# How to Create Nice Use Cases of Mathematical Optimization ?

NTTDATA Mathematical Systems Inc.
Takahito Tanabe (tanabe@msi.co.jp)

# Our Company Profile

We call ourselves **MSI**

- **Name** — NTT DATA Mathematical Systems Inc.
- **Office location** — Shinanomachi, Shinjuku-ku, Tokyo
- **History** — **Founded in 1982** as Mathematical Systems Inc.
  Joined NTT DATA group in February, 2012
  Changed name to NTT DATA Mathematical Systems Inc. in September, 2013
- **Common Stock** — 56 million yen
- **Financial Information** — Net Sales : 1700 million yen
  Ordinary Income : 305 million yen
  (April 1,2018 to March 31,2019)
- **Number of Employees** — **115** (as of April 1, 2020)

Technical staff : about 87

| Background | | Degree | |
|---|---|---|---|
| -Scientists | : 65% | -Master | : 67% |
| -Engineers | : 10% | -Ph.D. | : 14% |

- **Business** — Packaged software development and sales
  Analysis and Consulting services
  Entrusted development of software

# Our Company Profile (Our latest projects)

1. Optimize the production plan for a new smart factory
2. Update the existing credit model with the latest technologies
3. Arrange biological data for machine learning and visualization
4. Create a new middleware for a quantum computer
5. Enable process simulation and GPU acceleration
6. Create a search engine that responds to ambiguous phrases
7. Provide a lecture of basics of data analysis useful for business
8. Process data for cross tabulation systems
9. Add functions to programs that have been maintained for 30 years
10. Implement anomaly detection engine to embedded system
11. Improve the accuracy of image processing DL by 5%

…

**Rather than specific AI technologies,**
**We provide the right solution for each client.**

# Our Company Profile (Solutions/Technologies)

**Data Mining Machine Learning**

demand forecast
image classification
outliner analysis
data-fusion
Bayesian network
recommendation
sparse modeling

**Text Mining**

call center log analysis
patent mining
nurse's record analysis
text classification
chat-bot

**Numerical Optimization**

resource management
financial engineering
production scheduling
staff rostering
logistics optimization
resource planning
energy management

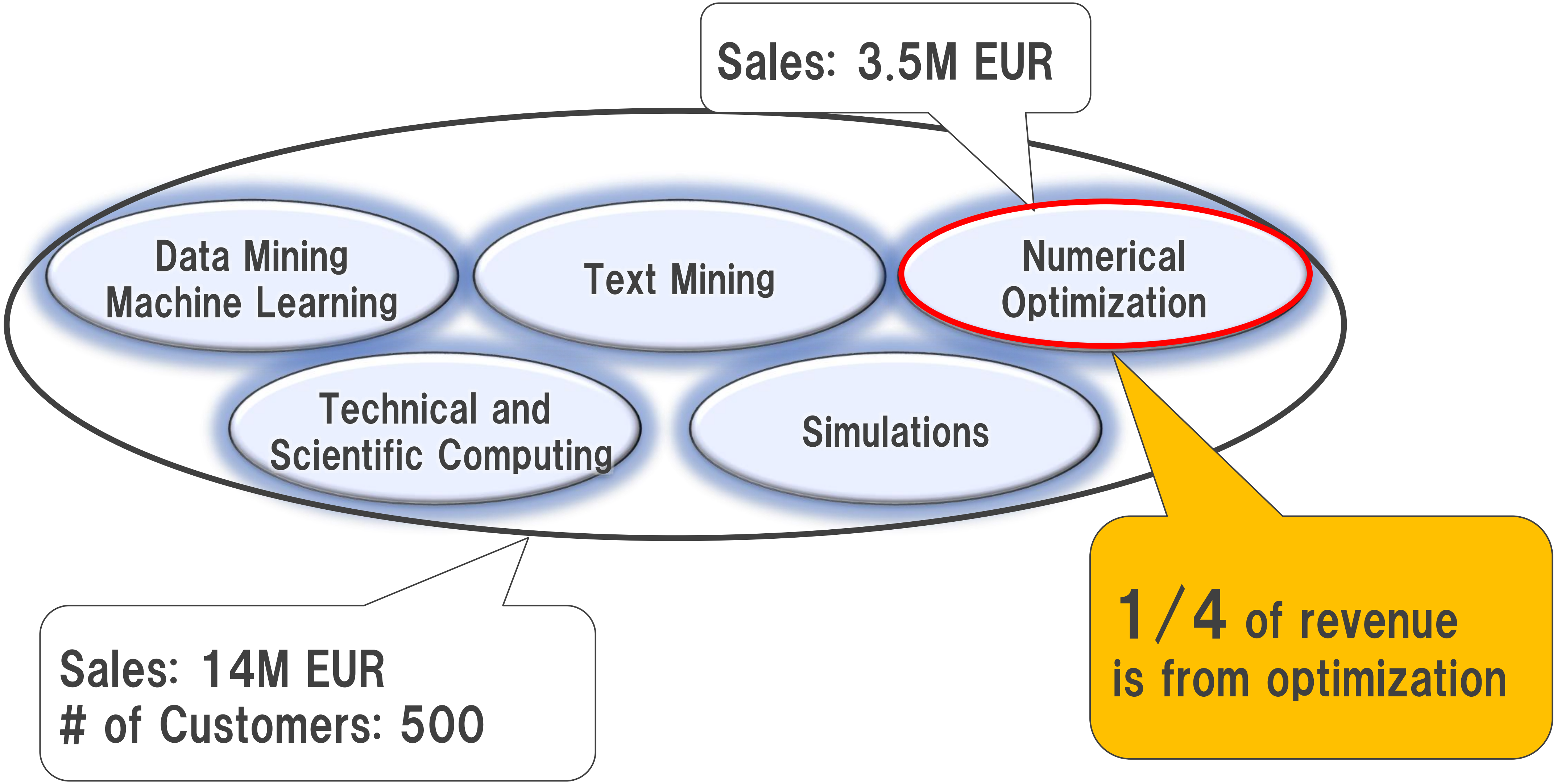
**Technical and Scientific Computing**

inverse problem analysis
semantic web analysis
computational geometry
image processing
reverse engineering

**Simulations**

agent simulation
social system simulation
traffic simulation
facility management
montecarlo simulation

# Our Company Profile (in Figure)



# Now, we have become..

## Leading OR company in Japan

- Over 25 years of Experience in OR
- Clients : Automotive manufacturer, Energy, Railway, etc..

Usecases from 'Mathematical Systems User Conference 2019':

Tokyo Gas Co., Ltd.:
Toward implementation of logistics optimization of liquefied natural gas (LNG) sales business using lorry vehicles

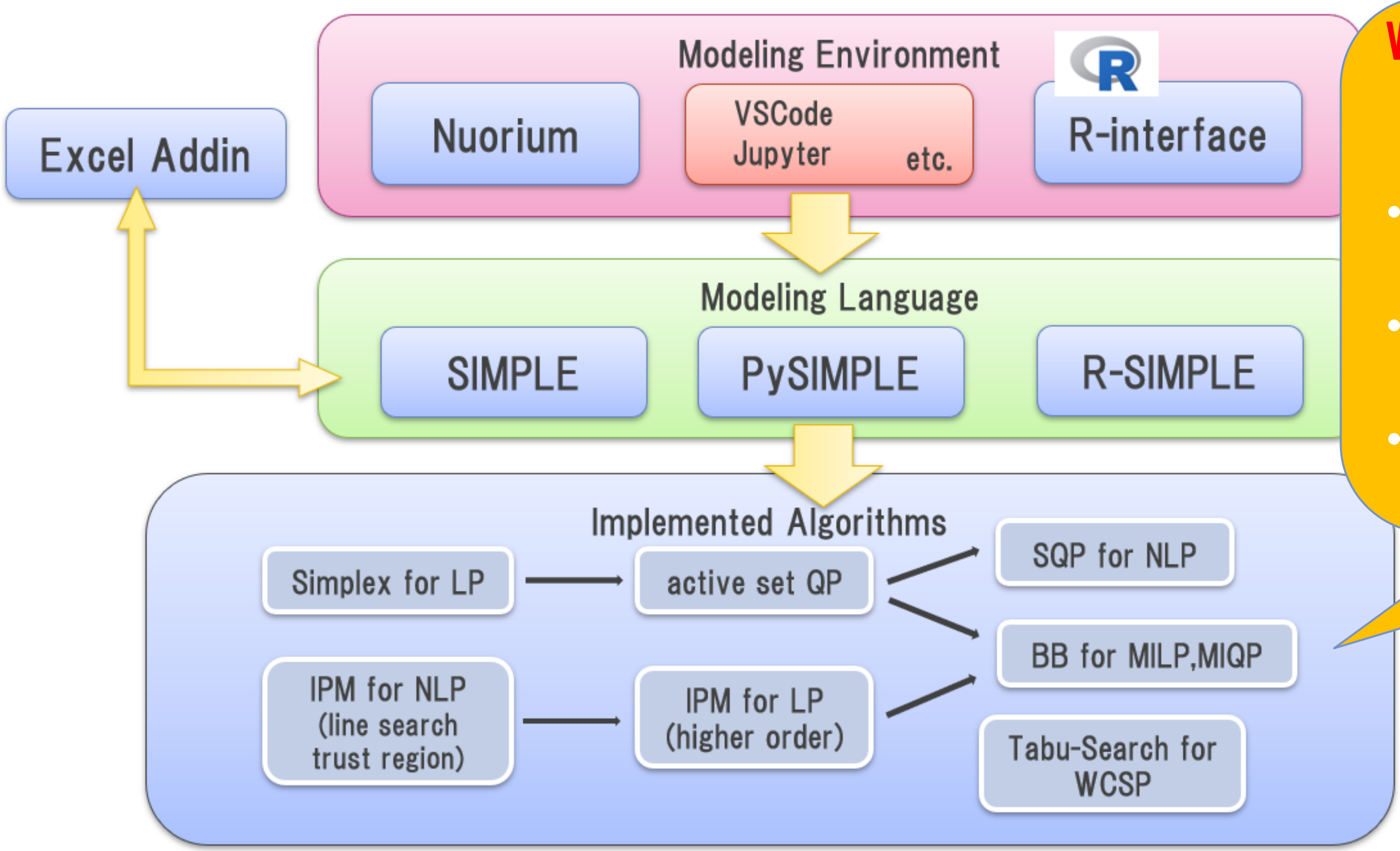
Railway Technical Research Institute:
How did Nuorium Optimizer changed Track maintenance

