DENSO
Crafting the Core

Practical Advantage of Route Optimization Systems

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DENSO CORPORATION

DENSO Future direction

Crafting the Core— Crafting a new core with our technologies in anticipation of change

Due to companies from other industries entering the market and fierce technological competition, the automotive industry is currently approaching a paradigm shift, which is said to occur once every 100 years. Fully understanding the wave of changes that it faces, DENSO will clear the way for a new motorized society by enhancing and evolving its technologies.

DENSO Efficient Driving

DENSO envisions a future in which mobility is more efficient and driving is more fun. We are developing electrified technologies for a wide range of vehicles, from gasoline and diesel vehicles to HEV, PHEV, EV and FCV, to improve efficiency with better management of electric, kinetic and heat power. By predicting road conditions and charting the best course, our goal is to reduce energy loss, so people can drive as they wish while also being environmentally friendly.

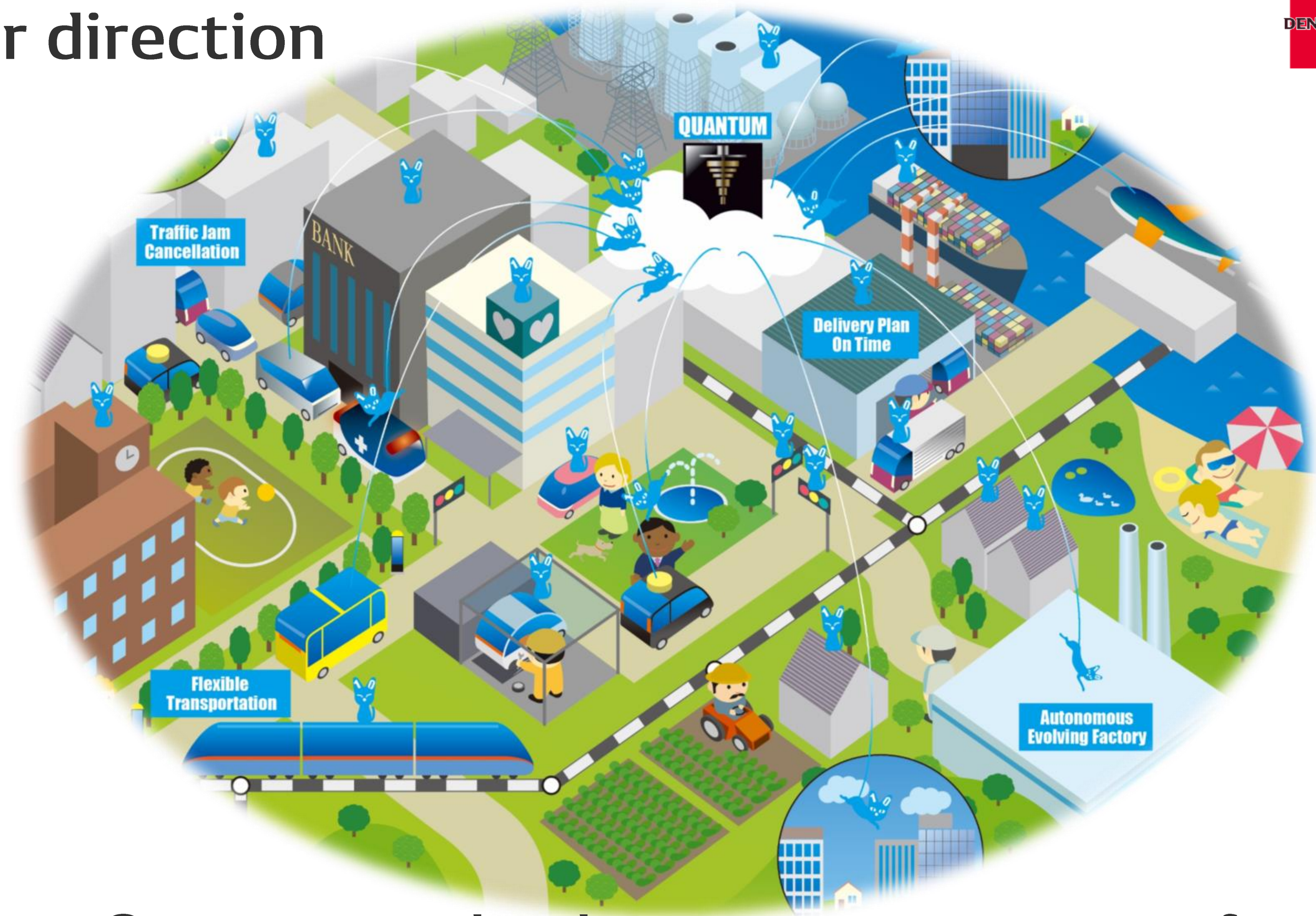
DENSO Connected Driving

DENSO envisions a future in which mobility is connected inside and outside of the vehicle, including cars, people and infrastructure, as well as new services. It brings us new experiences for traveling, and helps us develop automated driving systems that are more convenient and comfortable yet extremely energy efficient. Of course, security issues have emerged from connectivity, such as hackers and data leaks, but with an unwavering focus on safety, DENSO will help protect people and cars.

DENSO Automated Driving

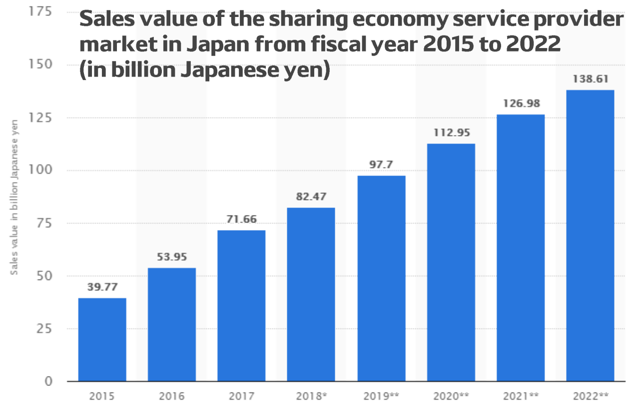
DENSO envisions a future in which everyone can travel freely and safely, regardless of their age or physical condition. That's why DENSO is deeply focused on advances in safety and security. Our goal is to evolve our sensing, information & communication and AI technologies to eliminate limitations to mobility.

