DRAFT
Concept Note

National Mission on Quantum Technology & Applications (NM-QTA)

1. Context/ Background:

Quantum Technology is one of the 9 missions of national importance, being driven by the Prime Minister's Science and Technology Innovation Advisory Council (PM-STIAC) through the (Principal Scientific Advisor) PSA's office to leverage cutting edge scientific research for India's sustainable development. The areas of focus be in fundamental science, translation, technology development and towards addressing issues concerning national priorities. This may include quantum computing, quantum communication and quantum materials required for building indigenous capability and trained manpower.

2. Introduction:

Quantum Technology is based on the principles of quantum theory, which explains the nature of energy and matter on the atomic and subatomic level. It concerns the control and manipulation of quantum systems, with the goal of achieving information processing beyond the limits of the classical world. Quantum principles will be used for engineering solutions to extremely complex problems in computing, communications, sensing, chemistry, cryptography, imaging and mechanics. For example a quantum computer will be able to process massive data sets in ways not possible with even today's most advanced super computers. Quantum computers leverage the unique properties of matter at nanoscale. They differ from classical computers in three fundamental ways: First, quantum computing is not built on bits that are either zero or one, but on qubits that can be overlays of zeros and ones. Second, qubits do not exist in isolation but instead becomes entangled and act as a group. These two properties enable qubits to achieve an exponentially higher information density than classical computers. The third difference lies in the way that quantum computers do their work. While binary computers conduct massive numbers of arithmetic calculations sequentially, a quantum computer calculates all possible outcomes concurrently and settles on a potentially correct answer through constructive interference; it "cancels out" all the wrong answers. As the R&D in this field continues, the resulting technology will directly impact how we communicate, travel, conduct financial transactions, and even treat illnesses. Some of the future applications of quantum technology will be autonomous vehicle navigation, weather modelling & prediction, transportation planning, pharmaceutical development, secure financial communications, resource exploration, sensing and quantum encryption among the many others. For example, quantum technology could potentially help a Government air carrier seamlessly reschedule, reroute, and rebook a cancelled flight. It would also provide much better security when paying bills online. It would even make more precise medical imagers (MRIs) possible. Quantum computers can improve models of chemical reactions and material design, leading to more sophisticated and effective drug design, better batteries, and exotic materials with improved electrical or mechanical functions. Quantum field has not yet matured for commercialization, due to the extreme scientific challenges involved.

With a solid research base and workforce founded on significant and reliable government support, it can lead to the creation of innovative applications by industries, thereby stimulating economic growth and job creation, which will feed back into a growing quantum-based economy. The government's financial and organizational support will also ensure that both public and private sectors will benefit. A comprehensive National Quantum Initiative will establish standards to be applied to all research and help stimulate a pipeline to support research well into the future.

3. International Status

In 2004 the United States came up with a detailed roadmap for developing the science and techniques required to start building a quantum information processor. Other nations - China in particular - also made serious efforts and committed substantial resources towards advancement in this emerging frontier. Recently recognizing the threat of losing their advantage in these rapidly emerging areas, the US government has recently taken up the National Quantum Initiative Act which aims to significantly ramp up research activities and funding in this area. China has also recently announced the creation of a 11.4 billion dollar (investment for 2 years) National Laboratory for Quantum Information in the city of Hefei, to make China a global leader in quantum technology. One of the highlights of these developments was the demonstration of quantum cryptography through free space across to a satellite paving the way for potentially doing quantum cryptography across intercontinental scales. In 2016 the European initiative on quantum computing, coordinated by the European Commission's Future and Emerging Technologies Flagship on Quantum Technologies unveiled its roadmap for the next 10 years for Quantum Information Science and Technology. The planned budget of the European roadmap was around one billion Euros, with investments in the areas of quantum communication, quantum computing, quantum simulation, quantum metrology, sensing and imaging, quantum control, and quantum software and theory. This is in addition to the significant programs run by countries like Germany, The Netherlands, Denmark and Sweden. Russia's effort in quantum information science and technology is coordinated by the Russian Quantum Centre which has announced that they are on the road to achieving quantum supremacy. Australia also has a very well-funded nationwide initiative on quantum information science and technology, with several participating universities and institutes such as the Centre for Quantum Software and Information in Sydney and the University of Sydney's Microsoft Quantum Laboratory. Canada too has set up an Institute for Quantum Computing (IQC) at the University of Waterloo. Dedicated research centers in the field have been established worldwide, in leading universities as well as in top-notch IT companies. Some examples are: MIT (USA), YQI (Yale, USA), Princeton (USA), IQIM (Caltech, USA), Simons Institute (Berkeley, USA), Station Q (Santa Barbara, USA), ETH (Switzerland), QuTech (Delft, The Netherlands), CQIF (Oxford, UK), CQT (Singapore), IQC (Waterloo, Canada), NII (Tokyo, Japan), CQC2T (Australia). There are dedicated research laboratories in China and Russia too; and they have reached the top level in quantum computing and communication technology. Major IT companies, such as IBM, Google, Microsoft, and Intel, heavily support some of these centers; and also carry out in-house research. Of course, research efforts in various defence laboratories are hidden. For many of these centers, the financial investment is hundreds of millions of dollars; and a major part of that goes towards the installation of high-technology laboratories (electronics, cryogenics, lasers, clean rooms, atomic scale lithography, sensors and detectors with high accuracy, and so on).

Industry: In March 2018, Google Inc. announced the launch of its 72 qubit quantum computer dubbed as the "bristlecone" processor. This was just one step in the race to build a full fledged quantum information processor. The previous lead in the field was held by IBM who had a 50 qubit system working in their lab. D-Wave systems was among the first lab outside research universities that had come up with a quantum processor back in 2007. This processor had limited capabilities and it could not be considered a universal quantum computer. Apart from Google and IBM, Intel and Microsoft also have active research programs for developing a full scale quantum computer. Rigetti in the US is also another recent startup company working towards this goal. Most of the big industry players are working in close collaboration with academic institutions at present to explore the possibilities of quantum computing. It is noteworthy that companies like Rigetti and IBM have already started working on and making public a "full quantum stack" that has at its bottom a quantum information processor built on constantly improving technologies. The higher layers have control systems or operating systems, quantum programming environments and applications most of which are available through the cloud. In areas like quantum cryptography, the field has matured to the extent that off-the-shelf products are available. The field is primarily driven and dominated now by startups incubated in research labs during the past decade. Using its world's first quantum satellite called "Micius", China had already demonstrated transmission of images from the country to Austria and researchers at the National University of Singapore had built a nano-satellite with a quantum communication payload. Scientists of the University of Waterloo have also demonstrated the first quantum key distribution transmissions from a ground transmitter to a quantum payload on a moving aircraft.

4. National Status

Quantum computers store and process information using quantum two level systems (quantum bits or qubits) which unlike classical bits, can be prepared in superposition states. This key ability makes quantum computers extremely powerful compared to conventional computers when solving certain kinds of problems like finding prime factors of large numbers and searching large databases. The prime factorization quantum algorithm has important implications for security as it can be used to break RSA encryption, a popular method for secure communication. Indian physicists and engineers are preparing for a deep dive into the quantum world that holds the secrets for developing exciting technologies for computing, communication, cryptography and many more.

a) ISRO's Quantum Satellite:

Quantum communication exploits a bizarre phenomenon of quantum mechanics – called "quantum entanglement" – in which photons (which are particles of light) are "linked" together in such a way that they affect one another no matter how far apart they are. They appear to be connected to each other, as if by magic, and behave as a single physical object. Because a third party cannot tamper with the photons without destroying their "entanglement", there's no way to eavesdrop undetected. Raman Research Institute (RRI) in Bengaluru has joined hands with the Indian Space Research Organization (ISRO) to develop the quantum technologies that ISRO's satellites would need to establish such a network. Keeping that in view, they have initiated a mega project called "Quantum Experiments Using Satellite Technology" which will play a key role in developing these technologies in the coming years.

b) DST's initiative on Quantum Technology:

The transition of quantum science and technology from a field of active interest in research laboratories to one that can be applied in day to day life is also the opportune moment that provides the space for many startup companies to form and develop. The directed research program of QuEST (Quantum Enabled Science and Technology) evolved by DST is therefore a key starting point in making an incrementally greater impact in this area than what the nation could do at the micro and nano scales. The scheme draws upon the existing deep strengths within academic institutes across India to support interdisciplinary research projects in key verticals involving quantum technology, while simultaneously developing key foundational strengths in important core areas. QT research, operational implementations, Human resource availability and technology development are in rudimentary stage. It is being disruptive and paradigm shift technology, focus needs to be set on development of national mission to aggregate all stakeholders to be at par with international efforts.

c) QT related research in Academia:

Compared to the world-wide development, the existing expertise and facilities available in India are limited on the theoretical side and severely lacking on the experimental side. To build up the field of quantum technologies from this stage, even in carefully selected areas, is a significant challenge. The only established experimental group in India which is working on superconducting quantum devices is the Quantum Measurement and Control (QuMaC) Lab in TIFR . At the Indian Institute of Science Education and Research (IISER) in Mohali, researchers are using spin as a quantum state, and have run quantum algorithms on a five-qubit device. At IISER Pune, the focus is on how to network quantum processors and at quantum information and artificial intelligence for quantum control. While the focus is not explicitly on developing quantum computers, they are one of the most successful groups in the country in terms of their research output. To make the best use of the available expertise, IISc, Bangalore has put together a structure involving people from different departments. This centre aims to deliver quantum enhanced technologies. Its experimental program will focus on superconducting qubit devices, sources and detectors for quantum communications, and quantum sensors.

5. **Focus on Industry:**

According to 4.0 Industrial Revolution, Research, advances in quantum computing and the development of fault-tolerant algorithms is now transforming this “holy grail” scientific technology into something realistic which will help surpass applications in traditional computation. With these new developments, it will be interesting to see who will build the next ground-breaking quantum computer and benefit from it. The market for quantum computing is highly competitive but companies are investing in internal R&D, acquihiring and strategic mergers and acquisitions. The interest in the field is also coupled with a lack of talent in the quantum computing industry. While on one hand, there has been considerable growth in research and development in the field of quantum information science over the coming decade, this field — an amalgamation of science and engineering is also facing an acute talent shortage, thanks in part due to the requirement of highly skilled talent. The transition of quantum science and technology from a field of active interest in research laboratories to one that can be applied in day to day life is also the opportune moment that provides the space for many startup companies to form and develop. Some of these startups have the potential to be the next IBM, Intel, Apple, Sony or Samsung. It is therefore important that there is sufficient in-house knowledge base, resources and talent built up in research laboratories around the country providing such potential startup companies a foundation and and a space to emerge, grow and even dominate in the global scale.

