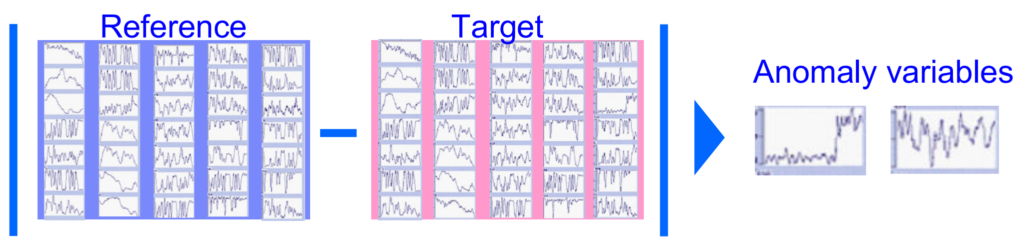
- Source of hardness
  - There are *comparable* configurations but the measure for them to be comparable is unclear with presence of large variance.
- How to solve better
  - Develop method to compare a pair of configurations with given accuracy based on theory of Brownian motion. (Osogami 2007)

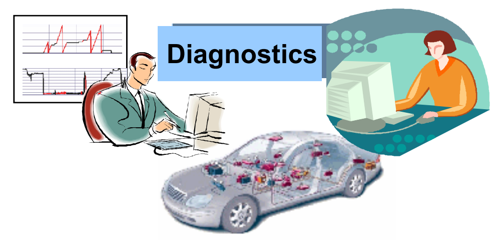
① An optimal configuration is estimated.

② Compare its performance with the best one found so far by minimum simulations based on a theory of Brownian motion