Japan International Cooperation Agency:
Optimal matching of Japan Overseas Cooperation Volunteers

# Our optimization toolbox: Nuorium Optimizer

Nuorium Optimizer : Solver Developed by MSI

- Platform: Windows, macOS, Linux （AWS etc..）
- Interface : C++, Python, R




We will greatly appreciate collaboration work with

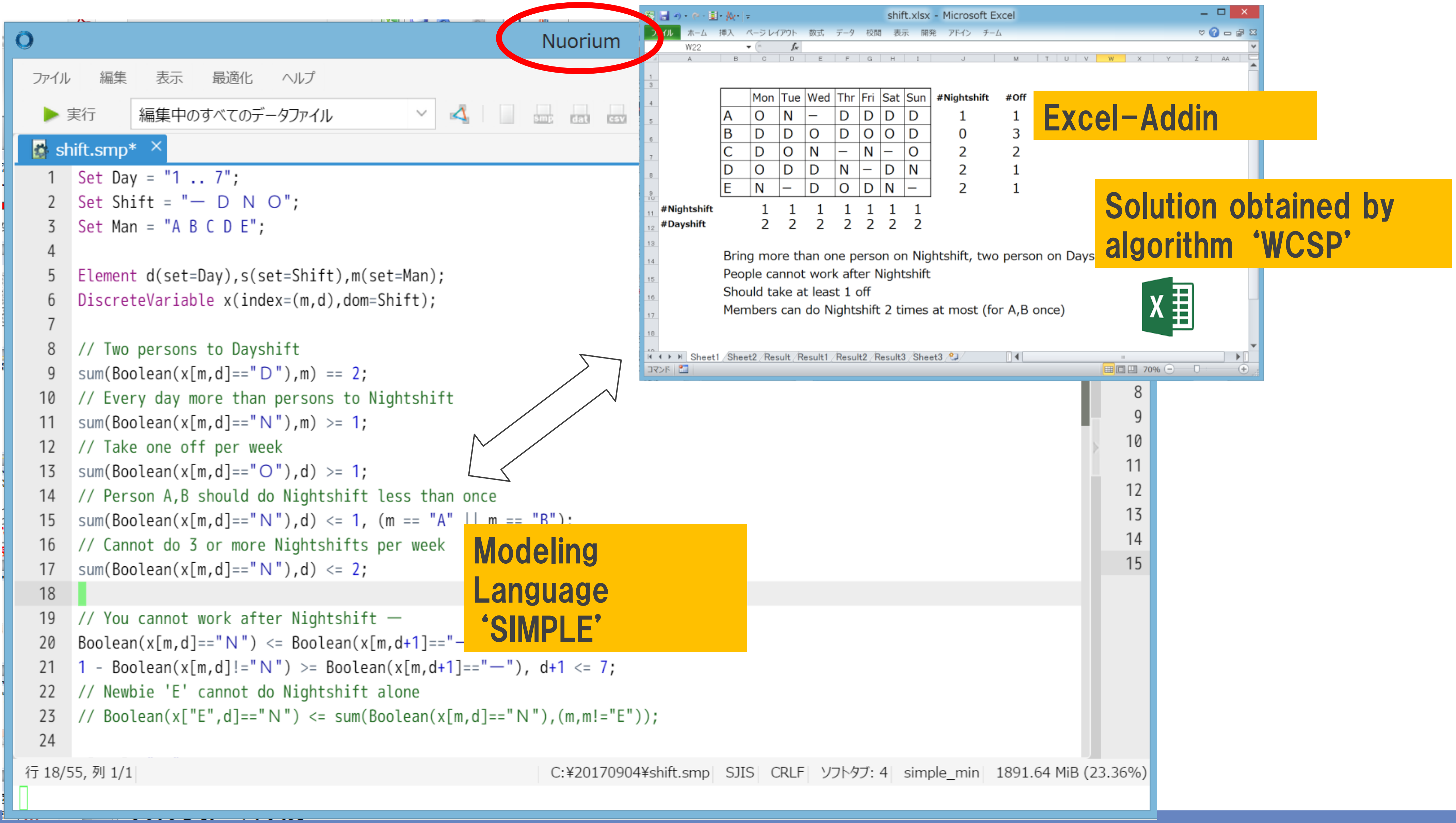
- UG Framework（Yuji Shinano) on MIP parallelization
- HiGHS（Julain Hall et al.） on LP/QP simplex
- WLS（Umetani Shunji) on IP local search

# Simple Demonstration: Staff rostering example

- ✓Bring at least one person on Nightshift, two person on Dayshift everyday
- ✓People cannot work after Nightshift
- ✓Shoud take at least 1 off
- ✓Members can do Nightshift 2 times at most（just once for A,B)

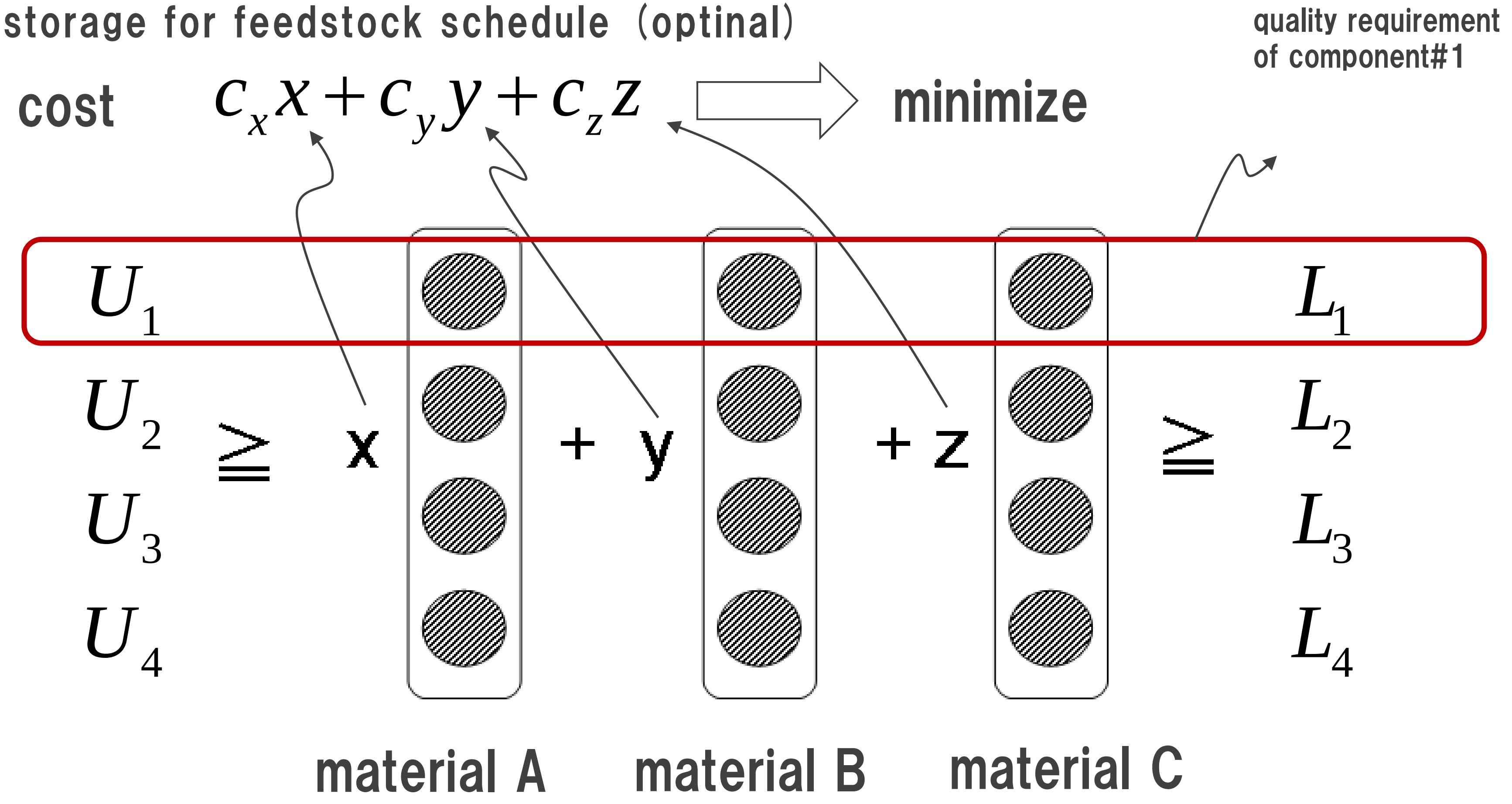
| | Mon | Tue | Wed | Thr | Fri | Sat | Sun | #Nightshift | #Off |
|---|---|---|---|---|---|---|---|---|---|
| A | O | N | – | D | D | D | D | 1 | 1 |
| B | D | D | O | D | O | O | D | 0 | 3 |
| C | D | O | N | – | N | – | O | 2 | 2 |
| D | O | D | D | N | – | D | N | 2 | 1 |
| E | N | – | D | O | D | N | – | 2 | 1 |
| #Nightshift | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| #Dayshift | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | |

# Simple Demonstration: Staff rostering example



# Simple Demonstration: Blending row materials

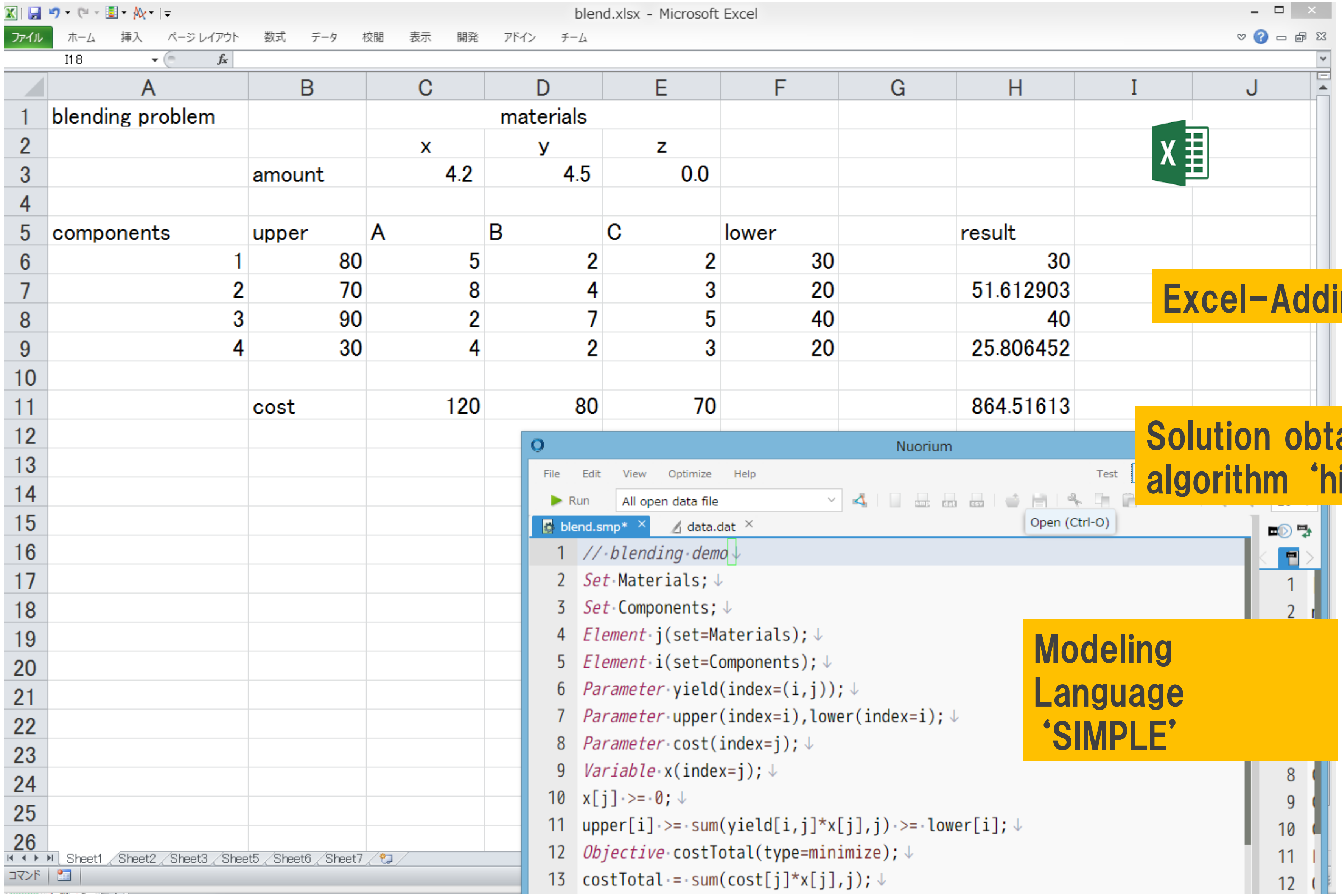
- ✓ Blend row materials (ex. crude oil)
- ✓ Minimize the cost within the quality requirement
- ✓ Manage storage for feedstock schedule (optinal)






NTT DATA

# Simple Demonstration: Blending row materials




**Excel-Addin**

**Solution obtained by algorithm 'higher order IPM'**

**Modeling Language 'SIMPLE'**





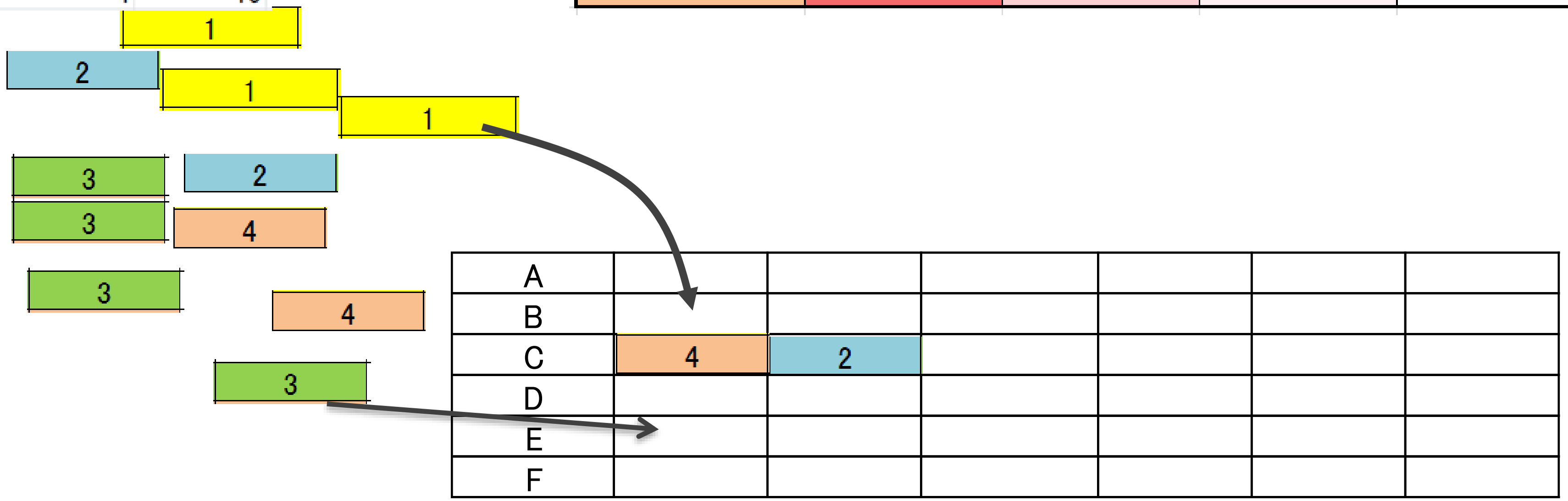
NTT DATA

# Simple Demonstration: Line dispatching

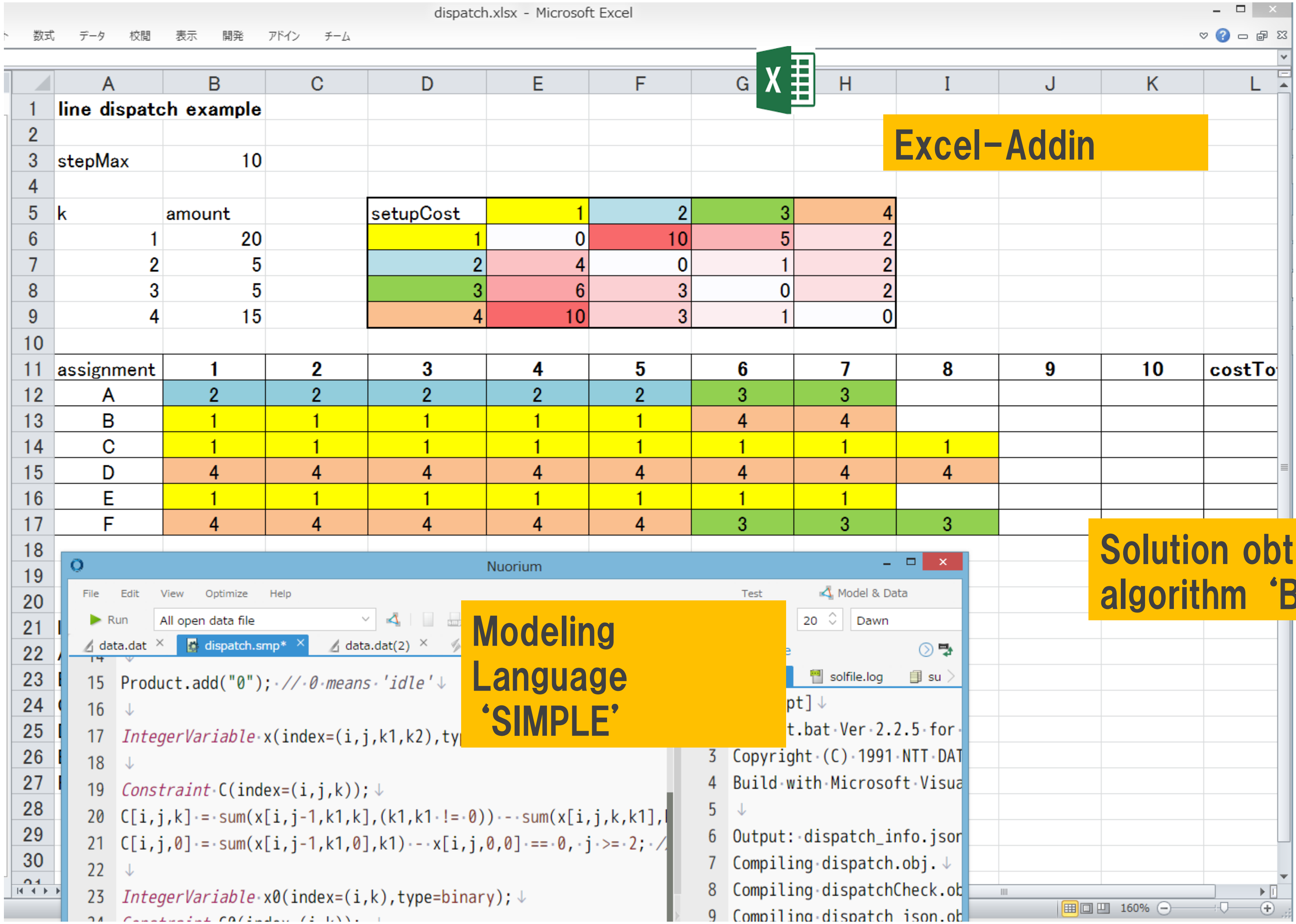
- ✓ Allocate line for production
- ✓ Produce amount as ordered
- ✓ Reduce setup cost as possible
- ✓ Load balancing

| k | amount |
|---|---|
| 1 | 20 |
| 2 | 5 |
| 3 | 5 |
| 4 | 15 |

| setupCost | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 0 | 10 | 5 | 2 |
| 2 | 4 | 0 | 1 | 2 |
| 3 | 6 | 3 | 0 | 2 |
| 4 | 10 | 3 | 1 | 0 |