6. **Problems to be addressed**

Research in Quantum Science has already brought some important advances in quantum technology such as the flash memory on mobile devices, superconductors for the medical machines in hospitals such as MRI machines or even the barcode readers that we are so dependent of today. But that’s just scratching the surface when it comes to the true potential of Quantum Technology. Some of the important developments are the discovery of quantum algorithms, quantum teleportation, super dense coding, remote state preparation, quantum cryptography, and several quantum communication protocols. National Mission on Quantum Technology promises to revolutionize the future computation and communication systems which will ultimately have huge impact on the Nation and our society as a whole. The scope of NM-QTA are:

i. **Frontier research in Quantum Science & Technology**: Control at the single quantum level and quantum limited measurements all drive forward our understanding of nature at the most fundamental level. Quantum information and Quantum technologies have provided a language and a means to push these fundamental investigations further into areas like the understanding of non-intuitive features of quantum systems like entanglement and other non-classical correlations, testing the foundations of quantum mechanics, getting a handle on mathematically describing generic open quantum evolution etc. The increase understanding as well as the ability developed to “think quantum mechanically” can lead to development of new quantum algorithms, initiation of new areas like quantum machine learning and quantum data mining and so on.

ii. **Information and quantum mechanics:** At the most fundamental level physical systems are quantum mechanical in nature. Information requires a physical realization for its existence; whether as markings on a sheet of paper, states of transistors in a microprocessor or as sound waves in air or any other such familiar or unfamiliar form.

Microprocessors allowed an efficient and fast means for storing, manipulating and in general processing information. Down to the nanoscale where most of the modern microprocessors operate, the laws of physics that determine which processes can happen and which cannot are essentially classical in nature. Consequently classical physics still delimits the nature and type of information processing that can be done. Quantum effects appear only as negligible corrections or as ignorable effects. The ability to control and manipulate physical systems at the level of quantum level efficiently and fast offers the promise of storing, manipulating and processing information in ways that are governed by the laws of quantum mechanics instead of those of classical physics. Living in the information age, it is only natural that pushing the boundaries of the small found its first and most promising potential application in quantum information processing of various kinds.

iii. **Quantum matters & material:** Natural science and technology are increasingly governed by quantum phenomena. For the world as a whole as well as in connection with its details, matter is of basic relevance having properties that are fundamentally based on quantum laws. The quantum idea connects all physical aspects and effects at the ultimate level on which the properties of the world emerge. Therefore quantum matter is in the focus when we observe phenomena in natural science and also when we develop sophisticated technologies. Clearly, within the frame of usual, macroscopic technological constructions (cars, mechanical machines, etc.) we do not need the quantum picture, but all those constructions are based on materials whose properties are fundamentally dictated by the quantum laws. The quantum picture is equally important for each relevant phenomenon in the world, that is, it is essential from gravity to materials science. Such materials can exhibit exciting physical phenomena whose description requires new quantum mechanical models to be developed. Examples include superconductors, magnets, topological insulators, and multiferroics.

iv. **Quantum computing:** Universal quantum computing is to date, the most ambitious potential application of Quantum Technology. It is known that the ability to manipulate information in ways not allowed by classical physics but still conforming to quantum mechanics can lead to the solution of large classes of computational problems using exponentially fewer resources like time and memory compared to the best known classical algorithm and its realization. Among these problems that become solvable with the advent of a quantum computer are some like the breaking of ubiquitous classical cryptographic schemes lending strategic importance to realizing the promise of quantum computing. Some of the anticipated applications for this capability include: # simulating chemical behaviour to enhance drug or materials discovery; # optimising logistical arrangements, such as task allocation in the NHS or the management of supply chains; and # increasing the speed and capacity of data analysis, enabling improvements in artificial intelligence.

v. **Quantum communication:** While sharing several features and aspirations with quantum cryptography, quantum communication is an area of active research in its own right. To extrapolate considerably, the eventual goal may be a quantum internet wherein quantum information is transmitted with only acceptable losses across large distances and then transduced across different physical realizations so that quantum computers can essentially communicate to each other. Quantum communication through satellite transmission is, in simple terms, the mixture of two distinct technological realms: quantum mechanics-based communication and satellite communication (SATCOM). The former is enabled by the transmission of information-carrying photons (particles of light) and cryptographic methods (such as quantum key distribution), and is often referred to as “unhackable.” Due to the law of quantum mechanics, the status of the photons used for the communication transforms and generates a warning signal when a hacker attempts to steal information. Given the increasing demand for secure communication in general, this technology is considered one of the most promising solutions for the future.

vi. **Quantum cryptography:** While conventional cryptographic methods may be susceptible to the attacks of an adversary having access to a quantum computer, quantum mechanics itself promises in-principle unbreakable cryptographic security through quantum key distribution. Quantum key distribution is a fast maturing technology already with several commercial applications in the market. However, practical considerations as well as the subtle and counter-intuitive features of quantum physics often mean that actual realizations of the proposed protocols still have gaps to be locked down if unconditional security is to be guaranteed. So there is still ample scope for advancement in security as well as for refinements in extending the range, applicability and ease of use of real world implementations of quantum cryptography.

vii. **Quantum metrology:** Precision measurements drive forward advances both in basic science and applied technologies. Analysing the impact of precision timekeeping enabled by the advent of atomic clocks would be one among the many ways of convincing oneself about the verity of the previous statement. Quantum technologies offer the next frontier in precision measurements in the form of quantum limited metrology. Using quantum tunneling to image at sub atomic resolution in scanning tunneling and atomic force microscopy, pushing the accuracy of atomic clocks even further by putting quantum phenomena to work and using quantum states of light to enhance the sensitivity of gravitational wave interferometers are but just a few applications of the same.

viii. **Quantum Sensing:** Sensing is closely related to metrology but the focus is on detection rather than on quantification. Quantum systems in superposed or entangled states can be used to build sensors with efficiencies considerably better than the best classical sensing devices. Precision magnetometry and inertial guidance with Nitrogen vacancy centres in diamond, photon detection using quantum tunnelling etc. are just a few of the emerging approaches to building quantum enabled sensors. Quantum sensors based on Atom interferometry offer unprecedented advantages in studying and measuring fundamental constants, inertial sensing and precision metrology. Quantum mechanics also provides for fundamentally new ways of sensing like quantum ghost imaging in which an obstacle in the path of a light beam is detected without sending even a single photon through that path. Quantum sensing offers great potential. in several areas including magnetic field based global navigation, biological imaging, neuroscience and related fields.

ix. **Quantum-enhanced imaging:** Increased control of quantum effects also offers opportunities to improve upon the capabilities and resolution of conventional imaging systems. The several examples of potential quantum-enhanced imaging systems and their possible applications, includes: #cameras capable of imaging through obscuring material such as dirty water or fog, one use of which may be to help guide autonomous vehicles; • cameras that can see around corners, with military and civilian uses; #cameras that can take 3D images, with applications including prototype development in manufacturing and improved robot capability; #cheap, portable sensors for imaging invisible gases, which could be used to detect leaks; and # medical imaging systems that avoid the need for harmful radiation.

7. National Gap areas

Although, India is poised to tap into next big advances in quantum technologies, Compared to the world-wide development, the existing expertise and facilities available in India are very limited. To build up the field of quantum technologies from this stage, even in carefully selected areas, is a significant challenge.

i. **Lack Of Resources At The Undergraduate And Graduate Level:** From an Indian standpoint, a key barrier is the lack of resources in quantum computing to allow undergraduate and graduate students to foray into the field. In the West, quantum computing is largely taught at the graduate level and students are required to have knowledge of higher mathematics and quantum physics. Students who have a background in Physics and computer science can make a foray in quantum computing but there are only a few institutes in India teaching quantum computing and the foremost is Raman Research Institute, HRI Allahabad and IISc which has a centre for research in quantum computing.

ii. **Increase University-Level Adoption:** If India wants to build a quantum-ready workforce, beef up manpower in R&D and compete at a global stage with players like China, US and Canada, it will have to develop quantum science and engineering as its own discipline, at the graduate level. This will have to be coupled with new faculty and deepening engagement with industry players. This would also require an increased investment in setting up QT research centres in public-private partnerships to speed-up quantum research and development. Also, the Government will have to play a proactive role in generating awareness about quantum science at secondary school level.

iii. **Build Technical Infrastructure To Advance Quantum Technologies:** For India to capitalise on quantum computing, the government and stakeholders will need to identify the infrastructure needed along with training and engagement to advance quantum tech development in India. Besides, evaluating the quantum landscape from a technical and policy perspective, India will have to maintain the technical infrastructure by setting up innovation labs to develop and test quantum technologies.

8. Aims and Objectives

Aims: The specific operational goals of the NM-QTA are to:

1. Evolve a long-term strategy (10 years) with short-term (5years) targets and associated calculated investiments. An integrated approach and convergence model for academia, industry and government organizations to jointly accelerate the growth of the quantum technology ecosystem.
2. Develop and demonstrate Quantum Computers, Quantum Communication and Produce quantum algorithms and new applications.
3. Develop conventional technology and intellectual property needed to support and enable quantum technology
4. Engineer, industrialize and and connect to economic growth, jobs creation, and maintain a competitive advantage as a global supplier of quantum devices, components, systems and expertise while continuing to play a leading role in engaging globally in the development of quantum technologies.
5. Support the free flow of people, innovation and ideas between academic, industrial and government organisations
6. Nurture in the development of world-class industrial quantum technology workforce.
7. Continue the fundamental research needed to support these NM-QTA goals and those that arise from the capabilities of quantum technologies

Objectives

1. To promote and foster R&D in Quantum Technologies and related areas like quantum computing, quantum cryptography, quantum communication, quantum metrology and sensing, quantum enhanced imaging etc.
2. To develop and demonstrate quantum computer, quantum communication (Fiber and Free Space), Quantum key distribution.

3. To develop technologies, prototypes and demonstrate associated applications pertaining to national priorities.
4. To develop infrastructure pertaining to development of these technologies.
5. To enhance high end researchers base, Human Resource Development (HRD) in these emerging areas.
6. To establish and strengthen the international collaborative research for cross fertilization of ideas.
7. To enhance core competencies, capacity building and training to nurture innovation and Start-up ecosystem.

