Detailed Project Report of

TIH Foundation for IoT and IoE

TIH TECHNOLOGY INNOVATION HUB FOR IoT & IoE TRUST IN TECHNOLOGY
A VENTURE OF INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

TIH FOUNDATION FOR IOT & IOE
3rd Floor, IITB-Monash Research Academy Building
IIT Bombay Campus, Mumbai 400076 Maharashtra, India
office.tih@iitb.ac.in | www.tih.iitb.ac.in
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TIH

भारतीय प्रौद्योगिकी संस्थान मुंबई
पवई, मुंबई-400 076, भारत
Indian Institute of Technology Bombay
Powai, Mumbai-400 076, India

Office : 2572 3488, 2576 7001
Res. : 2572 3738, 2576 8000
Fax : 91-22-2572 3546
E-mail : director@iitb.ac.in
Website : www.iitb.ac.in

Subhasis Chaudhuri, Director
शुभाशिस् चौधुरी, निदेशक

IIT Bombay

MESSAGE

The technologies in cyber physical space system is soon going to dictate the economy and India cannot be left behind. The Department of Science & Technology (DST) is the nodal department for the promotion of Science & Technology in the country. One of the DST's mandates is to identify new and emerging S&T areas in the context of national development goals and to initiate timely interventions for fostering the thus identified areas. To do this, the DST has set up the National Mission on interdisciplinary area for Cyber-Physical Systems (CPS) has been set up to fulfil this mission. IIT Bombay has been chosen to work on IoT (Internet of Things) and IoE(Internet of Everything. I take this as an opportunity for IIT Bombay to contribute towards nation building and work towards developing eco-system for channelizing commercialization and novel technologies for stationary and self- driven IoT and IoE spanning the cyber and physical sub-systems and cyber physical systems which is the one of the aims of the TIH Foundation for IoT and IoE, IIT Bombay.

The activities envisioned under this Mission and the Foundation will provide a great fillip to Indian manufacturing via the invention of new products, services and the creation of skilled young human resource at all levels (from technicians to, researchers and entrepreneurs) and will become a key contributor to realizing the vision of "Digital India." I believe that this Foundation has the potential to become the world's premier hub where disruptive yet practical ideas on IoT for system-level implementation are conceived, prototyped, tested and handed over to capable partners for commercialization and deployment in various industries. Being in the country's commercial capital, having the most successful business incubator- SINE and effective industrial interactions through IRCC and Research park in IIT Bombay, the Foundation will bring in a unique synergy. We at IIT Bombay look forward to continue to serve the nation with a beacon of progress.

I wish TIH Foundation for IoT and IoE a great success in their mission.

(Subhasis Chaudhuri)

Place: Mumbai
Date: 15.09.2021

भारतीय प्रौद्योगिकी संस्थान मुंबई
पवई, मुंबई - ४०० ०७६, भारत

Indian Institute of Technology Bombay
Powai, Mumbai 400 076, India

दूरभाष/Phone : (+91-22) 2572 2545
फैक्स/Fax : (+91-22) 2572 3480
वेबसाइट/Website : www.iitb.ac.in

IIT Bombay

Message

IIT Bombay welcomes the establishment of the Technological Innovation Hub in the area of IoT and IoE (TIH-IoT) under National Mission on Interdisciplinary Cyber Physical Systems (NM-ICPS). The NM-ICPS is a very novel concept and IIT Bombay would like to congratulate DST for this innovative approach towards technology development and industry collaboration. IIT Bombay has a strong portfolio of technologies and expertise in the area of cyber-physical systems such as sensors, networking, security, intelligence, analytics, etc. which can be further strengthened and leveraged through TIH-IoT by means of translational research, deployment, and commercialization. It will be our endeavor to set an example so that in future such Hubs take pride in adapting our model. The Dean R&D office (IRCC) will provide all its support to make this center a huge success.

With regards,

संकायाध्यक्ष, शोध एवं विकास
Dean, Research and Development
कृते निदेशक, आय आय टी मुंबई
For Director, IIT Bombay

Prof. Milind Atrey

Dean (R&D)

Place: Mumbai

Date: 14th September

Society for Innovation & Entrepreneurship

IIT Bombay SINE Business Incubator

September 15, 2021

"IIT Bombay - an Institute of Eminence - has a vibrant academic campus with strong undergraduate and postgraduate programs. Even on the research front, IITB has emerged as one of the top Indian institutes in the world. Today, it provides a strong entrepreneurial culture and innovative landscape through its Technology Business Incubator SINE. Addition of Technology Incubation Hub (TIH) to IITB's innovation ecosystem would provide a great opportunity for students for hands-on experience with start-ups and incubate technologies developed through the iHub-IoT-IITB, the TIH in IIT Bombay. Faculty in collaboration with industry and other TIHs will get opportunities to further strengthen Industry-Academia collaboration. TIH innovators shall get further support from SINE in their entrepreneurial journey. Through such initiatives, we would be able to leverage synergies of R&D, Innovations, Applied Research, Incubation, and Entrepreneurship to take the country on the path of Industry 4.0."

Dr. Santosh J. Gharpure
Professor In-Charge, SINE

IIT Bombay, Powai, Mumbai - 400 076. Phone: +91 22 2576 7016/7055/7072 Telefax: +91 22 2572 1220
www.sineiitb.org

भारतीय प्रौद्योगिकी संस्थान मुंबई
पवई, मुंबई-400 076, भारत
Indian Institute of Technology Bombay
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वेबसाईट/Website : www.iitb.ac.in

iit bombay
हीरक जयंती २०१८
Diamond Jubilee 2018
Achieving Excellence Together

Prof. Ravindra D. Gudi
Professor, Department of Chemical Engineering
AI & ML Chair Professor
Professor In charge – IIT Bombay Research Park Foundation

Tel: +91-22-25767231
Tel: +91-22-25765921
Email: ravigudi@iitb.ac.in

MESSAGE...

Transforming businesses and manufacturing using IoT/ IoE, digitalization and AI & ML tools is increasingly overwhelming the drive towards productivity advancement in various sectors. Industry 5.0 and 6.0 also promote massive personalization in cyber physical systems. In this context, the National Mission on Interdisciplinary Cyber Physical Systems (NM-ICPS) is indeed very relevant. The establishment of the Technological Innovation Hub at IIT Bombay in the area of IoT and IoE (TIH Foundation for IoT and IoE) under the aegis of NM-ICPS is an exciting development.

The IIT Bombay Research Park Foundation (IITB-RPF), which provides an ambience for industry R&D in various sectors to co-locate their labs and design centers on the IITB campus, is particularly excited about this development. The presence of TIH Foundation for IoT and IoE provides a huge collaborative opportunity for the industry member companies in the research park to both leverage as well as contribute to further the state-of-the-art in research and technology advancement activities that would be carried out at the hub.

IITB-RPF welcomes the establishment of the TIH Foundation for IoT and IoE at IIT Bombay and looks forward to facilitating closer engagements and interactions between its industry member companies and the TIH Foundation for IoT and IoE.

Ravindra D. Gudi

Professor-in-Charge,

IIT Bombay Research Park Foundation

भारतीय प्रौद्योगिकी संस्थान मुंबई
पवई, मुंबई-400 076, भारत
Indian Institute of Technology Bombay
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दूरभाष/Phone : (+91-22) 2572 2545
फैक्स/Fax : (+91-22) 2572 3480
वेबसाईट/Website : www.iitb.ac.in

IIT Bombay

CERTIFICATE

Name of the TIH: **TIH Foundation for IoT and IoE, IIT Bombay** Technology Vertical: Vertical **Internet of Things (IoT) and Internet of Everything (IoE)**

1. This is to certify that the Detailed Project Report (DPR) on the Technology Vertical **Internet of Things (IoT) and Internet of Everything (IoE)** is prepared and submitted to Mission Office, NM-ICPS, DST is as part of implementation of Technology Innovation Hub (TIH) at **Indian Institute of Technology Bombay, Powai, Mumbai – 400076, India** under National Mission on Interdisciplinary Cyber-Physical System (NM-ICPS).

2. This is to certify that this DPR has been checked for plagiarism and the contents are original and not copied/taken from any one or from any other sources. If some content was taken from certain sources, it is duly acknowledged and referenced accordingly.