# Simple Demonstration: Line dispatching demo




Excel-Addin

Solution obtained by algorithm ‘BB’

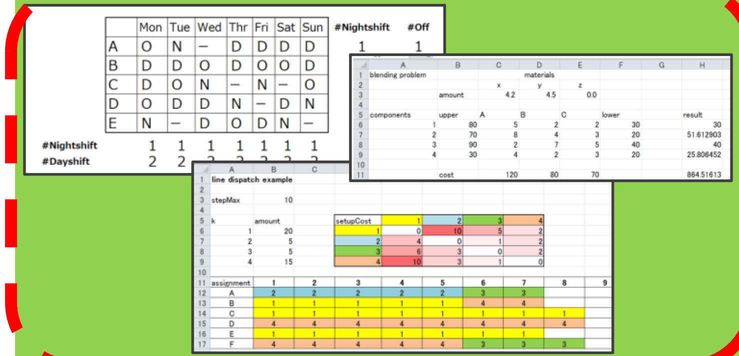
Modeling Language ‘SIMPLE’

# Classifying applications/mathematical optimization model

Simple Demonstrations

Easy (toy) | Fair | Real Usecases | Hard (intractable)

**Real World**



Gas-Supply routing
Retailer's Staff scheduling
Railload maintenance
…

Tokyo Gas Co., Ltd.: Toward implementation of logistics optimization of liquefied natural gas (LNG) sales business using lorry vehicles

Railway Technical Research Institute: How did Nuorium Optimizer changed Track maintenance

Japan International Cooperation Agency: Optimal matching of Japan Overseas Cooperation Volunteers

Supply-chain global optimization
Full-automatic vehicle routing
…

**Math. Model**

#var,#cons ~ 50
Optimal solution in sub-second.

#var,#cons ~ $10^{4-5}$
Fair solutions available in several min.

#var,#cons > $10^6$
feasible solution not always available

# Typical Communication #1 (easy application ⇔ easy model)

| | Easy (toy) | Fair | Hard (intractable) |
|---|---|---|---|
| Real World | Potential Users: "It's good to know !" | Gas-Supply routing<br>Retailer's Staff scheduling<br>Road maintenance | Supply-chain global optimization<br>Full-automatic vehicle routing<br>・・・ |
| Math. Model | MSI: "Just look how it works !" | #var,#cons ~ $10^{4-5}$<br>Fair solutions available in several min. | #var,#cons > $10^6$<br>feasible solution not always available |




NTT DATA

# Typical Communication #2 (difficult/huge model ⇒ …)

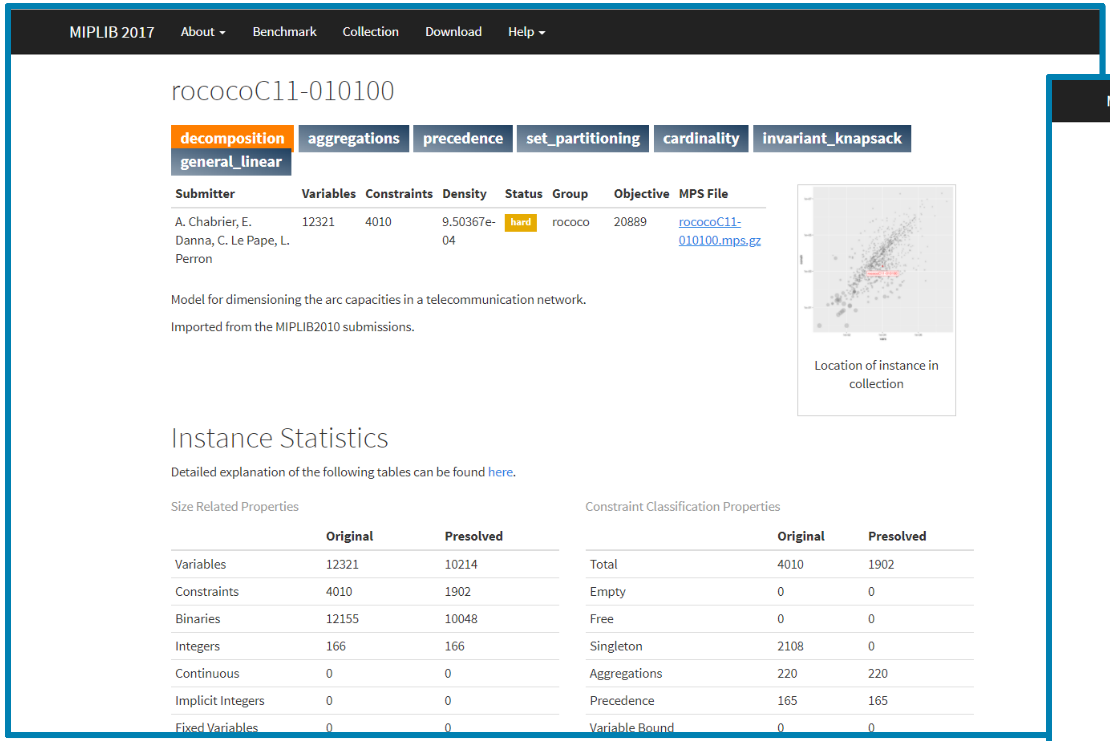
| | Easy (toy) | Fair | Hard (intractable) |
|---|---|---|---|
| Real World |  | Gas-Supply routing<br>Retai | |
| Math. Model | #var,#cons ~ 50<br>Optimal solution<br>in sub-second. | | |

Potential Users:
"Interesting !
But how does it imipact my job ?"

MSI:
"It worked! Fascinating, isn't it ?"

# Current Development of ParaNUOPT（Nuorium Optimizer powered by UG solver）

- ParaNUOPT first solved the following open instances from MIPLIB2017
  - gen-ip016（in 71498 seconds, on PC cluster with 19 cores）
  - rococoC11-010100（in 32368 seconds, on PC cluster with 9 cores）
- We are now developing ParaNUOPT on a general cloud HPC cluster.



MIPLIB 2017 About Benchmark Collection Download Help

rococoC11-010100

decomposition aggregations precedence set_partitioning cardinality invariant_knapsack general_linear

| Submitter | Variables | Constraints | Density | Status | Group | Objective | MPS File |
|---|---|---|---|---|---|---|---|
| A. Chabrier, E. Danna, C. Le Pape, L. Perron | 12321 | 4010 | 9.50367e-04 | hard | rococo | 20889 | rococoC11-010100.mps.gz |

Model for dimensioning the arc capacities in a telecommunication network.

Imported from the MIPLIB2010 submissions.

Location of instance in collection

Instance Statistics

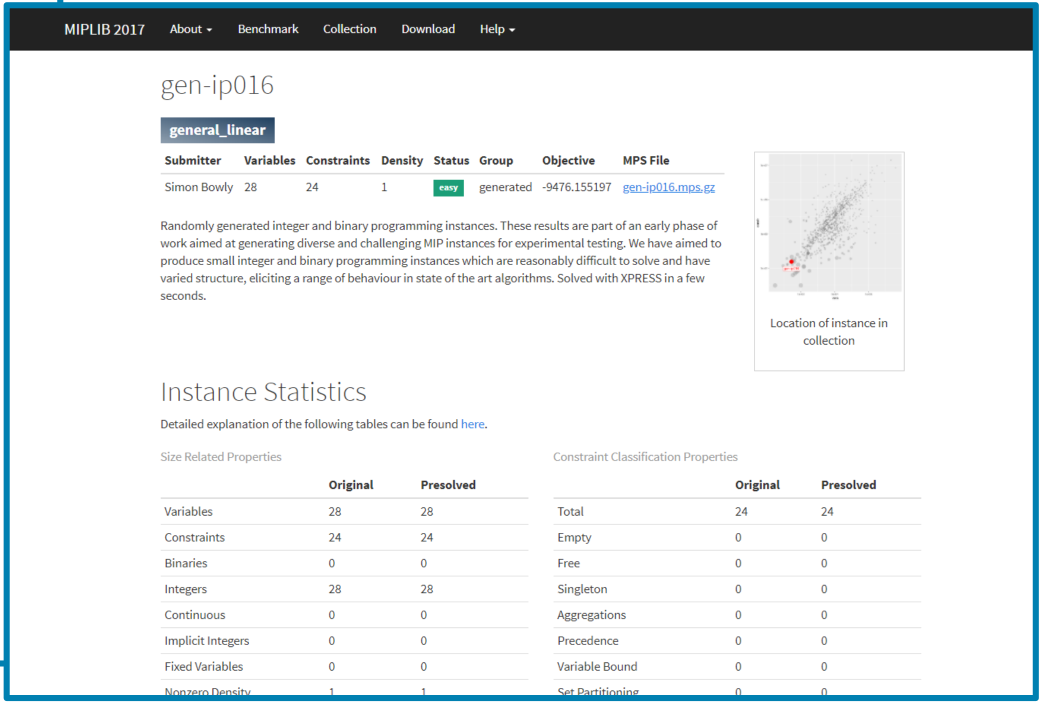
Detailed explanation of the following tables can be found here.

Size Related Properties

| | Original | Presolved |
|---|---|---|
| Variables | 12321 | 10214 |
| Constraints | 4010 | 1902 |
| Binaries | 12155 | 10048 |
| Integers | 166 | 166 |
| Continuous | 0 | 0 |
| Implicit Integers | 0 | 0 |
| Fixed Variables | 0 | 0 |

Constraint Classification Properties

| | Original | Presolved |
|---|---|---|
| Total | 4010 | 1902 |
| Empty | 0 | 0 |
| Free | 0 | 0 |
| Singleton | 2108 | 0 |
| Aggregations | 220 | 220 |
| Precedence | 165 | 165 |
| Variable Bound | 0 | 0 |



MIPLIB 2017 About Benchmark Collection Download Help

gen-ip016

general_linear

| Submitter | Variables | Constraints | Density | Status | Group | Objective | MPS File |
|---|---|---|---|---|---|---|---|
| Simon Bowly | 28 | 24 | 1 | easy | generated | -9476.155197 | gen-ip016.mps.gz |

Randomly generated integer and binary programming instances. These results are part of an early phase of work aimed at generating diverse and challenging MIP instances for experimental testing. We have aimed to produce small integer and binary programming instances which are reasonably difficult to solve and have varied structure, eliciting a range of behaviour in state of the art algorithms. Solved with XPRESS in a few seconds.