9. Strategy

The National strategy for quantum technologies was drawn up by the Prime Minister's Science and Technology Innovation Advisory Council (PM-STIAC) through the (Principal Scientific Advisor) PSA's office to leverage cutting edge scientific research for India's sustainable development. Its recommendations are designed to build the early framework for quantum technologies in the country. DST is the nodal Department for promotion of Science & Technology in the country. DST also mandated to identify new and emerging S&T streams and take up necessary initiatives for timely promotion of thus identified streams. The Quantum Technology research in India will be co-ordinated under the umbrella of National Mission on Quantum Technology & Applications (NM-QTA) programme. Thus, the NM-QTA programme would institute research through academic collaborations and foster in depth investigations to understand the processes and phenomena behind quantum technology leading to the development of quantum based applications. A dedicated group of scientists, in collaboration with several other national academic and research institutions of excellence, associate with Industry, Other Ministries/ Departments of GoI and would carry out major research programs under directed research and extramural funding mechanisms. It will also bridge significant workforce gaps in the country that exist between the world's leading quantum researchers and industrial engineers, and catalyze a new sector in the science, technology, engineering and math (STEM) workforce. To ensure that India leads the way in the development of quantum technologies, the Government's significant investments into the programme is recognised internationally as excelling means and we are well-placed to realise the potential benefits from these technologies, and to compete against competition from other nations that are investing heavily in the field.

To foster R&D in these areas, it is essential to

a) Obtain a worldwide overview of these research areas, from top Indian as well as foreign experts.
b) Assess the research base in India, and devise an umbrella programme to boost the existing Indian research activity in the field.
c) Select the topics to support, particularly on the experimental side, in which Indian researchers can make significant contributions.
d) Formulate a hiring/training policy to acquire experienced researchers in this subject, covering both positions and timely start-up grants.
e) Suggest a creation of a dedicated centre of excellence in this field, as a national effort, with appropriate budget, infrastructure, and scientists and engineers.
f) A strategy and roadmap to foster R&D, international collaborations in this field.

10. Outcome driven R&D- Top Level Challenges

Top Level Challenges primarily are output-driven and encompass an overarching objective; if successfully realized they have a multiplier impact i.e., it would lead to positive spinoffs, build virtuous cycles and feed into number of different sectors. Apart from the high impact quotient, a Top Level Challenge also involves a significant degree of difficulty either in terms of knowledge creation, ecosystem design or technology deployment, or their combination. By the very nature of things, a Top Level Challenge may not be met by a single agency, organization or group of individuals. It would consist of multiple players and involve multiple technologies. The investments that would be required to tackle a Top Level Challenge would be enormous, but the payoffs would be just as rewarding. These are investments for a large section of society, and the payoffs are in the form of benefits that diffused quickly and make a difference in the lives of our people.

Under the Programme of Technology Development, a number of Top Level Challenges will be funded. Proposals would be invited from public and applicants can be individual or a team (with any affiliation). These will be time-bound projects with a working prototype as the delivery. Some of the challenges with massive potential impact on society or, critical for India could be funded to 2-3 individuals/teams. IP will be shared as per GOI Policy.

11. Centre for Development of Quantum Technology (C-DOQ)

Centre for Development of Quantum Technology (C-DOQ) emerges as a vital strategic asset to serve as the primary vehicle for managing complex change initiatives. In academic institutions, a centre of excellence often refers to a team mandated to focus on a particular area of research; such an entity may bring together faculty members from different disciplines and provide shared facilities. C-DOQ is the core of the implementation of the NM-QT Mission as all major activities will be carried out through this centre. It will have five different wings which will focus on Technology-Translation-Applications-Opteration-Commercialization. It will build linkages and collaborations with network of research institutes and labs across India and abroad.

The objectives are to carryout translational research and establish world- class Center for Quantum Technology in specific fields of Quantum Technology in India. C-DOQ would support and encourage innovative technology-based start-ups, industries, PSU that have an application and/or impact in the core sectors of the economy in our country. The C-DOQ would also provide the incubation centres for start-ups with necessary guidance, tech support, infrastructure, access to investors, networking, and facilitating a host of other resources that may be required for the start-up to survive and scale. Government and industry/ industry associations will be encouraged to participate. C-DoQ would work in close collaboration with Industry to create symbiotic relationship and world class products development. It will emphasize on development of infrastructure tools for direct application of basic and applied research leading to Technology Development, including development of new areas of QT applications/ platforms. It will provide the ecosystem for application based technology development and deployment. C-DoQ will also be responsible for delivering commercial technology, and taking ideas / concepts or prototypes and turning them into marketable products by way of proactive coordination, communication and interfacing for technology transfer to the industry. These would work closely with Startup ecosystem, Corporate, Governments and regulatory bodies as well. These would include webinars, events, workshops, grand challenges, hackathons and also online courses with live projects. International network – C-DoQ would connect to a global network of leading labs and institutes and researchers that can enable close research collaborations. It shall be joint collaborative mechanisms that C-DOQ shall manage, contribute and monitor. Value addition and service provision shall be the driving force for C-DOQ. The existing and successful models and best practices shall be adopted while establishing C-DOQ. Devices such as transistors and lasers exploit the fact that very small objects, such as electrons in crystals, can have only certain fixed energies. Because quantum effects are inherently fragile, they can be used to create exquisitely sensitive and precise devices. The counterintuitive aspects of quantum physics allow them to perform some tasks not possible in the classical world.

Under NM-QT Mission, it is proposed to follow a technology life cycle approach, addressing all stages viz. Knowledge-Translational-Applications-Operational-Commercialization, even at the macro-level. Therefore, it is proposed to create Centre for Development of Quantum Technology (C-DOQ) The Centre combines internationally recognised expertise in quantum technology with a statutory mandate to support Indian Government in various fields of priorities. To fulfil this mandate, it must build and operate key infrastructures to meet current needs and provide essential services. One of the key objectives for the C-DOQ is to support industry with transferring research results into applications, focusing particularly on start-ups and small & medium-sized enterprises (SMEs). Professional staff will co-develop and maintain the technical infrastructure enabling the basic science and technology transfer activities of the users, both on-site and remote. They will Identify critically needed infrastructure and encourage necessary investments by working with government and stakeholders, as well as industry and academia. This will push the frontiers of knowledge and innovation the farthest and fastest.

The key specialisms of the centre are:

1. Components and technology: development and assembly of quantum devices or industry-ready clocks, measurement devices and sensors
2. Calibration and services: building measuring stations that can define and calibrate the components and technologies listed above.
3. User platforms (“user facilities”): making fibre optic networks and technology platforms available for prototype development and small batch production
4. Business incubators, training, public relations, support for technology transfer: providing and operating an incubator laboratory for transferring quantum technologies to applications; training centres for engineers
5. Publicity and media coverage: The quantum technologies community must pursue a consistent and inspiring message with media organisations to ensure public awareness and understanding develops in parallel with the technology. The quantum technologies programme and the quantum hubs will work with the media to grow awareness of the programme worldwide.

To fulfil the above key specialisms defining the C-DOQ, there are five areas that need to be addressed in crafting an effective policy:

I. **R&D Base (Removing Institutional Boundaries and Creating Workforce):** This wing of C-DOQ focusses on generation of new knowledge and intellectual property. It also deals within institutional boundaries with little coordination. For example QuEST, an initiative of DST has sponsored R&D at a number of universities in different disciplines to address QT requirements. However, coordination and collaboration among these university researchers is difficult. The creation of cross-cutting teams with diverse expertise is seen by many as vital to success. Many observers and researchers contend that partnerships that encourage such collaboration will lead to greater progress than working alone. Also, scientists and industry representatives contend that current academic education and workforce training programs are insufficient for continued progress in QT R&D, which requires a diverse, cross-cutting range of skills and expertise that varies from one application to another. For example, while a deep knowledge of quantum mechanics, taught in physics departments, is required for QT basic research and applications development, disciplines taught in other departments—such as computer science, applied mathematics, electrical engineering, and systems engineering—are needed as well. Multidisciplinary QT centers at universities and national labs can be seen as one possible solution to this problem.

II. **Translation Research (Technology and knowledge transfer):** A key challenge in the development of QT is the gap between university research efforts and industrial development. University laboratories cannot properly engineer QT, given their central mission of education and research, and lack of dedicated engineering teams. Industrial QT efforts will produce first-generation quantum technologies. However, there is a limited engineering workforce to fabricate and test this new type of technology and a severe shortage of quantum software developers to bring quantum computers and devices to users. The C-DOQ will become a proving ground for academic, government, and industrial scientists and engineers to pool their resources for technology developments and to provide a QT talent pool for the future development of quantum computers, quantum communication networks, and quantum sensors.

III. **Applications:** This wing of C-DOQ will focus on research and development of a particular family of quantum technologies, or a suite of closely related technologies, including supporting technology, control systems, software and user interfaces, and theoretical co-design of applications or algorithms mapped to the technology. For Example, Quantum communication would deal with a range of practical, real-world quantum-protected communications systems for a range of applications, from high-value financial transactions to everyday consumer applications. The core capability will be a range of quantum key distribution (QKD) technologies, including those operating over optical fibre and free space links systems. It will build a large-scale quantum network in the India.

IV. **Operational:** Advancement of QT applications depends heavily on the generation of novel quantum materials and on improving the tools needed to fabricate them and package hardware that may currently fill a room into usable forms. These challenges are not yet fully understood, but scientists generally agree that advancement in QT R&D depends upon solving them. The new technologies, as well as the businesses and services that develop around them, are expected to affect many major sectors including healthcare, defence, aerospace, transport, civil engineering, telecommunications, finance and information technology.

V. **Commercialization:** Rules and regulation should not present a barrier to the use, deployment and commercialisation of quantum technologies. The National Programme should ensure regulators and standards bodies are aware of the capabilities of the technologies under development, so that regulations are formulated to realise the full potential of these technologies. Test-beds and road-mapping should be considered as a route to development of the regulations by government. For quantum technology industries to flourish in the India, we need academia, business and government to work together. These three key partners must form an alliance that will allow faster commercialisation: making sure that industry is involved early in the development of new technologies and that laboratories understand the needs of the market. This will attract inward investment, and ensure that core research and early commercialisation activities are seen as fertile ground for investment by international companies. In this way, government support can help to bridge the gap between academia and industry, and create the right environment for their cooperation, accelerating the launch of our quantum technologies industry.

