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Leveraging AI & ML with Quantum Computing: India’s Roadmap & Defence Strategies

Lt Col Pradeep Singh

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Abstract

Artificial Intelligence (AI) and Machine Learning (ML) are transforming defence capabilities worldwide. Concurrently, quantum technologies quantum computing (QC), quantum sensing, and quantum communications promise paradigm-shifting advantages and corresponding strategic risks. This article examines how India can combine AI/ML with quantum computing to create a resilient, sovereign, and strategically advantageous defence posture. It surveys existing Indian policy and institutional initiatives, outlines defence-relevant applications (secure communications, decision-support, sensing, cryptography/post-quantum resilience), analyses technical and organizational challenges, and presents a practical national roadmap with recommendations across R&D, industry, procurement, workforce development, and governance. The article argues that an integrated AI–Quantum strategy, rooted in the National Quantum Mission and responsible AI frameworks, can deliver asymmetric advantages for India's national security while maintaining democratic values and operational safety.(DoST, n.d.)

Keywords: quantum computing, artificial intelligence, machine learning, defence strategy, National Quantum Mission, India, post-quantum cryptography

Introduction

Rapid advances in AI/ML and nascent but accelerating progress in quantum technologies present both opportunities and threats for national defence. AI provides powerful pattern recognition, predictive analytics, autonomous decision-support, and logistics optimization. Quantum computing promises new classes of algorithms for optimization, simulation, and cryptanalysis; quantum sensing can deliver orders-of-magnitude improvements in detection sensitivity; and quantum communications (e.g., quantum key distribution, QKD) offers fundamentally new modalities for secure communications. For India a major regional power with expanding defence ambitions and a growing domestic tech ecosystem the strategic challenge is to integrate AI/ML and quantum technologies to both exploit opportunities and mitigate vulnerabilities while retaining operational sovereignty. Recent Indian government initiatives such as the National Quantum Mission (NQM) and formal frameworks for AI governance provide a foundation for such integration but coordinated defence-specific action is required to translate policy into capability(DoST, n.d.).

Background: Why AI + Quantum Matters for Defence

Complementary capabilities

AI/ML and quantum computing are complementary. AI/ML excels at learning from data and making fast inferences at scale; quantum computing (particularly quantum annealers and emerging gate-model devices) promises algorithmic speedups for certain optimization, sampling, and simulation problems that are central to planning, logistics, cryptanalysis, and materials discovery. Hybrid architectures classical AI pipelines augmented by quantum accelerators or quantum-inspired algorithms can unlock faster trajectory optimization for autonomous platforms, more efficient resource allocation, and improved cybersecurity analytics. Quantum sensing (atomic clocks, magnetometers, interferometers) enhances detection of stealthy threats (submarines, underground facilities, or low-observable UAVs), while quantum communications enable future-proof secure links. Together, these technologies reshape the contours of situational awareness, command and control, and resilience in contested environments(Global Quantum Intelligence, 2025).

Strategic urgency

Early action is vital due to three key drivers: the cryptographic risk posed by future quantum computers to current public-key systems, the global race in quantum and AI defence capabilities, and the industrial opportunities from quantum-AI convergence for defence and dual-use applications. India's NQM and DRDO initiatives acknowledge these factors, providing funding and institutional support for defence-relevant R&D. (Kumar et al., 2025).

Quantum-Enhanced AI/ML

Quantum computing augments AI and ML performance by accelerating core data processing operations. Quantum ML algorithms, such as quantum support vector machines and quantum clustering, promise speedup in pattern recognition, classification, and dimensionality reduction tasks essential for analyzing battlefield data streams.

Additionally, quantum computers optimize complex resource allocation and logistics problems, alleviating bottlenecks classical methods struggle with in real-time military settings. Quantum neural networks, leveraging quantum state interference, may offer superior performance in learning from high-dimensional, noisy datasets common in signal processing and cyber warfare. These advancements enable enhanced predictive capabilities, threat detection accuracies, and agile autonomous systems in defense, proving quantum-AI/ML convergence a force multiplier.