Our direction



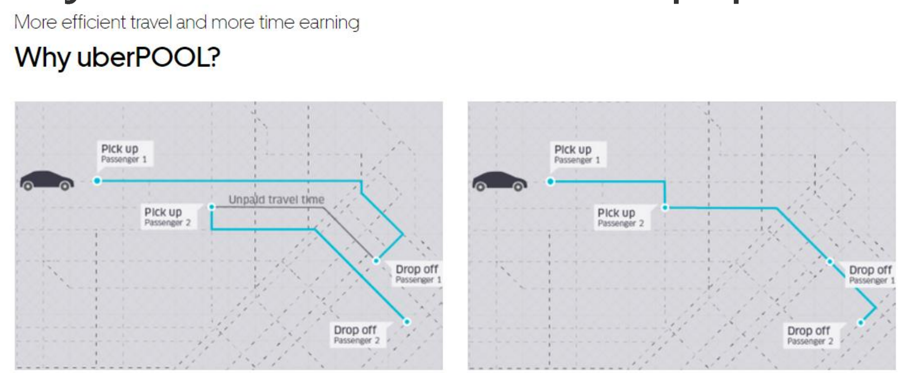
Quantum technology creates new era of Mobility, Factory and Society IoT

Sharing economy is one of the market with growth potential



https://www.statista.com/statistics/795505/japan-sharing-economy-market-size/

Sharing economy with transport system like Uber becomes popular

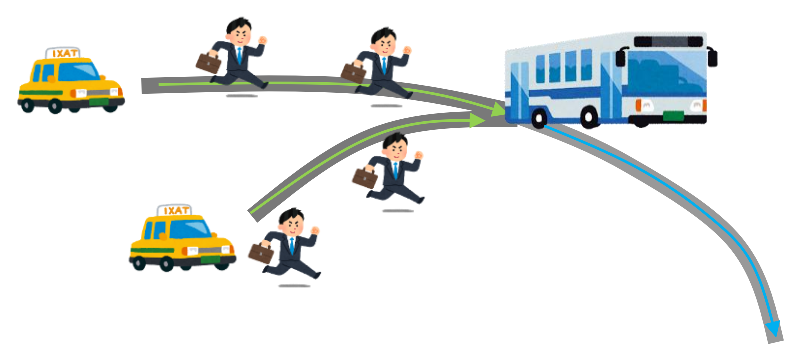


https://www.uber.com/ride/express-pool/

We would propose optimization of advanced transport system with sharing

Current：ride-sharing

Future：multi modal sharing

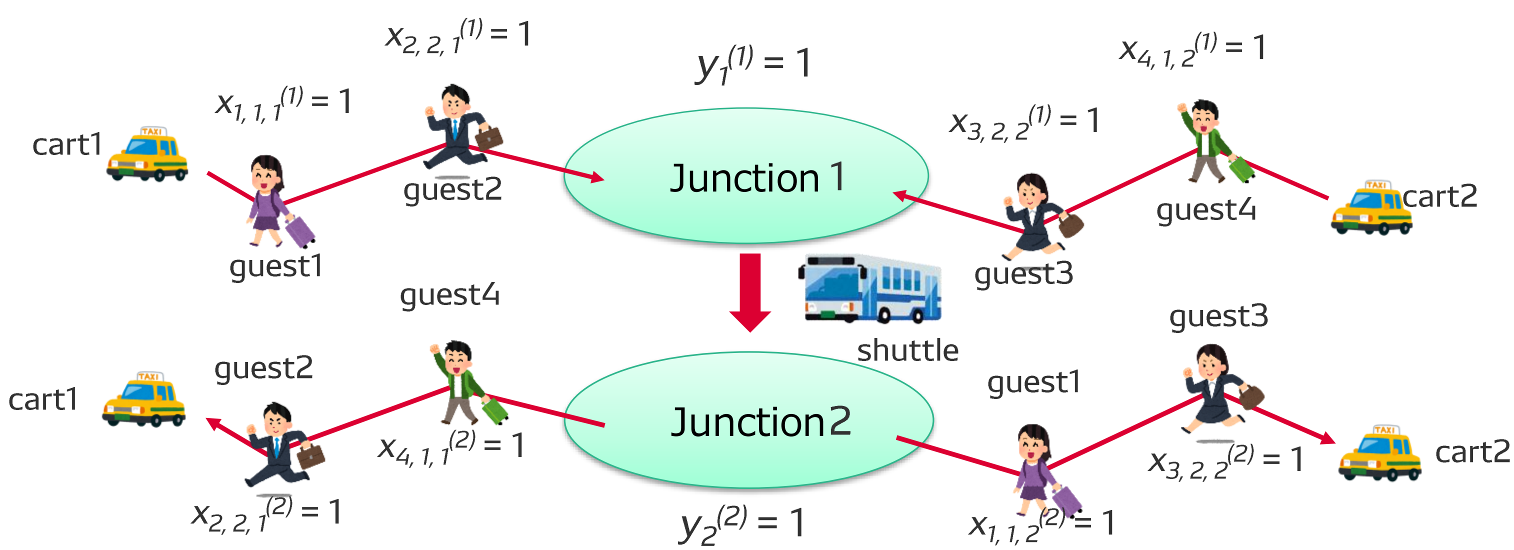


- x variables for carts: $x_{g,t,c}^{(1)}$: pick up, $x_{g,t,c}^{(2)}$: drop off

$x_{g,t,c}^{(1)}$ — 1: pick up / drop off guest g at time t for cart c; 0: not pick up / drop off guest g at time t for cart c