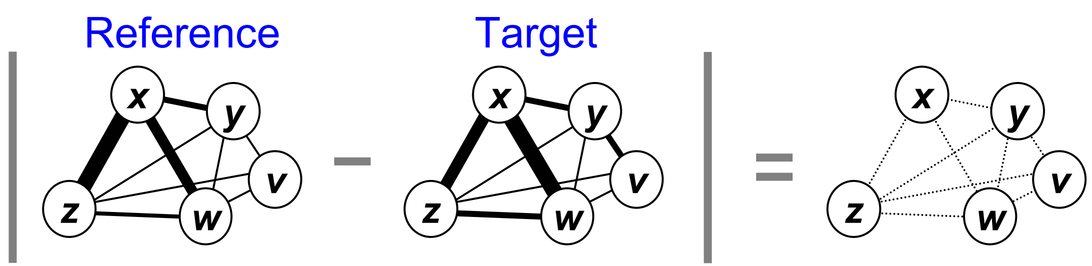


Time Series Analysis for Anomaly Detection



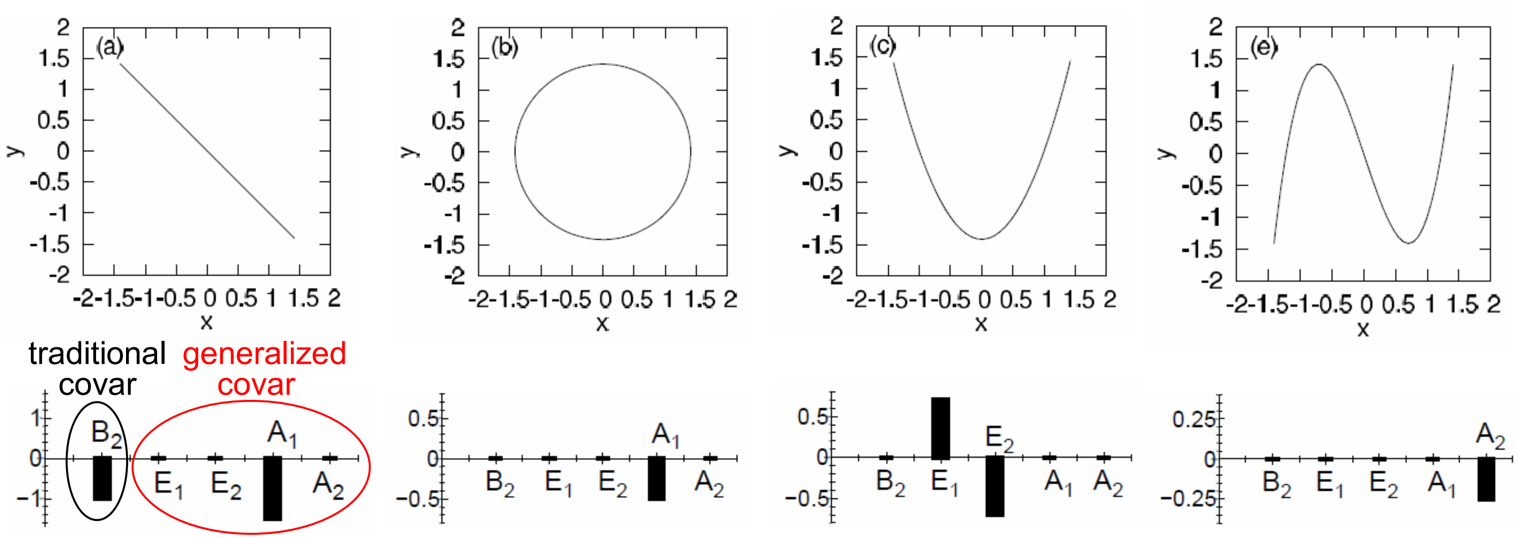


- Given reference and target sets of time series data, find the variables whose behaviors in target data set is *abnormal*.
  - Abnormal with respect to correlation with others.
- Source of hardness
  - *Strong* and *nonlinear* correlation
    - Correlation matrices are dense.
    - Differences of linear correlation matrices are not informative.

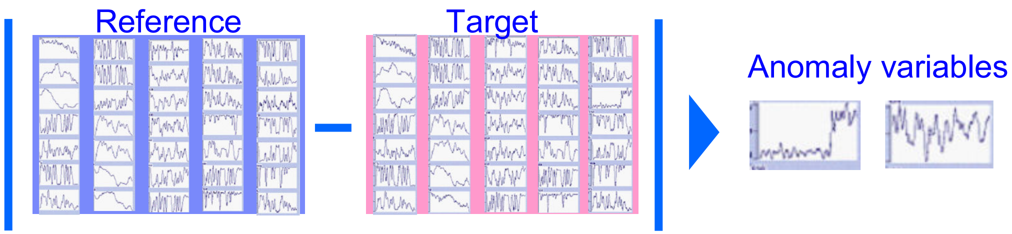


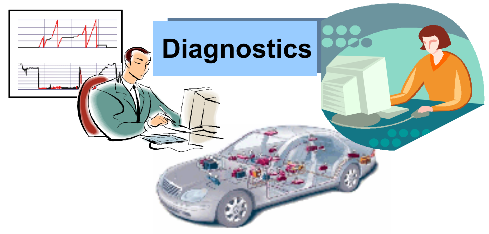
Time Series Analysis for Anomaly Detection

- How to solve better
  - Defined four generalized covariances (Ide 2005)



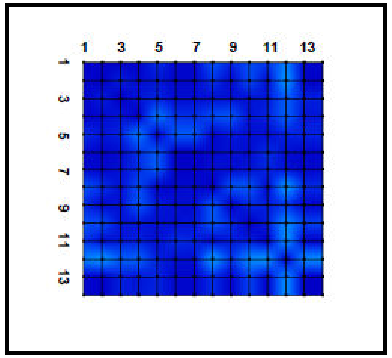
Time Series Analysis for Anomaly Detection