3. The DPR will be implemented as per the Terms, Reference and Clauses stated in Tripartite Agreement signed on **07/12/2020** between Mission Office, DST, **Indian Institute of Technology Bombay, Powai, Mumbai** and TIH Foundation for IoT and IoE.

Date: 15/09/2021

Place: Mumbai

Leena Vachhani

Prof. Leena Vachhani
Name(s) and Signature(s) of Project Director

Endorsement from the Head of the Institution

1. Certified that the Institute welcomes participation of **Prof. Leena Vachhani** as the Project Director(s)/~~Co- Principal Director~~ for the Technology Innovation Hub (TIH) and that in the unforeseen event of discontinuance by the Project Director, the **TIH Foundation for IoT and IoE** will identify and place a suitable faculty as Project Director for fruitful completion of the TIH activities.

2. Certified that the Host Institute shall provide basic facilities, faculty support and such other administrative facilities as per Terms and Conditions of the award of TIH, will be extended to TIH.

3. As per Tri-partite Agreement, the Host Institute (HI) shall play its role and fulfill its responsibilities for the success of TIH.

Date: 16.09.2021

Place: Mumbai

Signature of Head of Institution

Name: Prof. Milind Atrey

अनुसंधान एवं विकास
Dean, Research and Development
कृते निदेशक, आय आय टी मुंबई
For Director, IIT Bombay

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List of Acronyms

AI:	Artificial Intelligence
ASIC's:	Application Specific Integrated Circuits ATC: Air Traffic Control
ATM:	Air Traffic Management Systems
BIS:	Bureau of Indian Standards
CDAC:	Centre for Development of Advanced Computing
CDEEP:	Centre for Distance Engineering Education Program
CEN:	Center of Excellence in Nanoelectronics
CEP:	Continuing Education Program
CII:	Confederation of Indian Industry
CISF:	Central Industrial Security Force
CNN:	Convolutional Neural Networks
CoAP:	Constrained Application Protocol
CPS:	Cyber Physical Systems
CRN:	Cognitive Radio Networks
CRPF:	Central Reserve Police Force
DL:	Deep Learning
DREAM:	Drone based Electromagnetic and Magnetic System
DTF:	Device testing facility
FOCUS:	Food and Consumer Safety Solution
GPU:	Graphic Processing Unit
H2H:	Human-to-Human
HI:	Host Institute
HILS-AIM Lab:	Simulation and Hardware-in-Loop Simulation, AI and ML laboratory
HILS:	Hardware in Loop Simulations
ICT:	Information and Communication Technologies
IETF:	Internet Engineering Task Force
IETS	Inelastic Electron Tunneling Spectroscopy
TIH-IoT:	Innovation Hub for Internet of Things and Everything in Indian Institute of Technology
IoE:	Internet of Everything
IoT:	Internet of Things
LiDAR:	Light Detection and Ranging
LOAF:	Lab-On-A-Farm
LPWAN:	Low Power Wide Area Networks
LSTM:	Long Short-Term Memory
M2M:	Machine-to-Machine
MAC:	Medium Access Control
MeitY:	Ministry of Electronics and Information Technology
MEMS:	Micro Electro-Mechanical Systems
ML:	Machine Learning
NCPRE:	National Centre for Photovoltaic Research and Education

NDT:	Non-Destructive Testing
NEMS:	Nano Electro-Mechanical Systems
NM-ICPS:	National Mission on Interdisciplinary Cyber Physical Systems
NSG:	National Security Guard
PoC:	Point of Care
QIP:	Quality Improvement Program
QoS:	Quality of Service
RAF:	Rapid Action Force
RPF:	Rapid prototyping facility
SAIF:	Sophisticated Analytical Instrument Facility
SAM:	Service Available Market
SAP Lab:	Sensor, Actuator and embedded Processing Laboratory
SILS:	Software in Loop Simulations
SINE:	Society of Innovation and Entrepreneurship
SIS:	System of Interconnected Systems
SMU:	Source Measurement Units
SPM:	Single Point Mooring
TAM:	Total Available Market
TBI:	Technology Business Incubator
TRL:	Technology Readiness Level
UAV:	Unmanned Aerial Vehicles
VIP Lab:	Vision and Image Processing Laboratory
VOS:	Volatile Organic Compounds
WSN:	Wireless Sensor Networks

Executive Summary

The Department of Science & Technology (DST) is the nodal agency for the promotion of Science & Technology in the country. One of the DST's mandates is to identify new and emerging S&T areas in the context of national development goals and to initiate timely interventions for fostering the thus identified areas. The interdisciplinary area of Cyber-Physical Systems (CPS) is identified as one such emerging field, progress in which is expected to have a significant impact on health care, agriculture, manufacturing, urban transportation, water distribution, energy, urban air quality, and governance.

TIH Foundation for IoT and IoE (TIH-IoT), IIT Bombay is set up in the technology vertical-Technologies for Internet of Things (IoT) & Internet of Everything (IoE). The aim is to develop an eco-system for channelizing commercialization and to develop novel technologies for stationary and self-driven IoT and IoE spanning the cyber and physical systems. It will develop technologies for devices ranging from ultra-low power to high power, various communication ranges and target various climatic conditions depending on the industry requirements and government needs of national importance. The TIH-IoT would act as a premier hub for disruptive yet practical ideas on IoT for system-level implementation, prototype development, tested and handed over to capable partners for commercialization and deployment in various industries. A typical portfolio of these industries would include agriculture, aquatic, automobiles, defence, healthcare, nuclear, process, smart cities, smart energy, space, structures and telecommunication applications. The intellectual focus of the TIH-IoT is System of Interconnected Systems (SIS) with the aim of providing end-to-end solutions using networked devices for a defined objective. The SIS is a step towards Industry 4.0 revolution where existing and new devices are interconnected to support digitization of industries by incorporating IoT standards and making them smart industries.

The focus of TIH-IoT would be on development of highly knowledgeable human resource, building a vibrant start-up ecosystem, establishing a symbiotic network of academia, financial institutes, industries and other institutions, including international organizations. This will help the country to become a pioneer in technology led economic growth and prepare India to be the world leader in the technology arena. TIH-IoT would strive to emerge as a polestar in IoT and IoE technology area through creation of self-sustaining innovation continuum by fostering translational research for technology development. TIH offers to disseminate the knowledge and education to reach large enthusiast by providing the IoT course with different difficulty levels starting from Skill Development, Basic, Advance and finally to Elite level where at the end of the Elite level course the candidate will gain the maximum knowledge and can be considered as an IoT Expert.

The vision of NM-ICPS is to build Cyber-Physical Systems expertise and develop technologies on interdisciplinary and inter-ministerial problems. The TIH-IoT aims to fulfill this vision by emerging as a world leader in Internet-of-Things (IoT) and Internet-of-Everything (IoE) technology solutions through in-house R&D, contact with world leaders in this area and preparing industry for the transformation. Being the end-to-end solution provider will allow TIH-IoT to approach the problem with an uncluttered mind and propose solutions that are not constrained by specifications. It will also enable reaching the commercialization and deployment stage of numerous use-cases in various sectors of the industry, focusing on Agriculture and Healthcare in parallel with Security and Industrial sectors.

The TIH-IoT defines R&D focus as to provide technology solutions and eco-systems for commercialization to "Reliable IoT "with the concept of "Fit & Forget". The concept of "fit and forget" is motivated from addressing integrated approach on addressing challenging problems on the deployable, adaptable, safe, secured and reliable features of IoT. These features enable the end-user to develop trust in the technology. In order to foster R&D and address challenging problems along with identified gaps in the domain of IoT and IoE, the technology development at TIH are categorized and will be used to solve the challenging problems.

The proposed solutions would enable digitization and automation for smooth operation and timely maintenance, a step towards Industry 4.0. It involves careful study, development, and analysis of IoT devices, secured deployment, and data analytics to infer relevant information. Furthermore, the TIH-IoT would be involved in various technical aspects of its technology focus on health monitoring, diagnostics, operation, and analysis leading to predictive maintenance, safety, etc.