- y variables for shuttle: $y_j^{(1)}$: pick up, $y_j^{(2)}$: drop off

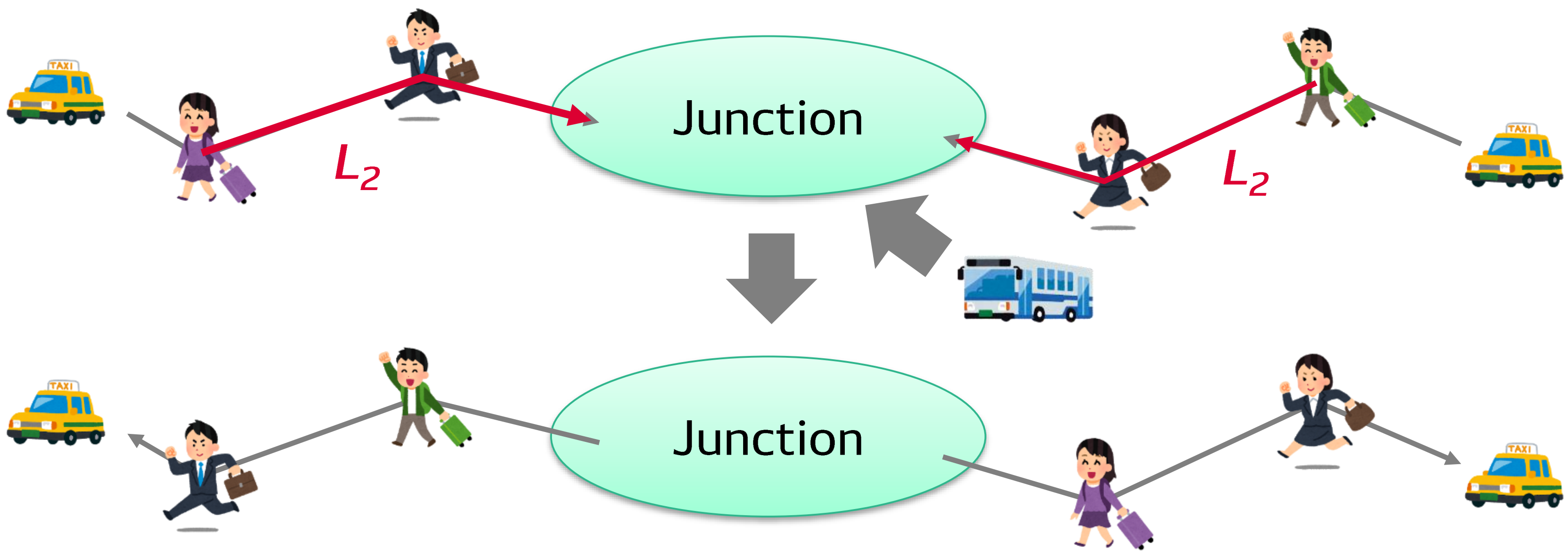
$y_j^{(1)}$ — 1: stop at the junction for picking up / dropping off guests; 0: not stop at the junction for picking up / dropping off guests



Objective: cart distance

$$L_2 = \sum_{c=1}^{C} \sum_{t=1}^{T-1} \sum_{g_2=1}^{G} \sum_{g_1=1}^{G} \ell_{g_1,g_2} x^{(1)}_{g_1,t,c} x^{(1)}_{g_2,t+1,c} + \sum_{c=1}^{C} \sum_{j=1}^{J} \sum_{g=1}^{G} \ell_{g,j} x^{(1)}_{g,T,c} y^{(1)}_j$$

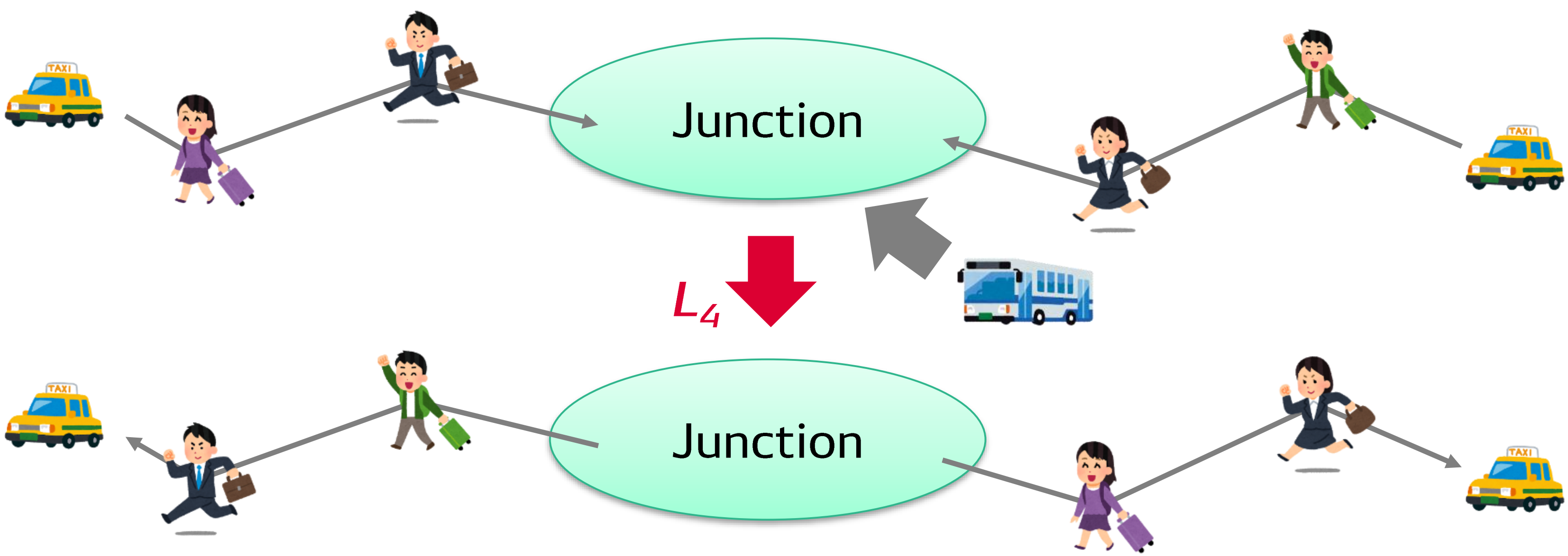
Cost (distance) from the first guest position to the last guest position and from the last guest position to the junction of shuttle coming



Objective: shuttle distance

$$L_4 = \sum_{j_1=1}^{J} \sum_{j_2=1}^{J} \ell_{j_1,j_2} y_{j_1}^{(1)} y_{j_2}^{(2)}$$

