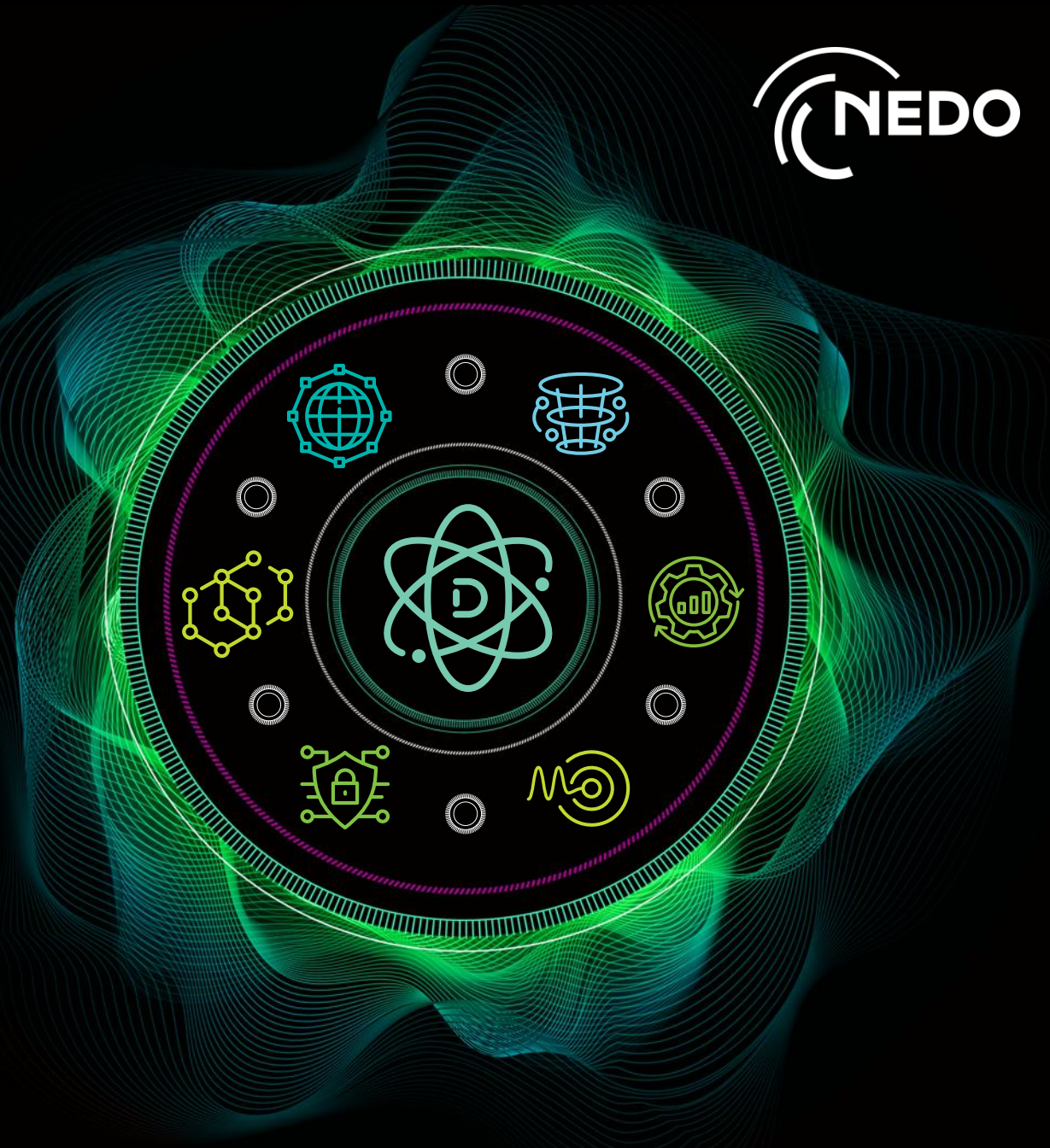
Quantum Computing Use Cases

Factory Equipment Layout Optimization Using Quantum Computers

OKI



New Energy and Industrial Technology Development Organization (NEDO)

OKI: Factory Equipment Layout Optimization Using Quantum Computers [2022/05] 1/4

Validation

Industry	Discrete Manufacturing
Process	process design
Method	combinatorial optimization
Category	Ising*

Background

- **there is a constant labor shortage in the manufacturing industry due to the shrinking domestic labor force**
  - ✓ Labor shortages have become apparent at more than 94% of Japan's large companies and SMEs, and their business has been affected at 32%. *1
- In situations where it is difficult to resolve labor shortages quickly, **increased productivity increases the need to maintain production with limited staff.**
  - ✓ Amid intensifying international competition due to globalization, **it is urgent to improve productivity to reduce manufacturing costs in order to strengthen product competitiveness.**
- **In order to improve productivity in factories, it is necessary to minimize the moving distance (line of movement) of workers by optimizing the arrangement of shelves for storing parts necessary for production equipment and assembly.**
  - ✓ Since the arrangement of shelves and equipment is not based on the work process, **the troublesome movement of workers is a factor of inefficient productivity.**