This DPR describes the technologies mentioned int his document, provides a preview of the many research issues, and discusses the national and international state-of-the-art. Besides the development of highly knowledgeable human resource, this Innovation Hub intends to bridge the assessment of the anticipated skill gaps. India has a great potential in in IoT and IoE to come up with academic and research institutions in the field with deep scientific and analytical skills.

For the national building, TIH-IoT intends to focus on Agriculture, Healthcare, Smart Education, Security, Industrial Internet of Things to begin with. TIH-IoT intends to expand the verticals as per the requirement of the nation.

Through NM-ICPS, TIH-IoT will be associated with activities. The major mandates from NM-ICPS to the TIH-IoT through which TIH-IoT is expected to develop programs is

(i) Technology Development
(ii) HRD& Skill Development,
(iii) Innovation, Entrepreneurship & Startup Ecosystem
(iv) International linkages and collaboration

TIH formulated the process of evaluating each project proposal by forming the Review Committee comprising of 3 to 5 reviewers from the Expert Council which consists of representatives from the Academia, Industry and Government. Each project proposal is evaluated according to the criteria mentioned along with their scoring guideline. Initially Reviewers are assigned provided a brief executive summary of the project proposal to get a feel of the project and to form an opinion about any conflict of interest. Experts with No Conflict of Interest with the applicant and/or the proposals are then given full access to the proposal. The scoring guideline consists technical merit, industry relevance, research competence, potential socio-economic impact, budget and planning, category of the new technology/product etc. Reviewer has to go through the proposal and provide the score as well as justification of scores on the rating of 1 to 5. Based on the recommendations of all reviewers these projects are considered for the approval of funding.

The NM-ICPS is proposed to be implemented over five years. This DPR provides an overview of how TIH Foundation for IoT and IoE will operate on various aspects along with mentioning the details of the Foundation's aims and objectives which is in synchronization with the objectives of NM-ICPS.

1 BACKGROUND

In a world interconnected at many levels, it is natural that every enterprise aims to interconnect systems for Industry 4.0 revolution. This requires the development and appropriate deployment of devices for collecting reliable information, processing it, and making decisions that will further nurture the socio-economic goals. A mature and sustainable translational technology ecosystem for developing R&D in technologies for Internet of Things (IoT) and Internet of Everything (IoE) is necessary for enabling this transformation in industries. Single point contact for companies and government organizations willing to make the leap to Industry 4.0 will aid in the creation of this ecosystem. The TIH-IoT (Innovation Hub for Internet of Things and Internet of Everything in Indian Institute of Technology Bombay) is the first step.

A Technology Innovation Hub (TIH) to foster R&D in IoT providing secure, reliable, and adaptable technology solutions, and advising industry on their deployment was conceptualized by the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) as a single point contact for Indian industry in its quest for Industry 4.0. To leverage the strength of academia in innovation and benefit from proximity to the captains of industry, the NM-ICPS decided to set up this hub as a section 8 company in IIT Bombay. The vision of NM-ICPS of building Cyber-Physical Systems expertise and developing technologies on interdisciplinary and inter-ministerial problems are captured in this Detailed Project Report (DPR).

The TIH-IoT aims to fulfill this vision by emerging as a world leader in IoT and IoE technology solutions through in-house R&D, networking with world leaders in this area, and preparing the industry for transformation

2 PROBLEMS TO BE ADDRESSED

Currently, to meet the need to build innovative products and services, companies and other organizations have to either hire a diverse set of experts or divide the work into pieces that fit the skills of individual investigators and laboratories. While the former is cost prohibitive for rapid innovation, the latter leads to lack of coordination and missed opportunities for holistic innovation at the system- level. Take the example of building a networked system of smart sensors for monitoring activities that is fault-tolerant, reliable and scalable. Implementing this requires system conception and design, fabrication or procurement of sensors, secure and robust communication systems, intelligent control systems, monitoring systems, energy management and an option for smart semi-automated override. While there are a few organizations that can work on some of the components of such a project, very few, if any can claim to complete the end-to-end system development. This is this lacuna that TIH-IoT aims to address. It will be able to deliver upon the design, fabrication, integration and testing of such a project. Being the end-to-end solution provider will allow

TIH-IoT to approach the problem with an uncluttered mind and propose solutions which are not constrained by specifications dictated by others. It will also enable reaching the commercialization and deployment stage of numerous such examples in various sectors of the industry.
The key points from the survey available at Federation of Indian Chambers of Commerce and Industry (FICCI) on "Future of IoT"[1] ([1] http://ficci.in/spdocument/23092/Future-of-IoT.pdf)
are:

1. Asia-Pacific region is forecasted to become the largest global IoT region in terms of both connections and revenue by 2025.
2. Factors driving growth in India are Innovations in product offerings and Increasing operational efficiency.
3. The potential areas of market for IoT are Industrial, Agriculture, Healthcare and Security.
4. Fog/edge computing is a key digital trend in shaping IoT technology.
5. Secured IoT is an important concern to be addressed.
6. IoT deployment must address data security and privacy and wider adoption of IoT would require policies and frameworks to handle these concerns.

It is evident that the problems would be focused to address the mentioned key points. Mapping the problems to address mentioned key points are as follows:

1) How to create revenue from developing technologies of IoT and IoE?
2) How to channelize IoT technology for improving operational efficiency?
3) How to develop generalized IoT technologies to address multiple areas of Industrial, Agriculture, Healthcare and Security?
4) Which are the common technologies for Fog / Edge computing addressing multiple use-cases?
5) How to interface security concepts at device-level and system-level?
   Since IoT technology involves both physical and cyber systems, how to define industry standards for interconnecting various subsystems of physical and cyber systems?

In order to address raised questions in an integrated and multi-disciplinary way, the TIH-IoT would strive to provide Secured and Standardized IoT for Operation, Maintenance, and Predictive Analysis. The proposed solutions would enable digitization and automation for safe and smooth operation by timely/triggered system maintenance. The developed solution would further demand servicing, maintenance and early predictions and preventive actions on the same. In other words, the IoT technology require its own health monitoring. Moreover, the solutions must investigate deployable, adaptable, safe, secure, and reliable solutions. To address the commercialization of R&D outcomes, we would address the following challenging problems:

C1: Reliable IoT - Develop IoT with self-diagnostic capabilities addressing safety and security of the physical system, the cyber system, and their integration. In particular, a challenging problem is developing the IoT technologies such that user/customer does not require additional resources to be watchful on security and safety of its installations. Hence, the challenge is presented as developing technologies with the concept of "Fit & Forget" having self-diagnostic or self-alert capabilities to build trust in technology and make lives simpler.
C2: Eco-friendly IoT- Develop energy-aware and environment-friendly solutions that can have recyclable, reuse or bio-degradable components and be accountable for the carbon footprint.
C3: Hybrid IoT - Develop technologies for new CPS areas where diverse communication requirements and environmental conditions pose various physical safety and cyber security challenges. The focus is to develop "Hybrid IoT" to interconnect "land-air-water" and develop systematic testing and validation methodologies for acceptance of new use-cases.
C4: Easy-to-Develop IoT - Develop IoT solutions where any potential user can interface and develop solutions in new application areas without potential risk in physical safety and cyber security.

The TIH-IoT defines R&D focus as to provide technology solutions and eco-systems for commercialization to **"Reliable IoT "**with the concept of **"Fit & Forget"**.

The challenges C1-C4 are further addressed in proposed technology focus in the section 8.

3 AIMS AND OBJECTIVES

"*To become world's premier IoT hub where ideas for system-level implementation are conceived, prototyped, tested and handed over to capable partners for commercialization and deployment in various industries."*

The aim of TIH-IoT is to develop an eco-system for channelizing commercialization and novel technologies for stationary and self- driven IoT and IoE spanning the cyber and physical sub-systems and cyber physical systems. We will develop technologies for devices ranging from ultra-low power to high power, various communication ranges and target various climatic conditions. An interconnection of these devices using a cyber system will lead to development of intelligent systems. We will devise algorithms for intelligent, decentralized and autonomous operation of integrated technologies with humans in the loop by employing multidisciplinary concepts from communication, artificial intelligence (AI), big-data analytics, optimization, control, multi-agent systems and network science.