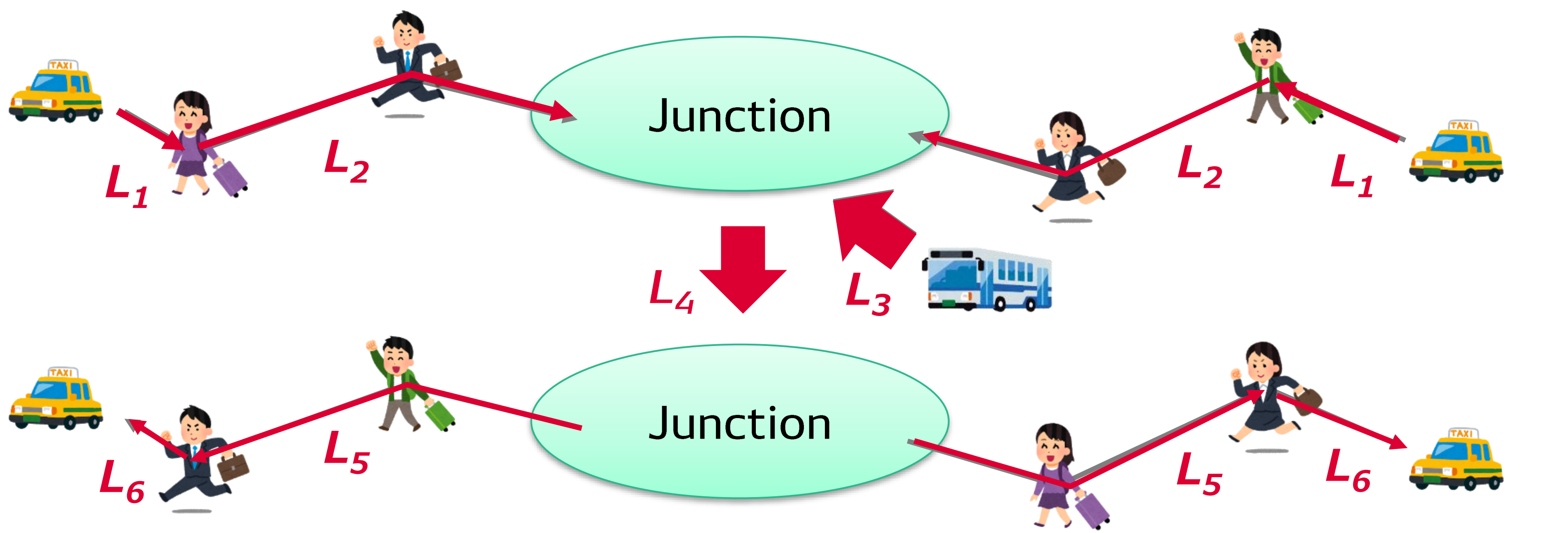
Cost (distance) between junctions of shuttle running



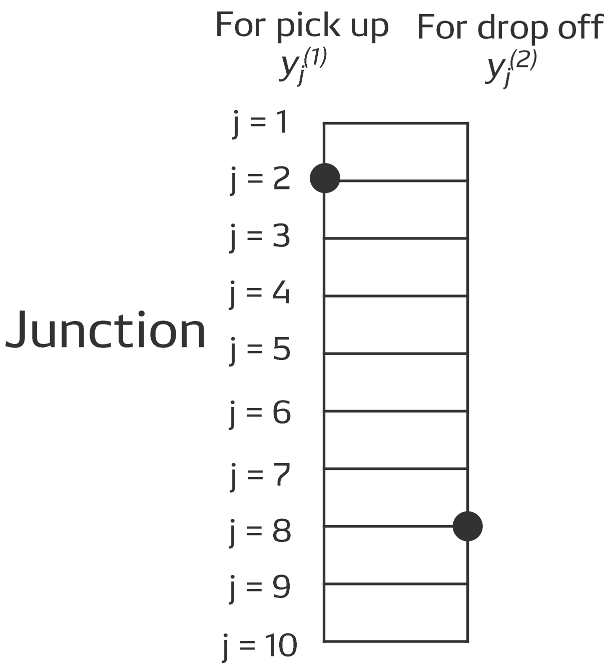
Total objective: cart and shuttle distance

$$L_1 = \sum_{c=1}^{C} \sum_{g=1}^{G} \ell_{j_g,g} x^{(1)}_{g,1,c} \qquad L_2 = \sum_{c=1}^{C} \sum_{t=1}^{T-1} \sum_{g_2=1}^{G} \sum_{g_1=1}^{G} \ell_{g_1,g_2} x^{(1)}_{g_1,t,c} x^{(1)}_{g_2,t+1,c} + \sum_{c=1}^{C} \sum_{j=1}^{J} \sum_{g=1}^{G} \ell_{g,j} x^{(1)}_{g,T,c} y^{(1)}_{j} \qquad L_3 = \sum_{j=1}^{J} \ell_{j_s,j} y^{(1)}_{j}$$

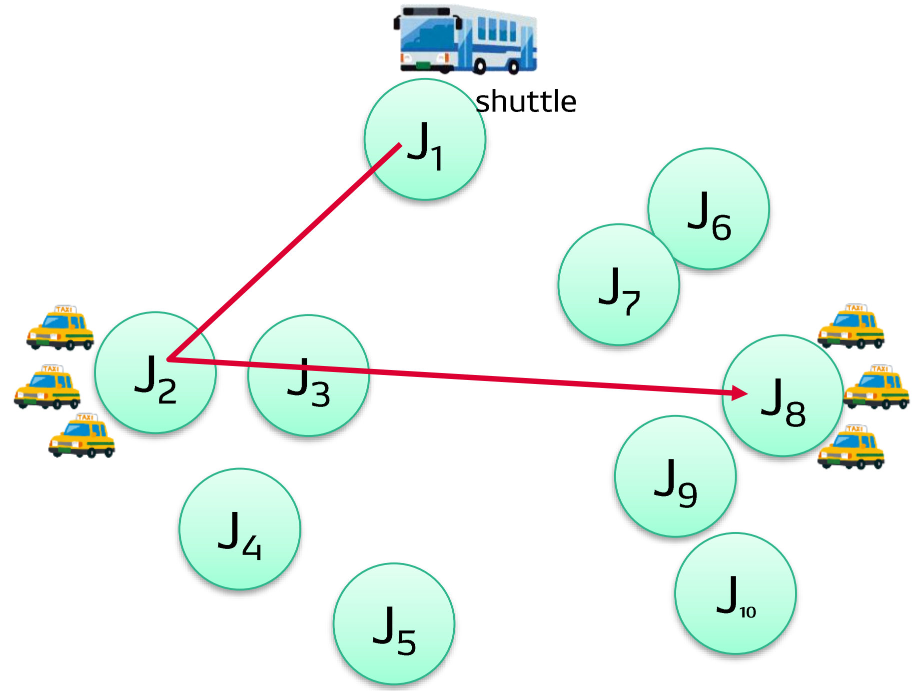
$$L_4 = \sum_{j_1=1}^{J} \sum_{j_2=1}^{J} \ell_{j_1,j_2} y^{(1)}_{j_1} y^{(2)}_{j_2} \qquad L_5 = \sum_{c=1}^{C} \sum_{j=1}^{J} \sum_{g=1}^{G} \ell_{j,g} y^{(2)}_{j} x^{(2)}_{g,1,c} + \sum_{c=1}^{C} \sum_{t=1}^{T-1} \sum_{g_2=1}^{G} \sum_{g_1=1}^{G} \ell_{g_1,g_2} x^{(2)}_{g_1,t,c} x^{(2)}_{g_2,t+1,c} \qquad L_6 = \sum_{c=1}^{C} \sum_{g=1}^{G} \ell_{j_g,g} x^{(2)}_{g,T,c}$$



Constraint: each shuttle is assigned to one junction for each pick up and drop off