Issues and motivation to be solved

- **As the number and types of equipment increase, the number of combination patterns becomes astronomical, and even with supercomputers, it becomes impossible to calculate the optimal layout when constraints such as the location of equipment are added,** said a factory for precision equipment that combines various types of equipment for production.
  - ✓ OKI's integrated LED plant manufactures multiple products with different manufacturing processes by sharing several hundreds of different types of equipment and having workers move between them.
  - ✓ **Optimal device placement for streamlining requires evaluation of 1,076 combinations, which would take about 1,051 years for a classical computer.**
- **OKI used the D-wave quantum annealer to verify the possibility of shortening the flow line (improving productivity) by calculating the optimum layout of semiconductor manufacturing equipment at its factory.**

Reference: Oki Electric Industry Co., Ltd., "Factory Equipment Layout Optimization Using Quantum Computers " (https://www.oki.com/jp/otr/2020/n235/pdf/otr235_r13.pdf), PR TIMES Co., Ltd. "OKI and OKI Data Apply Quantum Computers to Factory Optimization Problems" (https://prtimes.jp/main/html/rd/p/000000307.000017036.html)
*1: the Ministry of Economy, Trade and Industry: Current situation of labor shortage in manufacturing industry and utilization of foreign human resources, July 12, 2018
*Ising: A computing approach, mainly associated with quantum annealers and simulators specialized for the Ising model, in which a problem is first formulated as an Ising model and then solved computationally. It is particularly well suited to problems that involve finding the optimal combination from a vast number of possibilities.

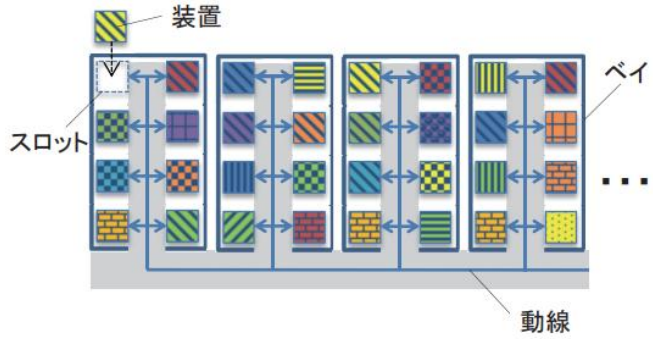
OKI: Factory Equipment Layout Optimization Using Quantum Computers [2022/05] 2/4

Validation

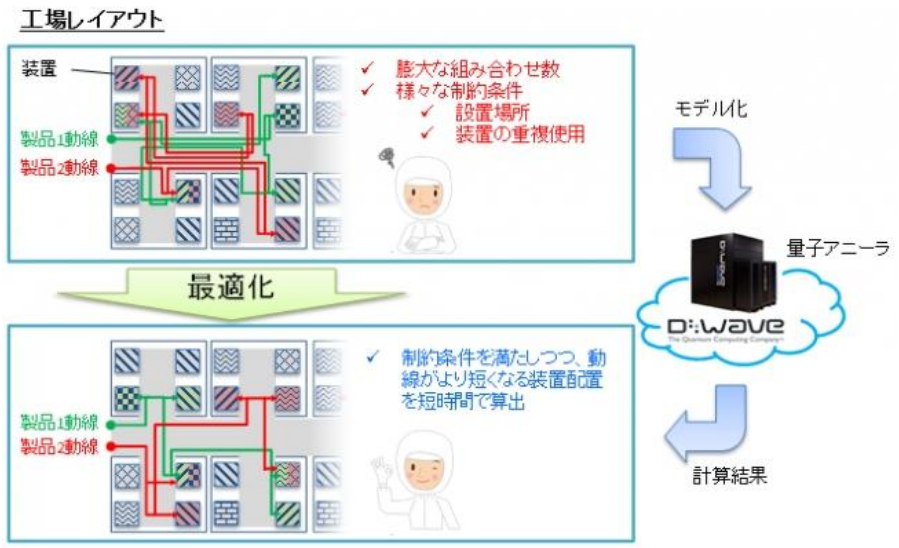
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Problem setting as a quantum computer (1/2)

