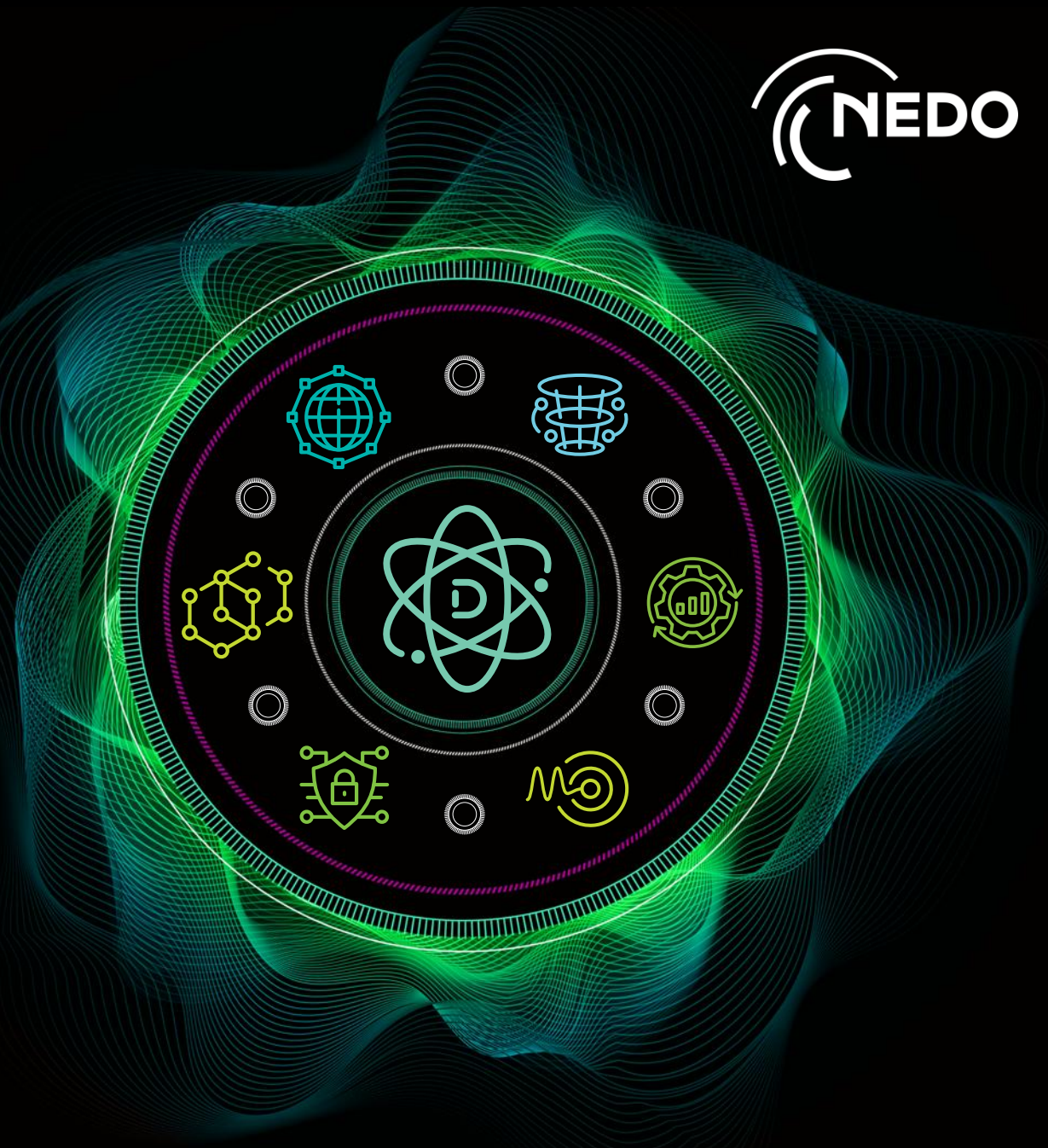
Quantum Computing Use Cases

Optimizing Collaborative Picking Plans for Humans and Robots in Warehouses

Dai Nippon Printing (DNP)



New Energy and Industrial Technology Development Organization (NEDO)

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Validation

Industry	Transportation
Means	land transportation
Method	combinatorial optimization
Category	Ising*