For pick up



For drop off

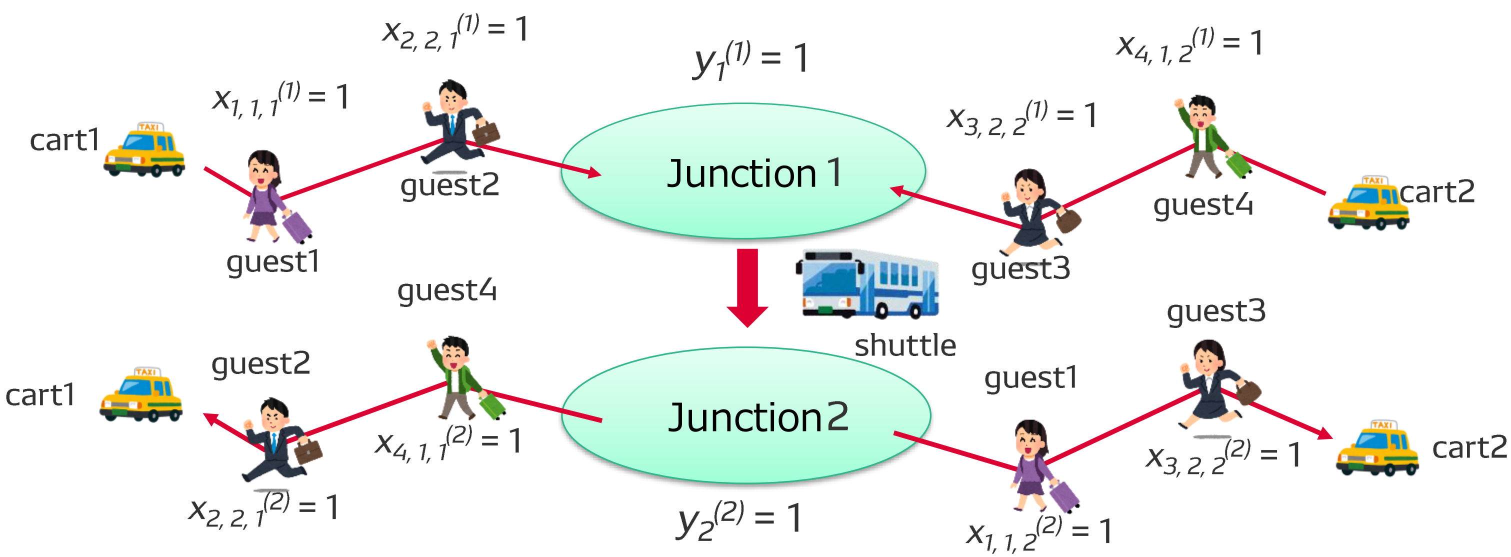
$$\lambda_{sh}\left(\sum_{j=1}^{J} y_j^{(2)} - 1\right)^2$$

Route Optimization for Multimodal Transport Systems (Qubits 2019 EU)

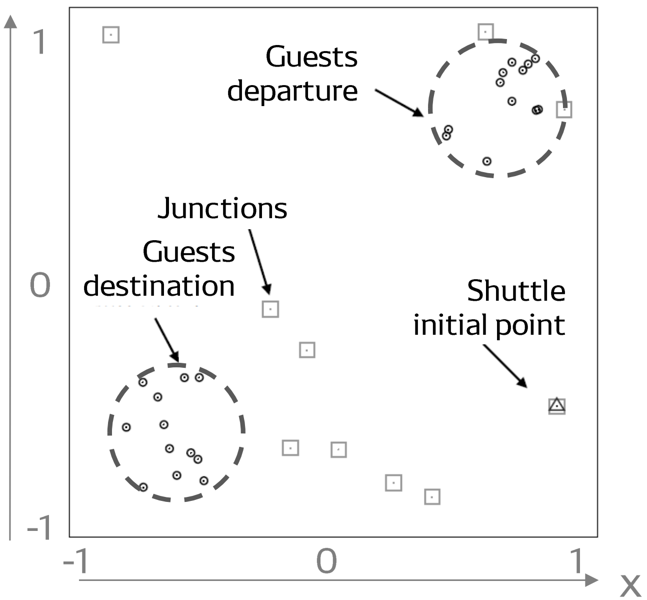
One-hot constraints: for each junction, guest, and cart and time

$$H = \sum_{i=1}^{6} L_i + \lambda_g \sum_{c=1}^{C} \sum_{t=1}^{T} \left(\sum_{g=1}^{G} x^{(1)}_{g,t,c} - 1 \right)^2 + \lambda_g \sum_{c=1}^{C} \sum_{t=1}^{T} \left(\sum_{g=1}^{G} x^{(2)}_{g,t,c} - 1 \right)^2 + \lambda_{tc} \sum_{g=1}^{G} \left(\sum_{c=1}^{C} \sum_{t=1}^{T} x^{(1)}_{g,t,c} - 1 \right)^2 + \lambda_{tc} \sum_{g=1}^{G} \left(\sum_{c=1}^{C} \sum_{t=1}^{T} x^{(2)}_{g,t,c} - 1 \right)^2 + \lambda_{sh} \left(\sum_{j=1}^{J} y^{(1)}_j - 1 \right)^2 + \lambda_{sh} \left(\sum_{j=1}^{J} y^{(2)}_j - 1 \right)^2$$

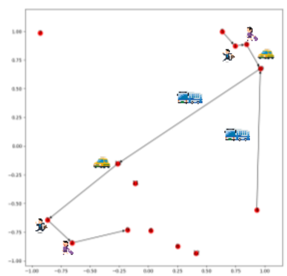
G: Num. of guests
C: Num. of carts
T: Num. of time
J: Num. of junctions



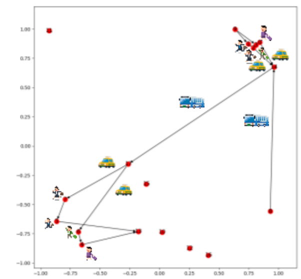
Problem settings



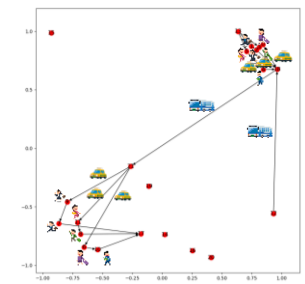
Optimal solutions (G = 2, 4, 6)