Location of instance in collection

Instance Statistics

Detailed explanation of the following tables can be found here.

Size Related Properties

| | Original | Presolved |
|---|---|---|
| Variables | 28 | 28 |
| Constraints | 24 | 24 |
| Binaries | 0 | 0 |
| Integers | 28 | 28 |
| Continuous | 0 | 0 |
| Implicit Integers | 0 | 0 |
| Fixed Variables | 0 | 0 |
| Nonzero Density | 1 | 1 |

Constraint Classification Properties

| | Original | Presolved |
|---|---|---|
| Total | 24 | 24 |
| Empty | 0 | 0 |
| Free | 0 | 0 |
| Singleton | 0 | 0 |
| Aggregations | 0 | 0 |
| Precedence | 0 | 0 |
| Variable Bound | 0 | 0 |
| Set Partitioning | 0 | 0 |

# What do users want ?

| | Easy (toy) | Fair | Hard (intractable) |
|---|---|---|---|
| Real World |  | Gas-Supply routing<br>Retai | |
| Math. Model | | | #var,#cons > $10^6$<br>feasible solution<br>not always available |

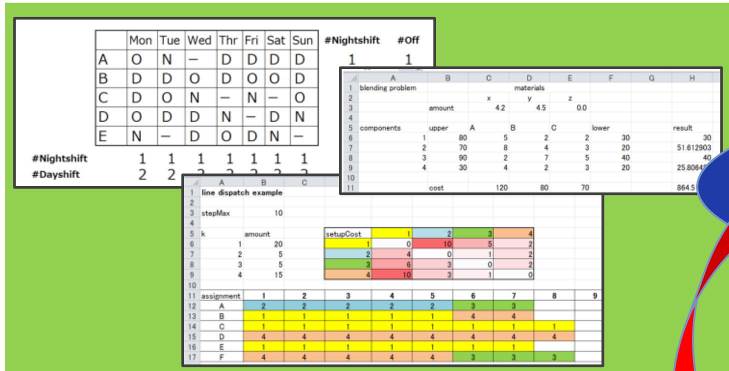
Potential Users:
"We'll buy solutions in THIS area."


MSI:
"We can provide solutions
in THIS area."



NTT DATA

# More Desirable Communication

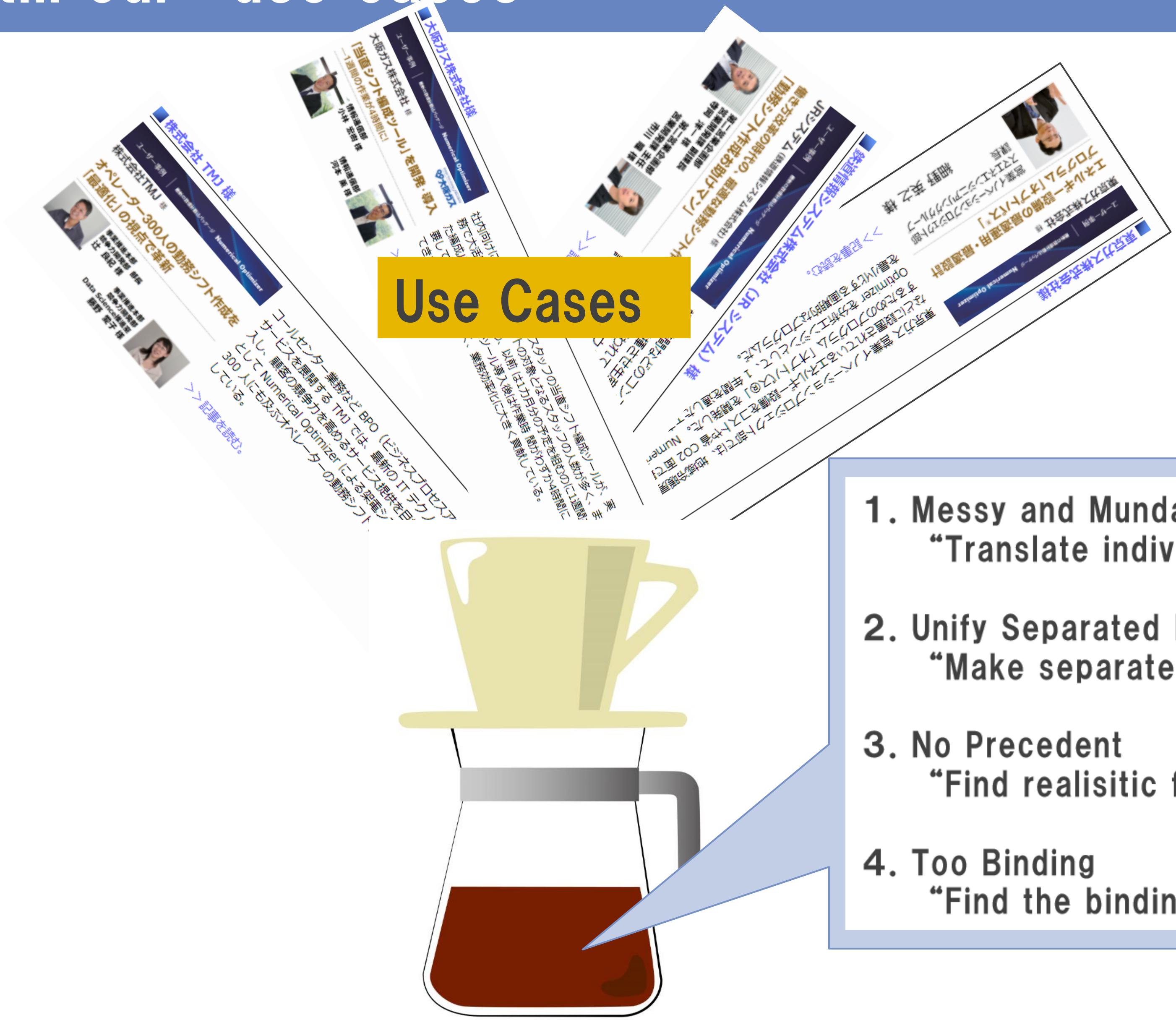
| | Easy (toy) | Fair | Hard (intractable) |
|---|---|---|---|
| Real World |  | Gas-Supply routing<br>Retailer' [partly hidden]<br> | |
| Math. Model | #var,#cons ~ 50<br>Optimal soluti[on]<br>in sub-second. | | #var,#cons > $10^6$<br>feasible solution<br>not always available |



Potential Users:
"We have problems such that.."

MSI:
"For that, optimization might help.."

# Distill our ‘use cases’




1. Messy and Mundane
   “Translate individual expertise to shoulder drudgery !”

2. Unify Separated Decision
   “Make separate decision consistent !”

3. No Precedent
   “Find realisitic feasible solution !”

4. Too Binding
   “Find the binding constraint to improve decition !”

# Mathematical Optimization Users have Tasks such that ..

1. Messy and Mundane
   "Translate individual expertise to shoulder drudgery !"

2. Unify Separated Decision
   "Make separate decision consistent !"

3. No Precedent
   "Find realisitic feasible solution !"

4. Too Binding
   "Find the binding constraint to improve our decision !"

# Mathematical Optimization Users have Tasks such that ..

1. Messy and Mundane
   "Translate individual expertise to shoulder drudgery !"

2. Unify Separated D
   "Make s

3. No Prece
   "Find re

4. Too Bind
   "Find th

- ✓ Staff Rostering for next month
- ✓ Vehicle Dispatch for next week
- ✓ Cutting Stock Planning for delivery

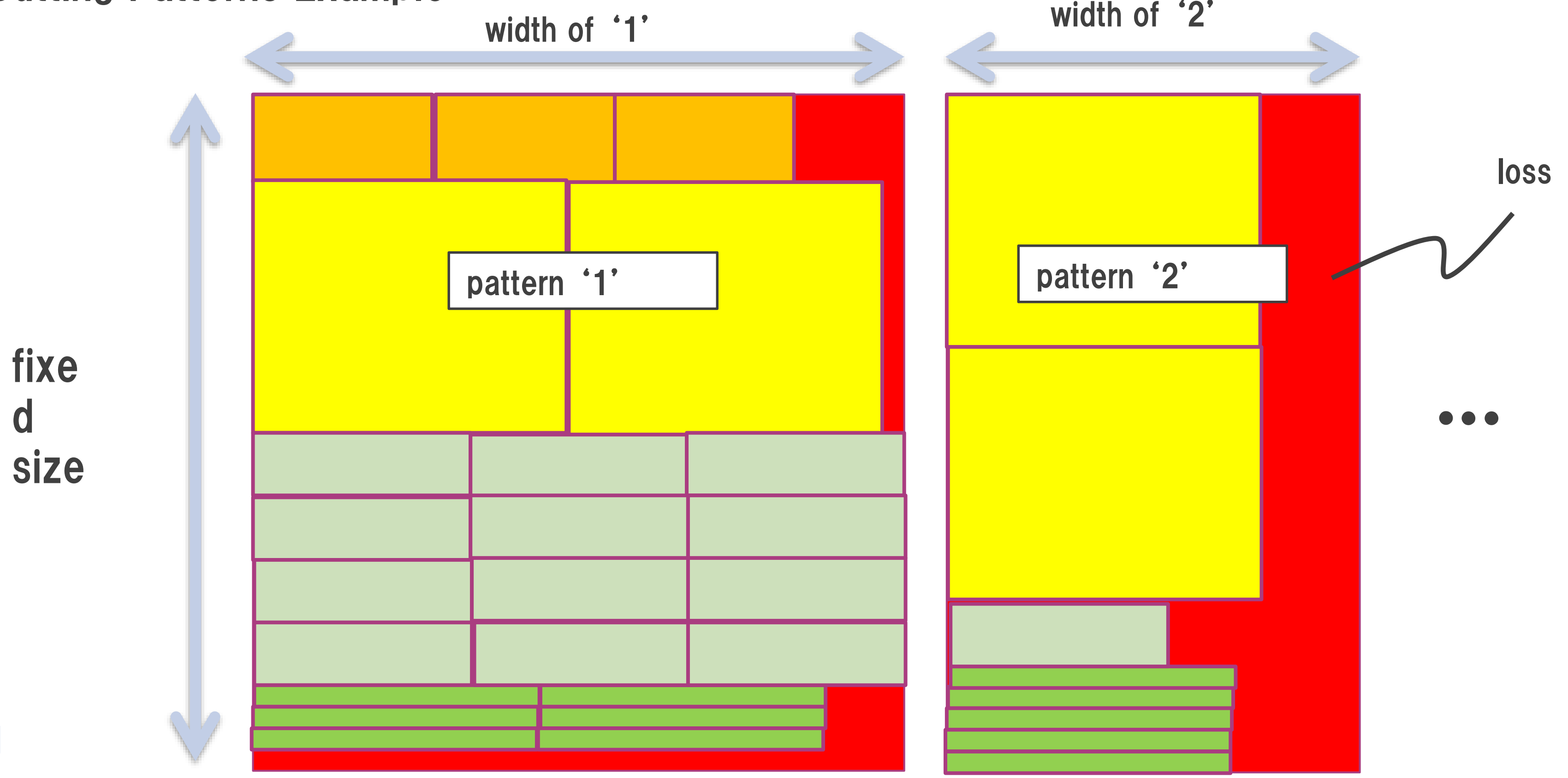
Slightly different setting,
Not well-documented,
Repetitive,
Difficult to find successor