India's Policy & Institutional Landscape

National Quantum Mission and National Coordination

The Government of India launched the National Quantum Mission (NQM) with an allocation of approximately ₹6,003.65 crore for 2023–2031 to promote R&D, human capital, and industry ecosystems in quantum technologies. NQM's strategic goals technology development, testbeds, and industry adoption are directly relevant to defence modernization plans and sovereign capability development. Complementary state and local initiatives (Quantum City proposals, Amaravati quantum facilities) highlight decentralized momentum but also the need for central defence coordination to ensure dual-use alignment and secure supply chains for sensitive components (DoST, n.d.) .

AI Governance and Defence Institutionalizations

NITI Aayog's National Strategy and subsequent Responsible AI principles propose a framework for trustworthy AI in India; meanwhile, the Ministry of Defence has institutionalized defence AI through bodies such as the Defence AI Council (DAIC) and Defence AI Project Agency (DAIPA), and has sponsored multiple AI projects and demonstrations. These structures create an environment where hybrid AI–quantum projects can be incubated under defence oversight, enabling mission-driven innovation while adhering to principles of safety, explainability, and human oversight (NITI Ayog, 2018).

DRDO and Sovereign Capability

DRDO's inauguration of dedicated Quantum Technology Research Centres and related experimental facilities underscores an emphasis on sovereign development of quantum communications, sensing, and post-quantum algorithms for defence. These facilities create testbeds for military use cases (secure links between command nodes, quantum sensing for naval and aerospace platforms) and allow classified, security-sensitive development within national structures. For operational adoption, DRDO must coordinate with services, defence procurement organisations, and industry to translate prototypes into deployable systems (Global Quantum Intelligence, 2025).

Defence Applications: Use Cases and Value Chains

This section classifies defence use cases for integrated AI–quantum capabilities, highlighting operational value, maturity, and near-term actionability.

1. Communications and cryptography (high strategic priority)

- **Quantum-resilient cryptography:** Given the potential future threat to RSA/ECC from fault-tolerant quantum computers, implementing post-quantum cryptography (PQC) across defence networks is urgent. Hybrid cryptographic strategies combining PQC algorithms with quantum key distribution (where feasible) can provide layered protection. Defence must prioritize cryptographic inventory audits, risk assessments, and staged migration plans (Kumar et al., 2025).

- **Quantum key distribution (QKD):** QKD offers information-theoretic key exchange over fiber or free-space links and is attractive for critical command links and diplomatic communications. Pilot deployments (e.g., point-to-point QKD between select installations) can help mature technology and secure supply chains for trusted components. However, QKD's operational constraints (distance, node trust, integration complexity) require careful feasibility studies and layered architectures.

2. Sensing, detection & intelligence (medium-high)

Quantum sensors can provide breakthroughs in navigation (quantum inertial sensors resistant to GPS jamming), gravimetry (subsurface detection), and magnetometry (submarine detection). Integrating AI/ML with quantum sensor outputs amplifies signal extraction from noisy environments, enabling earlier and more reliable detections. Defence applications include naval ASW (anti-submarine warfare), counter-UAV, and battlefield situational awareness. Pilot programmes co-developing sensors, ML fusion algorithms, and hardened platforms are essential.

3. Decision support, optimisation & logistics (near-term / hybrid)

Optimization problems mission planning, logistics routing under constraints, resource allocation are prime candidates for hybrid quantum-classical approaches. While near-term quantum advantage is not universal, quantum-inspired algorithms and quantum annealing can offer practical improvements when paired with ML-based predictive models. Defense logistics (spares forecasting, convoy routing under threat) and fleet management can be early adopters of hybrid solutions (Swayne, 2025).

4. Cybersecurity & threat hunting (near-term)

AI/ML is already central to defence cybersecurity (anomaly detection, behavior analytics). Quantum computing creates both threats (future cryptanalysis) and opportunities (randomness generation, novel cryptographic protocols). Integrating PQC migration with AI-driven cyber defences threat intelligence using ML models that are hardened to adversarial inputs will be a core element of a resilient cyber posture.

5. Simulation and materials discovery (longer-term)

Quantum simulation can shorten development cycles for new materials, sensors, and propulsion systems by enabling accurate modelling of complex quantum systems. Coupling these simulations with ML-driven surrogate models reduces computational cost and may accelerate prototype development in areas like stealth materials or energy storage. Defence labs and industry consortia should target dual-use material science projects to leverage commercial scale.

