T-QARD and DENSO: A Great Collaboration for Plant Optimization

Graduate School of Information Sciences,
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In collaboration with DENSO

TOHOKU
UNIVERSITY

Optimization the moment: Our team

DENSO

- A leading supplier of advanced automotive technology, systems and components for major automakers
- Collaboration with Tohoku University and Waseda University since Dec. 2015

DENSO × QUANTUM 3

DENSO
Crafting the Core

T-QARD

- Tohoku university Quantum Annealing Research and Development
- Established since Oct. 2017
- Core of collaborations via D-Wave machine in Japan
- We are making a consortium of companies for setting D-Wave machine in Japan

Tohoku University
-Break limit of your potential-
Quantum Annealing Research & Development
QARD
Supported by JST project for creating START

Our recent results are …

- ✓ **Optimization in Plant**
  - ✓ Today main topic
  - ✓ Safe and optimal control of Automated Guided Vehicles (AGVs)
  - ✓ We formulate its QUBO problem and demonstrate its efficiency
- ✓ **Optimization for Tsunami Evacuation**
  - ✓ Avoiding congestion and smooth evacuation
  - ✓ We formulate its QUBO problem and demonstrate its result for the case of Kochi in Japan
- ✓ Optimization in Quantum Clustering
  - ✓ Hybrid use of the D-Wave machine and Classical computers
  - ✓ Presented in AQC2018

DENSO × QUANTUM

DENSO

Crafting the Core

Tohoku University -Break limit of your potential-

Quantum Annealing Research & Development

QARD

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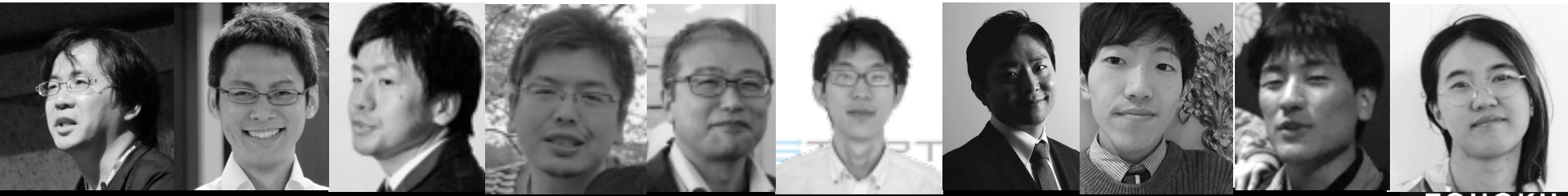

Optimization in Plant

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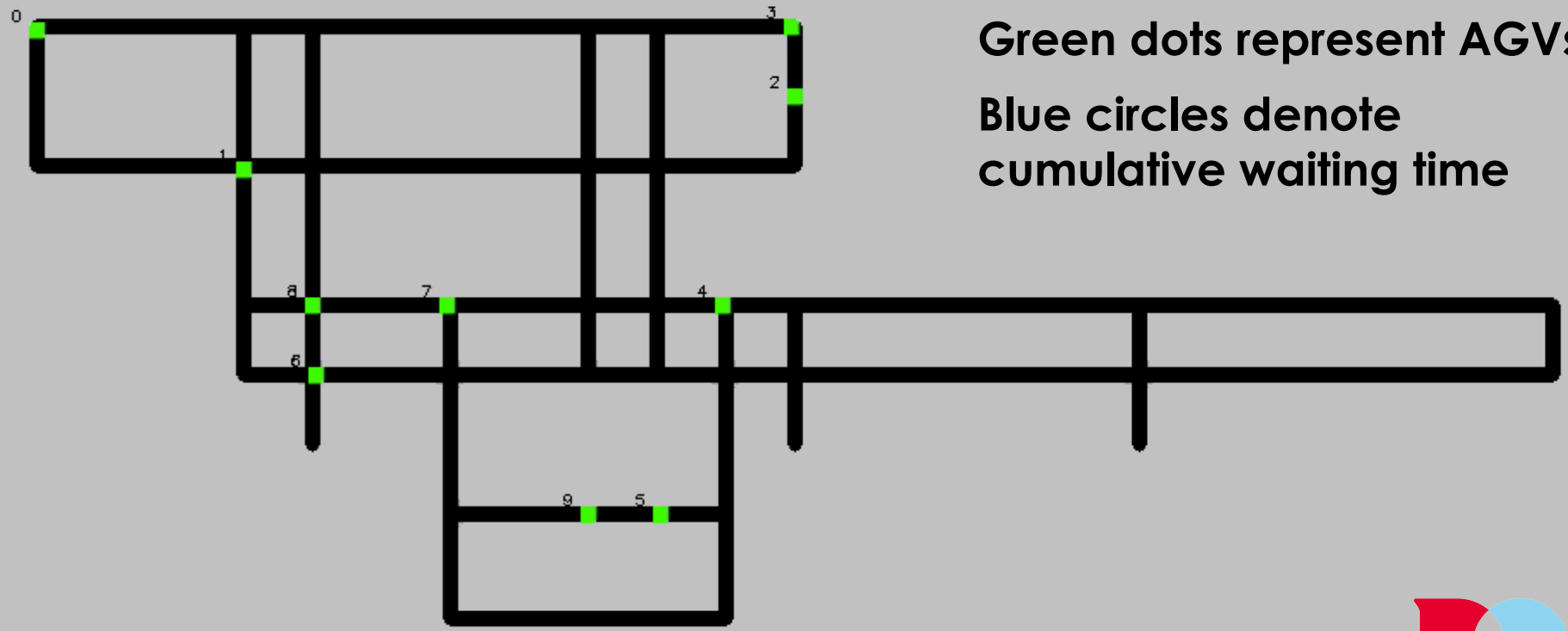