# A Cutting Stock Problem for Film Manufacturer (2017-)

✓ Cutting Pattern is 2D region tiled by rectangular products
✓ Fulfill the product demand
✓ Trade-off: Reduce (# of Cutting Pattern) ⇔ (amount of loss)

Make plan weekly for product demand
⇒ complex repetitive task

Cutting Patterns Example



# Mathematical Optimization Users have Tasks such that ..

1. Messy and Mundane
   "Translate individual expertise to shoulder drudgery !"

2. Unify Separated Decision
   "Make separate decision consistent !"

3. No Precedent
   "Find realis

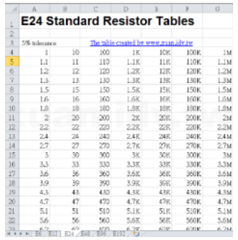
4. Too Binding
   "Find the b

- ✓ Buy cheap material, as long as our factory can accept.
- ✓ Receive the order, if it meets the production capacity.

Relevant (but separated) departments make individual decision, but they should be consistent.

# Manufacurer（Separate Department, individual decision）

demand




- ✓ blend row materials
- ✓ roster staffs
- ✓ select line for production
- ✓ allocate production resource
- ✓ manage storage for feedstock
- ✓ devise cutting pattern

feedstock

- ✓ plan shipment

factory

customer

- ✓ routing configuration
- ✓ assign route to vehicle

- ✓ arrange（half-finished）goods

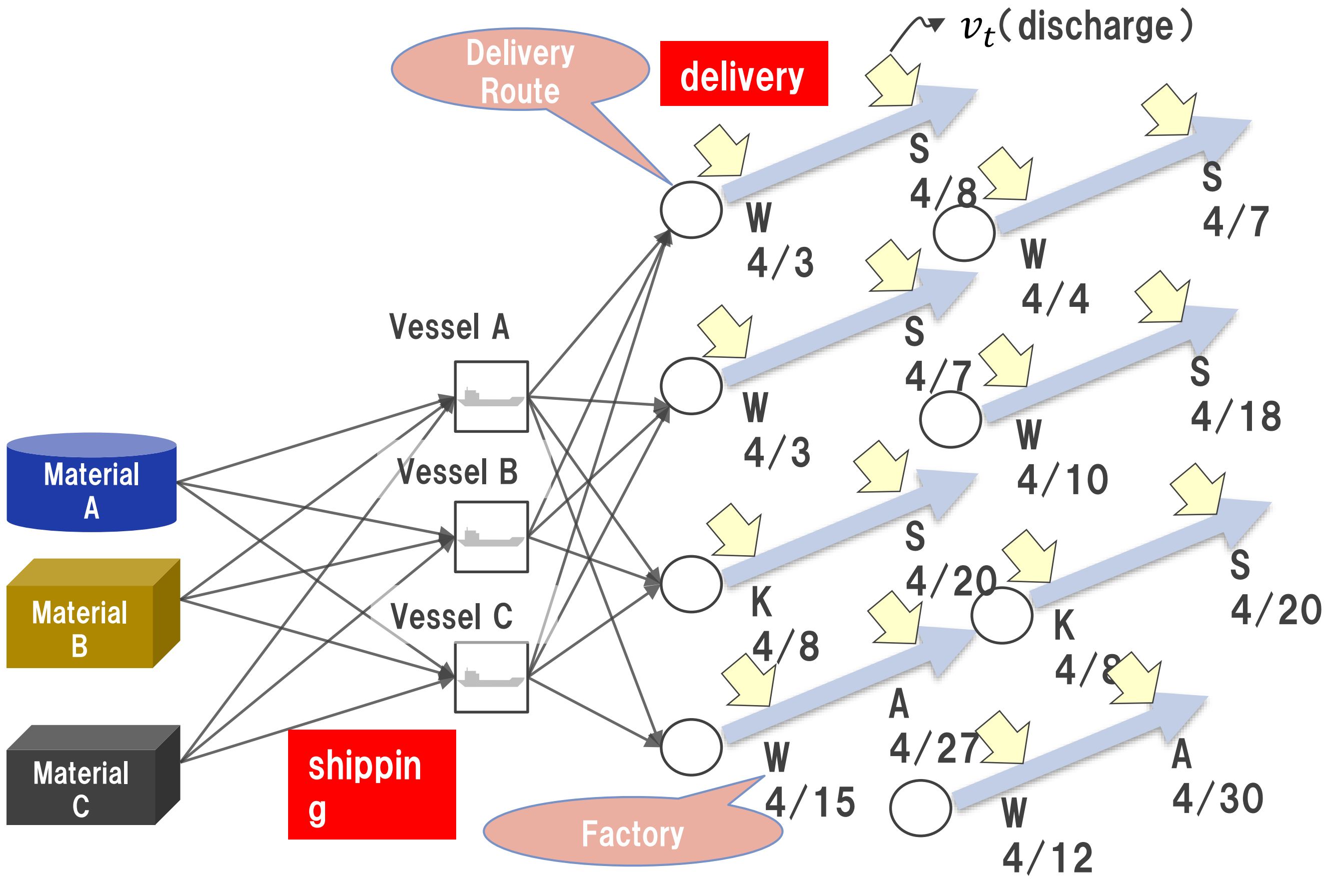
- ✓ stock allocation
- ✓ loading

warehouse/storage

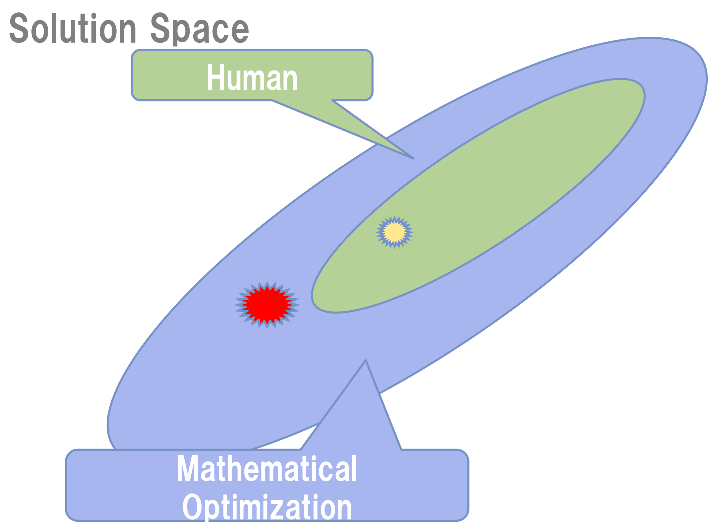
**Sales/Production/Delivery department separated ⇒ but decision should be consistent**

# Shipping Delivery Planning at a Japanese Manufacturer (2018-)

- ✓ Shipping & Delivery planning
- ✓ Material Purchase (loading) / production (unloading) should be consistent
- ✓ Aimed overall cost minimization




Purchase & Production should be consistent aiming at cost reduction.
⇒ Make separate decision consistent