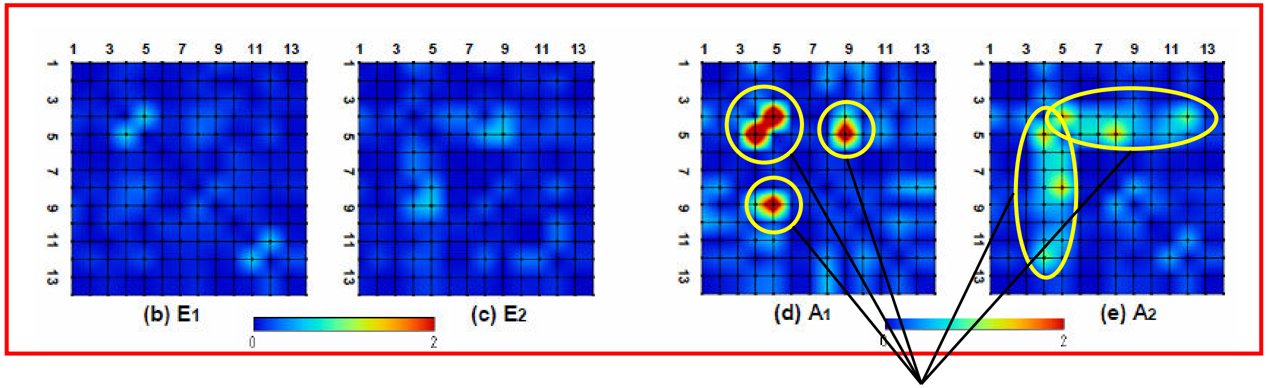
- Application in an automotive company
  - Analyzed electrical and physical sensor signals.
  - Anomaly sensor data were detected.

By linear correlation



No clear indication of anomalies.