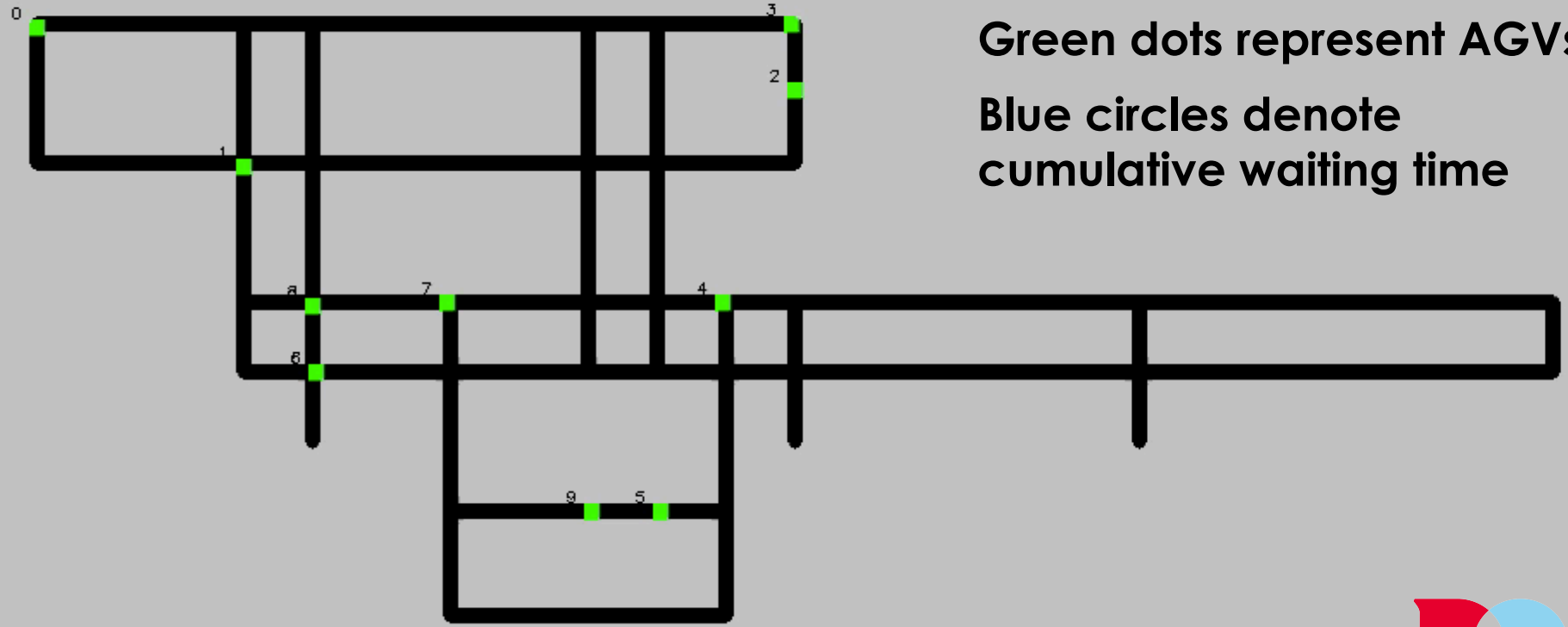
Green dots represent AGVs

Blue circles denote cumulative waiting time

Move: 70 %, Wait: 30 %, Safe: 100 %, Danger: 0 %

Conventional method in plant

Optimization in Plant



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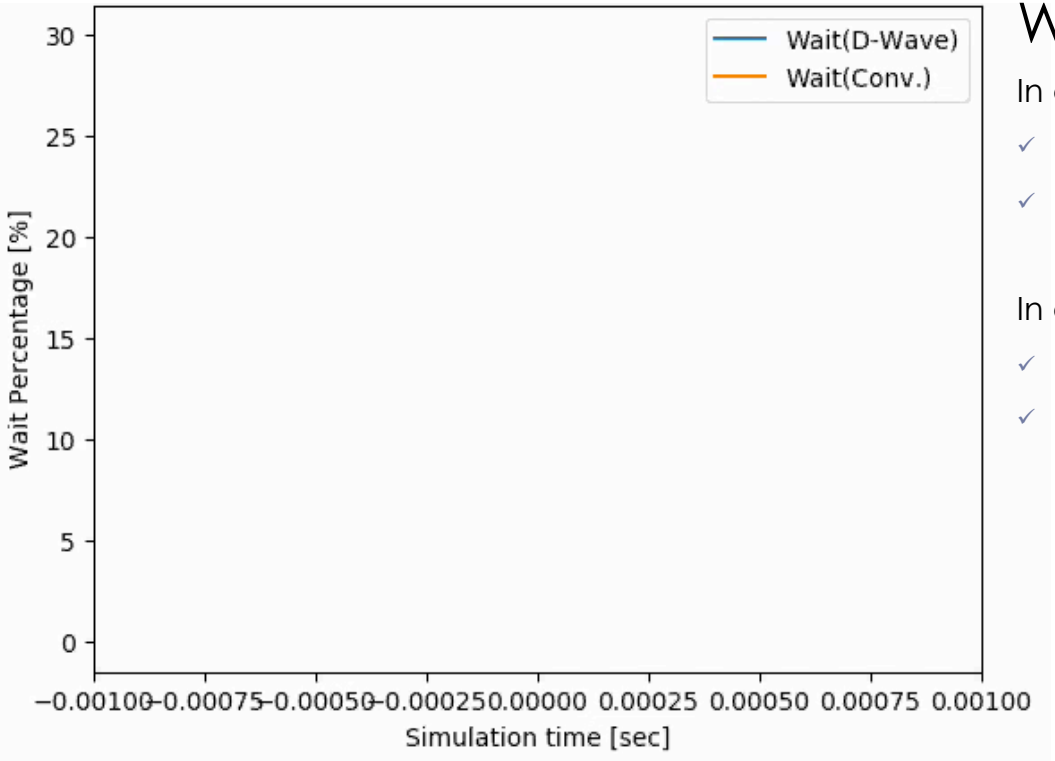
DENSO / QUANTUM

Optimization by D-Wave 2000Q

Optimization in Plant



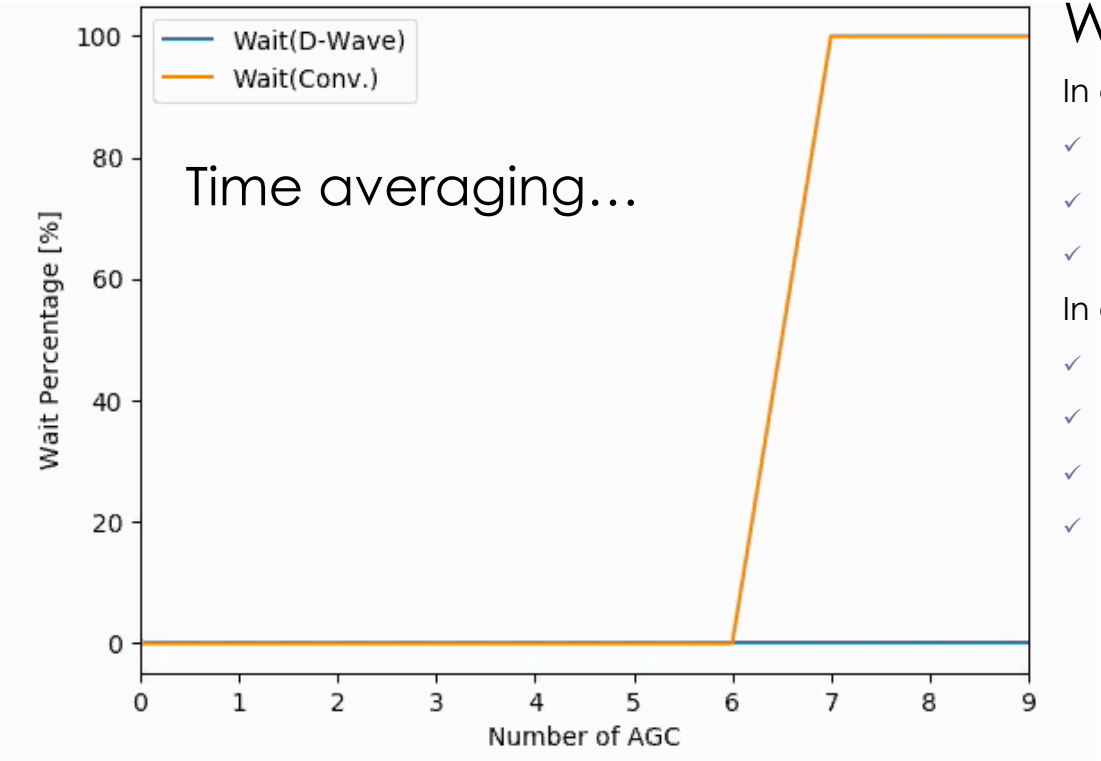
Waiting rate of AGV

In conventional method…

- ✓ Average waiting rate is **higher than 15 %**
- ✓ Average waiting rate converges to **20 %**

In optimization by QUBO…

- ✓ Average waiting rate is always **lower than 10 %**
- ✓ Average waiting rate converges to **5 %**



Waiting rate of AGV

In conventional method…

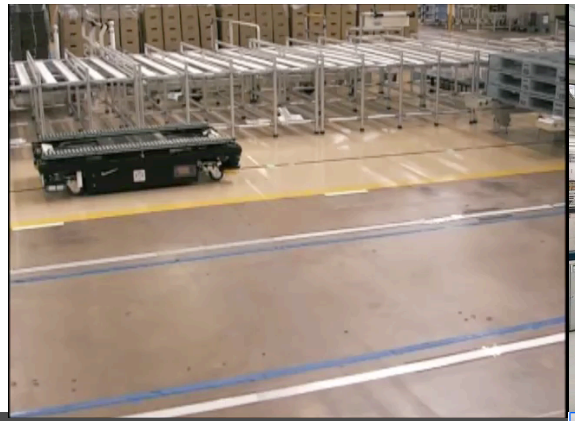
- ✓ Average waiting rate is **higher than 15 %**
- ✓ Average waiting rate converges to **20 %**
- ✓ Maximum waiting rate converges to **25 %**