Our vision is to become the world's premier hub where disruptive yet practical ideas on IoT for system-level implementation are conceived, prototyped, tested and handed over to capable partners for commercialization and deployment in various industries. A typical portfolio of these industries would include agriculture, aquatic, automobiles, defense, healthcare, nuclear, process, smart cities, smart energy, space, structures and telecommunication applications. The intellectual focus of the TIH-IoT is System of Interconnected Systems (SIS) with the aim of providing end-to-end solutions using networked devices for a defined objective. The SIS is a step towards Industry 4.0 revolution where existing and new devices are interconnected to support digitization of industries. TIH-IoT will bring a dedicated team of experts in sensing, signal processing, energy management, networking, network/data security, data processing, AI based decision making, planning, control, actuation, and multi-agent cooperation under one roof.

Our objective is to provide technology support for any service in developing IoT technology for SIS particularly to address the selected global problem of operation, maintenance and analysis. These include

- IoT device deployment / placement
- Protocols for data collection / processing storage / exchange of control commands
- Networking systems
- IoT Device-level and System-level optimization.

Implementing policies for standardizing the IoT/IoE technology for safe and efficient operation would be enablers for the ecosystem. A vibrant ecosystem of industrial and international collaboration will lead to continuous churn of innovative ideas. Leveraging its unique legal structure - the section 8 company – TIH-IoT would aim to implement nimble yet proper processes needed for rapid innovation. Hence, the following objectives are set for the TIH-IoT:

A. To generate knowledge in the IoT and IoE domain
B. Technology/product development
C. To develop ecosystem for support commercialization of innovative solutions through industry, entrepreneur and start-up
D. Human resource and skill development
E. To develop collaboration models
F. To contribute to industry standards
G. Setup state of the art laboratory facilities for research and testing

Each objective is not independently driven. An activity under one objective is an enabler for others under different scenarios. The details of various sub-objectives under each of these objectives are presented in the next section.

A. To generate knowledge in the IoT and IoE domain

Basic research on the IoT is classified into research on sensors, devices and data analysis. The research on sensors includes sensor modelling and fabrication, followed by their interfacing with the environment. Many applications require a very large number of sensors to be deployed. This leads to distributed sensor networks and their optimum deployment as an area of research. The large volume of data generated by these sensors may be analyzed locally through edge intelligence. However, it is more common to transmit the data to a hub or the cloud where more powerful computing architectures can be utilized. Maintenance free long life for these sensors require research into both long-life power sources as well as sensors which require minimal power to gather data and transmit it. Harnessing energy from the environment is a promising research area in this context. The sensors can be placed on both stationary

as well as mobile platforms. The former may lead to digital twins. The latter brings in additional challenges when there are multi agent systems in varied terrain - underwater, on-ground and aerial.

Challenge of appropriate analysis of the data brings in the domain of machine learning. Deep learning neural networks and generative adversarial networks are areas of active research. The domains of application include computer vision, cyber security and system modelling. Agent based models, distributed systems and batch scheduling also require these data analysis tools. The conclusion from data analysis can lead to either fault detection or state and parameter estimation. The system health estimation and system biology naturally lead to optimization through appropriate sensor network design. Fault tolerant controls are particularly important for navigation and guidance where human lives are at stake.

All of these are active areas of research which would be enhanced with the creation of the hub through interactions with national, international and industry experts. Moreover, the hub with the interaction of industry will bring new multidisciplinary areas of research which can be carried out easily with interactions with the IoT experts. We propose to set up laboratories for facilitating these activities and offering courses with a significant laboratory component which will utilize these laboratories. This will inspire students to take up these multidisciplinary research areas as their major projects or co-curricular activities in even greater numbers compared to the present. We propose to hire post-doctoral personnel with significant industrial research background and long-term commitment to the hub. They will be able to inspire and mentor doctoral students to take up translational research using the unique testing facilities to be set up for the hub. Wide variety of problems from the currently identified application verticals will be solved in collaboration with the experts in technical verticals. This opens up new research directions aligned with SIS technologies.

B. Technology/Product Development

The basic and applied research carried out with the resources of the hub will lead to specific products. These will include stationary devices for use in varied applications ranging from agriculture to large civil structures (e.g. bridges) to manufacturing and aerospace. The products will also be integrated into mobile platforms with underwater, on-ground and aerial applications. Challenges of large-scale sensor integration and networking will have to be solved through optimization. Secure data transmission over extended periods from these multi-agent systems and their analysis through the state-of-the-art machine learning algorithms to allow digital twins to be constructed is another challenge. Development of fault tolerant control algorithms for both stationary as well as mobile platforms and real time analysis of data from the mobile platforms are futuristic challenges which would be taken up as focused activities in edge computing. Ensuring cybersecurity in local networks with edge computing nodes is also addressed for developing reliable technologies. The devices would be test beds for integrating the technologies developed through basic and applied research and would be geared towards solving pressing problems of the nation.

Once a product has been developed and demonstrated in the laboratory, the valley of death between prototyping and commercialization needs to be crossed. This requires an assessment of the market, positioning of the product to the right set of customers and making sure that licensing opportunities are utilized. It is not easy for a technical innovator to excel in these and this is what leads to a low success rate of commercialization of technologies developed in universities and research organizations. The hub plans to be a game changer in this context by bringing together innovators, experts and established companies under the same umbrella. However, the crucial push will need to come from a technology business incubator.

The objectives of TIH-IoT is to undertake the product/technology developments in the following ways:

- HI-Driven + Collaborator-driven: Identify and map existing technologies with HI at TRL 3 or TRL 4 with the interested industry partner for commercialization. Accordingly, work towards bringing the technology to TRL 5 or TRL 6.
- HI-Driven: Identify existing technologies with HI at TRL 3 or TRL 4. Find the possibility of integrating two or more technologies and nurture it for commercialization.
- Industry-Driven: Start with an industry problem, look for existing technologies at TRL 2 and above. Work on the identified existing technology with industry and international experts.
- Student/Start-up-Driven: Recognize young minds (students) through various activities such as competitions, internships, workshops, courses, open calls etc. and channelize them for developing out-of-the-box IoT/IoE technology.

- TIH-IoT-Driven: Network with national and international experts in the domain area to cultivate futuristic industry 4.0 technologies.

The TIH will begin activities focused under listed objectives and identify specific technologies which are either aligned with market need or leading to a generic IoT/IoE solution which is applicable in multiple scenarios. Strategy plan describing strategy-1 and strategy-2 explained in next section is developed to serve the mentioned purpose. The objectives also involve risk assessment not only at the initial stage but also on a time-to-time basis. Based on the initial work plan, the TIH will evolve and expand its plan.

C. To develop ecosystem for support commercialization of innovative solutions through industry, entrepreneur and start-up

Society of Innovation and Entrepreneurship (SINE) is a leading technology business incubator based in the IIT Bombay. It has incubated 150+ start-ups since its inception in 2004 and boasts the highest success rate amongst all business incubators in the country. With a close-knit network of alumni, veteran legal advisory team and strong ties with angel investors and investor networks, SINE is a magnet for technology-based start-ups in this part of the country. Further, SINE has recently signed a few MoUs with international

Technology Business Incubators (TBIs) to explore the international market. The hub in IIT Bombay will be in the unique position to be able to leverage its proximity to SINE for mentoring start-ups for commercializing its products. This proximity will be both physical (both being located within the campus of IIT Bombay) and well as philosophical since many faculty members associated with the hub have interactions with SINE.

Under the objectives of building an ecosystem for startups, this hub will further complement the activities of SINE by providing technical mentorship (which sometimes is not available with SINE), to the start-ups because of the hub's close association with the industries. This would be facilitated by organizing events like 'Industry day', where we can invite several industry experts and leaders and allow them to interact with start-ups and do their match-making with industry mentors. Such an arrangement will also attract new start- ups working in IoT/IoE/SIS/Health-Monitoring domain to be associated with SINE and having technical mentorship from the hub. It is also to be emphasized that the establishment of this hub at IIT Bombay will create a positive cycle such that SINE and TIH would be helping each other and creating more opportunities for start-ups in the proposed domain.