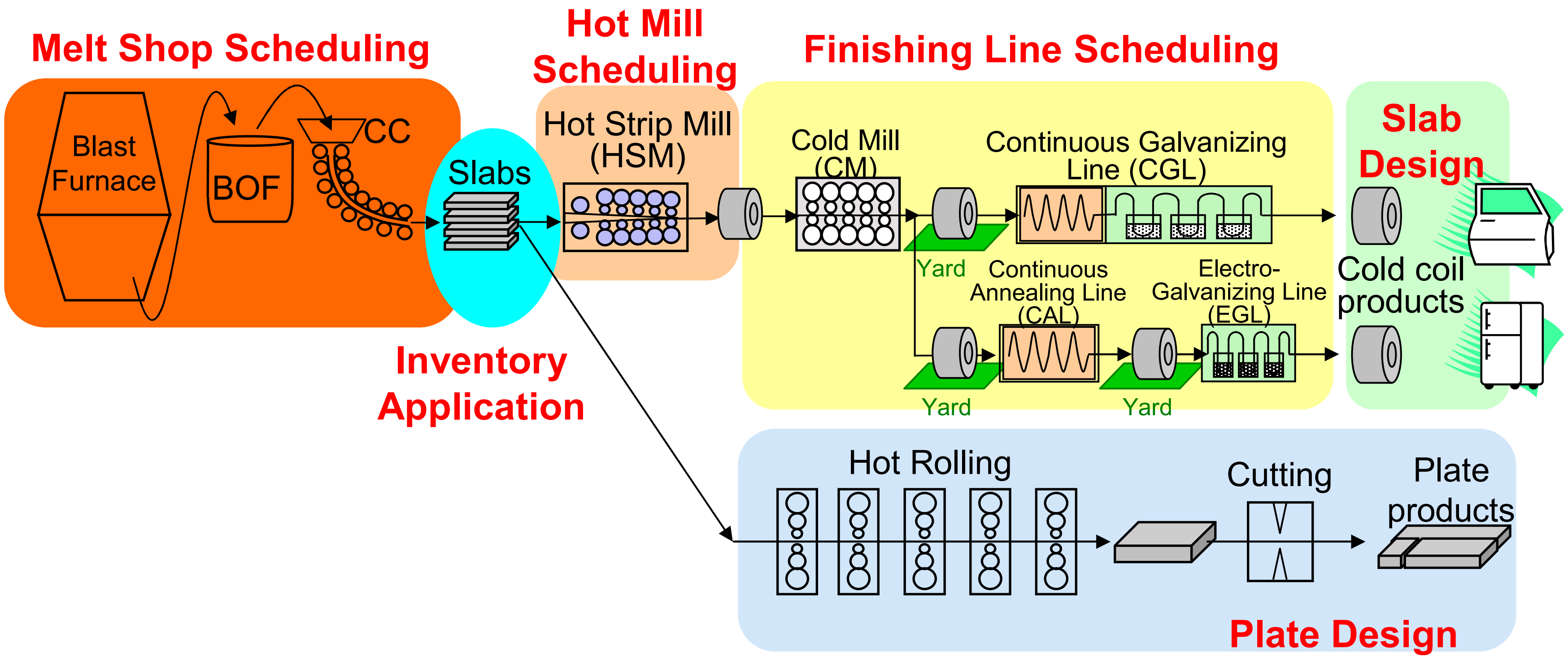
By non-linear correlation



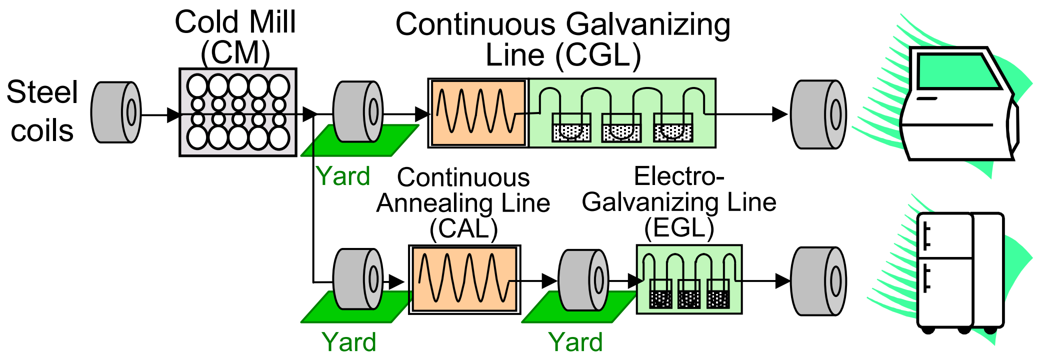
The generalized correlation matrices successfully detect hidden anomalies.

PDOS: Production Design & Operations Scheduling for Steel

- Reusable optimization assets for the steel industry developed by IBM Research
- Enable steel manufacturers to improve production efficiency and quickly respond to SCM

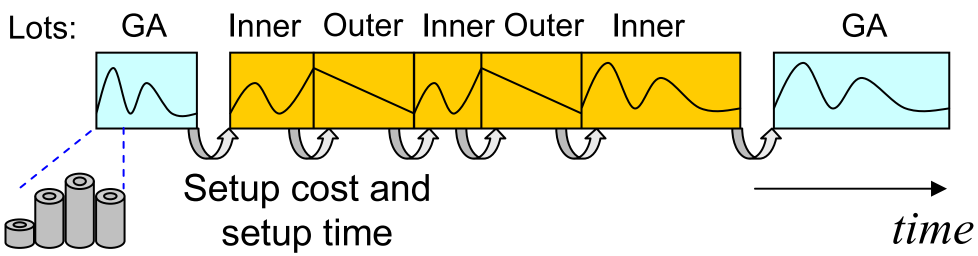


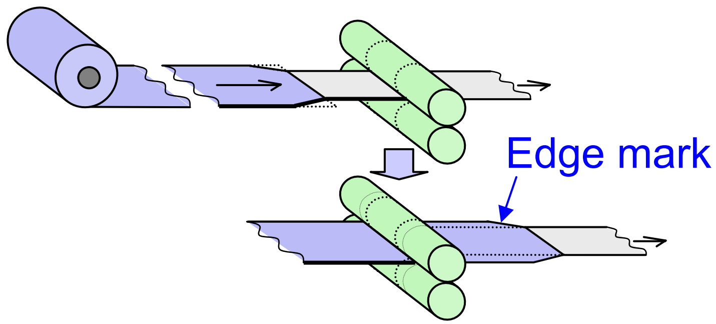
Finishing Line Scheduling (FLS)