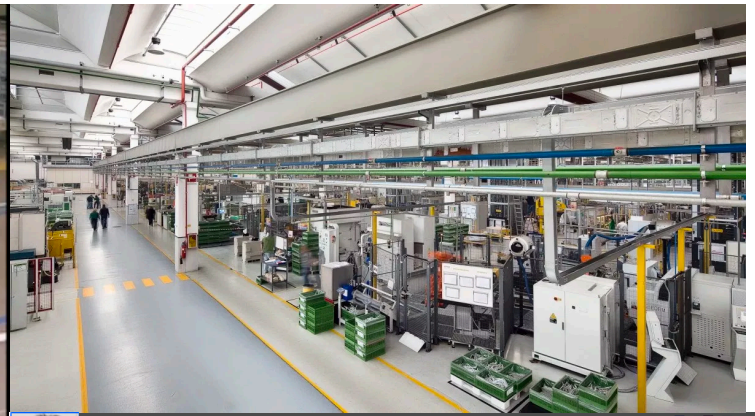
In optimization by QUBO…

- ✓ Average waiting rate is always **lower than 10 %**
- ✓ Average waiting rate converges to **5 %**
- ✓ Maximum waiting rate converges to **15 %**
- ✓ **Each AGV has similar waiting rate (flat)**

AGV in plant

- ✓ Automated Guided Vehicles (AGV) transports many different types of material
  - ✓ Repetitive movement of materials over a distance
  - ✓ Regular delivery of stable loads
- ✓ Navigation (Guided tape, Wire, Laser etc)
- ✓ Collision avoidance for safety but smooth control is needed

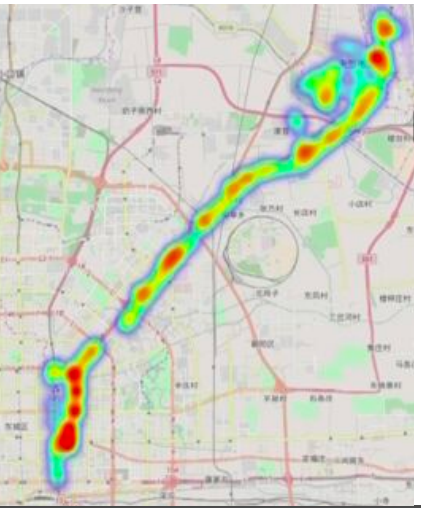




By courtesy of Goto (DENSO)

A lesson from Volks Wagen…

- ✓ Classical and Quantum optimization
- ✓ First (in classical way) find the optimal path, suboptimal and the other for QUBO
- ✓ Second (in quantum way) find the optimal choices for reducing the whole congestion



Before Optimization

$$F_{\mu,e}$$

which roads are occupied with the route

by classical way

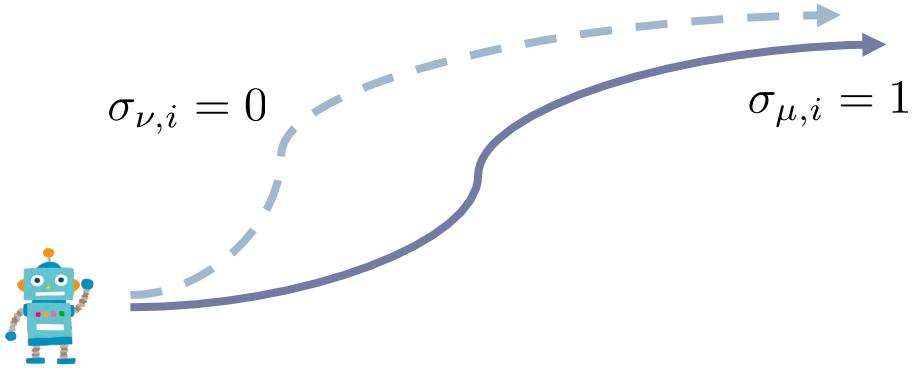
$$\sum_{e\in E}\left(\sum_{i=1}^{N}\sum_{\mu\in M_i}F_{\mu,e}\sigma_{\mu,i}\right)^2+\lambda\sum_{i=1}^{N}\left(\sum_{\mu\in M(x_i,s_i)}\sigma_{\mu,i}-1\right)^2$$

via Quantum annealing

After Optimization

In Plant, AGV moves …

- ✓ According to the provided task

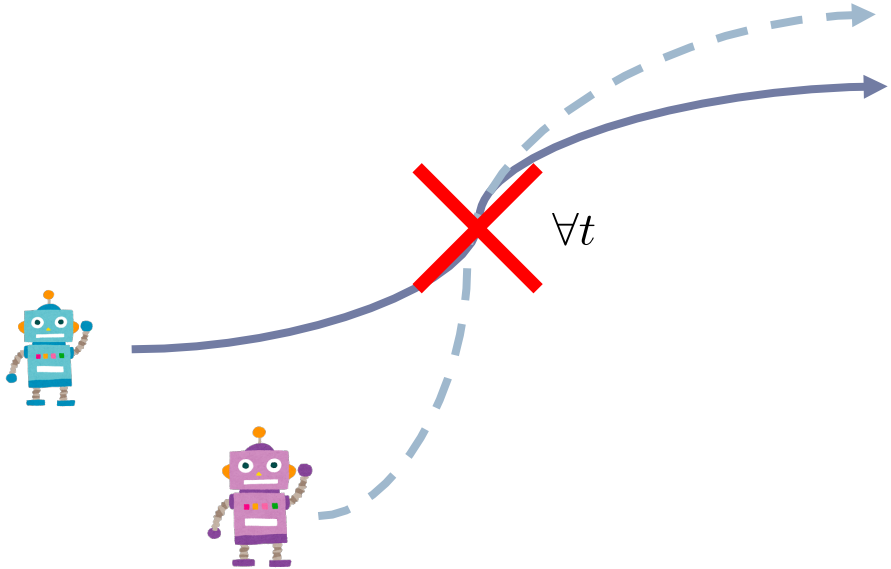


$$\mu, \nu \in M(x_i, s_i)$$

Our Problem Setting

In Plant, AGV moves …

- ✓ According to the provided task
- ✓ Not alone while avoiding simultaneous occupation of the same road **(Safety First)**