# Mathematical Optimization Users have tasks such that ..

1. Messy and Mun
   "Translate ind

2. Unify Separate
   "Make separa

3. No Precedent
   "Find realisitic feasible solution !"

4. Too Binding
   "Find the binding constraint to improve our decision!"

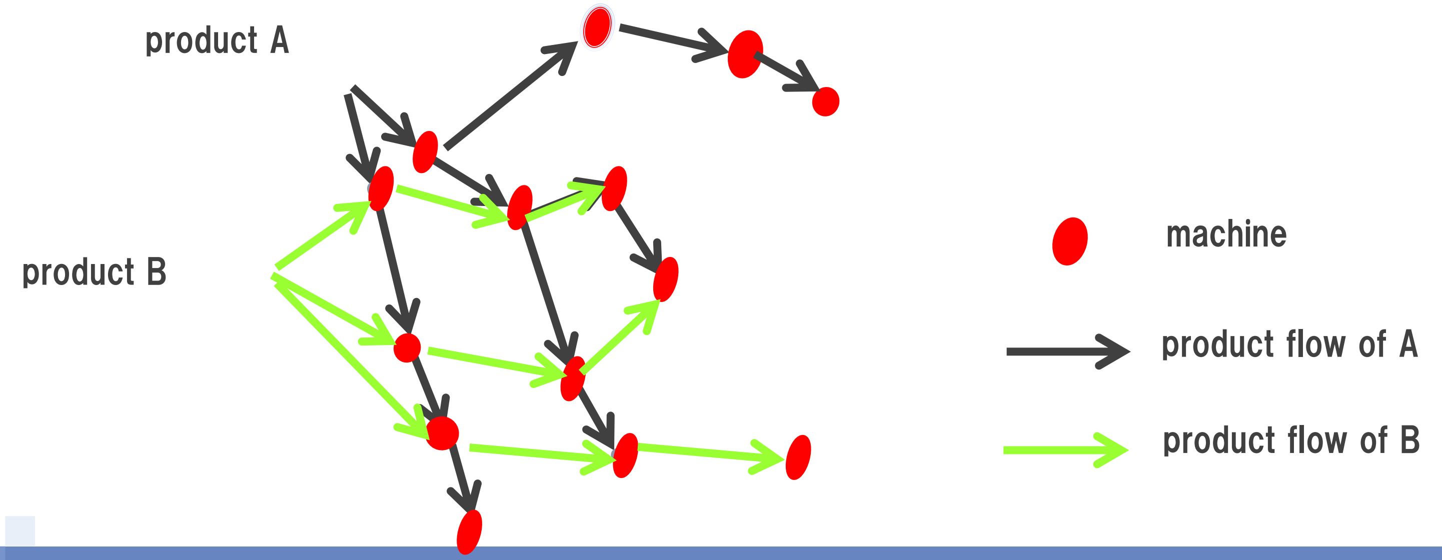
✓ See if production is possible with
the reduced facility / new row-material.
✓ Confirm that personel reduction do not affect the operation

Simulate the realistic outcome.
One realistic feasible solution will do.

# Production Resource Planning at a Japanese Manufacturer（2013-)

- ✓Each product has unique process flow
- ✓Each product requires certain machine resource we should allocate
- ✓Each machine need special equipment to handle each product' s process
- ✓Reduce equipment keeping the production output within the available machine resource

Achievement:  Reduced special equipments by 30～50%
# of machines : 60
# of products  : 48




No one knows if the production possible with reduced equipment.

⇒ Simulate the realisitic outcome.



NTT DATA

# LNG plant scheduling at Osaka Gas Company（2008-）

- ✓ Given the arrival date of LNG-vessels, determine LNG plant tank operation schedule（30days, daily, 18tanks）
- ✓ Move storage LNG and never miss the LNG conveyed.
- ✓ Constraint from equipment, facility cheking schedule.
- ✓ Output LNG density control is CRUCIAL,
  confirm if production possible with low-density LNG.

No one knows if the production possible with low-density LNG.

⇒ Simulate the realisitic outcome.

store（tank management）
blend（density control）

# Staff rostering at a Japanese Bank（2015)

- ✓ Bank headquarter wants to reduce staff.
- ✓ Check if the operation of backoffice with staff members reduced.

| | Mon | Tue | Wed | Thr | Fri | Sat | Sun |
|---|---|---|---|---|---|---|---|
| A | O | N | – | D | D | D | D |
| B | D | D | O | D | O | O | D |
| C | D | O | N | – | N | – | O |
| D | O | D | D | N | – | D | N |
| E | N | – | D | O | D | N | – |

Real feasible staff rostering works as ‘evidence’ and succeeded to persuade the backoffice.

⇒ Simulate the realisitic outcome.

# Mathematical Optimization Users have Tasks such that ..

1. Messy and Mundane
   "Translate individual expertise to shoulder drudgery !"

2. Unify Separated
   "Make separat

3. No Precedent
   "Find realisiti

4. Too Binding
   "Find the binding constraint to improve our decision !"

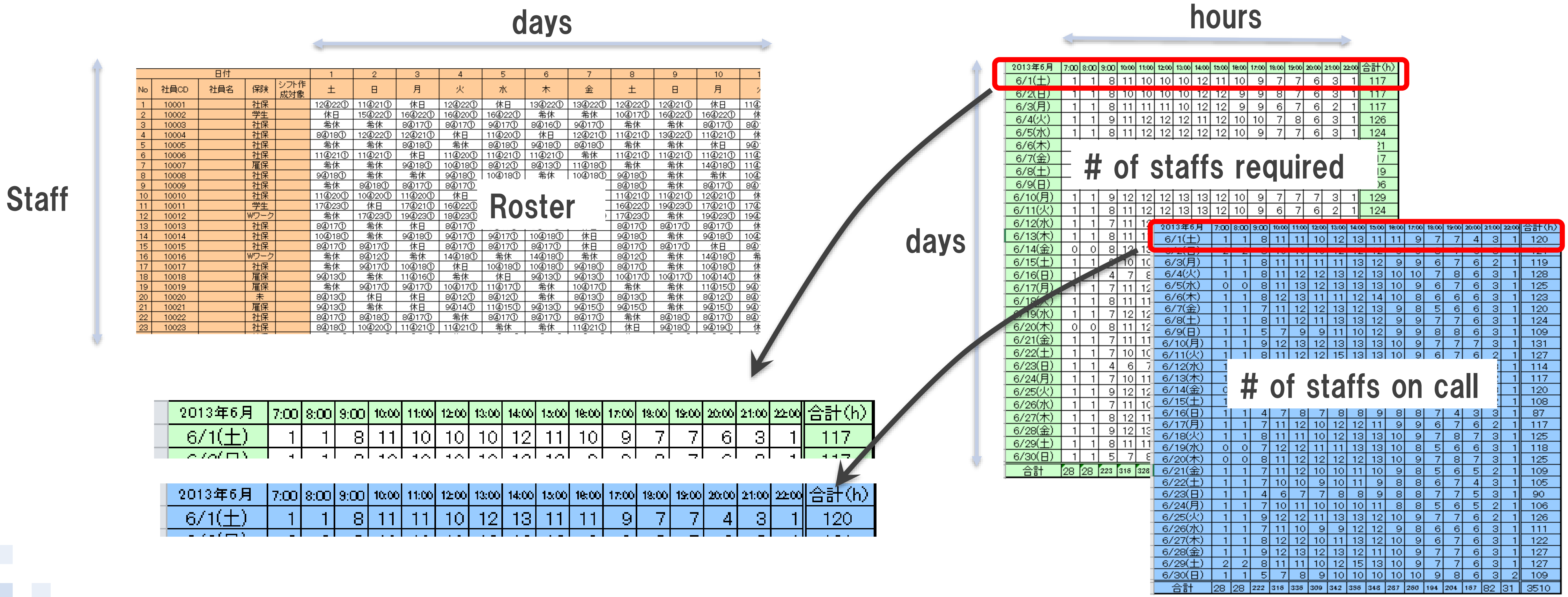
- ✓ Assign enough staffs on call but overwork prohibited!
- ✓ Reduce maintenance cost not sacrificing quality.

Find the source of the trade-off

# Staff Rostering at Call-Center (2012-)

Call loss should be minimzied with numerous staff constraint
⇒ Find the trade-off solution.

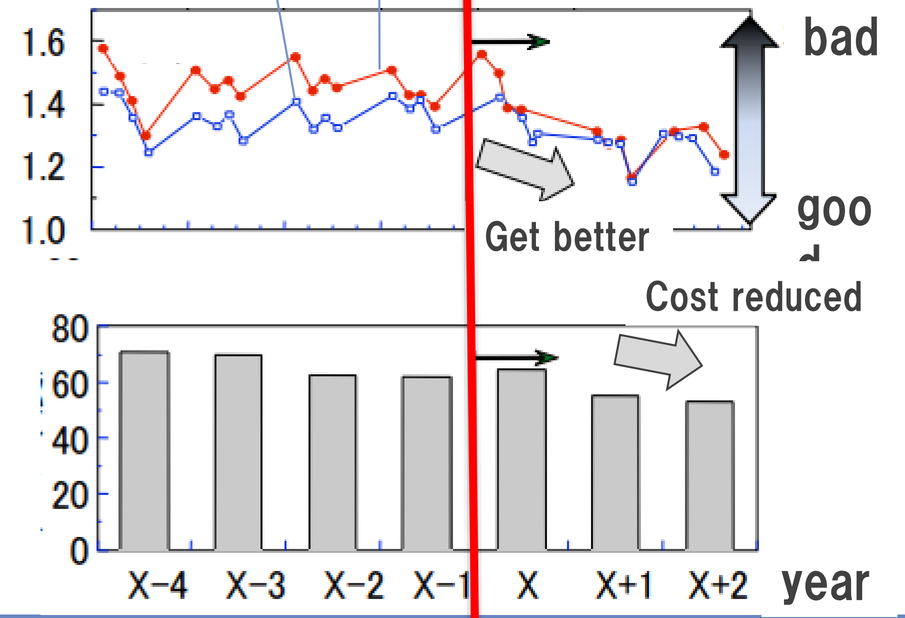
- ✓ Monthly staff rostering for upto 250 staffs
- ✓ Enough staff should be on call.
- ✓ Staff skill, vacation schedule, condition of employment should be satisfied.