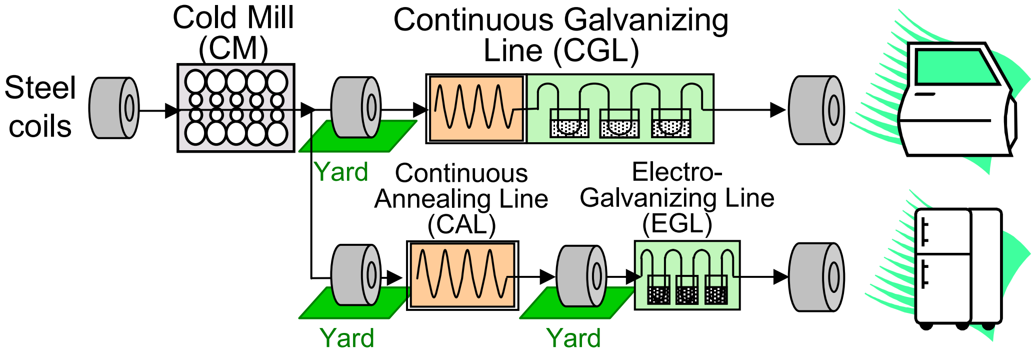
min (precedence violation,
yard overflow,
starvation of processes,
tardiness of coils,
setup cost between lots,
width/thickness jumps).

- Large scale job shop scheduling
  - About one month scheduling horizon with 20,000~25,000 coils.
  - Create production lots and sequences of coils within the lots.
  - Special care should be taken for surface quality of automotive panels.
  - Done manually only for a few days horizon (i.e., *unsolved* in practice).



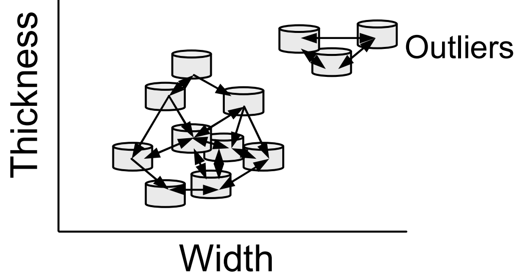


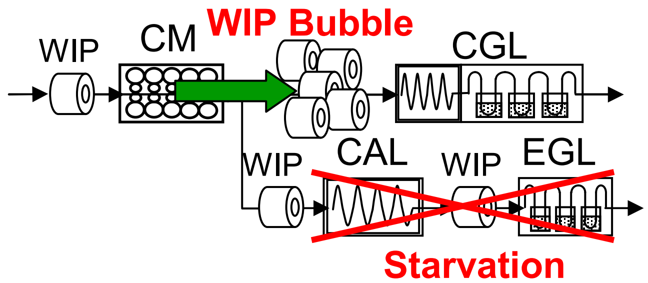
Finishing Line Scheduling (FLS)



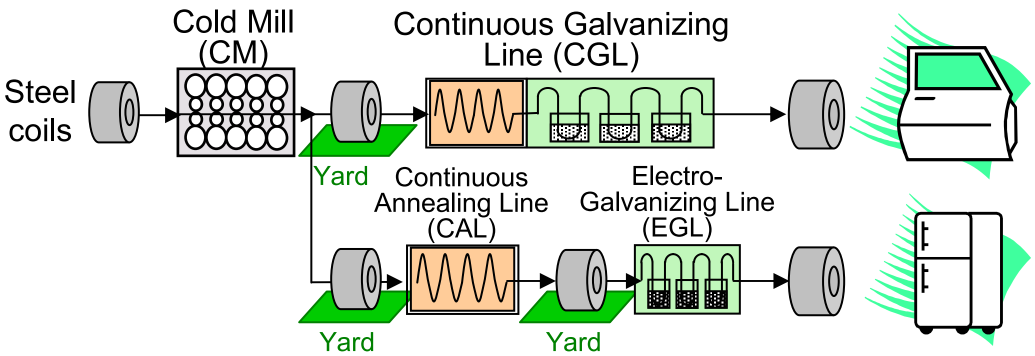
min (precedence violation,
yard overflow,
starvation of processes,
tardiness of coils,
setup cost between lots,
width/thickness jumps).

- Source of hardness
  - Mix of lot scheduling and coil sequencing.
    - Coils assigned to a lot may not be *sequenceable*.
  - Branch in the production flow after CM.
    - Bad CM schedule causes starvation on downstream lines.