Our Problem Setting

In Plant, AGV moves …

- ✓ According to the provided task
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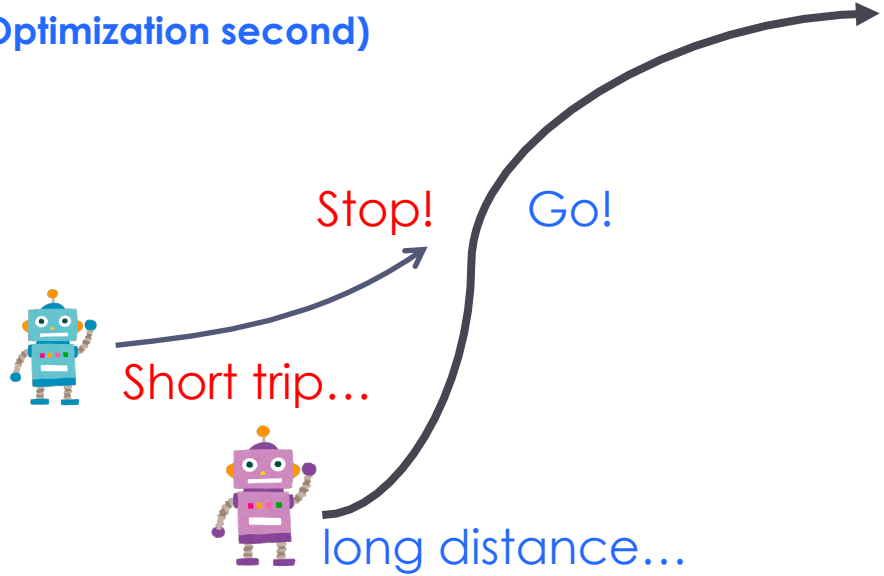
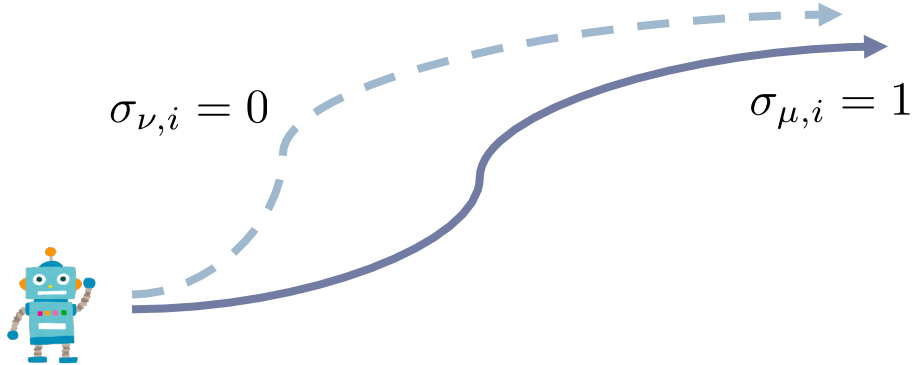
- ✓ As far as possible for efficiency **(Optimization second)**



Construction of QUBO

- ✓ Each AGV selects a single route via (0-1) representation

$$\lambda \sum_{i=1}^{N} \left(\sum_{\mu \in M(x_i, s_i)} \sigma_{\mu,i} - 1 \right)^2$$



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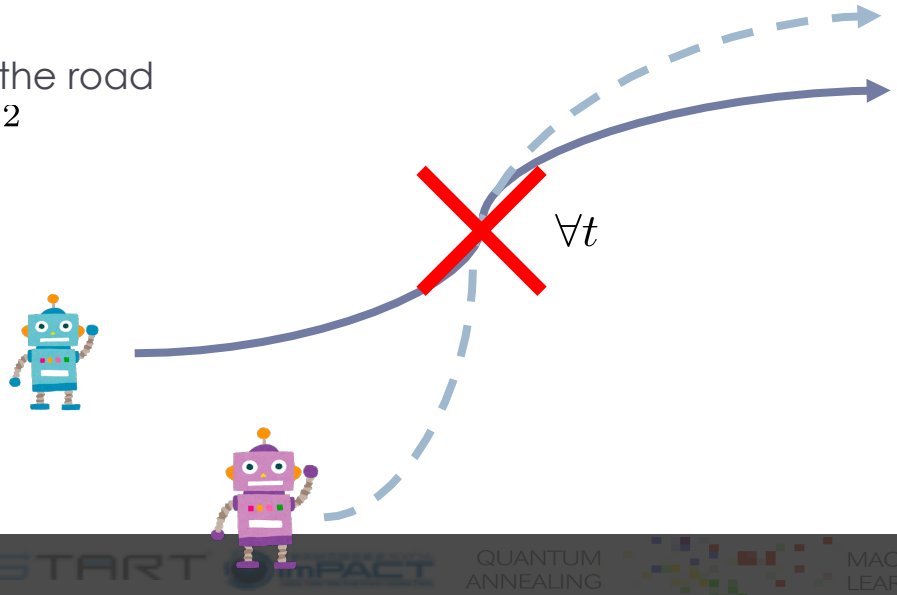
- ✓ AGVs can not share the same segment of the road

$$+ \sum_{e \in E} \sum_{t=1}^{T} \left(\sum_{i=1}^{N} \sum_{\mu \in M(x_i, s_i)} F_{\mu,t,e} \sigma_{\mu,i} \right)^2$$



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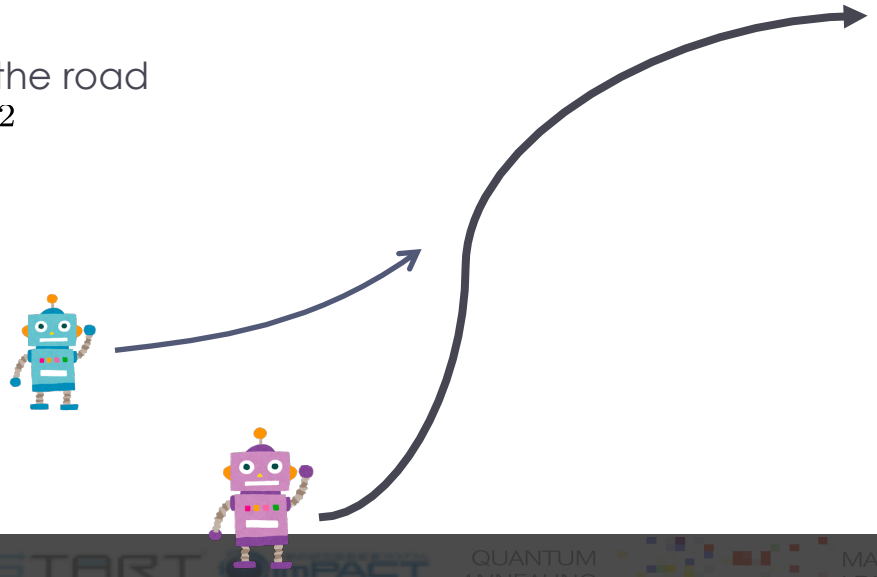
- ✓ and goes as far as possible for efficiency

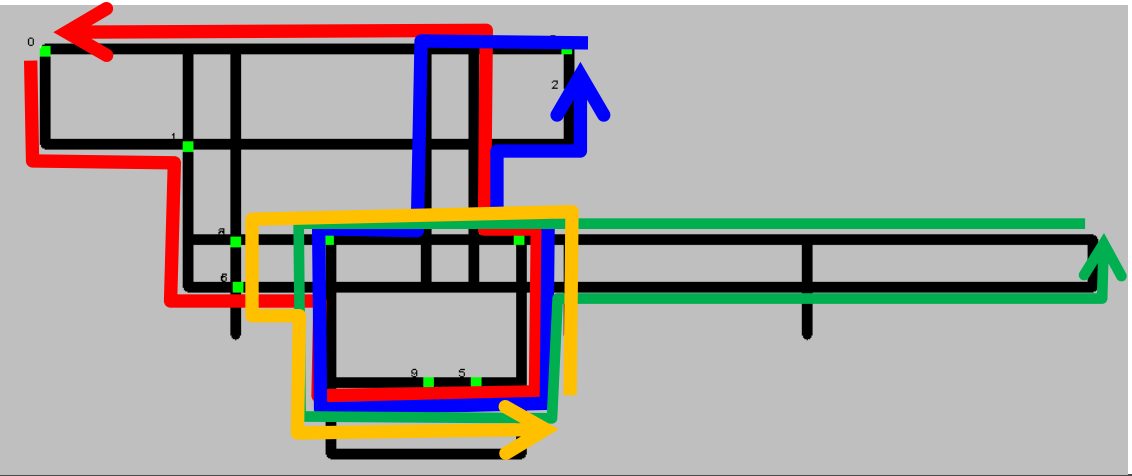
$$-a \sum_{i=1}^{N} \sum_{\mu \in M(x_i, s_i)} d_\mu \sigma_{\mu,i}$$



