🟤 TITLE: Quantum Operational Intelligence System — Phase 1: Quantum Problem Formulation

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1. Introduction

IBM Quantum backends experience fluctuations in:

- Load
- Noise
- Queue depth
- Error rates
- Hardware availability

Because of this, researchers struggle to choose the *best backend* for running their quantum circuits.

Quantum Operational Intelligence System (QOIS) solves this by predicting the optimal backend using AI + Quantum Optimization.

Phase 1 focuses on converting this real-world challenge into a mathematical optimization problem suitable for quantum algorithms.

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2. Problem Statement

Given multiple IBM quantum backends with different characteristics:

- Queue Length
- Error Rates
- Downtime Probability
- Number of Qubits
- Calibration Performance
- Throughput

Goal: Select the best backend for executing a user's quantum circuit.

This is a **resource allocation optimization problem**, ideal for quantum optimization.

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3. Why Quantum Optimization?

Backend selection involves:

- Multiple conflicting factors
- Dynamic system behavior
- Real-time decision making
- Multi-criteria optimization

This makes it ideal for quantum optimization methods such as:

- **QUBO** (Quadratic Unconstrained Binary Optimization)
- **QAOA** (Quantum Approximate Optimization Algorithm)

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4. Decision Variables

Let there be **N** quantum backends.

Define a binary variable for each backend:

$$x_i = \begin{cases} 1 & \text{if backend i is selected} \\ 0 & \text{otherwise} \end{cases}$$

Example:

Backend	**Variable**
ibm_osaka	x□
ibm_brisbane	x□
ibm_jakarta	x□

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5. Objective Function

We want to:

- Minimize queue length
- Minimize error rate
- Minimize downtime probability
- Maximize number of qubits
- Maximize reliability

$$Cost = w_1 Q_i + w_2 E_i + w_3 D_i - w_4 B_i$$

Where:

Symbol	Meaning
Q_i	Queue length
E_i	Error rate
D_i	Downtime probability
B_i	Number of qubits
w_1–w_4	User-defined weightage

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6. Constraint: Select Exactly One Backend

$$\sum_{i=0}^{N-1} x_i = 1$$

Ensures that **only one backend** is chosen.

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7. Full Mathematical Formulation (QUBO)

$$\text{Minimize: } \sum_i x_i \,(w_1 Q_i + w_2 E_i + w_3 D_i - w_4 B_i) + \lambda(\textstyle\sum_i x_i - 1)^2$$

This expands into a **QUBO matrix** that will be used in **Phase 2 (QAOA)**.

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8. Data Inputs Used

Using IBM Quantum API + Qiskit Runtime, the system fetches:

- Live backend operational status
- Queue depth
- Error rates
- T1 / T2 coherence times
- Calibration data
- Qubit topology
- Gate fidelity

- Throughput statistics

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9. Expected Outputs of Phase 1

Phase 1 produces:

- A complete mathematical formulation of backend selection
- QUBO-compatible structure
- JSON representation of variables & parameters
- Python script to extract live backend metrics
- A clear explanation for judges

This output feeds directly into **Phase 2: QUBO + Circuit Architecture**.

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10. Conclusion

Phase 1 establishes the **mathematical foundation** for QOIS.
We transformed the backend-selection challenge into a **quantifiable optimization problem** ready for quantum processing.

This completes the **Superposition Phase**, preparing the system for QAOA in Phase 2.