Technical & Organizational Challenges

Hardware and supply chain fragility

Quantum hardware (superconducting qubits, cryogenics, photonics, trapped ions) requires specialised components and supply chains that are currently global and fragile. For defence applications, trusted domestic or allied suppliers and secure manufacturing lines are critical. India's investments (quantum cryogenics facilities, quantum reference labs) are steps forward, but scaling to resilient industrial production requires sustained capital and policy support .

Algorithmic readiness and hybrid integration

Quantum advantage is problem-specific. Many defence workloads will require hybrid quantum-classical pipelines; developing algorithms and interfaces, and determining where quantum acceleration yields measurable gains, are active research areas. Defence R&D needs career-spanning collaborations between quantum physicists, ML researchers, and systems engineers to create deployable stacks(Aluri, 2025).

Talent and workforce development

High-quality talent in quantum engineering, quantum-aware software engineering, and ML is limited. India must expand graduate programmes, vocational training, and service-specific upskilling. Defence labs should create fellowship tracks and industry partnerships to attract talent, while academic curricula should embed quantum information science alongside ML courses. NITI Aayog has highlighted talent shortages in AI; quantum exacerbates this gap. (NITI Ayog, 2018).

Security, verification & standards

Quantum and AI systems for defence must meet rigorous standards for reliability, explainability, and security. Certification frameworks for quantum devices (e.g., component provenance, side-channel resistance) and AI validation protocols (robustness, adversarial safety) are required. India should participate in international standardisation bodies while developing domestic standards tailored for defence contexts (Kumar et al., 2025).

Ethics, command & control, and human oversight

Autonomy raises complex ethical and legal questions. Defence use of AI (especially combined with quantum-enhanced sensors) must enshrine human-in-the-loop controls for lethal decisions, consistent with international humanitarian law and national policy. Layered governance operational doctrine, technical guardrails, and auditing is necessary to prevent misuse or unintended escalation.

A Practical Roadmap for India (2025–2035)

Below is a staged roadmap that prioritises rapid practicality, sovereign capability, and responsible governance. Each phase corresponds to a 3–4 year horizon; timelines overlap and should be resource-driven rather than calendar-fixed.

Phase 1 (2025–2028): Secure, Pilot, and Institutionalize

Objectives

- Harden cryptographic posture (crypto inventory, PQC pilots)
- Establish defence quantum testbeds (DRDO/Service labs)
- Launch joint AI–Quantum grand challenges and seed projects
- Create fellowship programmes and service exchanges for talent

Key actions

1. **Cryptographic audit & PQC migration plan:** Mandate a defence-wide crypto inventory and begin PQC pilot deployments in non-mission-critical channels. Implement hybrid key-management where QKD is road-tested for point-to-point links.
2. **Testbeds and secure facilities:** Expand DRDO quantum research centres and create classified testbeds for communications, sensing, and ML-quantum integration. Encourage partnerships with IITs, IISc, and industry.
3. **Joint research programmes:** Issue defence-industry-academia calls for hybrid algorithms (optimisation, sensor fusion) with milestones oriented to deployable prototypes. Fund translational projects through NQM and defence R&D budgets.

Phase 2 (2028–2032): Scale, Deploy, and Secure Supply Chains

Objectives

- Develop domestic manufacturing for critical quantum components
- Deploy quantum-resilient communications in prioritized domains
- Integrate quantum sensors into naval/aerospace platforms

Key actions

1. **Trusted supply chains:** Incentivize domestic manufacturing (cryogenics, photonics, control electronics) via defence procurement preferences and industry clusters (e.g., Quantum City). Implement security vetting for suppliers(TNN, 2025).

2. **Operational deployments:** Field QKD links for strategic command nodes, integrate quantum sensors into select platforms for trials, and adopt hybrid optimization tools in logistics and mission planning. Establish cross-service interoperability standards.
3. **Workforce scale-up:** Expand graduate fellowships, service pay scales for technical officers, and course pipelines in universities to produce engineers with dual quantum/ML skills.

Phase 3 (2032–2035+): Mature, Innovate, and Maintain Strategic Edge
Objectives

- Achieve sovereign capability across critical quantum stacks
- Maintain continuous PQC migration and cryptographic agility
- Lead in strategic dual-use innovations and allied collaboration

Key actions

1. **Sovereign quantum stacks:** Establish domestic full-stack capability (hardware to software and middleware) for defence-grade systems, with export controls and allied interoperability frameworks.