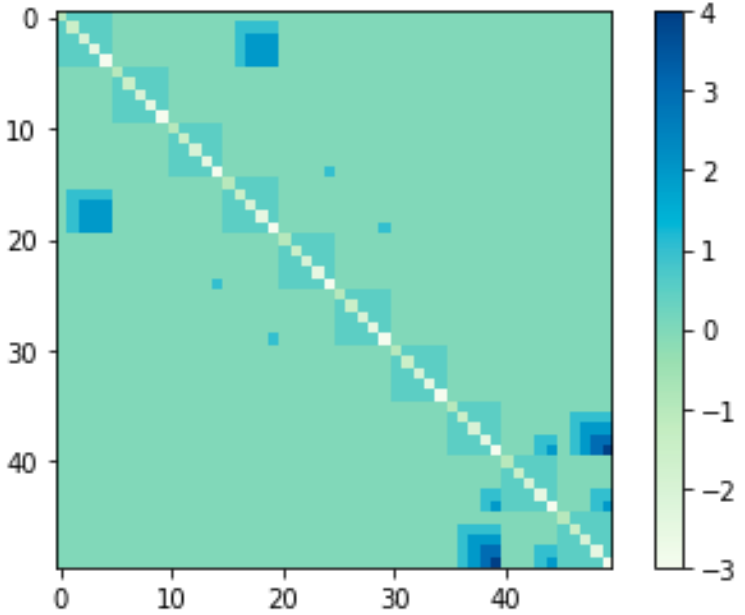
QUBO for our plant (DENSO corporation)

Simulation Setting

- ✓ Number of AGVs: **10**
- ✓ Provided tasks are **5 reds**, **2 blues**, **2 oranges** **and** **1 green** (different tasks)
- ✓ Optimization is performed for each three-node step

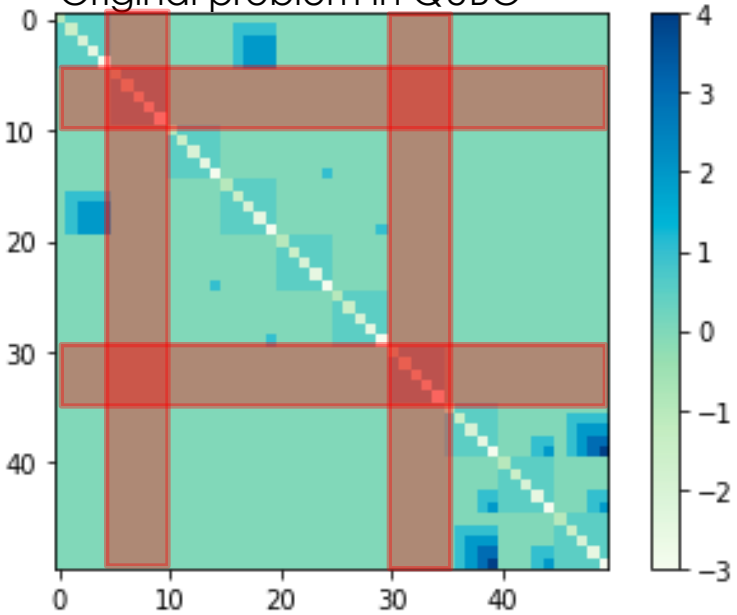


Generated QUBO from a plant

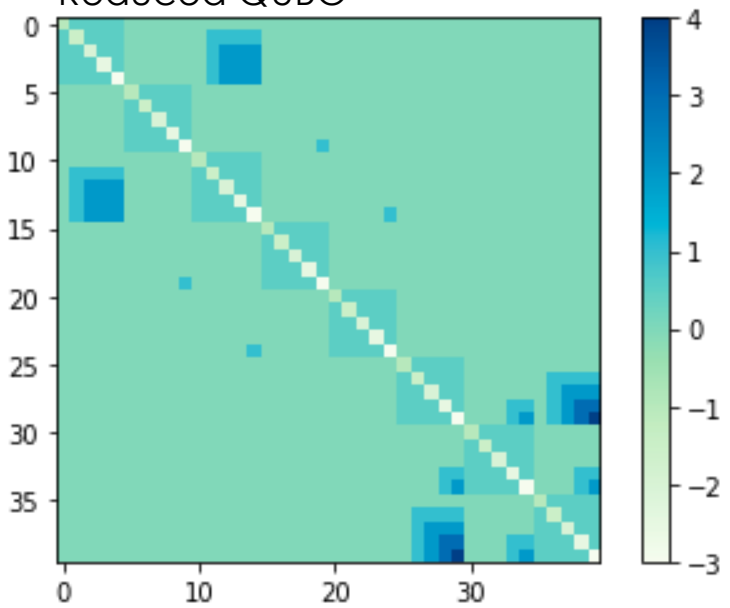


QUBO reduction for quick response

Original problem in QUBO



Reduced QUBO



Post Processing and comparisons with the other methods

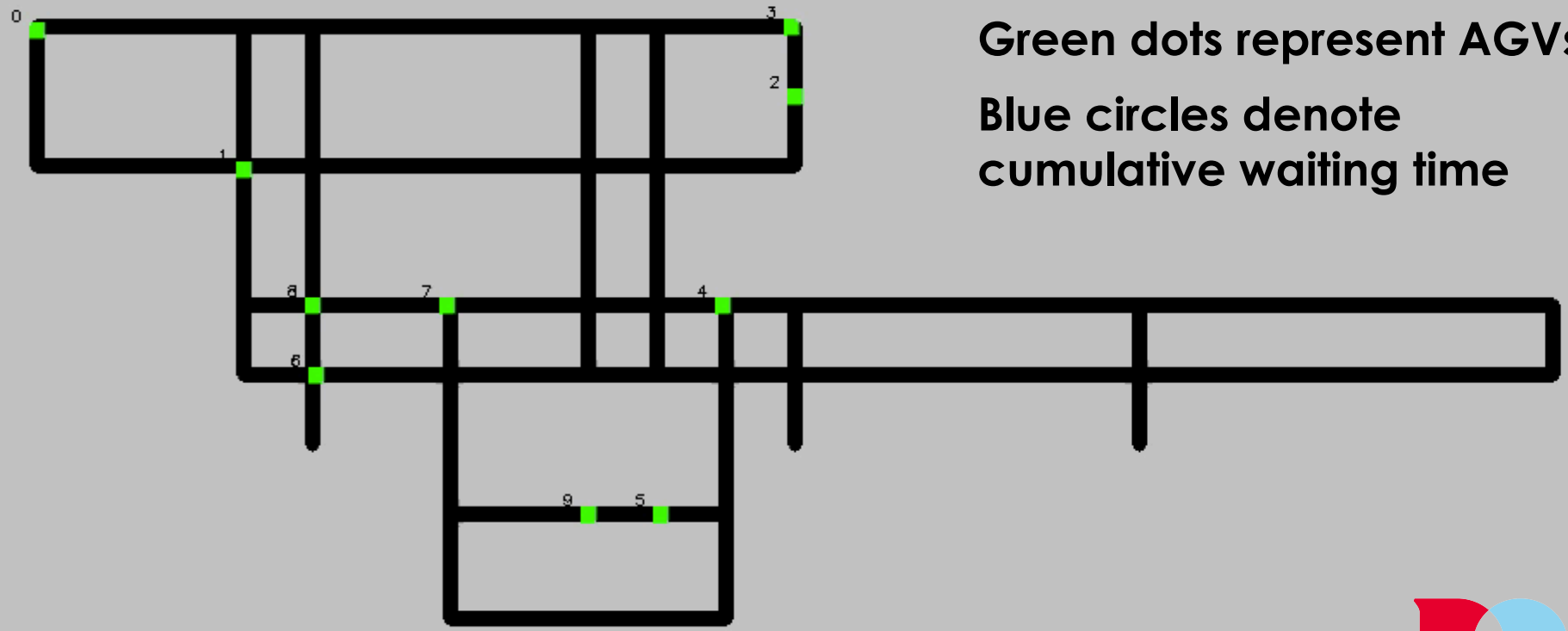
Output does not always satisfy constraints (as you know…)