With this design, each such Center will, on one hand have forward and/or backward linkage with each other; on the other, they will work in tandem with experts/ institutions outside- the Mission funded projects, other initiatives of government and international institutions. In the highly networked mode as each center would be, they will be equipped and funded sufficiently to function independently as stand-alone entity, however they would leverage each other's strengths and the power of collaboration to produce synergistic outcomes (See Fig). This would ensure that there is a dynamic functional model where technologies being focused are driven by market demands and are well synchronized.

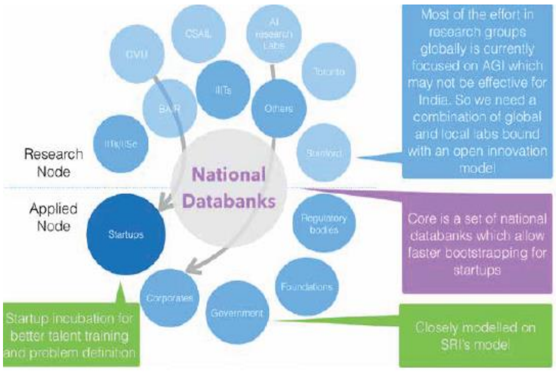


Fig 3.4: Proposed Functional Model under the Mission

12. Public Private Model & Revenue Model

C-DOQ funding would be prioritized with those having a public private model. This would ensure that research output have Industry buy in and thus are relevant to some extent. However it is difficult to attract private capital without proof of pilot in place, especially in a country like India, even for cutting edge areas of research such as QT. Thus initial pilot phase would be driven by Govt. funding and in later years for Scale and growth phase, it is suggested to bring in 20-30% capital from private pools, with majority of that capital coming in post 3 years, where enough output would be visible to private capital.

The core area of output will be five revenue channels with a focus on creating a self sustaining model post initial 5 years of investments,

Applied QT & Engineering - R&D sponsored by Industry, Govt. or Start-ups leading to outputs in forms of innovative product or services that can be leveraged by them.

IP Creation and Licensing (could also lead to new ventures) - Selecting a few ideas to co-create with Start-ups or Industries or Government with an aim to spinning it off into independent ventures. This could be done in a for profit setup inside the C-DOQ with enough autonomy for execution. For this close linkage be built with Industry accelerators and VC/PE funding ecosystems.

Training and Consulting - Helping Industries & Govt. learn how to innovate their processes and leverage QT strategically in their efforts, while increasing the base of QT engineers by offering open source courses for faster adoption

Policy Guidance and help in formulation - Policy creation for rapid and just adoption of QT across various stakeholders, while minimising long term risks working closely with Regulators, Govt. and Industry together.

Strategic areas of focus - Aggregating the requirements across verticals from Govt., Industry for offering QT and addressing their core requirements and bootstrapping QT applications

13. Major Activities proposed under the mission

I. **R&D, Translation and Technology Development:** NM-QTA driven research quantum computing and quantum internet aims to develop scalable prototypes of a quantum computer and inherently safe quantum internet, by bringing world-class scientists, engineers and industry together in an inspiring environment. The goal for research with core public funding is to increase support for collaborative R&D projects researching topics in quantum physics with particular relevance for applications. There will therefore be a focus on projects that have above-average prospects for technical applications, especially when the step from research to application is being taken for the first time. This must go far beyond the basic demonstration of technical feasibility. The research projects should therefore include concrete applications and involve the users from an early stage, e.g. in collaborative R&D projects between science and industry, or involving public users. The current set of research topics for new quantum technologies must not be considered as an exhaustive list, but as a continuously growing one. The main idea behind is to maintain stable and sustained core programs that can be enhanced as new opportunities appear and restructured as impediments evolve. Sustained core programs will allow established researchers to continue their work, give students confidence that QT is a field with a future, and provide a solid base for translating laboratory demonstrations into marketable technology.

II. **Quantum Technology Translation**: A key challenge in the development of QT is the gap between university research efforts and industrial development. University laboratories cannot properly engineer QT, given their central mission of education and research, and lack of dedicated engineering teams. Industrial QT efforts will produce first-generation quantum technologies based prototypes. However, there is a limited engineering workforce to fabricate and test this new type of technology and a severe shortage of quantum software developers to bring quantum computers and devices to users. The NM-QTA will become a proving ground for academic, government, and industrial scientists and engineers to pool their resources for technology developments and to provide a QT talent pool for the future development of quantum computers, quantum communication networks, and quantum sensors.

III. **Quantum Technology Research Infrastructure**

QT is moving into a new era that demands added components not present in the current research infrastructure. Quantum information science has progressed to a stage where many research needs outpace capabilities of individual laboratories. Just like the large shared telescopes in astronomy and the sophisticated shared fabrication facilities in nanotechnology, quantum science requires large-scale facilities and supporting infrastructure. Such facilities will provide stable, sustainable scientific and engineering platforms for QT and software prototyping. Professional staff will co-develop and maintain the technical infrastructure enabling the basic science and technology transfer activities of the users, both on-site and remote. They will Identify critically needed infrastructure and encourage necessary investments by working with government and stakeholders, as well as industry and academia. This will push the frontiers of knowledge and innovation the farthest and fastest. The key specialisms of the centre are:

- Components and technology: development and assembly of quantum devices or industry-ready clocks, measurement devices and sensors
- Calibration and services: building measuring stations that can define and calibrate the components and technologies listed above.
- User platforms (“user facilities”): making fibre optic networks and technology platforms available for prototype development and small batch production
- Business incubators, training, public relations, support for technology transfer: providing and operating an incubator laboratory for transferring quantum technologies to applications; training centres for engineers
- Publicity and media coverage: The quantum technologies community must pursue a consistent and inspiring message with media organisations to ensure public awareness and understanding develops in parallel with the technology. The quantum technologies programme and the quantum hubs will work with the media to grow awareness of the programme worldwide.

IV. **Human Resource Development (HRD):** One of the major focus of NM-QTA will be on Human Resource Development in advanced areas of Quantum Technology.
It will have the following categories of Internships/fellowships

- Graduate Internships (6 months)

- Post-Graduation Fellowships (24 months)
- Doctoral Fellowships (36 months extendable by another 6 months)
- Post-Doctoral Fellowships (12 months)
- Faculty Fellowships (Tenure track of 3 years term)
- Tenure track Chair Professors (3 year term, Open for both domestic and International researchers)

V. Enterpreneurship, Innovation and Start-Up Ecosystem Development

One of the key objectives for NM-QTA is to support industry with transferring research results into applications, focusing particularly on start-ups and small & medium-sized enterprises (SMEs). DST in collaboration with Technological Development Board (TDB) can become a catalyst in facilitating emergence of competent first generation entrepreneurs in and transition of existing entrepreneurs into growth-oriented QT enterprises through entrepreneurship consulting, education, training, research & institution building through promoting and encouraging entrepreneurship in QT. TDB will be funding agency while DST will have the responsibilities have responsibility of establishing Technology Business Incubators (TBI). The TBI's role will be Provide initial Capital/Seed Financing, Enhance management bandwidth, Accelerate the product development, Provide help in building prototype, market validation and business plan, Facilitate access to an ecosystem, Engage with thought leaders of Quantum community worldwide, Accelerate access to sources of future capital, In house business and strategy team to help develop the intricacies of the entrepreneurs' business, Engagement with thought leaders in QT and markets. Intellectual Property Rights (IPR) and Copy Rights will be governed by existing IPR Policy/ Rules. In addition to mentoring startups, DST may also host periodic talks and panel discussions to share knowledge and bring together experts and visionaries from academia, industry and International experts, if required. In the initial stage DST should engage with entrepreneurs to help them refine their product concept.

VI. International Collaborations: With existing mechanisms of DST, International Collaborations will be built at the levels of researchers, thematic domain areas, creating quantum hubs, to leverage international best practices in India. There will be exchange of students, faculty and sharing of advanced infrastructure. It ensures access to international technologies, research facilities, and expertise in QT. HRD will be the one of the main focus in such activities.

14. Target Beneficiaries

For India, there are few vertical focus areas that would be followed as guidance in terms of priority, such as:

QUANTUM CLOCKS based on trapped ions and atoms can measure time with unprecedented accuracy.

QUANTUM IMAGING involves the detection and timing of single photons to beat classical limits, making the invisible visible. Novel imaging systems can allow us to look around corners or through fog.

QUANTUM SENSORS can enable the detection of motion, light, electric and magnetic fields, and gravity with an accuracy that surpasses many conventional technologies.

QUANTUM COMPUTING is expected to perform tasks that are intractable for conventional machines. While IBM's Blue Gene supercomputer would take millions of years to crack common forms of data encryption, future quantum computers should be able to do it in a few seconds. They should also allow us to design materials with completely new properties.

QUANTUM COMMUNICATIONS can be secure against hacking, and may enable networked quantum cloud computing.

MARKETS AND IMPACTS Quantum technologies have a huge range of applications in many sectors, including:

- Oil and gas. Gravity surveys with quantum sensors could aid discovery of oil and gas resources, and increase yields – potentially worth trillions.
- Environment. Quantum sensors for measuring gravity could aid flood prevention by allowing us to monitor the water table more accurately.
- Data security. An increasing amount of confidential information is shared on communication networks. Quantum communications can increase data security on networks, reduce theft of sensitive information and promote trust in network based products and services.
- Defence and aerospace. These major exporters are highly dependent on precise navigation, timing and sensing, all of which will be improved by quantum technologies. For example, quantum sensors for gravity might be used to detect buried explosives.
- Civil engineering. New gravity sensors can also reveal underground structures such as buried pipes and sinkholes.
- Telecommunications. Tiny ultraprecise quantum clocks will allow denser communications traffic, and could militate against the risk of GPS jamming or failure.
- Finance. With an ever increasing need for extremely accurate time stamping, financial markets will also benefit from the new generation of quantum clocks.
- Cities. Quantum sensors will enable smarter use of energy, water and other utilities, to achieve higher environmental standards and efficiency.
- Leisure, security and industry. These sectors can all benefit from new types of camera that use low light levels, see in 3D and look around corners.

15. Legal Framework:

NM-QTA aims at the development of new technologies, processes, and products. Being interdisciplinary in nature, groups of researchers, institutes, academics, and industry have to work in tandem while developing technologies. The overall ambits of the whole issues of IPR, Patents, revenue sharing, are to be governed under existing legal frame of Government of India.