# Railway maintenance scheduling at railway technical research institute (2000-)

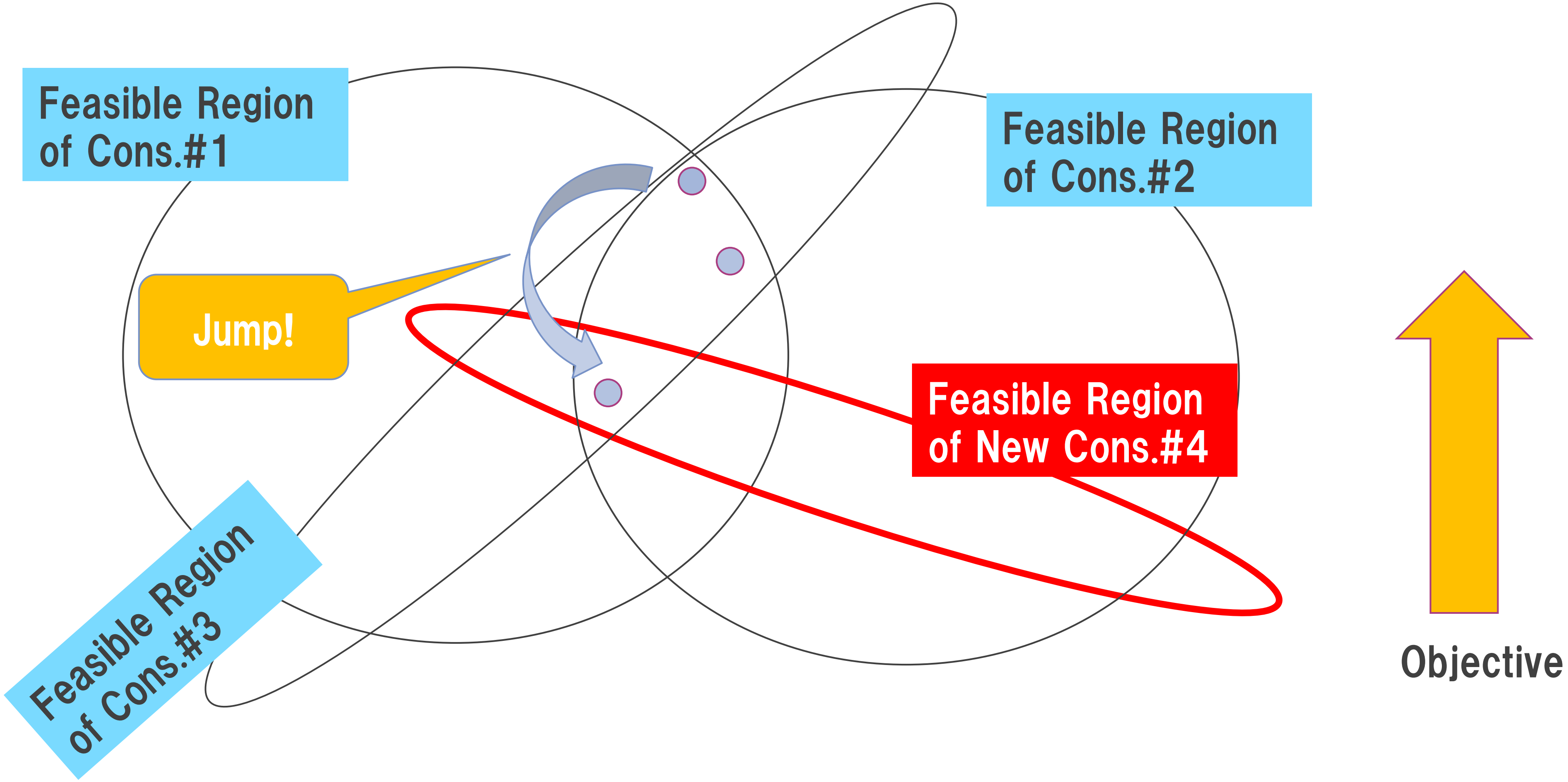
- ✓ Given the result of measurement, plan the maintenance schedule using MTT.
- ✓ Cost should be reduced **not sacrificing** safety.

MTT




Strike the balance of cost and safety
⇒ Find the trade-off to improve.

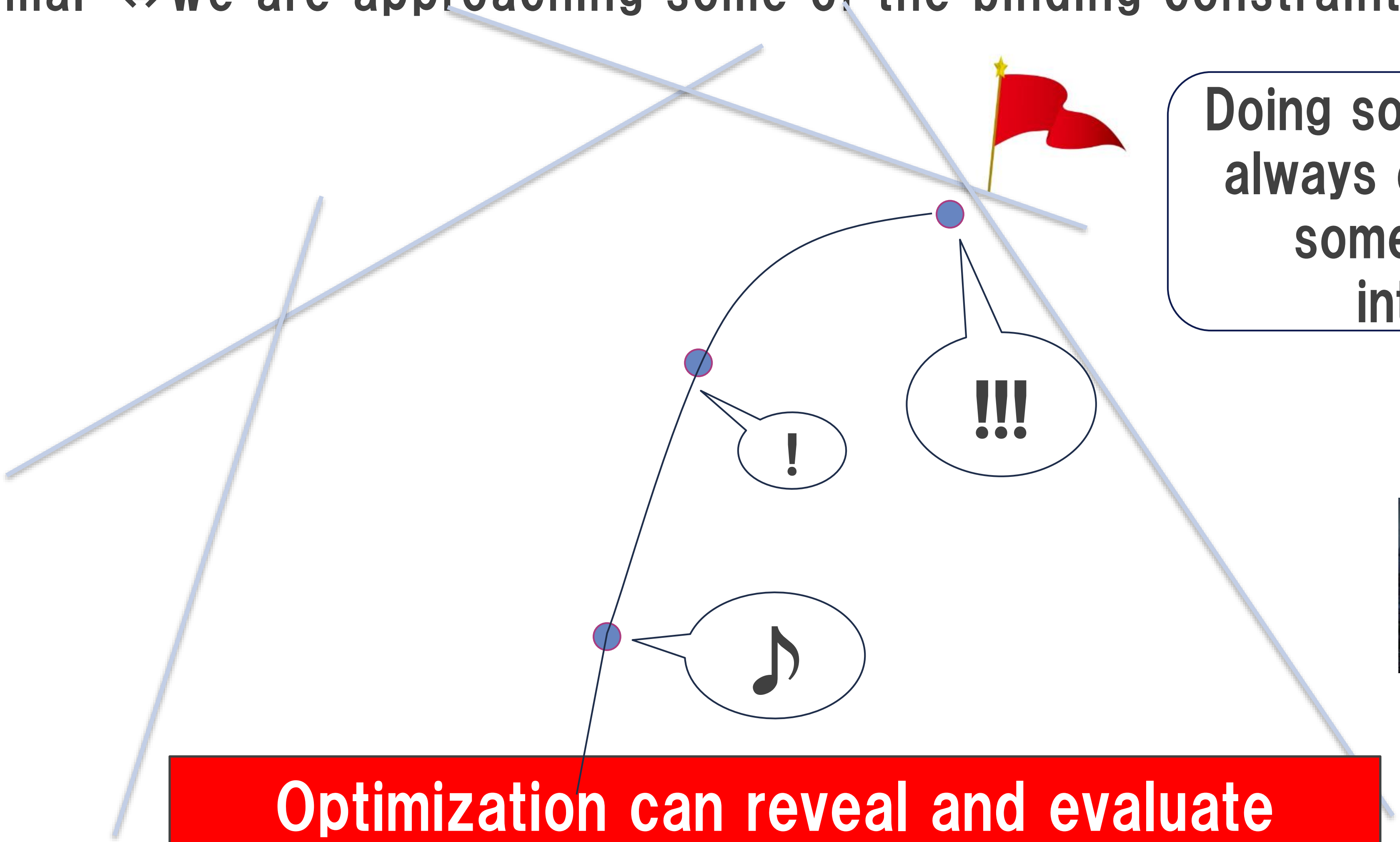
# Core competency of mathematical optimization #1




**Optimization can clarify the impact of constraint**

# Core competency of mathematical optimization #2

'Nearly optimal' ⇔We are approaching some of the binding constraint.

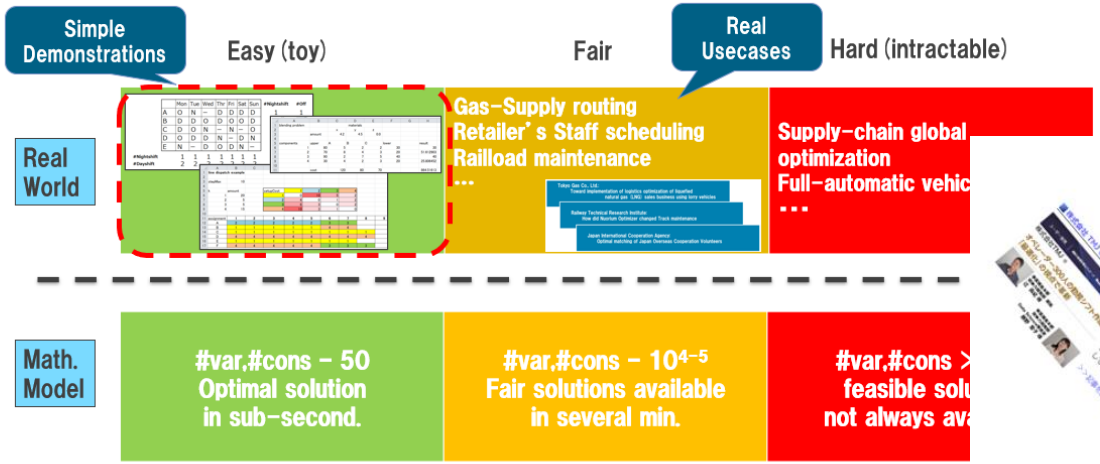



Doing something new always conflict with some other' s interest.

**Optimization can reveal and evaluate the Binding Constraint**

# Thank you very much for listening !

[https://www.msi.co.jp/nuopt/english](https://www.msi.co.jp/nuopt/english)





1. Messy and Mundane
   "Translate individual expertise to shoulder drudgery !"
2. Unify Separated Decision
   "Make separate decision consistent !"
3. No Precedent
   "Find realisitic feasible solution !"
4. Too Binding
   "Find the binding constraint to improve decition !"

We call ourselves **MSI**

| | |
|---|---|
| **Name** | NTT DATA Mathematical Systems Inc. |
| **Office location** | Shinanomachi, Shinjuku-ku, Tokyo |
| **History** | **Founded in 1982** as Mathematical Systems Inc.<br>Joined NTT DATA group in February, 2012<br>Changed name to NTT DATA Mathematical Systems Inc. in September, 2013 |
| **Common Stock** | 56 million yen |
| **Financial Information** | Net Sales : 1700 million yen<br>Ordinary Income : 305 million yen<br>(April 1,2018 to March 31,2019) |
| **Number of Employees** | **115** (as of April 1, 2020)<br>Technical staff : about 87<br>Background -Scientists : 65% -Engineers : 10%<br>Degree -Master : 67% -Ph.D. : 14% |
| **Business** | Packaged software development and sales<br>Analysis and Consulting services<br>Entrusted development of software |

NTT DATA

Trusted Global Innovator