- First we take many outputs from D-Wave machines (Advantage point)
  - 1000 samples are generated via D-Wave 2000Q
- We pick up several solutions without crash accidents between AGVs **(Safty first)**
  - We have the remaining about 400 samples without any crash accidents
- The remaining samples do not always satisfy the constraints for selecting a single route
  - We pick up the satisfiable solution while maximizing the efficiency of AGVs **(optimal second)**

Comparison with the other tools for solving the QUBO

- CBC solves about 0.02 sec. and Gurobi solves about 0.004 sec. via optimization under constraints
- Waiting rate
  - **Conventional method: 20 %, CBC and Gurobi: 7 %, and D-Wave 2000Q: 5 %**
  - Fujitsu digital annealer can also yield the similar result to one by D-Wave 2000Q (in 7 sec!)

Optimization in Plant



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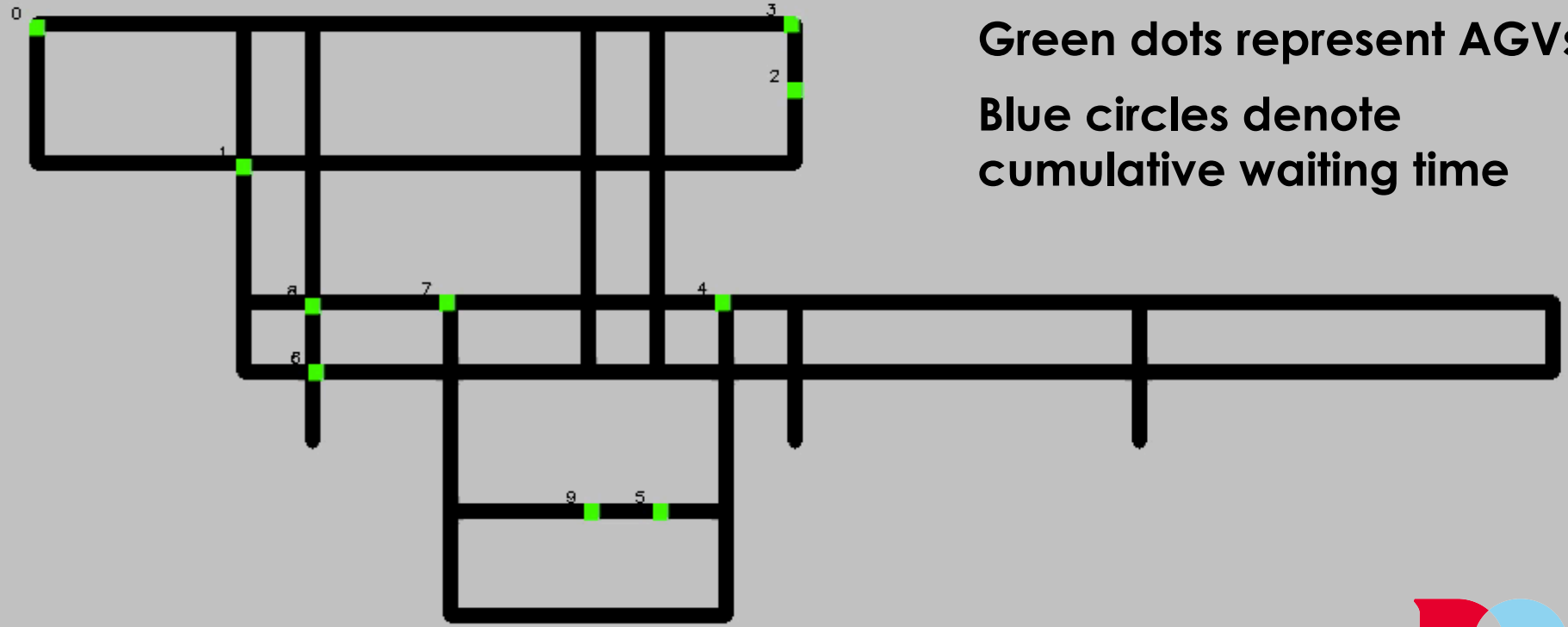

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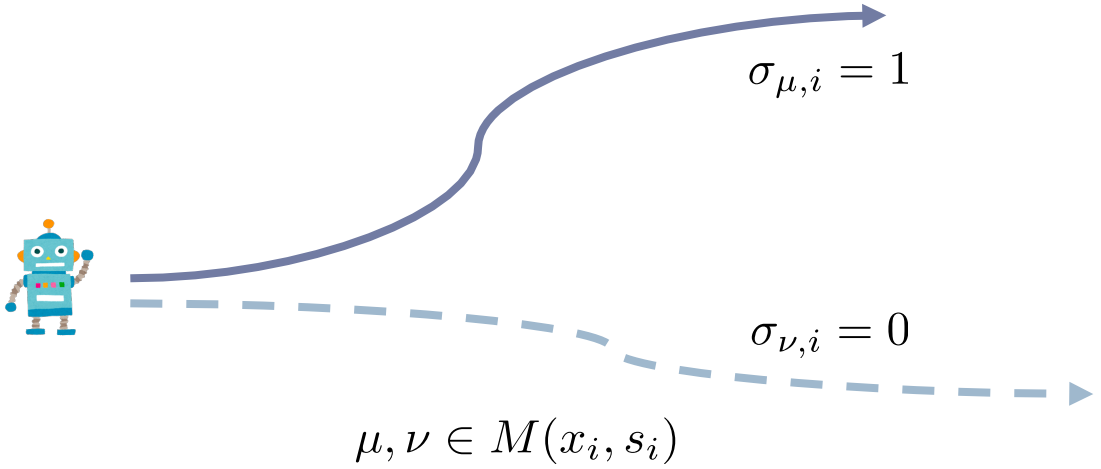
Optimization by D-Wave 2000Q

Tsunami Evacuation

In Evacuation, people moves …

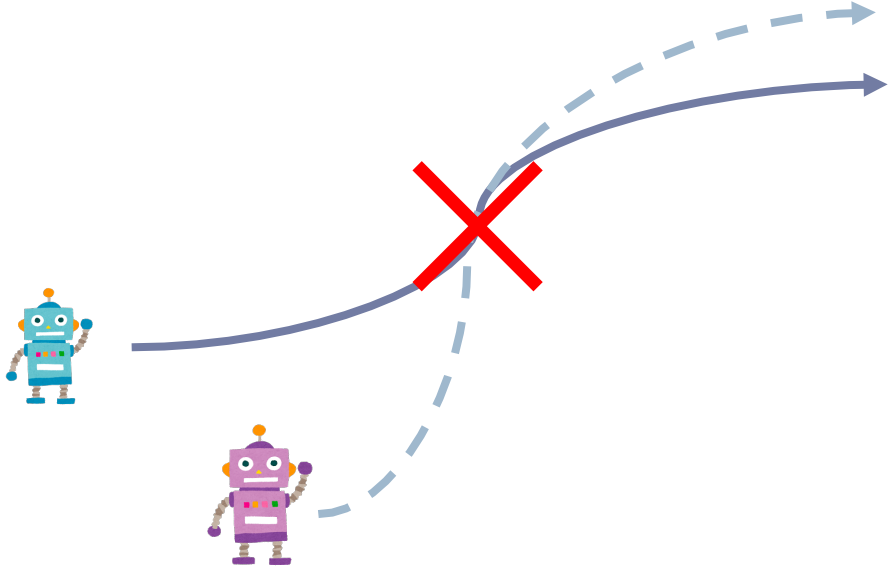
- ✓ Go to the predetermined safe spots



Our Problem Setting

In Evacuation, people moves …

- ✓ Go to the predetermined safe spots
- ✓ Do not gather the same spot and segment in roads for reducing congestion **(Safety First)**