Established industries too have shown interest in a start-up-based product development model. Many established industries would like to avoid allocating resources for futuristic product development. They would prefer to outsource this to a start-up with some seed funding. However, they are reluctant to commit to this activity given the dismal success rate of technology start-ups, which are not part of this kind of ecosystem. The presence of the hub with its strong fundamental research background, provision for multiple and rapid prototyping of products through the state-of-the-art laboratories and start-up mentoring through SINE will encourage industries to look at this as a viable mode for development and commercialization of futuristic products. A few leading industries have already shown interest in this concept and we are confident that the success of the first few will lead to a deluge in future.

D. HRD and Skill Development

The IIT Bombay's faculty have offered several short-term courses on IoT providing various aspects of this multidisciplinary domain. Recently, a sequence of course modules has been structured and proposed for delivery through TEQIP III program. These course modules are designed by faculty from various disciplines and have been augmented with modules on delivering exposure on hands-on. The key objective for human resource development in the focused area is to offer courses leading to certificates of Certified IoT/IoE Engineer. The TIH-IoT plans to enhance the course curriculum proposed under TEQIP III program, add modules on relevant industry standards with the help of Confederation of Indian Industry (CII) authorities and implement it in online mode. The majority of the course component will be offered online with the help of CDEEP so that working professionals and a large pool of interested students can easily take up for their enhancement.

TIH Plans to offer the IoT courses in the major categories as below to reach out to maximum possible enthusiasts who would like to learn the IoT:

a) Certified courses

b) MTech and minor programs from IITB + supporting sub-modules of MEngg in entrepreneurship offered by DSSE (Desai Sethi school of Entrepreneurship) designed for working professionals.

The key motivation to offer certified online courses is to develop skilled IoT professionals in industry. Completing shorter goals through certified courses which will have value in the industry hiring, would be an attraction for working professionals. Moreover, our TIH-IoT would benefit by channelizing the industry problems through this large pool of skilled personnel.

a) Certified courses

The proposed IoT- course structure, as explained using Figure 1, will have various levels and *each level will have its own value*. Each level will encompass various theoretical and practical modules which will be delivered via online lecture sessions and lab sessions. Further, online course material, live sessions for troubleshooting/organizing labs will be provided to give comprehensive knowledge.

The course structure is divided in four major levels to reach out to large group of enthusiasts with or without knowledge of components of IoT/ technical background. The structure of course is briefed in Figure 1 as:

1. Skill Building
2. Basic
3. Advance
4. Elite

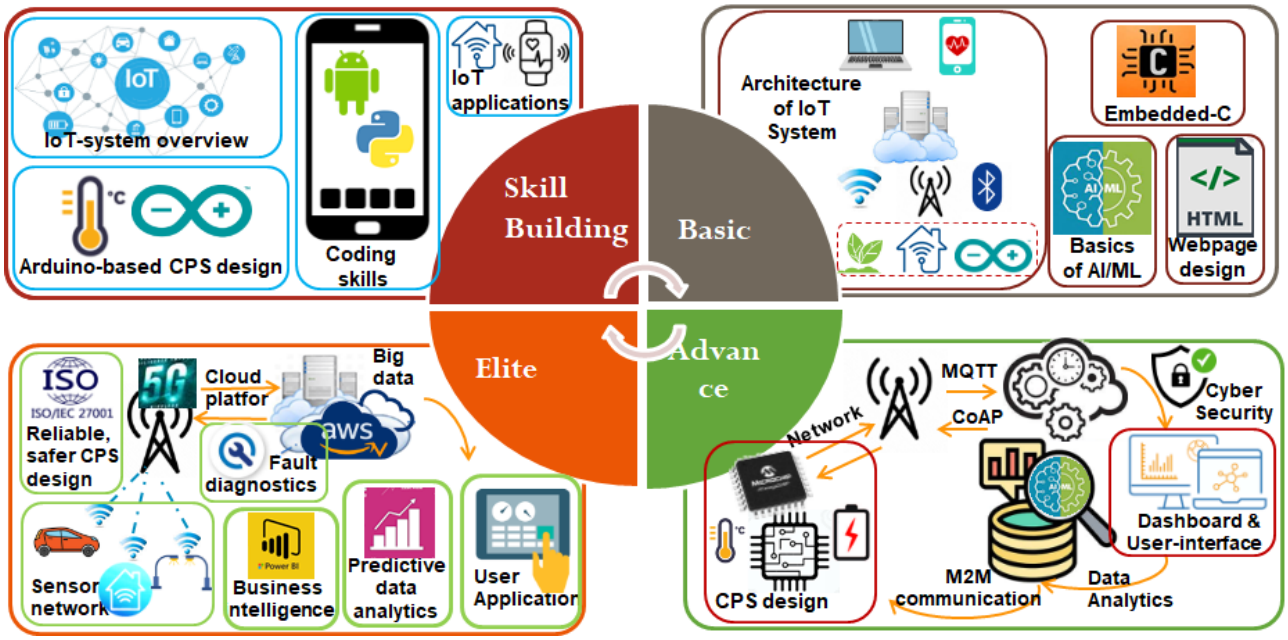


Figure 1: Course structure for certified IoT engineer

Each course module is independent in itself but has connectivity within the sub-topics and concept enhancements in next level. The skill building course has been specially designed for enthusiast who would like to acquire knowledge in the IoT and do not have any prior technical knowledge. The course will enlighten the audience about the overview of IoT-system, Arduino-based cyber physical system (CPS) design, python coding and connecting the IoT-systems with cloud server for various applications. The basic level course will cover connects, technical terminologies, system architectures required to design CPS, embedded C programming, concepts of AI/ML and human machine interface design. The Elite level course will elaborate more on designing electronic hardware (CPS), multi-sensor IoT-system concepts, networking protocols, cloud computing, cyber security, data analytics and machine-machine communication of IoT-system. The advanced level course will elaborate more on reliable, safer CPS design as per regulatory protocols, multi-sensor IoT-system networking, 5G communication for IoT system, big data, predictive data analytics, business intelligence (like Power Bi), fault diagnostics in IoT system. On completion of all levels, an IoT engineer will have exposure on applying Machine Learning concepts to networked devices.

The modules are designed with inputs from industry experts so that each level has a potential value in the job market at various levels. Certain modules at each level will also have a laboratory component to provide hands-on

exposure. These laboratory modules requiring algorithm development can be tested remotely by either virtual lab concept or tested offline by collecting data from the TIH- IoT computing resources. Those laboratory modules which require physical presence can be planned within the TIH-IoT resources or with CII assistance (nation-wide laboratories in various industries and academia) on a weekly basis or over the weekend. The national projects on "Talk to a teacher" can be integrated well with the delivery of modules to enhance the quality of course delivery. Exposure to the state-of-the-art laboratories of the hub and interaction with experts will inspire the working professionals to innovate in domain specific IoT devices and propel their respective organizations towards Industry 4.0 revolution.

b) MTech and minor programs from IITB + supporting sub-modules of MEngg in entrepreneurship offered by DSSE.

Further, the aim is to offer a master degree to those who are willing to invest more time, will be proposed for discussion and approval to the IIT Bombay Senate. Transferring the credits earned in completing IoT certification levels and an industry-aligned masters level project would be explored as a possibility for eligibility and completing the MEngg degree. The DSSE, IIT Bombay is soon going to offer MEngg for working professionals and the credit structure of MEngg program has industry relevant modules and one such module is IoT to develop synergy with entrepreneurship in IoT.

We plan to leverage another set of HRD and skill development activities in the hub through international level student competitions for demonstration of basic IoT devices. The experience of the IIT Bombay student community in conducting Techfest - the largest technology competition festival in the country will be leveraged for making this IoT centric competition the premier futuristic technology demonstration platform in India. The experience of IIT Bombay faculty members in mentoring such activities will be an additional benefit. Our experience in being a nodal agency for national level programs of this nature (e.g. India Innovation Growth Program) and a culture of encouraging extracurricular technical activity geared towards international student competitions will be an added fillip to such IoT device development and demonstration platforms. The competitions will be geared mainly towards the national and international student community. This does not address the needs of the working professionals. In order to ensure their involvement in the IoT revolution in India envisaged through this hub, we plan to conduct training programs and skill building workshops aimed at upgrading the advanced skills of working professionals.