Background

- **Sharp growth in e-commerce demand and severe labor shortages:**

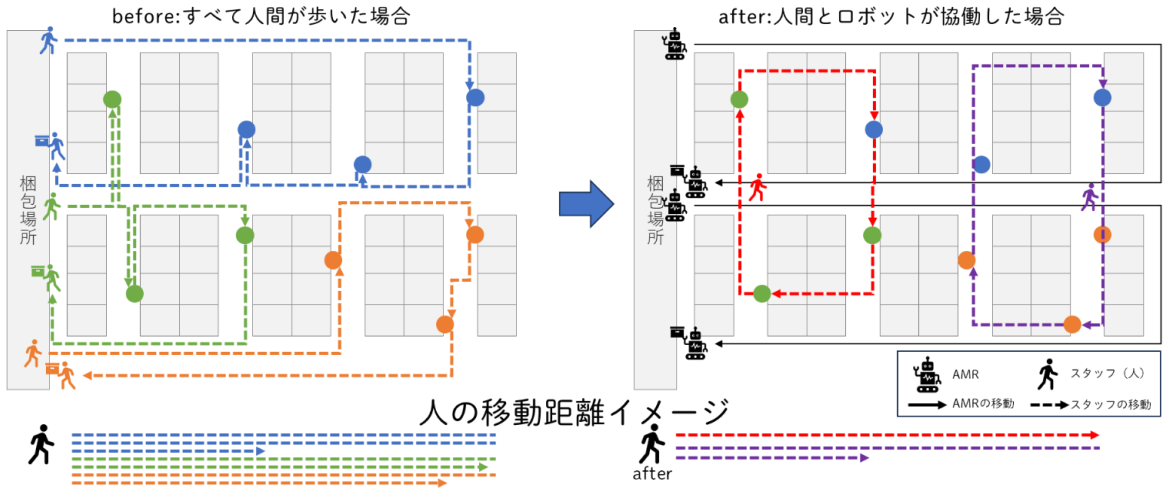
With the rapid spread of e-commerce sites, B2C small-lot deliveries have increased sharply, and **labor shortages in logistics warehouses handling this demand have become more serious. Picking operations involve significant product-search and walking burdens, creating a strong need for greater efficiency**

- **Need for labor saving in small and medium-sized warehouses:**

For many small and medium-sized logistics warehouses, **it is difficult to introduce fully automated warehouses because of the high capital investment required**. As a result, practical approaches to labor saving and efficiency improvement are being explored, such as replacing part of manual picking operations with autonomous mobile robots (AMRs)

- **A constantly changing on-site environment:**

Because workers, multiple robots, and obstacles move within the same space, **route planning is required that can reduce collisions, congestion, and losses caused by passing while tracking positions and operating conditions**



Reference: AI and Robot Department, New Energy and Industrial Technology Development Organization (NEDO), "Cyber-Physical Development Project for Quantum-Classical Hybrid Technologies" (https://www.nedo.go.jp/content/800030349.pdf); "Dai Nippon Printing and BIPROGY Begin Full-Scale Research on Improving Logistics Operations Efficiency Using Quantum Technology and AI" (https://www.dnp.co.jp/news/detail/20176524_1587.html); "Professionals in DNP #1: What Kind of R&D Created DNP Annealing Software, Which Derives Optimal Options 10 Times Faster?" (https://www.dnp-innovationport.com/news-report/topics_20221208/)

*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.

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Issues and motivation to be solved

- **Need for real-time planning**:

It was necessary to formulate picking plans in real time that minimize the total of robot travel time and worker walking time, while taking into account the enormous number of possible movement routes in a large warehouse, various constraints, and ongoing changes in on-site conditions

- **The barrier of combinatorial explosion in classical computing:**

Since a formulation that minimizes passing conflicts and congestion among robots and workers becomes a complex quadratic programming problem (an extension of multi-agent path planning), the solution space is extremely large, and **it has been difficult for conventional classical computers (such as MIP solvers) to derive practical solutions at realistic speeds (on the order of seconds)**

- **Use of the strengths of Ising machines:**

To overcome this challenge of computational explosion and achieve both the speed and accuracy required in the field, the applicability of Ising machines (quantum annealing and quantum-inspired technologies), which are well suited to high-speed processing of combinatorial optimization problems, was examined

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Problem formulation for quantum computer

- **Objective Function to Be Optimized:**
  - ✓ **Minimize both the travel time, taking into account time losses caused by robots passing each other, and the worker waiting time for robots**
- **Main Constraints:**
  - ✓ **One-hot constraint:** Each robot must select exactly one candidate route at a time
  - ✓ **Practical business and operational constraints:** Comprehensively reflect the actual physical warehouse layout, the correspondence between shelves and locations, the attributes of the items to be picked (such as item count and slip information), and the sequence of work procedures
  - ✓ **Loss minimization while allowing collisions/passings:** Instead of simply prohibiting collisions or entry, this approach uses a unique formulation that quantifies slowdown and avoidance loss time during passing events based on actual warehouse operations and incorporates it into a QUBO (quadratic unconstrained binary optimization) model
- **Types of Input Data:**
  - ✓ Actual picking slip data from an in-house warehouse (approximately 500 items, with 32 to 35 tasks)
  - ✓ Warehouse layout drawings (including actual shelf dimensions), average worker walking speed, required picking time at each location, and robot motion behavior parameters
- **Why Classical Methods Are Difficult:**
  - ✓ The problem of minimizing time losses caused by robots passing each other cannot be formulated as a linear programming problem, so **methods based on general-purpose classical solvers require substantial computation time**. This makes them difficult to apply to situations where results must be returned instantly in response to real-time changes