- **OKI's LED factory manufactures several products with different manufacturing processes using partially overlapping equipment.**
  - ✓ The manufacturing process describes the order of the manufacturing process and the equipment used.
  - ✓ The worker processes the parts according to the manufacturing process, moves them to the equipment of the next process, and performs other processes throughout the manufacturing process.
  - ✓ In the factory, a plurality of small rooms (bays) with processing equipment are gathered and formed, and the bays and the equipment in the bays are connected by passageways so that workers can come and go freely.
- The problem of **optimizing equipment placement and minimizing flow lines**. **Since this is a factory that manufactures multiple products, the average value of flow lines of each product is an evaluation index** Defined as
  - ✓ Calculated by weighting each product by the ratio of the number of products manufactured (the ratio of the number of lots) because shortening the flow line of products manufactured in larger quantities contributes to shortening the overall flow line.
- To apply **quantum annealer** to a flow optimization problem **Formulate with QUBO (Quadratic unconstrained binary optimization) model**



factory layout



Schematic diagram of flow optimization (shortening) by quantum annealing

Reference: Oki Electric Industry Co., Ltd., "Optimization of plant layout using quantum computer" (https://www.oki.com/jp/otr/2020/n235/pdf/otr235_r13.pdf)
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OKI: Factory Equipment Layout Optimization Using Quantum Computers [2022/05] 3/4

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Problem setting as a quantum computer (2/2)

Problem setting as a quantum computer (Advanced)

problem setting	• Optimize equipment layout to manufacture multiple products and minimize flow lines to complete products
quantum computer Hardware	• Leverage D-wave's cloud platform (Product type unknown)
Implementation	• Perform the following optimization calculations multiple times until the solution converges Run (takes about 30 minutes)
objective function	• distance of the operator's line of motion
Constraints	• Always place one unit per slot (Second Term in Equation (3) in the Right Figure) • One device is always placed in one slot (the third term of equation (3) in the right figure).
Variables	• Unknown number of variables • Exceeds logical variables that can be solved by a D-Wave machine with limits between qubits, so breaks up the problem and iterates

$$x_{s,d} = \begin{cases} 1：スロットsに装置dを配置する \\ 0：それ以外 \end{cases}$$

QUBO variable

$$E(\boldsymbol{x}) = \sum_{u,t,s',s''} x_{s',d_u[t]} \cdot x_{s'',d_u[t+1]} \cdot L(s',s'')$$

$$+\sum_{s}\left(\sum_{d} x_{s,d} - 1\right)^2 \cdot p \qquad (3)$$

$$+\sum_{d}\left(\sum_{s} x_{s,d} - 1\right)^2 \cdot p$$

Objective Function of QUBO Model for Minimizing Traffic Line Distance

- S ′ and S ′ ′ are slots in which devices used in the tth and t+ 1th processes are arranged, respectively.
- L(S ', S' ') is the distance between slots S ', S' '
- $d_u[t]$ is the equipment used in the t-th process of product u
- p is the penalty factor

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OKI: Factory Equipment Layout Optimization Using Quantum Computers [2022/05] 4/4

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Expected business benefits

- The equipment arrangement before optimization (present arrangement) was compared with the optimization calculation result, and the quality of shortening of the flow line was evaluated. Calculations are made by **simulating a simulated environment of two products and three lot ratios**.
- Optimization of the equipment **reduces the travel distance of both products.**
  - ✓ The layout is calculated to reduce the flow lines of products with a large number of lots more intensively.
- **A flow line shortening of 20% or more has been realized in all lot patterns.**

(a) ロット数比 (製品1):(製品2)＝1:4

	最適化前	最適化後	増減率
製品 1	1,510	1,284	−15%
製品 2	2,876	2,036	−29%
平均	2,603	1,886	−28%

(b) ロット数比 (製品1):(製品2)＝1:1

	最適化前	最適化後	増減率
製品 1	1,510	961	−36%
製品 2	2,876	2,307	−20%
平均	2,193	1,634	−21%

(c) ロット数比 (製品1):(製品2)＝4:1

	最適化前	最適化後	増減率
製品 1	1,510	832	−45%
製品 2	2,876	2,484	−14%
平均	1,783	1,162	−24%

Results of optimization calculation of flow distance when manufacturing multiple products
(Distance is normalized, so units are arbitrary)

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More use cases are available on our website. We invite you to explore them.
https://www.quantum-computing-use-cases.nedo.go.jp/english/

More Use Cases

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This collection of use cases was obtained as a result of the work commissioned by the New Energy and Industrial Technology Development Organization (NEDO) "Cyber-Physical Development Business of Quantum/Classical Hybrid Technology/Study of Use Case of Quantum Technology" and the “Post-5G Information and Communications System Infrastructure Reinforcement R & D Project (Quantum Industrialization)/Comprehensive Study for Promoting the Industrialization of Quantum Computers”.