National Intellectual Property Rights (IPR)

The Union Cabinet has approved the National Intellectual Property Rights (IPR) Policy on 12thMay 2016 that shall lay the future roadmap for IPRs in India. The Policy recognizes the abundance of creative and innovative energies that flow in India, and the need to tap into and channelize these energies towards a better and brighter future for all.

The National IPR Policy is a vision document that encompasses and brings to a single platform all IPRs. It views IPRs holistically, taking into account all inter-linkages and thus aims to create and exploit synergies between all forms of intellectual property (IP), concerned statutes and agencies. It sets in place an institutional mechanism for implementation, monitoring, and review. It aims to incorporate and adopt global best practices to the Indian scenario.

The Policy recognizes that India has a well-established Trade-RelatedAspects of Intellectual Property Rights (TRIPS)-compliant legislative, administrative and judicial framework to safeguard IPRs, which meets its international obligations while utilizing the flexibilities provided in the international regime to address its developmental concerns. It reiterates India’s commitment to the Doha Development Agenda and the TRIPS agreement.

With this policy, India aims to place before the world a vibrant and predictable IP regime, which stimulates creativity and innovation across sectors, as also facilitates a stable, transparent and service-oriented IPR administration in the country.

The Vision Statement of the policy is “An India where creativity and innovation are stimulated by Intellectual Property for the benefit of all; an India where intellectual property promotes advancement in science and technology, arts and culture, traditional knowledge and biodiversity resources; an India where knowledge is the main driver of development, and knowledge owned is transformed into knowledge shared."

The Mission Statement of the policy reads as follows: Stimulate a dynamic, vibrant and balanced intellectual property rights system in India to:

1. foster creativity and innovation and thereby, promote entrepreneurship and enhance socio-economic and cultural development, and

2. focus on enhancing access to healthcare, food security, and environmental protection, among other sectors of vital social, economic and technological importance.

The Policy lays down the following seven objectives:

1. IPR Awareness: Outreach and Promotion - To create public awareness about the economic, social and cultural benefits of IPRs among all sections of society.

2. Generation of IPRs - To stimulate the generation of IPRs.

3. Legal and Legislative Framework - To have strong and effective IPR laws, which balance the interests of rights owners with larger public interest.

4. Administration and Management - To modernize and strengthen service-oriented IPR administration.

5. Commercialization of IPRs - Get value for IPRs through commercialization.

6. Enforcement and Adjudication - To strengthen the enforcement and adjudicatory mechanisms for combating IPR infringements.

7. **Human Capital Development -** To strengthen and expand human resources, institutions, and capacities for teaching, training, research and skill building in IPRs.

Patent Rules

Under the provisions of section 159 of the Patents Act, 1970 the Central Government is empowered to make rules for implementing the Act and regulating patent administration. Accordingly, the Patents Rules, 1972 were notified and brought into force w.e.f. 20.4.1972. These Rules were amended from time to time till 20 May 2003 when new Patents Rules, 2003 were brought into force by replacing the 1972 rules. These rules were further amended by the Patents (Amendment) Rules, 2005 and the Patents (Amendment) Rules, 2006. The last amendments are made effective from 5th May 2006. The Patents Rules, 2003 (incorporating all amendments till 23-06-2017)

STANDARDS

A standard is a published document that serves as the fundamental building block for product or process development and defines usability, predictability, and safety. A standard ensuring intra- and inter-operability of goods and services produced and manufacturing compliance is mandatory for the future of QT. Many international organizations are developing relevant standards, their solutions are evaluated and utilized.

QTA AND PUBLIC POLICY

Advances in Quantum technology are making it possible to realize Quantum based devices. This explosion of QT holds tremendous potential to boost innovation, productivity, efficiency and, ultimately, economic growth and social value. The use of QT, however, raises many questions:

- What do individuals think about the QT and its activities
- What is the right trade-off between privacy, intellectual property rights and security and allowing society to benefit from QT driven innovations and better ways of living?
- How can we assess the impact of QT on existing communications, legal and regulatory

systems?

- How can society benefit most from QT?

MANAGING THE LEGAL AND REGULATORY RISKS

When adopting a new and potentially disruptive technology such as QT all the risks need to be identified and managed. That includes securing asset values and addressing the other legal and regulatory risks. Among other things, a failure to address legal and regulatory risk in relation to QT could result in a serious regulatory breach, attracting fines, reputational damage, and loss of business. In the following it is considered how to identify and manage such risks.

Privacy protection

Across the EU, the intellectual property right that could provide the most protection is the individual rights protection regime. It has limitations, as do copyright and patents in relation to QT. The law of confidentiality may provide some protection, depending on the particular information and its source. As the law in this area may provide only limited protection, it may sometimes be necessary to return to the basics: ensure that any disclosure is coupled with adequate contractual confidentiality provisions limiting further use and disclosure. Conversely, it will be essential to check that the implementation of QT has not infringed a third party's intellectual property or contractual rights.

Regulatory Frame Work

Over a period the usage of QT will spread in the country. That will eventually give rise to a number of issues related to usage of QT and related legal aspects. Therefore, there is need to think about the ethical and regulatory framework around QT, as it will increasingly impact on the lives of individuals and underpin customer service, innovation, quality and business operations.

Strengths of Legal Framework

a. India has established legal systems which has basic framework to address IPR, Patents and Copyrights.

b. Cyber Laws also are framed and/or operating at very broader level.

c. Required legal expertise, international exposure and the legal ramifications are well understood by the industry, government and other stakeholders.

Weakness of Legal Framework

a. There is no active participation of India in standards development, particularly, ISO, ITU, W3C, DIN, SAC and IEEE-SA.

b. India should have dedicated institutes/organizations, a group of experts who are continuously keeping track of process and participation.

c. Bureau of Indian Standards is the nodal agency for standards, there should be a core group within BIS to look into QT standards.

16. Environmental Impact:

QTA is a soft computing in nature and thus, there will not be any environmental impact. The programme is structured to be operated at academics, research organizations, IT industry and in existing immovable infrastructure. C-DoQ will be established at academic institutions where already built in building infrastructure is available. Thus, there are no new constructions, land acquisitions, dislocations and other environmental clearances are required.

a) Land acquisitions are not involved

b) Environmental clearances are not involved as it is based on green technologies

c) Forestry clearances are not required as there is no clearance of forest land or acquisitions are involved

d) Wildlife clearances are not required as the project is being implemented at existing academic institutions and there is no direct or indirect impact on wildlife.

ENVIORNMENT IMPACT ASSISMENT

S No	Approvals/ Clearances	Agency concerned	Availability (Y/N)
1	Land acquisition	State Govts	Not involved
2	Environment	MoEF & States	Not required
3	Forestry	MoEF & States	Not required
4	wildlife	MoEF & States	Not required

17. Technology:

The field of Quantum Computation, Information, Communications, and Cryptography has made explosive progress in recent years. It is an intensely pursued research area worldwide, because of its relevance to basic scientific research as well as its tremendous technological potential. The subject is interdisciplinary; its theoretical foundations are well established, and it is poised to develop revolutionary quantum devices in state-of-the-art facilities. The Indian research effort in this field is limited on the theoretical side, and severely lacking on the experimental side. Summary of present status in the field of Quantum Computation, Information, Communications, and Cryptography

Theoretical aspect

Computation: Several quantum algorithms have been discovered which demonstrate a large gain in computational complexity over the classical versions (e.g., quantum Fourier transform, database search, quantum walk, Hamiltonian evolution). But no systematic procedure for handling new algorithms exists. One research topic is to ground algorithms that need only limited quantum capability and not a general-purpose quantum computer, but which are still superior to the classical versions (e.g., Pattern recognition and boson sampling).

Simulations: This is likely to be the first useful application of quantum computers. Well known models in quantum physics can be easily simulated by quantum computers, and need only about 30 qubits to beat their classical versions. The ingredients involve linear algebra and sampling techniques. Verification protocols, i.e., how does one know that the results produced by the quantum computer iscorrect because it cannot be checked by a classical computer, are under active investigation.

Information: Methods to quantify and manipulate quantum correlations have been developed for simple quantum systems, but their generalization to many-body quantum systems is not understood in detail. Questions concern creation of specific correlations, their evolution, and their protection against environmental disturbances etc.

Quantum foundations: These cover the study of quantum correlations and quantum measurements. Understanding the nature of the correlations and the dynamics of quantum measurement can improve understanding of the quantum theory, as well as hint at what may lie beyond (interpreting the quantum theory as an effective description).

Error correction: This is essential for protecting all quantum devices, due to their high sensitivity to unwanted environmental disturbances. Error correction codes, methods of quantum control and feedback have been developed. They need to be tailored according to the requirements of the actual hardware (which determines the types of dominant errors).

Communications: Secure key distribution protocols have been designed and demonstrated over existing fiber-optic networks (lengths going up to 100 km), running around the clock for many days. These protocols can be broken by tampering with the coders/decoders at the ends, and so measurement device-independent quantum-key-distribution (MDI-QKD) methods have been designed. Multiple Input Multiple Output (MIMO) technologies have been developed to increase the bandwidth of communication channels. All these works, the technology is already commercial. The focus is on improving the key distribution rate and constructing quantum relay modules to send the signals over long distances. A major next step will be to repeat the same with wireless communications technology. That has been demonstrated over line-of-sight distances of 10 km, and the aim is to boost it so that it can reach satellites about 100 km away. Implementing this at the single-photon level is nontrivial. It has the potential to revolutionize secure communications, and many projects with military applications are underwaythough the details are often kept secret.

Cryptography: There is no need for developing complicated unbreakable codes since quantum communications can detect intrusion by an eavesdropper. Attacks that jam the communication channels cannot be countered, however, methods to protect against attacks that blind the transmitters/receivers are under active investigation.

Experimental aspects

Nuclear Magnetic Resonance (NMR) implementations: These have provided demonstrations of many quantum protocols using pseudo- pure quantum states. Standard NMR machines are used and systems upto10 qubits can be realized. Most implementations use liquid state NMR, with specifically designed molecules acting as quantum registers. But liquid crystal and solid-state NMR are also under exploration. The technology cannot go beyond (roughly) 10 qubits; and so this is not the way to scale up to a practical quantum computer.

Quantum dots and atomic impurities: These can act as individual qubits, and can be realized with semiconductor technology and careful lithography. Heterostructures, phosphorous impurities in silicon, nitrogen vacancy centres in diamond, are some of the possibilities being explored. Studies are so far at the two-qubit level. Keeping the errors below a threshold is the major challenge.