G=2, C=1, T=2, J=10
Cost = 4.289,
Num. of variables = 28,
234 embedded qubits



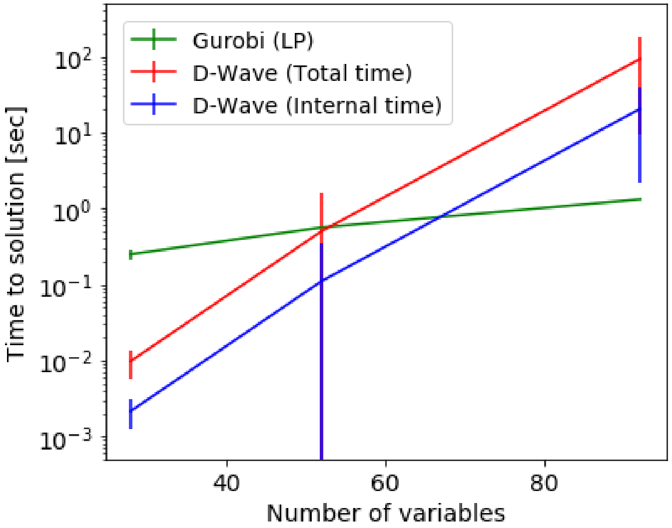
G=4, C=2, T=2, J=10
Cost = 6.489,
Num. of variables = 52,
406 embedded qubits

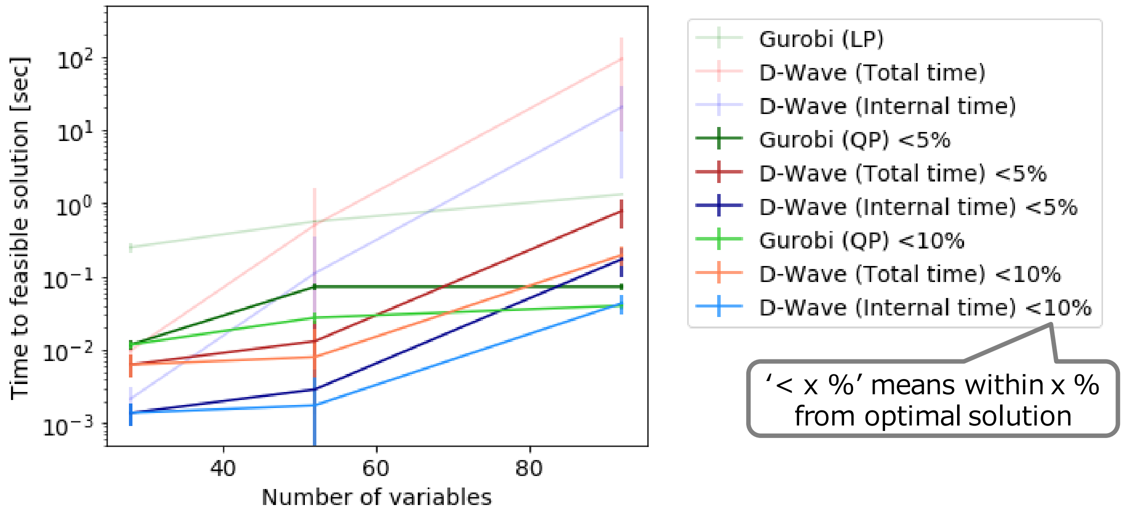


G=6, C=3, T=2, J=10
Cost = 8.156,
Num. of variables = 92,
1488 embedded qubits

Gurobi : optimized within constraints space
(Gurobi version 8.10, Intel i7 4770K 32GB RAM)
D-Wave: $\lambda_g = 1.0$, $\lambda_{tc} = 1.0$, $\lambda_{sh} = 4.0$
(QUBO generation was greatly supported by PyQUBO)

D-Wave 2000Q: optimum and feasible solution (gap 5%, 10%) details





$$TTS(p) = t_c \frac{log(1-p)}{log(1-P_0)}$$

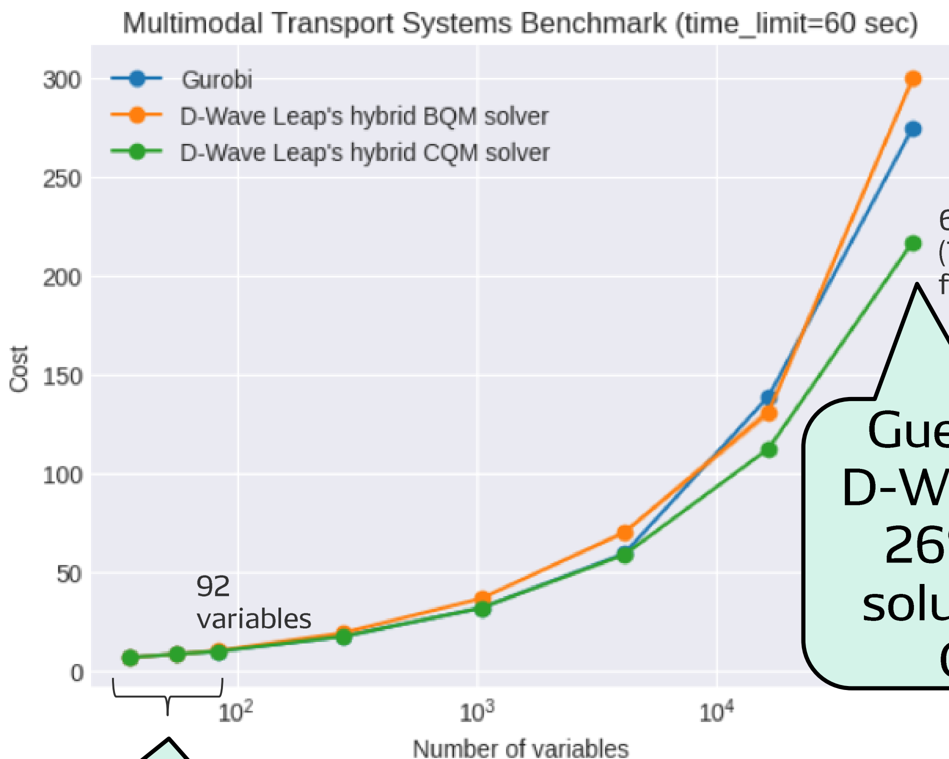
$p = 0.99$
t_c = run time / num. of sol.
P_0 = Percentage of optimal sol.

$$TTFS(p) = t_c \frac{log(1-p)}{log(1-P_0)}$$

$p = 0.99$
t_c = run time / num. of sol.
P_0 = Percentage of feasible sol.