The transformation of established industries from the traditional method of working to Industry 4.0 is mired in pitfalls. The usual challenge is considered to be the upgradation of existing machinery to make them compatible with this new philosophy. However, a greater challenge is likely to be the reluctance of personnel in giving up control over processes. This has two causes - a genuine desire to improve the process based on personal experience by refusing to believe the conclusions from data analysis and a fear of being irrelevant in the new world. The involvement of personnel from established companies in the collaborative research activities in the TIH-IoT has the potential to address both these issues. Therefore, TIH-IoT plans for niche courses for specific industries involving innovation, entrepreneurship and technical modules to drive the relevant industry towards SIS technologies leading to Industry 4.0. Personnel trained in IoT device development and data analysis would not have the fear of irrelevance and would be at the forefront of the efforts of the company to move towards Industry 4.0. The focused IoT technology development activity in the hub sponsored by a company would not only help that specific company but would have a ripple effect on other similar industries through the applied research necessary for that IoT technology development through existing students and research scholars. This would usher in an era of Industry 4.0 centric activity in all industries associated with the hub and could transform the face of industry in the country.

To summarize the HRD and Skill Development objectives under the umbrella of the TIH-IoT will focus on skill building as well as niche courses. Further, it aims to offer variety of courses listed as follows:

Skill building certified courses	Encouraging translational research
Courses to support MEngg degree program of IITB	Focused Ph.D. research (lab facility + mentoring through Post-Doc)
Offering courses with lab component	Curriculum based projects
Niche industry relevant training	Interactions with experts
Seminar/Conference	International Competition

E. To develop collaboration models

The TIH-IoT will encourage novel and innovative collaborative technology development in the focused area. For this, collaborations with various entities is listed next.

TIH-TIH collaborations: Developing technologies for IoT and IoE require experts from multiple domains relevant to the TIH themes such as cyber security, robotics, automation, data science, artificial intelligence, agriculture, underwater, etc. Hence, TIH-IoT has lots of scope of collaboration with other TIHs. We would explore the possibility of defining the scopes of work for each TIH in a collaborative technology development project. Further, defining the application vertical for each TIH would give opportunity for each TIH to customize the technology and lead in the commercializing the customized technology in the assigned application vertical. In particular, a collaboration model with similar benefits to each participating TIH would be explored. The basis for cost-sharing would be the scope-of-work and cost- benefit analysis. For example, scope of TIH-IoT can be defined as

- IoT device deployment / placement
- Protocols for data collection / processing storage / exchange of control commands
- Networking systems
- IoT Device-level and System-level optimization

As a first step for TIH collaborations, we have submitted a proposal for joint Indo-Korea collaborations in CPS to DST with TIH – Cyber Security (IIT Kanpur) and TIH-AI&ML (IIT Kharagpur). Such kind of joint proposals would be encouraged and initiated by TIH-IoT in future as well. Collaboration possibility in the proposal on VR Corridor (details available in Annexure-I) would also be explored under the TIH – TIH collaboration framework.

Tier-II collaborations: Tier-II collaborators or sub-hubs are very important collaborators for the TIH-IoT. There would be two kinds of collaborative models.

1) ***Bridge:*** The Tier-II collaborator(s) would act as a bridge between multiple TIHs for any complementary expertise. An example is our collaboration with CDAC, Kolkata, where their expertise would be utilized in prototyping and channelizing commercialization for not only collaborative projects but also for the TIH-IoT exclusive technologies. Similar mechanisms will be explored with other CDACs. Further, the collaboration model with CSIR- CEERI, Pilani is being worked out. Details of these collaborative models are presented in Annexure-III.
2) ***Satellite:*** The Tier-II collaborator(s) would support all the activities that TIH-IoT is involved in, but at a smaller scale. An initiative on collecting collaborative work on technology development from IIT Dharwad faculty has been taken. We plan to further increase the scope of activities with our satellite TIHs which would include all kinds of activities from TIH-IoT. Our vision is to grow nation- wide and accordingly moderate the TIH-IoT activities through its satellite hubs.
3) ***IITB support:*** Centres in IITB are support mechanisms for networking and provide organizational strength to the TIH-IoT. These IITB centres has several collaborations in the given domain area both at national and international levels. The effort would be to channelize this activity through TIH-IoT for increasing the TRLs. The TIH-IoT also realizes that active participation with national and international partners would induce a more innovation driven approach. The future mode of engagement with other institutions thus would incorporate strategies which would look for complementary expertise and as well as strengthening the already existing expertise. We would thus identify such partners at both national and international level so that the ideas proposed here are well taken forward. Mechanisms to have joint activities would be explored to faster launch of TIH activities at larger scale and multiple stakeholders.

F. To contribute to the Industry standards

The Industry standards play an important role in standardizing the technology along with defining rules and regulations for safety and operations. We cannot ignore this aspect when commercializing the technologies is the prime objective of the TIH-IoT. We plan a couple of novel methods to accelerate technology development to the commercialization process.

1) ***Defining Industry Standards for IoT technologies:*** It is evident that IoT and IoE technologies are interconnecting physical and cyber systems. Moreover, each physical and cyber system is combination of multiple technologies. Hence, there is a need for defining interconnections between the existing or forthcoming standards for these technologies. The TIH-IoT would plan the activities to fill this gap such that Indian industries/ start-ups are benefited. In this regard, we have initiated talks with Confederation of Indian Industry (CII) and further connect with the Institute of Quality and the Bureau of Indian Standards (BIS).
2) ***Introducing Literature on Industry Standards in course curriculum:*** The planned course structure on IoT leading to MEngg degree is designed for working professionals. Incorporating the concept of Industry standards in the course structure would target the root-cause of industry-academia gap. Learning about the standards and regulations in

academia would benefit the process of commercialization. This is because the technology development phase would include the fair idea of standards and certification process to be cleared once the technology is developed. We plan to connect with industry experts in this domain to deliver course contents primarily designed by industry experts.

G. Setup state-of-the-art laboratory facilities for research and testing

The IIT Bombay has MEMS (Micro Electro-Mechanical Systems), NEMS (Nano Electro-Mechanical Systems) and nanofabrication facilities as a part of NCPRE (National Center for Photovoltaic Research and Education), Center for Machine Intelligence and Data Science (C-MInDS), National Center of Excellence in Technology for Internal Security (NCETIS), Parimal and Pramod Chaudhari Center for Learning and Teaching (PPCCLT) and CEN (Center of Excellence in Nanoelectronics). These facilities can be used for the fabrication of some of the sensors considering their usage charging model. Moreover, facilities for making mechanical, optical and chemical sensors are also available across various departments. Probe stations for the device characterization and analog/RF measurement instruments are partially available across various departments. Several material characterization facilities are available in SAIF (Sophisticated Analytical Instrument Facility) IIT Bombay. All the aforementioned facilities can be used based on the institute charging model. The activities of the TIH can be streamlined and accelerated by having following entities in the Hub: Experts, Skilled personnel, Prototyping facility, Testing facilities, Industry partners, National/International collaborators, etc.

The TIH-IoT would aim to develop sophisticated facilities that would enable faster product design such as prototyping and testing facilities. The proposal is to cluster these facilities in the following way:

a) Sensor, actuator and embedded processing laboratory (SAP Lab)
b) Rapid prototyping facility (RPF)
c) Device testing facility (DTF):
d) Simulation and Hardware-in-Loop Simulation, AI and ML laboratory (HILS-AIM Lab)

The listed facilities give a synergy for developing and testing technology for not only individual aspects of IoT Technology but also for an integrated solution for application verticals. More details on these facilities are provided in Annexure-IV with their mapping to the technology demonstrations. The purpose of the individual facility is described next.