Quantum optics: Optical and microwave devices are heavily used for quantum communications, where they have to run in the single-photon regime. They are also used for many tests of quantum foundations, because of their low errors and high stability. Making photons interact is difficult, but with limited interactions they can implement specialized quantum tasks (e.g., boson sampling) better than their classical counterparts.

Ion traps: These can form a quantum register with nearest-neighbour interactions. Periodic traps have been made by using lasers, and they can hold 10's of qubits (maybe even 100 qubits). Sustaining coherence long enough for these qubits, so that thousands of quantum operations can be performed, is the technological challenge.

Superconducting qubits: Transmon qubits (constructed from Josephson junctions) in cavity-QED circuits have the lowest error rates at present. The technology involved is scalable to large numbers of qubits, but the creation of specific interactions between qubits is a design challenge. Systems with 5-10 qubits have been demonstrated; IBM has even made one publicly available over the internet as "Quantum Experience". Research institutes and IT companies are pursuing this with major investments.

Topological qubits: These offer the best protection against errors. But they are composite states that are very difficult to prepare and are yet to be demonstrated convincingly. They have other applications in condensed-matter physics as well.

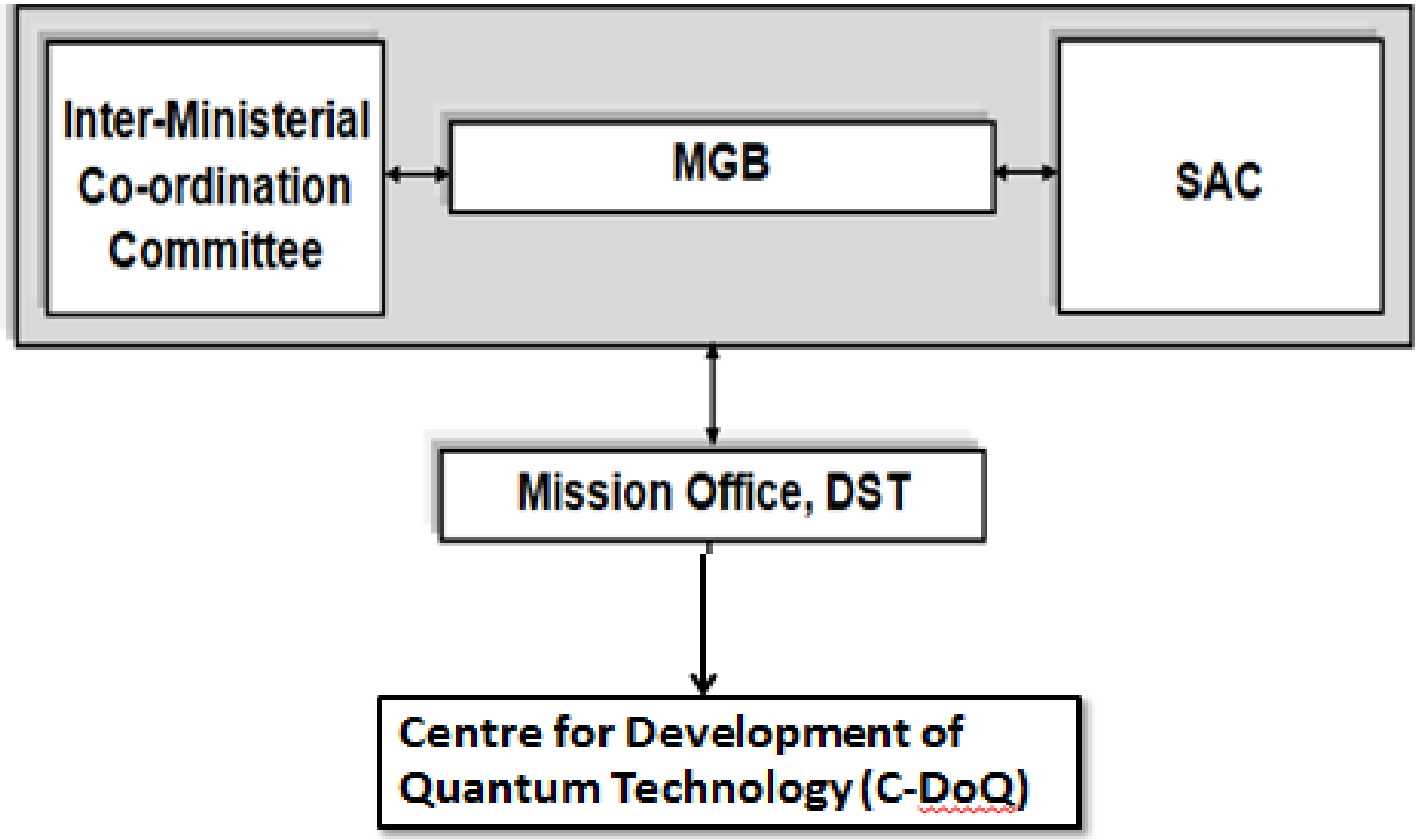
Adiabatic computers: These are devices to tackle specific relaxation problems and use quantum annealing. A company called D-wave is marketing them, but without any error correction mechanism. It is, therefore, unclear whether there is any improvement in the results because of genuine quantum effects, or whether suitable classical algorithms can be equally efficient.

18. Management

The envisaged Misson is of very high value, is spread over five years and the outcomes vital for the country. The stakeholders are spread across the country- government departments, industry, entrepreneurs, academic community etc. – being the direct stakeholders and every citizen, an indirect beneficiary of the technology. The mission follows the technology life cycle approach- idea to product and with such a broad bandwidth of stakeholders, the mission is going to be very complex.

The Mission will be implemented through the establishment of a Special Purpose Vehicle (SPV) i.e., Centre for Development of Quantum Technology (C-DoQ). C-DoQ could have five wings each dealing with Technology-Translation-Applications-Opprtunities-Commercialization. The Mission shall also bring synergies with and co-fund some of the select Centers established by other Ministries/ Departments, like M/o Electronics, D/o Heavy Industry etc which have mandate to implement mission critical applications in industry. Under the Mission C-DoQ will also create a proximal Technology Business Incubator (TBI) or link with existing TBIs. All wings of C-DoQ will work in a distributed model in the sense that all the incubatees may not necessarily be physically located in the TBI but may avail the services at their own location. Interdisciplinary approach is a focus of the Mission. Scientific Advisory Committee (SAC) and Inter-Departmental Stakeholders Committee (IDSC) will ensure the co-operation and working together of all stakeholders.

Management Structure: A lean and nimble Mission Management structure in the form of Mission Governing Board (MGB) is proposed. The MGB will be supported by a Scientific Advisory Committee (SAC) and Inter-Departmental Stakeholders Committee (IDSC). In addition, there will be Subject Expert Committees, Sectoral Committees, Cluster Committees and International Advisory Committees to look into the specific requirements of Mission Implementation. Each of these Committees will have subject experts, academicians and industry partners will be involved in implementation of projects. Mission will create a database with initial target of 100 experts to be involved in implementation of projects.



Delegation of Powers: The MGB will be the apex authority to provide the guidelines for implementation and operating the Mission, including decisions on all Mission related matters. The MGB will approve all components, activities and other proposals aimed to promote the objectives of the Mission and determine the level of support for each and review their performance. MGB will also set overall directions, goals, vision and targets.

Autonomy to C-DoQ: C-DoQ will be established as a Special Purpose Vehicle (SPV) for implementation of the NM-QTA. Governing Body of C-DoQ will have full autonomy in devising their internal processes and procedures for achieving the targets/deliverables subject to the general directions of MGB. The Centre Governing Body (CGB) will have full financial and administrative powers, including re-appropriation of the budget within the ceiling of sanctioned budget; hiring of the appropriate manpower as per industry standards; sign Memorandum of Understanding (MoU) with national and International institutions and industry; approve Collaboration foreign visits; partner with industry; receive and give projects in the domain areas of NM-QTA to academia, R&D institutions, Industry and other funding agencies. CGB will have power to link and support existing TBIs or to create a new TBI for incubation. CGB will also evolve specific targets for the Centre in consonance with the MGB directions and monitor the progress to report to MGB.

Mission Co-ordination Office, DST: Mission Co-ordination Office at DST will facilitate the Mission co-ordination and facilitate the implementation. It will be headed by a Mission Director at the level of Scientist-H/G, consisting of 10 project personnel. The Office will be located at DST. The Mission Office will establish a cloud based online Platform for interaction of Scientists and Experts from across the world to generate awareness, speed-up knowledge dissemination and to encourage self-learning in scientific research and innovation. A dynamic portal containing details of projects, infrastructure, researchers, publications, patents, PhDs, technologies and a digital medium for international experts to participate and for discussions and advice to be communicated to an appropriate Committees i.e., MGB, CGB, IDSC or SAC.

A mechanism to educate all stakeholders like Line Ministries/ Departments/ Industry/ Industry associations/ State Governments/ R&D Institutions/ Academia has been built in the Mission Management. IDSC will also facilitate in connecting the Mission to stakeholders. Also, Mission will provide scientific literature/ information on NM-QTA to academicians, students and scientists for awareness generation. For the above purposes of education and awareness generation, a series of conferences, workshops, brain storming sessions and online platform & Web Portal and initiation of a dedicated Indian Journal of QT through NISCAIR-CSIR or related organisations are planned under Mission.

Role and Details of Positions at Mission Co-ordination Office, DST

The Mission Office at DST will be responsible for Co-ordination and implementation of the Mission. The activities like preparation of guidelines, release of RFP, selection of Host Institutes, signing of MoUs, release of funds, evaluation, preparation of budget, Organizing meetings of MGB, IDSC, SAC and other sub-committees constituted by MGB and initiation of actions as per recommendations/ approvals. The following positions are proposed for the Mission Office, DST

S No	DESIGNATION/ Grade	No of Posts	Level
1	Mission Director (Scientist-H/G) (1)	1	Level-15/14
2	Project Scientist-F (3) Financial Consultant (1)	4	Level-13A
3	Project Scientist-D (5) Under Secretary (1)	6	Level-12
	Total	10	

International Advisory Committees (IAC)/ Working Groups/Sub-Committee etc.

For effective monitoring of the schemes DST shall constitute IAC/ WG. The members would be drawn from International organisations, stakeholders, such as Government, academia, research institutions, end-users organizations and industry.

19. Finance

The sources of financing for the schemes are public funds through Department of Science & Technology, Govt. of India. No external sources are intended.