- Time to feasible solution increase dependence on variables suppressed compared to time to solution (suppressed percentage decrease)
- Most feasible solutions of D-Wave were within 10%
- Embedding would be an issue to get better results

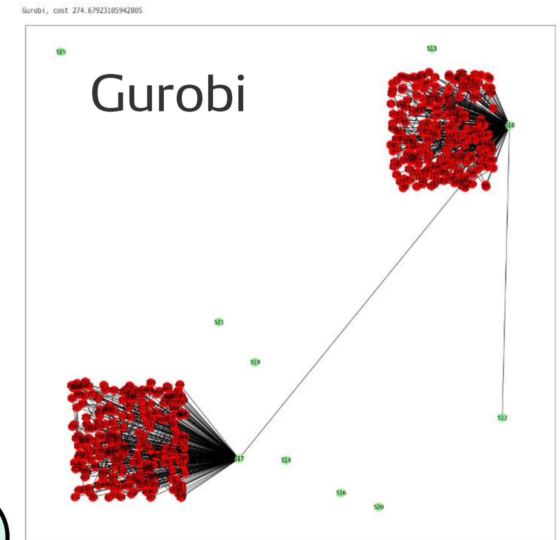
Route Optimization for Multimodal Transport Systems (Latest results by D-Wave HSS)

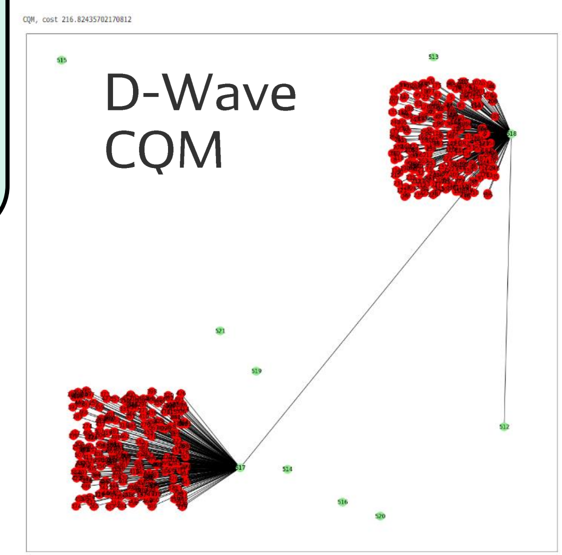


Guest = 256, D-Wave CQM : 26% better solution than Gurobi

Guest = 2, 4, 6, same solution (Qubits 2019 EU)

(Gurobi version 9.52, AMD EPYC 7713 1024GB RAM)

