Quantum computing in the supply chain ecosystem: from scheduling to traffic control

Efficiency is the key for handling operations in supply chain. Further, the amount of data in business operations of manufacturers and logistic companies is increasing by the day.

Quantum computers could provide the solution to the increasing need of data analysis, development of decision models and optimization of resource management and logistics on the fly.

This article presents an overview of the status and applications of quantum computing to supply chain and logistics.

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Quantum mechanics and quantum computing

Quantum mechanics is the theory that describes the dynamics of microscopic particles [1] [2]. In this theory, "quantum" particles are described by probability distributions, e.g. we never know with certainty their position or speed.

This probabilistic nature of quantum particles leads to two non-classical phenomena which are the basis of quantum computation: **superposition**, e.g. quantum particles can be simultaneously in two places; and **entanglement**, which is a perfect correlation between particles, for which a measurement on one particle leads instantaneously to the change of the state of the others.

Calculations on a classical computer are based on the binary system, where

the information is carried by bits assuming value 0 **or** 1.

On a quantum computer [3] [4], i.e. a computer which processes information using quantum particles, the smallest unit of information is the quantum bit (or **qubit**). The qubit is the state of a quantum particle, which due to the superposition property of quantum particles can **simultaneously** assume value 0 **and** 1.

This feature, together with the entanglement between qubits, makes a quantum computer more efficient at certain types of data-intensive applications and calculations which would be harder to perform on a classical computer. As an example, k qubits can potentially represent 2^k bits of information. Further, quantum algorithms have been developed to: solve optimization problems (quantum annealing [5]), find patterns and correlations that point toward a solution (Grover algorithm [6]), exchange a cryptographic key in a "super-secure" way (BB84 protocol [7]), or even exponentially speed-up classical operations (Quantum Fourier transform [8]).

Quantum annealing and applications to the supply-chain ecosystem

Several key players in the supply chain ecosystem, from manufacturers to terminals and logistic providers, are constantly searching for new technologies that boost higher performances and profits[1].

For instance, the progress in numerical techniques, data science and artificial intelligence are examples of how logistic services benefit of new technologies to explore business and decision models and to optimize operations.

Several big industry players are currently investigating quantum computing for practical **optimization problems**, such as scheduling and decision making.

Optimization algorithms have been developed for quantum computers, with particular success in solving Quadratic Unconstrained Binary Optimization problems (**QUBO**), which is a class of optimization problem with binary variables. Examples of such problems are the "travelling salesman problem" and "the job-shop problem" [9]. These types of problems are very common in logistics and supply chain, and are mainly related to the optimization of operations, such as crane scheduling, traffic control or optimization of deliveries.

The most common quantum computers used for solving QUBO problems are **D-Wave** architectures[2]. This quantum computer uses the property of every physical system to move towards its lowest energy state (think about a mountain stone rolling down to the valley). **Quantum annealing** is a way of using this property in quantum systems to quickly converge to the optimal point of a problem.

[1] Check, e.g., https://www.dhl.com/nl-en/home/insights-and-innovation/thought-leadership/trend-reports/quantum-computing.html

[2] https://www.dwavesys.com/

In quantum annealing we map a cost function we want to optimize (e.g., a likelihood function) to a quantum computer function (called *potential* or *hamiltonian*). The qubits will then evolve towards the minimum of this function via thermal fluctuations (classical) and quantum fluctuations (tunneling). These two different qubit evolutions are sketched in Figure 1.

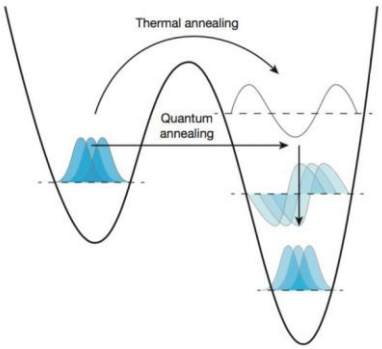

Figure 1: Quantum and Classical annealing evolutions. Source: Biamonte (2017).

The additional quantum fluctuations available on a quantum computer improve the performance in spanning the solution space of the optimization problem. This decreases the chance to end up in local minima.

Research on D-Wave architecture for practical tasks includes:

- route scheduling[3]
- flight gate assignment[4]
- self-driving vehicles[5]
- asset sustainment[6]
- portfolio optimization[7]

Besides optimization, **simulations** and **artificial intelligence** are also considered in the context of quantum computing.

In fact, it has been shown that quantum algorithms may provide a quadratic speed-up compared to their classical counterparty for simulation problems [10] and even an exponential speed-up for machine learning problems [11]. Few examples of the latter are quantum principal component analysis (QPCA) [12], quantum support vector machine [13] and quantum machine learning [14] [15].

Conclusions

Researchers are currently looking at possible applications of quantum computing to the entire supply-chain ecosystem.

Many organizations, from the industry to governments, are preparing for the potential impact of quantum computing on their operations.

The rise of this new technology leads to the need for each organization to understand if and how quantum computing can be a **competitive advantage** to their business, in which ways it impacts the **security** of the organization and which type of **risks** can emerge by using (or not using) quantum computing.

At **Quantum Quants** we are actively investigating the business possibilities

[3] https://www.dwavesys.com/sites/default/files/Dwave_Toyota_Case_Study_V4.2F.pdf
[4] https://www.dwavesys.com/sites/default/files/handout_lobe.pdf
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[7] https://www.dwavesys.com/sites/default/files/12_Tues_PM_FinlPort.pdf

via **feasibility studies** of quantum solutions for e.g. distribution and transport, real-time dispatch, vehicle routing, staff scheduling, resource planning and assignment, etc.

We are currently creating and implementing algorithms for supply-chain problems on the **AWS Braket cloud service**[8], which we run on an actual D-Wave architecture with 5000+ qubits[9].

We believe that the possible performance enhancements offered by quantum computing are very exciting and it could benefit every supply-chain ecosystem player by **improving operations planning, task scheduling**, **decreasing the cost** and, last but not least, **reducing the environmental impact** of the business.

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About Quantum Quants

Quantum Quants helps businesses to get insights on applications of quantum computing to the financial industry, data science and supply-chain.

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