Cost Estimates

The cost estimates are arrived based on discussions/ deliberations with stakeholders, existing government schemes and tacit knowledge available with the Department. The Mission cost estimates for the scheme duration: both year-wise, component-wise segregated into recurring and non-recurring expenses:

Amount in Crores

S No	Component	Budget Head	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
1	**Technology Development and Translation**	Recurring	78	150	540	720	300	**1788**
		Non-Recurring	52	100	360	480	200	**1192**
		Sub-Total	130	250	900	1200	500	**2980**
2	**C-DoQ**	Recurring	200	280	500	240	80	1300
		Non-Recurring	300	420	750	360	120	**1950**
		Sub-Total	500	700	1250	600	200	**3250**
3	**HRD**	Recurring	60	90	150	90	30	**420**
		Non-Recurring	40	60	100	60	20	**280**
		Sub-Total	100	150	250	150	50	**700**
4	**Innovation, Entrepreneurship, and Start-ups Ecosystem**	Recurring	60	80	88	40	20	**288**
		Non-Recurring	90	120	132	60	30	**432**
		Sub-Total	150	200	220	100	50	**720**
5	**International collaborations**	Recurring	0	30	42	48	30	**150**
		Non-Recurring	0	20	28	32	20	**100**
		Sub-Total	0	50	70	80	50	**250**
6	**Mission Management Unit (MMU)**	Recurring	100	0	0	0	0	**100**
		Non-Recurring	0	0	0	0	0	**0**
		Sub-Total	100	0	0	0	0	**100**
	Total	Recurring	498	630	1320	1138	460	**4046**
		Non-Recurring	482	720	1370	992	390	**3954**
	Grand Total in Rs Crore		**980**	**1350**	**2690**	**2130**	**850**	**8000**

20. Time Frame

21. Cost Benefit Analysis

Cost benefit analysis (CBA) is a systematic process for calculating and comparing the benefits and costs of a project; the analysis requires factoring in all the costs and all the benefits and their proper quantification. The difference between the costs involved and the benefits delivered indicates whether the planned action on the project is advisable. A government invests in order torealise economic, social, environmental and cultural benefits for the community it represents. As such, the justification for public investment in R&D warrants public scrutiny and review as with all other areas of public decision making.

A closer look points out to CBA being grounded in welfare economics; its application to traditional infrastructures, such as transport, water, energy is firmly established. The main categories of costs associated relate to the present value of capital, labour cost, other operating costs, such as materials, energy, communication, maintenance, etc., negative externalities, like air pollution or noise during construction and operations, and decommissioning. However, the use of CBA to evaluate R&D activities gets hindered by the intangible nature and the uncertainty associated to the achievement of research results.

R&D activities are similar to other projects when it comes to investment but are unique when it comes to the benefit side of the projects. While for applied research, development and innovation most benefits accrue to direct and indirect users (firms, consumers, researchers and students) for fundamental research it is usually impossible to identify who will be the ultimate beneficiaries of a discovery. Further, R&D projects are also peculiar in a way that some producers of services are also their beneficiaries. Scientists produce knowledge, but are also users of such knowledge. The process is embodied in the production of knowledge outputs (i.e. technical reports, preprints, working papers, articles in scientific journals and research monographs) and their degree of influence on the scientific community in form of citations. Likewise students and young scientists who spend a period working on projects are likely to earn higher human capital relative to their peers. The socio-economic value of this benefit can be the expected incremental lifelong salary earned by such individuals over their entire careers.

It is important to note, however, between the value of knowledge outputs (publications) and the value of knowledge per se embodied in scientific publications. The former is usually predictable, while the latter is often immeasurable. Also, the technology developed out of R&D efforts may not always see light of the day as its fate depends on market environment, cost effectiveness, competing technologies, cheaper imported products and host of other factors.

If successful, benefits of technology to consumers may also derive from the practical application of a research effort (e.g. reduction of Green House Gases (GHG) and air pollutant emissions; improved energy efficiency; reduction of vulnerability and exposure to natural hazards; improved health conditions, or simply lower production cost and sale price, etc.) and may not always be envisaged or visible upfront. In most cases, there is a potential but largely unknown future use-benefit; while it is conceptually important to acknowledge its role; classical cost-benefit analysis methods are often unable to quantitatively determine it, even if research on the topic is ongoing. It seldom happens that an evaluator of research is confident of being able to make predictions on the economic value of applications of fundamental research.

Experience gathered over time suggests that most important outcomes of R&D investment- like new knowledge, skills and experience, are intangible and unquantifiable, their benefits may not be realised for some years and their impact may be felt in entirely unrelated areas. Against this backdrop, there have been efforts to do cost-benefit analyses of R&D activities but there is no established method developed yet; more so, for a Mission which also has human resource development, start-up ecosystem and international collaboration in its ambit.

22. Risk Analysis

Research and Development (R&D) has a bearing on the growth of society and gets reflected through the investments made by the governments. However, the implementation of technological innovation through R&D projects comes with challenges as they are rife with risks and uncertainties at every stage. The outcomes are equally fraught with risks related to social, technological, economic, environmental, legal, ethical, political factors. Risks could be internal or external; those that originate from the operational, technological and organizational aspects of the project are internal, while risks that originate from the market and supplier aspects can be classified as external.

R&D inherently always carries an element of risk because it involves trying out new, untested ideas. A common risk is that new or modified products or services prove to be more difficult or costly to develop than anticipated. At times, the projects may become unwieldy and may find foreclosure a better option than persisting with it. There is a finite possibility that product developed may be commercially unsuccessful, though it may have all the anticipated characteristics. It is equally possible that product may get dwarfed or overwhelmed by a competing or a new technology. Development of a product turning out to be unworkable is another risk. Poor management of projects and human factors could be yet another reason for project failure.

As projects grow in complexity due to advancing technology, the failure rate for development projects has also become higher. Also, with product life cycle becoming shorter; there is a pressure on firms to periodically introduce new products as part of their business strategy and to stay afloat. Studies have shown that roughly 80 percent of new product development projects fail before completion and more than 50 percent of projects fail to make returns on the investment of time and money. Project teams are becoming increasingly cross-functional in nature which opens more avenues for project failure. Then, there are risks external to the technologies and buried in spaces around the project. Finally there are risks around intellectual property in the modern technology-rich world. It needs to be acknowledged that there won't always be a return on the investment in R&D and it is possible to lose the outlay entirely in certain cases. On the other hand, returns from R&D can be also considerably greater than for other investments. However, an R&D project to improve an existing product or service has a far higher chance of success than one aimed at creating a new product or service but the rewards are likely to be far lower. Taking a synoptic view and taking the risk aspect in stride, it makes sense to view R&D as an investment in future.

23. Outcomes

NM-QTA programme success criteria, expected outputs/ deliverables, units, baseline data and measurable outpus/ deliverables are provided below:

PHYSICAL (NUMBER OF UNITS) AND EXPENDITURE IN RS. CRORE (FINANCIAL) FOR EACH COMPONENT

Components	Year 1		Year 2		Year 3		Year 4		Year 5		Total	
	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial
I. Technology Development	90	130	15	250	310	900	500	1200	160	500	1075	2980
II. C-DoQ	1	500	0	700	0	1250	0	600	0	200	1	3250
III. HRD	3300	100	2000	150	4000	250	3400	150	2000	50	14700	700
IV. Innovation and Start-up ecosystem	240	150	180	200	400	220	300	100	150	50	1270	720
V. International collaborations	0	0	5	50	7	70	8	80	5	50	25	250
VI. Mission management Unit	1	100	0	0	0	0	0	0	0	0	1	100
Grand Total	3632	**980**	**2200**	**1350**	**4717**	**2690**	**4208**	**2130**	**2315**	**850**	**17072**	**8000**

Measureable Deliverables

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
1	To promote and foster R&D in Quantum Technology (QT) and related applications like Quantum Satellites, quantum communication, Quantum key distribution (QKD), Quantum materials, quantum sensors etc.	Increased core researchers base in advanced and cutting technologies	No of researchers in QT	100	1000
2	To develop technologies, prototypes and demonstrate associated applications pertaining to national priorities.	A set of technologies, tools, algorithms to feed into some of the national priorities	No of technologies	0	360
3	To enhance high-end researchers base, Human Resource Development (HRD) in these emerging areas.	Delivery of next-generation technocrats, Scientists, Engineers, Skilled and semi-skilled workforce.	No of students	200	12000
4	To establish and strengthen the international collaborative research for cross-fertilization of ideas.	Global standard Collaborative research for some of the India specific issues.	No of collaborations	0	40
5	To enhance core competencies, capacity building and training to nurture innovation and Start-up ecosystem.	Start-up companies, job creation and economic growth	No of start-ups	3	800
6	To set up world-class interdisciplinary collaboration centre for development of Quantum Technology (C-DoQ) with various wings around the country, with a substantial amount of funding to enable them to achieve	Dedicated translational research center aimed at Academic to Industry	No of C-DoQ	1	1

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
	significant breakthroughs.				
7	To involve Government and Industry R&D labs as partners in the collaboration centers. Incentivise private participation to encourage professional execution and management of pilot scale research projects	Enhanced participation of private industry in R&D, PPP model demonstration in technology development	No of partnerships developed	0	12
8	To set mission mode application goals and foundational themes for excellence for C-DoQ. Set up QT test beds at C-DoQ and its wings.	Proven prototypes, national test beds for sector-specific solutions	No of prototypes/ testbeds	0	50
9	To tie up with incubation centers and accelerators to foster close collaboration with entrepreneurship eco-system	Enhanced delivery mechanism	No of incubation centers	0	15
10	To address some of the National issues and development of sector-specific solutions.	Technologies to address some of national issues.	No of domain-specific solutions	0	50
11	No of Research Papers published	New knowledge generation	Number	20	1000
12	No of start-ups in QTA		Number	3	800
13	Number of Center of Quantum Technology (C-DoQ)	Dedicated translational centers	No of centers	1	1
14	Number of new tools created	New processes developed	Number	2	50
15	Number of Solutions created for Govt Departments/ Organizations	New solutions	Number	0	100
16	Number of Best Practices developed	Best practices	Number	0	200

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
17	Number of UG/PG fellowships awarded	Preparation of next-generation technocrats	No of fellowships	0	10000
18	Number of Ph Ds/ Post-Docs	Delivery of next generation researchers	No of fellowships	10	2000
19	Number of faculty Trainers Trained	Generation of pool of trainers	No of trainers	30	500
20	Number of implementing agency selected	Scaling up of QT activity	Number	10	100
21	Requests received from Govts etc	Acceptability of QT	Number	0	50
22	No of student training programmes organized	Delivery of skilled human resource	Number	2	100
23	Number of entrepreneurship development programmes organised	Start-up culture enhancement	Number	0	100
24	No of the new QT application areas identified	Scaling up of QT in various areas	No of areas/ Sectors	0	50
25	Number of tie-ups with industry	Academic-Industry interactions	No of tie-ups	0	12
26	Number of proposal received for Venture capital/seed money etc.	Start-ups	No of start-ups	0	800
27	Number of international collaborative research projects started/completed	Cross-fertilization of ideas	Number	1	20
28	No of cluster-based network projects started	Directed research	Number	2	50
29	Number of awarenessprogrammes launched	Development of scope of QT	Number	0	25

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
30	Number of participants benefited through awareness programmes	Scale and volume	Number	0	2500
31	No of national workshops/ conferences organized	Development of intellectual networks and interactions	Number	5	25
32	Number of collaborative international conferences organized	Development of international networks	Number	2	8
33	No of QT Infrastructure projects started/implemented	Technology platforms	Number	0	12
34	Number of international experts participation in QT	Attracting attention of experts from abroad	Number	0	50

Success criteria: NM-QTA will be considered a success if the measurable outputs/ deliverables mentioned in above table are achieved. Indicators are evolved considering the overall objectives of the programme, existing baseline data and investments that is contemplated on the programme. Though seems to be ambitious but achievable.