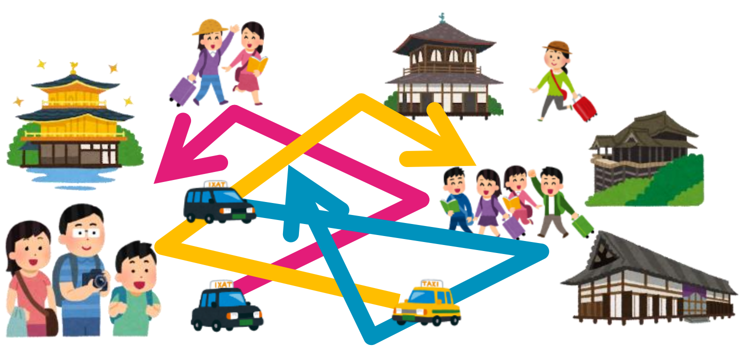


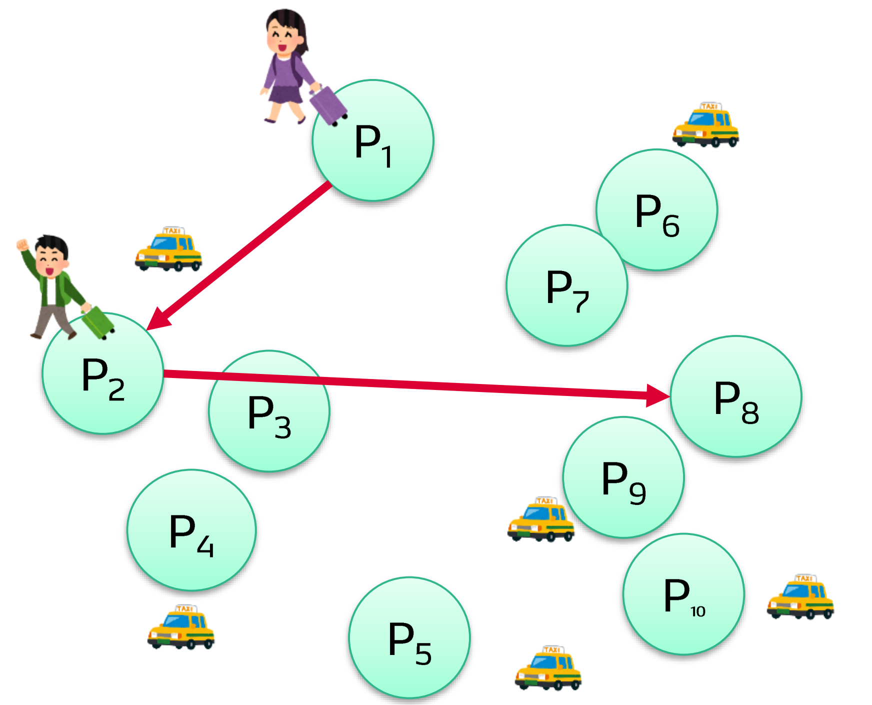


On-demand taxi assignment

Popular places in Kyoto

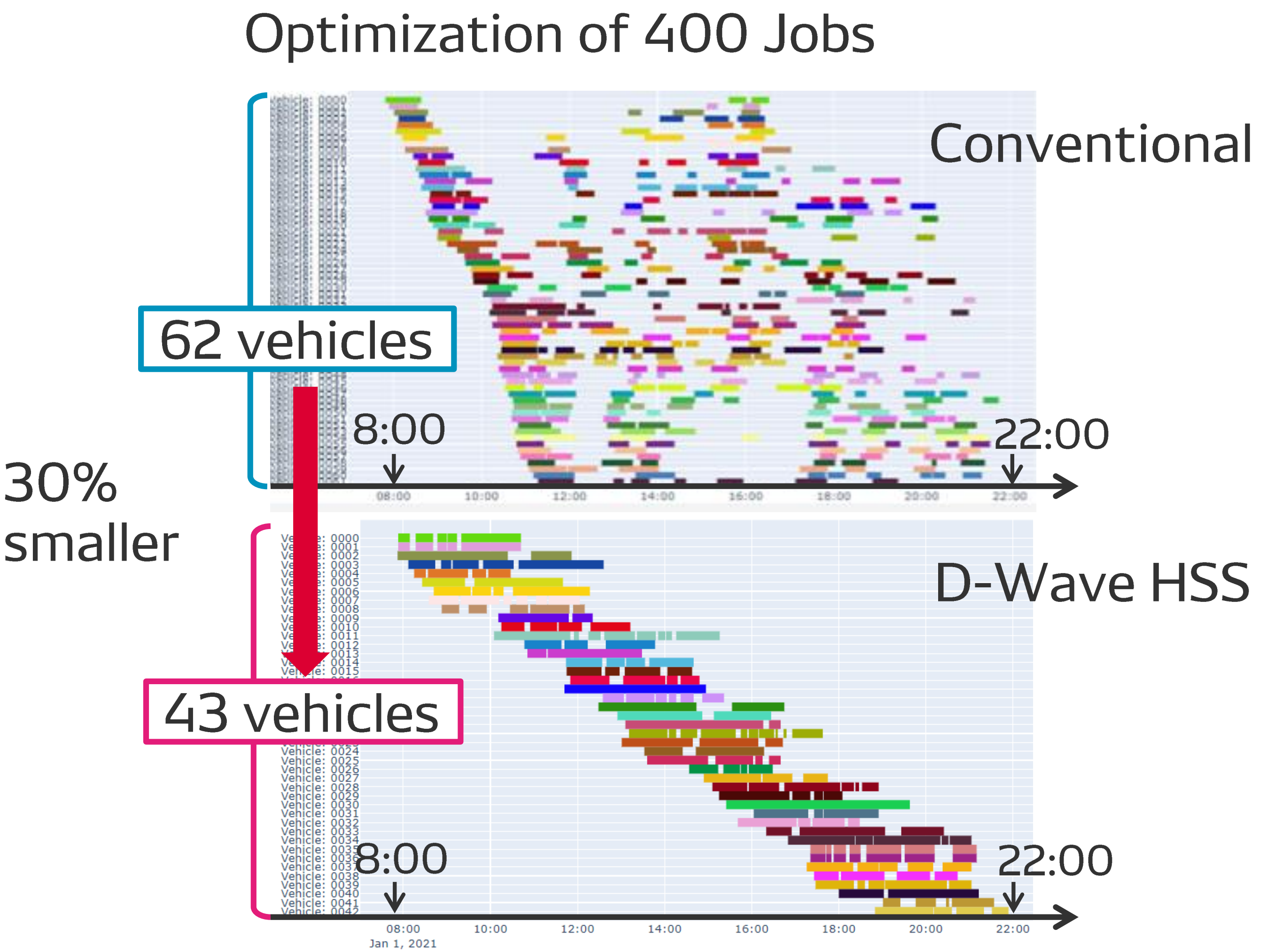
https://www.kyoto-plazahotel.co.jp/map





With the on-demand requests in advance, the schedule of taxi is optimally assigned

On-demand taxi assignment



The number of vehicles achieves 30% smaller

Akira Miki / Advanced Research & Innovation Lab.

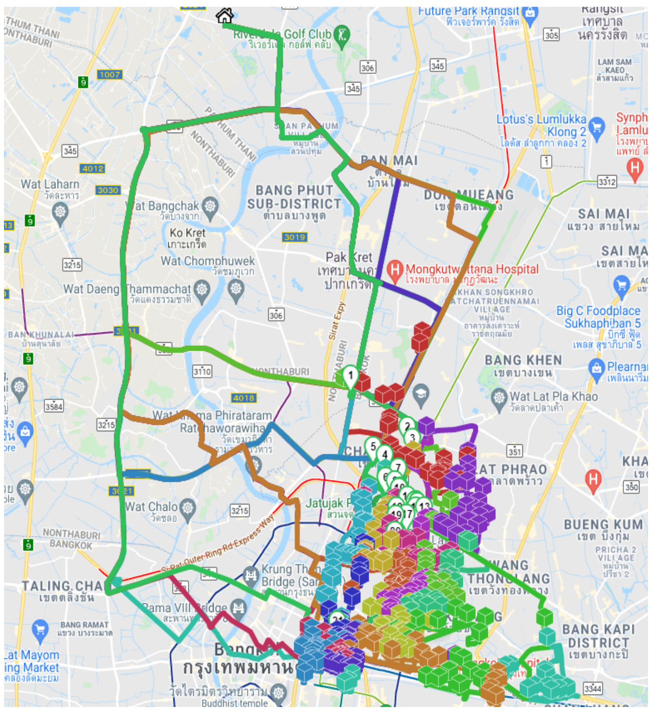
Collaboration with Toyota Tsusho, TTMI

Results of vehicle routing, utilizing TTMI real data

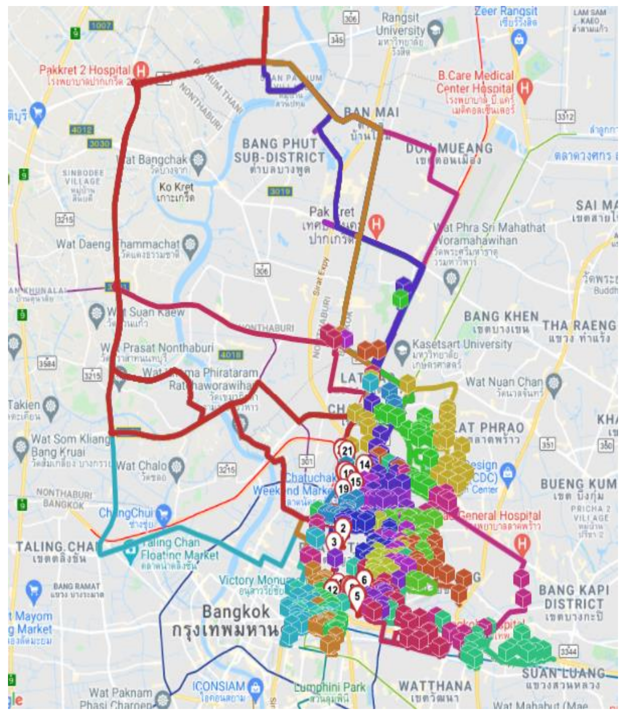
TOYOTA TSUSHO

Toyota Tsusho Mobility Informatics (Thailand) Co., Ltd.

D-Wave HSS outperform conventional method in terms of both computational time and solution quality



TTMI (Conventional method)



DENSO (D-Wave HSS)

Number of drop point: 399

	TTMI	DENSO
Number of vehicles	18	18
Distance [km]	1744.4	1584
Driving Time [min]	4054	3761
Calculation time [min]	6	4.5

DENSO

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