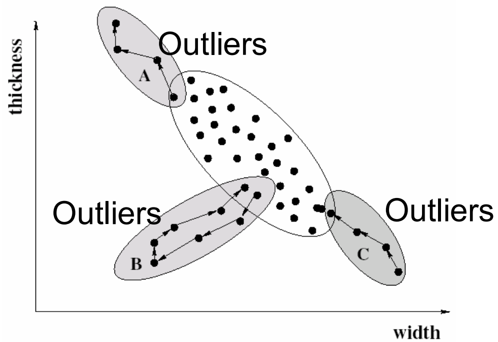


Finishing Line Scheduling (FLS)



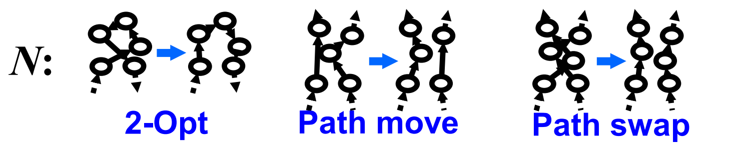
min (precedence violation,
yard overflow,
starvation of processes,
tardiness of coils,
setup cost between lots,
width/thickness jumps).

- Our solution (Okano et al. 2004)
  - Cluster coils to reduce problem size and group sequenceable coils.
  - Apply VRP algorithm considering yard capacities and safety stock levels.
  - Apply geometric TSP algorithm to sequencing of coils within lots.

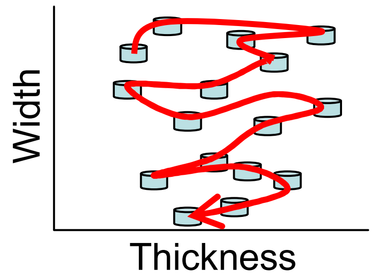


VRP algorithm

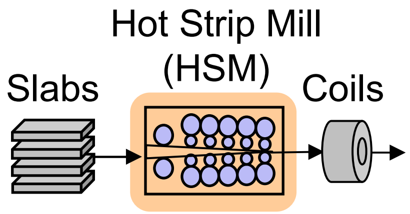
$$s \leftarrow \arg\min_{s' \in N(s)} f(s') \mid f(s') < f(s)$$

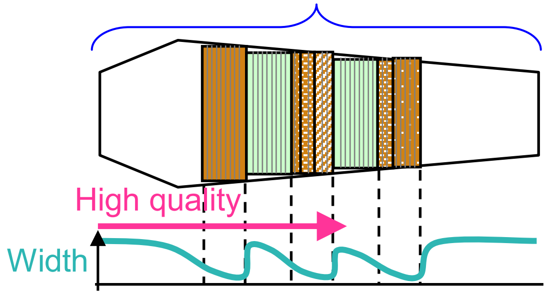


Geometric TSP



Hot Mill Scheduling





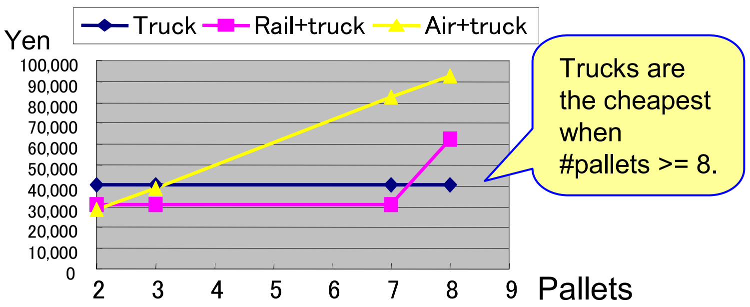
max lengths of rounds
min width/thickness jumps
subject to roller quality
constraints, due dates, etc.

- Create k rounds of rolling schedule
  - Maximize the lengths of rounds in order to maximize the use of rollers
  - Rollers are damaged by rolling thin coils and recovered by rolling thick coils.
- Source of hardness
  - Assignment of slabs rolled into thin coils to multiple rounds
- Our solution (Hama and Yoshizumi 2006*)
  - Assign clusters of slabs to the blocks in rounds by integer programming.
    - Take into account roller recovery, release and due dates, etc.
  - Apply local search.

* in Japanese

Future Work: Reduction of CO2 Emission

- Source of hardness
  - Eco-*un*friendly cost structure.
    - Economical choice leads to increase of CO2 emission.
- How to solve?
  - Create eco-friendly cost structure, infrastructure, and culture
- Our experience in logistics
  - Logistics network design by matching freights and carriers on a spatial-temporal network



Cost of transport from Tokyo to Osaka