24. Evaluation

Evaluation is key to enhancing the overall effectiveness of any initiative in reaching its stated goals and objectives. The process of evaluation circumscribes gathering, monitoring and analyzing data, to demonstrate that the actual outcomes of the efforts and activities are in consonance with stated goals and objectives; this in turn is important to informed decision making and resource allocation. Furthermore, evaluation provides with a mechanism to document the implementation and progress and share with stake-holders. It is important to recognize that evaluation unlike planning, evaluation is not a one-time activity and goes along with monitoring. It should be a regular, ongoing and incremental process.

INDICATORS

Indicator	Purpose & Description
Input indicators	Input indicators are quantified and time-bound statements of the resources financed by the Mission, and are usually monitored by routine accounting and management records. They are mainly used by managers closest to implementation, and are consulted frequently (daily or weekly). They are often left out of discussions of project monitoring, though they are part of essential management information. An accounting system is needed to track expenditures and provide data on costs for analysis of the cost effectiveness and efficiency of project processes and the production of outputs.
Process indicators	Process indicators monitor the activities completed during implementation, and are often specified as milestones or completion of sub-contracted tasks, as set out in time-scaled work schedules. One of the best process indicators is often to closely monitor the project's procurement processes. Every output depends on the procurement of goods, works or services and the process has well defined steps that can be used to monitor progress by each package of activities
Output indicators	Output indicators monitor the production of goods and delivery of services by the Mission. They are often evaluated and reported with the use of performance measures based on cost or operational ratios. The indicators for inputs, activities and outputs, and the systems used for data collection, recording and reporting are sometimes collectively referred to as the project physical and financial monitoring system, or management information system (MIS). The core of an M&E system and an essential part of good management practice, it can also be referred to as 'implementation monitoring'.
Outcome indicators	Outcome indicators are specific to a Mission's purpose and the logical chain of cause and effect that underlies its design. Often achievement of outcomes will depend at least in part on the actions of beneficiaries in responding to project outputs, and indicators will depend on data collected from
Impact indicators	Impact indicators usually refer to medium or long-term developmental change to which the project is expected to contribute. Dealing with the effects of project outcomes on beneficiaries, measures of change often involve statistics concerning economic or social welfare, collected either from existing regional or sectoral statistics or through relatively demanding surveys of beneficiaries.

More specifically, Monitoring and Evaluation systems provide the project owners and the other stakeholders with regular information on progress relative to targets and this enables them towards:

1. Accountability: demonstrating to funding agency, beneficiaries and implementing partners that expenditure, actions and results are as agreed or can reasonably be expected in the situation.
2. Operational management/Implementation: provision of the information needed to co-ordinate the human, financial and physical resources committed to the project and to improve performance.
3. Strategic management: provision of information to inform setting and adjustment of objectives and strategies.
4. Capacity building: building the capacity, self-reliance and confidence of beneficiaries and implementing staff and partners to effectively initiate and implement development initiatives.
5. The key indicators: Indicators may be qualitative or quantitative variables that measure project performance and achievements. Indicators are developed for all levels of project logic i.e. indicators are needed to monitor progress with respect to inputs, activities, outputs, outcomes and impact, to feedback on areas of success and where improvement is required.

25. Inputs, Outputs and Outcomes for the Mission

For evaluation to be effective whether of the Mission or any component thereof, it should be built-in as an integral part of the planning process. When mission, its goals and objectives are developed with care, the objectives offer implicit evaluation parameters and therefore, it becomes important to capture them. Following sections identify the outputs and outcome that can be used to undertake evaluation of the Mission, at the level of programme- namely Technology Development, HRD& Skill Development, C-DoQ, Innovation, Entrepreneurship& Start-up Ecosystem and International Collaborations.

Technology Development

Technology Development			
Component	**Inputs**	**Outputs**	**Outcomes**
Expert driven new knowledge generation/Discovery	Funds Review	New Knowledge	Generation of Intellectual property New QT application areas Manpower of high order skills
Development of products/ prototypes from existing knowledge (by experts or teams)	Funds Review Evaluation	Proofs of Concept Prototypes	Generation of Intellectual property New QT application areas Manpower of high order skills Closer interaction between industry &academia Prototyping facilities
Technology/ product delivery in specific sectors(by experts or teams)	Funds Review Evaluation	New technologies / products/ solutions	New QT technology/ products/ solutions Generation of Intellectual property Closer interaction between industry &academia Manpower of high order skills Prototyping/ Translational research facilities Increased business in QT

Center for Development of Quantum Technology (C-DoQ)

C-DoQ			
Mission component	**Inputs**	**Outputs**	**Outcomes**
C-DoQ	Funds Stakeholder participation Evaluation	Centers of international standing established New Knowledge Trained human resource New educational material	New knowledge and Intellectual Property Manpower of high order skills New areas for research and development
	Funds Stakeholder participation Evaluation	Centers of international standing established New Knowledge Trained human resource	New knowledge and Intellectual Property Manpower of high order skills New areas for research and development
	Funds Stakeholder participation Evaluation	Centers of international standing established New Knowledge Trained human resource Prototypes/ products/ technologies	Enhanced capabilities of translational research Technology solutions for India New products/ processes Manpower of high order skills Intellectual property Reduced gap between Academia, Industry & R&D laboratories
	Funds Stakeholder participation Evaluation	Centers of international standing established New Knowledge Trained human resource Ready to deploy technologies	Institutions of translational research Technology solutions for India New products/ processes/ IP Manpower of high order skills Innovation, Entrepreneurship and Start-up ecosystem Reduced gap between Academia, Industry & R&D laboratories

Human Resources Development (HRD)

HRD			
Mission component	**Inputs**	**Outputs**	**Outcomes**
Graduate Internships	Funds Review	Graduates exposed to problem-solving	Trained Professionals

HRD			
Mission component	**Inputs**	**Outputs**	**Outcomes**
Post-Graduation Fellowships	Funds Review	Post-Graduates exposed to problem-solving	Trained Professionals
Doctoral Fellowships	Funds Review	Young professionals trained in QT	IP/ Technology generation Pool of trained professionals
Post-Doctoral Fellowships	Funds Review	Young professionals with advanced knowledge of QT	IP/ Technology generation Pool of trained professionals with advanced knowledge
Faculty Fellowship	Funds	Faculty with advanced exposure to QT	IP/ Technology generation Mentors for UG, PG and Doctoral students
Chair Professor	Funds	Specialist in QT	IP/ Technology generation Mentors for UG, PG and Doctoral students Improved ecosystem for teaching and research New educational material

Innovation, Entrepreneurship & Start-up ecosystem

Innovation, Entrepreneurship & Start-up ecosystem			
Mission component	**Inputs**	**Outputs**	**Outcomes**
GCC - Grand Challenges and Competitions	Funds Evaluation	Ideas/ concepts/ challenges Prototypes	Start-ups New QT application areas
PRomotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	Funds Evaluation	Young Entrepreneur	Employment generation Increased business in QT
Entrepreneur In Residence (EIR)	Funds Evaluation	Entrepreneurs New ventures	Increased no. of start-ups Commercialized technologies Employment generation Increased business in QT
QT -Start-up	Funds Evaluation	New ventures Entrepreneurs	Increased no. of student start-ups Commercialized technologies Employment generation Increased business in QT Higher start-up success rate
Technology Business Incubator (TBI)	Funds Evaluation	Technology-based enterprises	Commercialization of technologies New technology/ knowledge/

Innovation, Entrepreneurship & Start-up ecosystem			
Mission component	**Inputs**	**Outputs**	**Outcomes**
			innovation-based start-ups Employment generation Increased business in QT Higher start-up success rate
Dedicated Innovation Accelerator (DIAL)	Funds Evaluation	Fast track commercialized technologies	Speedy commercialization of technologies Increased prospects of commercialization of technologies New technology/ knowledge/ innovation-based start-ups Increased business in QT
Seed Support System (SSS)	Funds Evaluation	New technologies/ solutions	Technology refinement and marketing support mechanisms New technology/ knowledge/ innovation-based start-ups Employment generation Increased business in QT
Strategic Information Services for Entrepreneurship (SISE)	Funds Evaluation	Centralized Strategic Information services established	Information on QT related patents Development of product/services based on identified patent Increased Entrepreneurship Identification of new areas for research

INTERNATIONAL COLLABORATION

International Collaboration (R&D and HRD)			
Mission component	**Inputs**	**Outputs**	**Outcomes**
International collaboration for dedicated research in QT	Funds Review	Identification of research areas for collaboration New Knowledge and experience	Adapting and implementing the newly gained knowledge and experience in Indian QT Ecosystem Benefitting from experiences of collaborators Recognition in International community Enrichment of Indian QT Ecosystem

For the Mission, where processes become relegated over deliverables, evaluation of outputs and outcome assumes paramount importance. Outcome evaluation assesses the extent to which outcome-oriented objectives with the focus being on outputs and outcomes (including unintended effects) but may also assess various processes to understand how outcomes are produced. Evaluation of overall Mission will be done by MGB, while that of its components, projects will be done by independent committees created for the purpose.