Our Problem Setting

In Evacuation, people moves …

- ✓ Go to the predetermined safe spots
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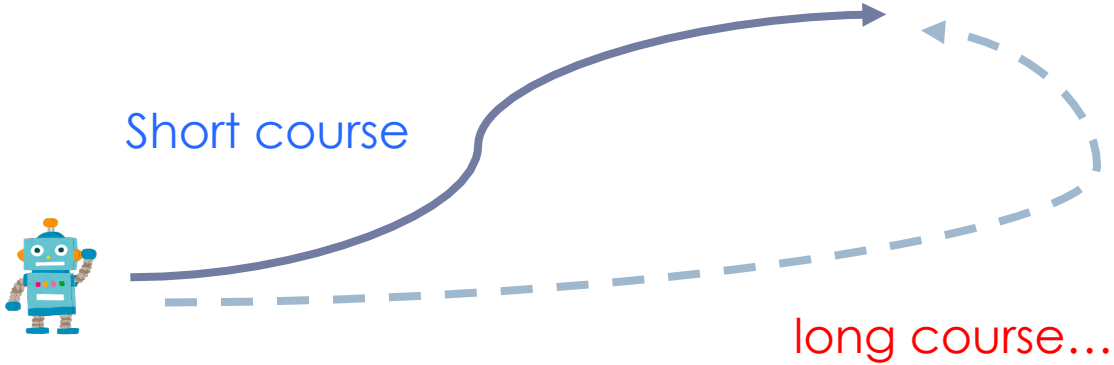
- ✓ As short as possible for efficiency **(Optimization second)**



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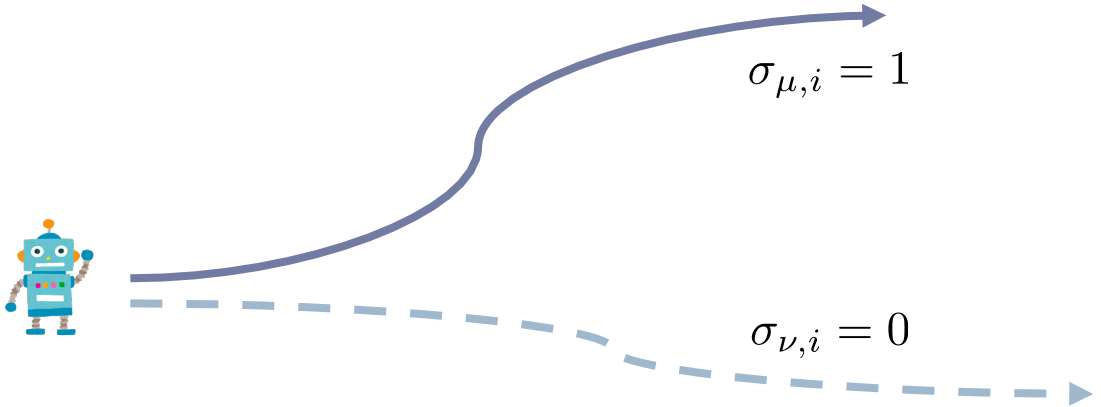

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- ✓ People does not share the same segment of the road in their routes

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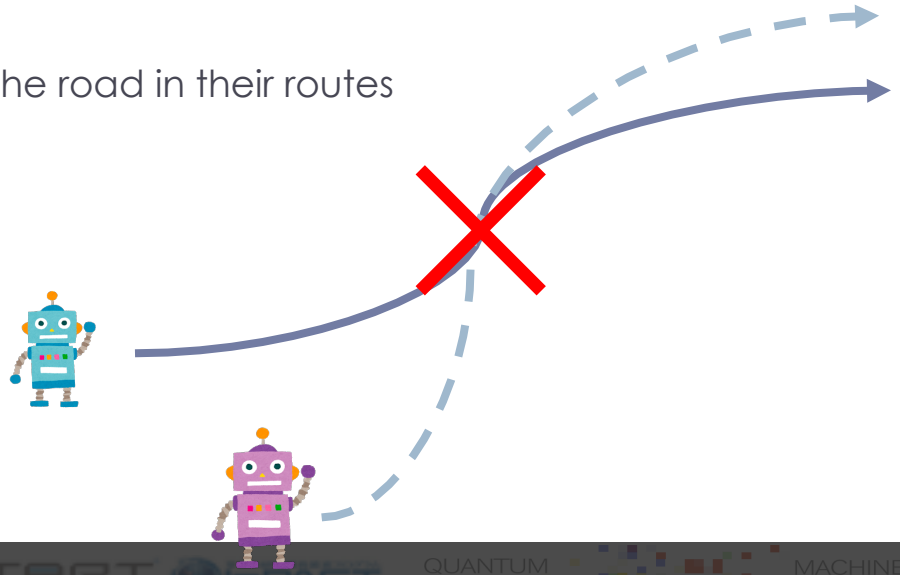

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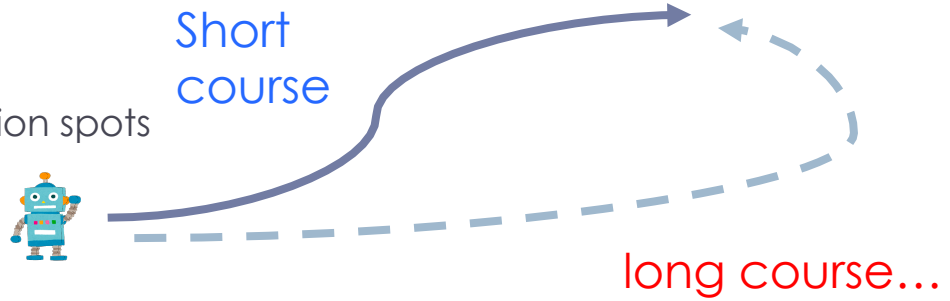
$$+ \sum_{e \in E} \left(\sum_{i=1}^{N} \sum_{\mu \in M(x_i, s_i)} F_{\mu,e} \sigma_{\mu,i} \right)^2$$

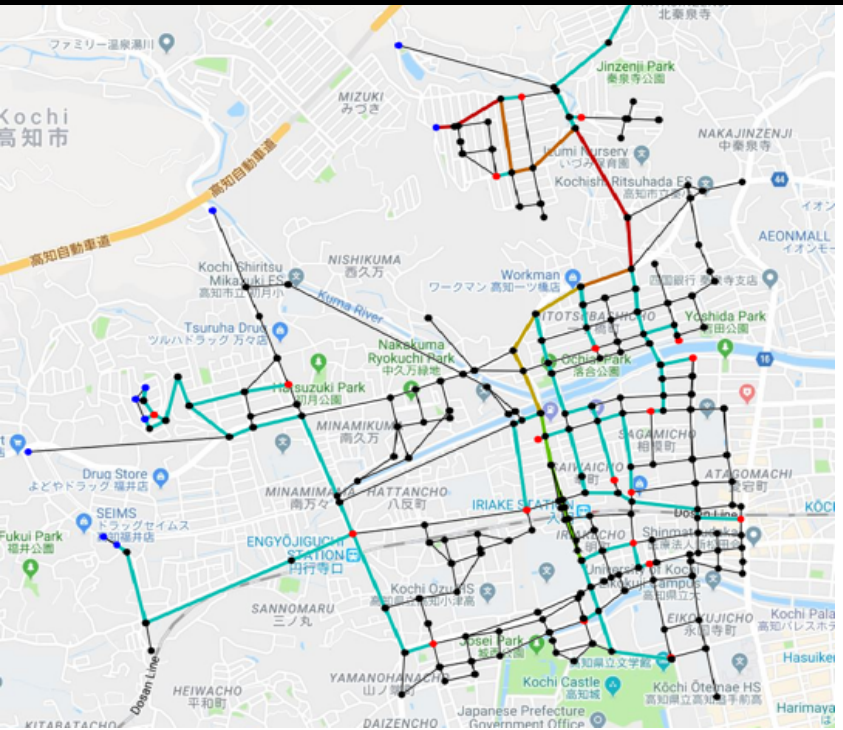
- ✓ We use only the shortest paths for evacuation spots