Robot path optimization (selecting the optimal route from candidate paths: solved using an Ising machine)

求解のための変数と定数：

●**決定変数：** x_{ik}（i番目のロボットがk番目の経路を選択する場合:1、それ以外の場合:0）

●**i番目のロボットのk番目の経路に対応した時間**（衝突がない場合）：R_{ik}

●**i番目のロボットのk番目の経路とj番目のロボットのl番目の経路とのすれ違いロス時間：** $F_{ik,jl}$

目的関数：

$$H = \sum_{i=1}^{N_A}\sum_{k=1}^{U} R_{ik}x_{ik} + \sum_{i=1}^{N_A}\sum_{j=i+1}^{N_A}\sum_{k=1}^{U}\sum_{l=1}^{U} F_{ik,jl}x_{ik}x_{jl} + \delta\sum_{i=1}^{N_A}\left(\sum_{k=1}^{U} x_{ik} - 1\right)^2$$

⇨ イジングマシンにより求解

（δ：ハイパーパラメータ（正の実数値））

Reference: AI and Robot Department, New Energy and Industrial Technology Development Organization (NEDO), "Cyber-Physical Development Project for Quantum-Classical Hybrid Technologies"
(https://www.nedo.go.jp/content/800030349.pdf)

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Expected business benefits

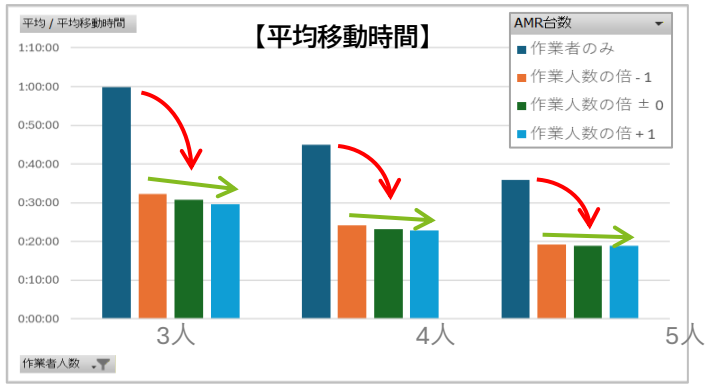
■ Quantitative Effects

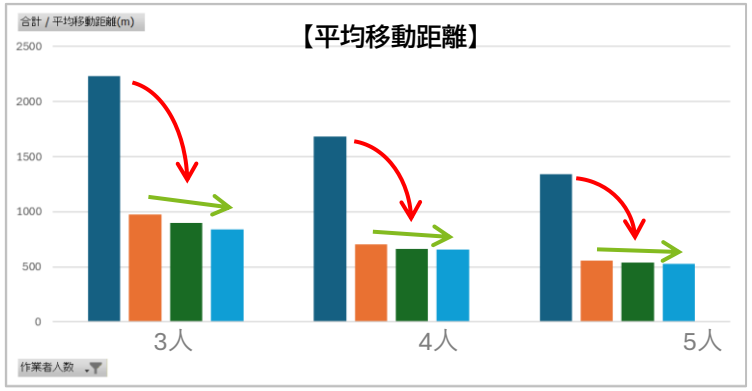
- ✓ **High-speed computation within one second, far exceeding the target:** standalone tests of the optimization SDK using actual on-site data (476 items, scale of 5 robots), **optimal route computation was achieved in less than one second, greatly surpassing the original target of within 3 seconds, specifically 0.329 seconds (with 5 workers) to 0.375 seconds (with 20 workers)**
- ✓ **Reduction in worker walking burden and travel time:** Results from demonstration experiments using a simulator showed that, compared with conventional operations in which only workers perform picking, **the introduction of robots together with processing by this optimization solver significantly reduced workers' average travel time and average travel distance, while successfully and safely completing all tasks**

■ Qualitative Outlook

- ✓ **Improved operational validity and on-site responsiveness:** In actual warehouse environments where conditions continue to change in real time, **the system can immediately present operationally feasible solutions (appropriate picking instructions) even when sudden tasks arise or delays occur, enabling flexible on-site operations.**
- ✓ **High implementation value in suitable environments:** A certain optimization effect has been technically confirmed, and if this application is applied to warehouses or factories with favorable conditions—such as environments where people and transport robots frequently and densely interact—**it is expected to deliver strong labor-saving effects and high cost performance.**

Picking plan optimization — simulation results





- When compared under the same number of workers, introducing robots and applying optimization significantly reduced the workers' average travel time and average travel distance
- As the number of robots increases, both travel time and travel distance tend to decrease

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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

New Energy and Industrial Technology Development Organization (NEDO)
AI and Robotics Department (e-mail: quantum_ai@ml.nedo.go.jp)

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”.