2. **Continuous security posture:** Institutionalise crypto-agility, continuous red-teaming with quantum-informed adversary models, and secure lifecycle management for AI–quantum systems.

3. **Strategic partnerships:** Deepen collaboration with friendly nations and multinational R&D consortia for standards, threat intelligence, and joint development of dual-use capabilities (Mishra & Cdr Nanda, 2025).

Governance, Procurement & Legal Considerations

Defence procurement reform

Procurement rules must be updated to allow classified, iterative R&D with industry (other-transaction-type authorities), rapid prototyping, and small-batch production for quantum components. Mechanisms should preserve security vetting while enabling startups to participate in sovereign supply chains.

Export controls & technology safeguards

Quantum technologies have dual-use risks. India should implement export controls aligned with non-proliferation norms and engage in multilateral dialogues to prevent irresponsible dissemination while allowing legitimate commercial growth.

Standards and certification

Create a national certification authority for quantum and AI systems in defence contexts. Certification covers component provenance, firmware integrity, side-channel hardening, and explainability/robustness metrics for AI models.

Legal and ethical frameworks

Clarify legal responsibilities for autonomous systems enhanced by quantum capabilities, ensure human oversight in lethal decision loops, and adopt transparent audit trails for AI/quantum systems used in operations. Align Indian practice with international humanitarian law and emerging norms on AI in warfare.

Building the Ecosystem: Industry, Academia & Startups

Public-private partnerships

Leverage NQM funds for public-private consortia that include defence primes, MSMEs, and startups. Defence labs should act as early adopters and anchor customers for nascent technologies, reducing market risk.

Centres of excellence & incubators

Establish defence-oriented quantum-AI centres of excellence in partnership with IITs, IISc, and selected states (e.g., Quantum City proposals) to co-locate talent, fabrication facilities, and testbeds. These centres should host classified and open projects with clear IP and revenue-sharing rules.

Incentives & procurement pathways

Use fast-track procurement for technologies meeting defined readiness thresholds, and provide R&D incentives and tax benefits for manufacturers of critical quantum components. Ensure procurement frameworks favour secure domestic sources where national security is involved.

Recommendations (Actionable & Prioritised)

1. **Immediate cryptographic triage:** Mandate a defence-wide crypto inventory and commence PQC pilots within 12 months. (High priority).

2. **Fund defence quantum testbeds:** Expand DRDO's quantum centres and co-fund university testbeds under NQM for classified use. (High priority).

3. **Launch an AI–Quantum Defence Challenge:** Annual competitive grants to develop hybrid algorithms for optimisation, sensor fusion, and cyber-defence, with transition pathways to services. (Medium priority).

4. **Develop trusted supplier lists and domestic manufacturing roadmaps:** Use incentives to create secure supply chains for cryogenics, photonics, and control electronics. (High priority)

5. **Scale workforce programmes:** Fund doctoral and vocational programmes, offer defence fellowships and industry secondments to build cross-disciplinary expertise. (High priority)

6. **Governance & standards body:** Create a defence quantum-AI certification authority to oversee validation, testing, and lifecycle security. (Medium priority)

Conclusion

AI/ML and quantum technologies together offer India a pathway to secure, sovereign, and strategically significant defence capabilities. The National Quantum Mission and nascent institutional mechanisms for defence AI provide a foundation, but success requires a focused defence roadmap: immediate cryptographic hardening, deployment of testbeds, supply chain development, workforce scale-up, and robust governance. Hybrid AI–quantum approaches well-governed, interoperable, and ethically constrained can yield asymmetric advantages across communications, sensing, decision support, and materials development. By coordinating policy, procurement, academia, and industry, India can not only protect its critical systems against future quantum threats but also harness quantum-AI innovations for national security and economic growth.

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About the Author

Lt Col Pradeep Singh is an alumni of Indian military academy. Commissioned into Regt of Artillery. He has served various terrains of the country. He is an M.Sc (Tech) and has done Post graduate diploma in business management in Information technology and system management from NMIMS. He has done various courses in AI, ML and AR/VR from various online platforms. He has done instructor in school of artillery. He has had the opportunity to serve in UN in Democratic Republic of Congo..