Results

T. Suzuki and M. Ohzeki: to be submitted

In Kochi city (South Western in Japan)



Conventional situation

- ✓ People has the shortest-path policy
- ✓ Several roads will be occupied with many people

Before Optimization

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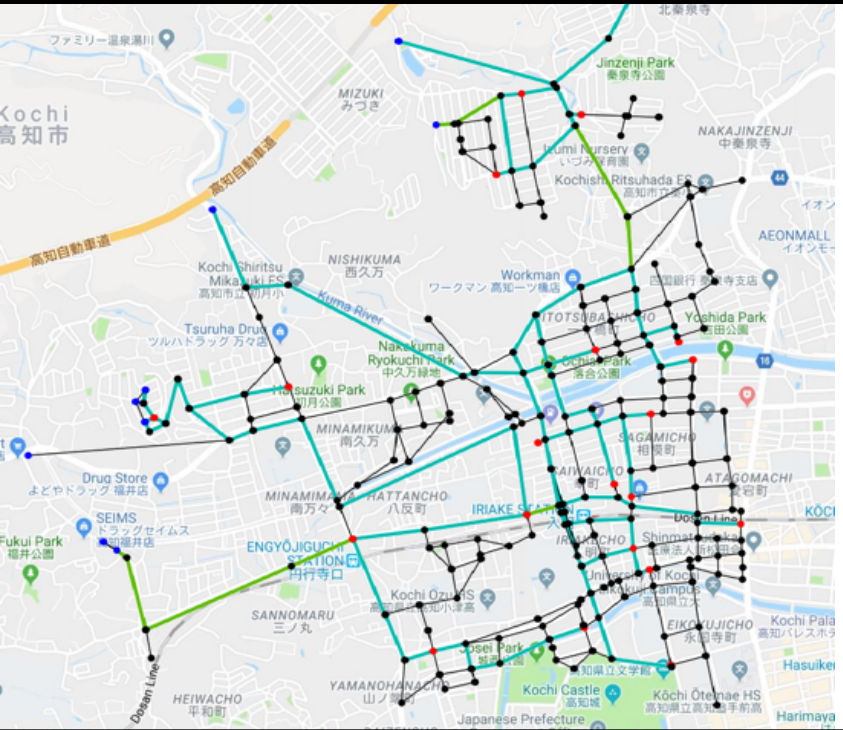

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Optimized situation

- ✓ People receives optimal directions into safe spots
- ✓ Occupation of the roads can be reduced
- ✓ Congestion will be relaxed

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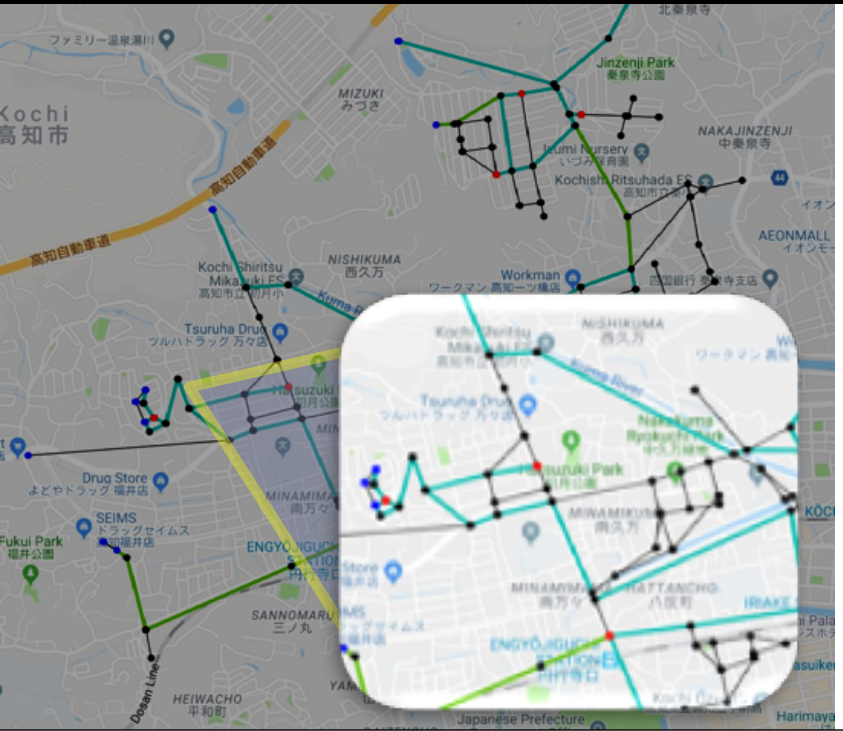

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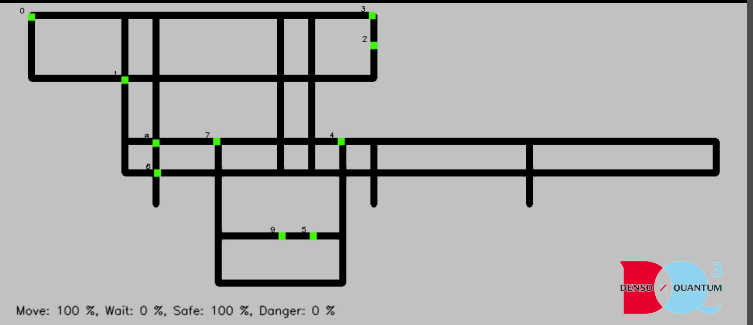
After Optimization

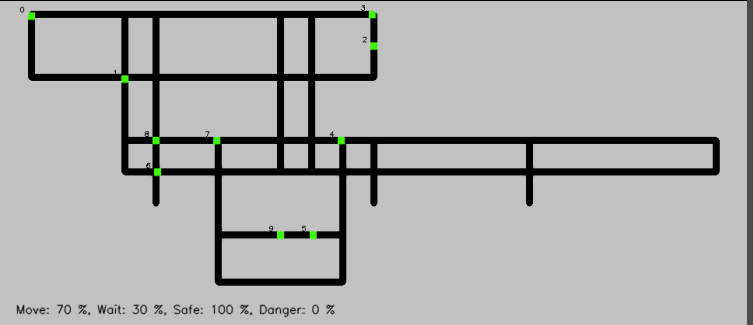
Summary

M. Ohzeki et. al. to be submitted

Optimization by D-Wave 2000Q



Conventional method in factory



Before Optimization

After Optimization

Optimization in Plant

- ✓ We formulate the optimization problem in plant as QUBO
- ✓ Optimal solutions attained by D-Wave machine are available

Optimization for Tsunami Evacuation

- ✓ We formulate the optimization problem for evacuation as QUBO
- ✓ Automatic system for optimization everywhere is established

Thank you for Qubits North America, see you again

DENSO
Crafting the Core

Tohoku University -Break limit of your potential- Quantum Annealing Research & Development
T-QARD
Supported by JST project for creating START