a) **Sensor, Actuator and Embedded processing laboratory (SAP Lab):** Core of IoT/IoE technology chain from the sensing to the transmission constitute IoT device & system, energy scavenging, energy storage and battery, power management and the networking. IoT device itself starts from sensors/actuators and continues with sensor interfacing, signal conditioning, processing and ends at the transceivers. SAP lab is an integrated design, testing, characterization and development lab covering all aforementioned stages. SAP lab will also facilitate the primary levels of full device integration and evaluating the sources of error and failures starting from sensor interfacing to the energy management, local processing overheads and compatibility evaluations. Ultimately SAP lab provides the platform for R&D engineers and designers enabling them to evaluate various designs and come up with a reasonable primary working integrated and working of the IoT/IoE chain from sensing to the transmission with functional and parametric evaluations.
b) **The Rapid Prototyping Facility (RPF):** To be inline with the main objectives of a technology innovation hub, any target product needs a complete prototype to be made within a consolidated facility ecosystem. Multi-disciplinary nature of IoT/IoE implies providing a multi- disciplinary prototyping facility in one place, which also helps in speeding up such important steps towards a product and high levels of TRL at 6 and above. Proposed facility abbreviated as RPF is exactly for the same goal. Facilities for screen printing for sensors and electrodes, sensor packaging, PCB (printed circuit board) manufacturing, injection molding, CAD-oriented mechanical design and mechanical prototyping machinery, 3D printing and full system prototyping will be setup and integrated in RPF lab, for seamless and rapid prototyping of the systems for the future products.
c) **Device testing facility (DTF):** A lot of emphasis is given on developing state-of-the-art testing facilities for raising the TRLs. One kind of testing facility is to test at the device-level while the other kind of testing facility is to test the system-level IoT/IoE solution. The device- level testing facility involves signal quality, benchmarking, electro-mechanical characterization, performance analysis, etc. It also includes a facility for testing the IoT/IoE device under various environmental conditions.

The System-level IoT testing facility would enable testing for stationary or self-driven (on a mobile platform) and their network under various environmental conditions. This one of its kind testing facilities would be developed in-house and would facilitate many challenging realistic scenarios as explained in section 8.

d) **Simulation and Hardware-in-Loop Simulation, AI and ML laboratory (HILS-AIM Lab):** This laboratory would facilitate training AI models on the sensor data generated for analysis and decision-making, conducting simulations to evaluate the performance of protocols that would be developed for networking of IoT devices. Hardware-in-loop simulation (HILS) is a resource-intensive approach to the testing, which requires multi-skilled teams that can setup and configure both the execution platform and the input/output (I/O) for a simulated environment. HILS would be used in real-time to validate designs and algorithms prior to the initialization of the actual operation of the system, which significantly accelerates the development cycle. It will also be integrated with IoT devices for testing design strategies and algorithms in presence of digitized environments. More about the HILS facility is explained in section 8.

4 STRATEGY

Considering the NM-ICPS objectives of building CPS expertise, developing multi-disciplinary technologies and solving inter-ministerial problems, we adopted a two-fold strategy to plan the stated developmental objectives and we will continue this strategy planning on a time-to-time basis (at least once a year). The high-level approach is shown in Figure 2.

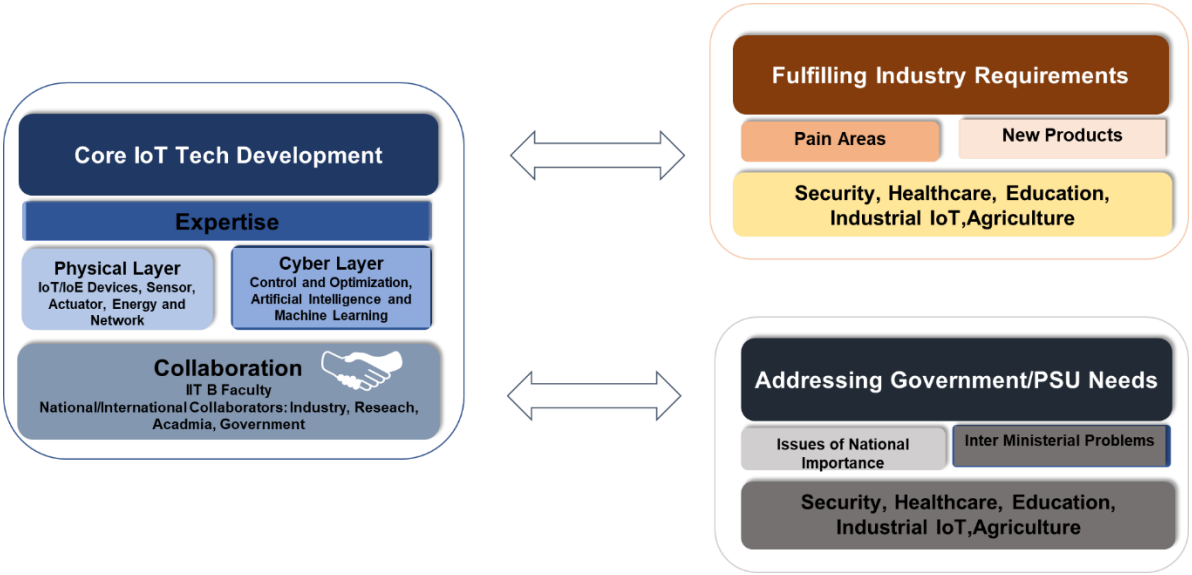


Figure 2: Strategic Plan

Strategy-1: Categorize the expertise in IoT framework and Core IoT Technology Development
Strategy-2: Fulfilling Industry Requirements and Addressing Government/PSU needs: Match the available expertise with industry interest in investing in use-cases

Strategy-1: Our intellectual focus of developing technologies for SIS is achieved by forming a team of IIT Bombay faculty members and their collaborators (national/international) working in the relevant area. The team expertise is grouped below (Figure 3) based on their primary expertise, though many of the team members have been working on solutions, which involve expertise in both.

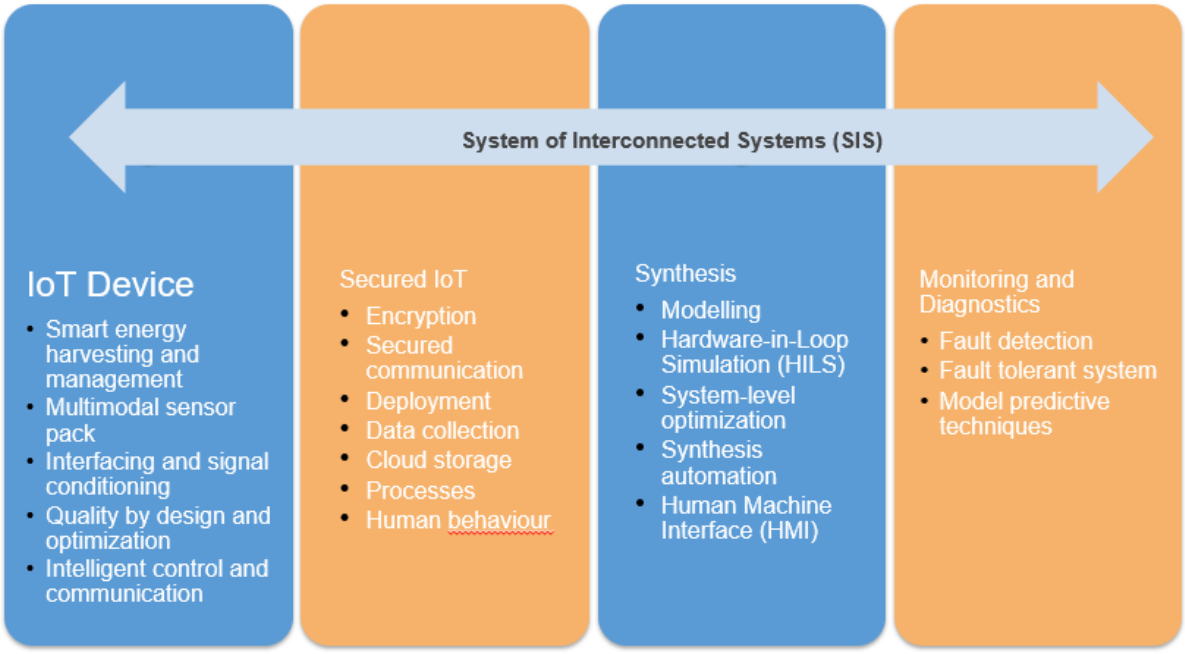


Figure 3: System of Interconnected Systems

The technical verticals are defined in Figure 4 are grouped to develop generic IoT technologies in identified application verticals, with the aim of enabling technologies for SIS:

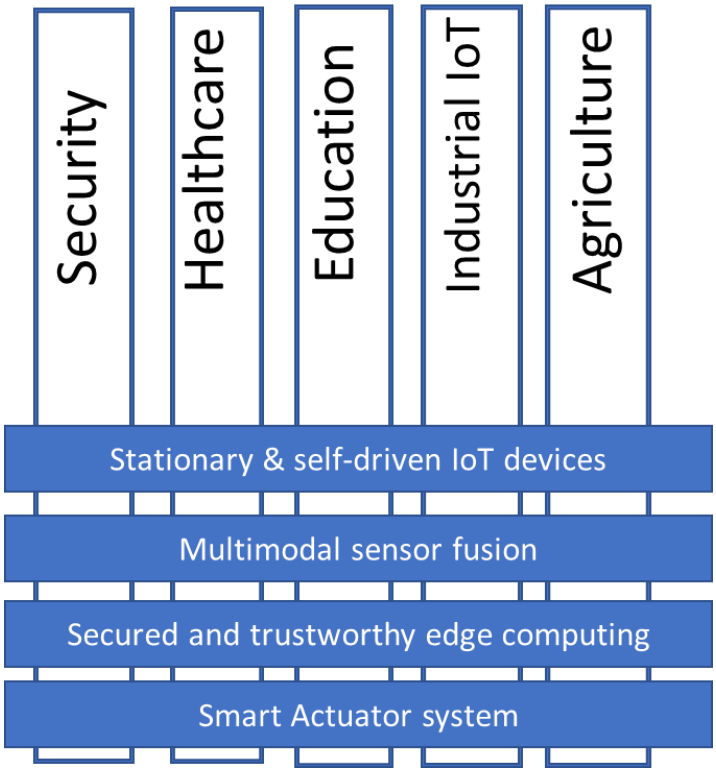


Figure 4: Core IoT technologies and application verticals

Strategy-2: With the NM-ICPS approach of assigning TIHs in different thematic areas and defining the need of self-sustenance TIHs, we took the advantage of being located in the financial capital of India. Considering that the TIH will

receive a major source of revenue from industry interactions, we focused on defining our use-cases received from various industries. These use-cases are received after interacting with the technology business leads of these industries. Further, we gave importance to the interdisciplinary and inter-ministerial use-cases. In particular, we considered those use-cases which can be applied in multiple domains with customization.

It is clear that the basis of selection for the technology demonstrations is based on the market need, national importance and/or inter-ministerial problems. Since the current market need is dictated by the COVID-19 situation, our technology focus is driven by the learnings of the COVID-19 situation and concentrate on self-reliance. Figure 5 describes our methodology in selecting technology demonstrations and the corresponding requirements for facility developments. It is clear that the importance is given to commercializing the demonstrated technologies and the feedback is important to be considered, if there is any step required for technology development. A major feedback can be industry standards to be followed or contributed.

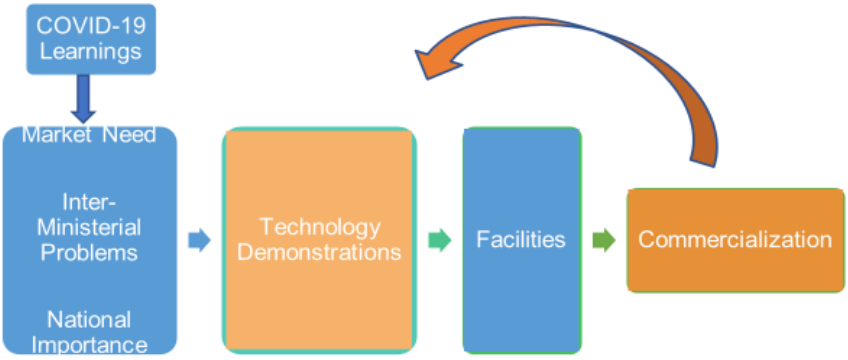


Figure 5: Basis for selection of technology demonstrations and facilities

With this strategy, the generic IoT technologies are now given the technology focus of Operation, Diagnostics, Monitoring and Analysis for Predictive Maintenance, Safety, etc. of SIS. Current and Post-COVID situation is also driving the technology developments towards minimizing the contacts. IoT based technology solutions to address operation, monitoring, maintenance and safety would automatically cater to minimizing the human contacts.

It is worth noting that Strategy-1 and Strategy-2 would be a repeated time-to-time basis for evaluating the identified use-cases and finding new use-cases in the technology focus area. For example, use-case on Smart Cities and IoT for

Renewable Energy are untouched in this DPR. These areas would be analysed soon with industry participation.

Operational Strategy

In order to achieve its goal, TIH-IoT will set up state-of-the-art laboratories for rapid prototyping, testing, simulation testbeds, algorithmic and computing facilities. This will give the right canvas to innovative minds and facilitate learning and commercialization. Thevarious activities of the hub which have been planned to cover its wide scope and achieve its objectives are:

Technology Development	Knowledge Generation	National/ International Collaborations
• Identify, develop and demonstrate use-aware SIS technologies • Analyse risk and market need on time-to-time basis • Connect with customer's need or nation's interests	• Interactions with experts Offering courses with lab component • Curriculum based projects • Focused Ph.D. research (lab facility + mentoring through Post-Doc) • Encouraging translational research	• Participation in joint projects • Developing standards and frameworks • Collaboration with research centers • Organizing international workshop/conferences • Supporting experts' visits/talks • Attracting international students

Human Resource Development	Industry Interactions	Commercialization
• Online certified courses • Industrial training • Skill building workshop • Seminar/Conference • Competition	• Solving critical problems • Offering industrial training • Innovative product design • Technology transfer • Laboratory facility	• Mentor network, legal support and angel investors funding • Office space on nominal rent • Seed funds • Organising "Industry Day"

- Technology development
  - Identify, develop and demonstrate use-aware SIS technologies
  - Analyze risk and market need on time-to-time basis
  - Connect with customer's need or nation's interests
- Knowledge Generation
  - Interactions with experts
  - Offering courses with lab component
  - Curriculum based projects
  - Focused Ph.D. research (lab facility + mentoring through Post-Doc)
  - Encouraging translational research
- National/ International Collaborations
  - Participation in joint projects
  - Developing standards and frameworks
  - Collaboration with research centers
  - Organizing international workshop/conferences
  - Supporting experts' visits/talks
  - Attracting international students
- Human Resource Development
  - Online certified courses
  - Industrial training
  - Skill building workshop
  - Seminar/Conference
  - Competition
- Industry Interactions
  - Solving critical problems
  - Offering industrial training
  - Innovative product design
  - Technology transfer
  - Laboratory facility

- Commercialization
  - Mentor network, legal support and angel investors funding with help from SINE (Society of Innovation and Entrepreneurship) in IIT Bombay
  - Office space on nominal rent
  - Seed funds
  - Organising "Industry Day"

Leveraging IIT Bombay Ecosystem

The multidisciplinary nature of the proposed domain is integrated in the hub by forming a strong team of faculty members from various disciplines working in the focused area. The activities of the proposed hub are streamlined through close interactions of groups within and among the technical verticals. The grouping is based on the technical expertise of the group members and their current involvement with the corresponding industry.

As described through the pictorial illustration in Figure 6, the main focus of TIH-IoT is developing technologies for SIS. These technologies are integration of technologies on various aspects of IoT technology. These individual technologies or their integrations at Technology Readiness Levels (TRLs) 2 or higher from Host Institute or collaborating institutes (currently CDAC and IIT Dharwad) are identified. The TRLs of these identified technologies are then raised with the resources of TIH. Further, the interfaces the industries, research park and entrepreneurs to bring the technology to market by bringing it to TRLs 6 and above. The TIH-IoT will have close interactions with the existing entities of the IITB involved in industry interactions and human resource development. These entities are Technology Business Incubator SINE (Society for Innovation and Entrepreneurship), Research Park, CDEEP (Centre for Distance Engineering Education Program) and QIP/CEP (Quality Improvement Program/Continuing Education Program) office. These entities are currently working independently and the proposed TIH will act as a bridge between them intensifying R&D culture in the industry and channelizing technologies in the HI to achieve higher TRLs as shown in Figure 6. In totality, the hub would bring an ecosystem benefitting the industry, academic collaborators, start-ups as well as IIT Bombay.

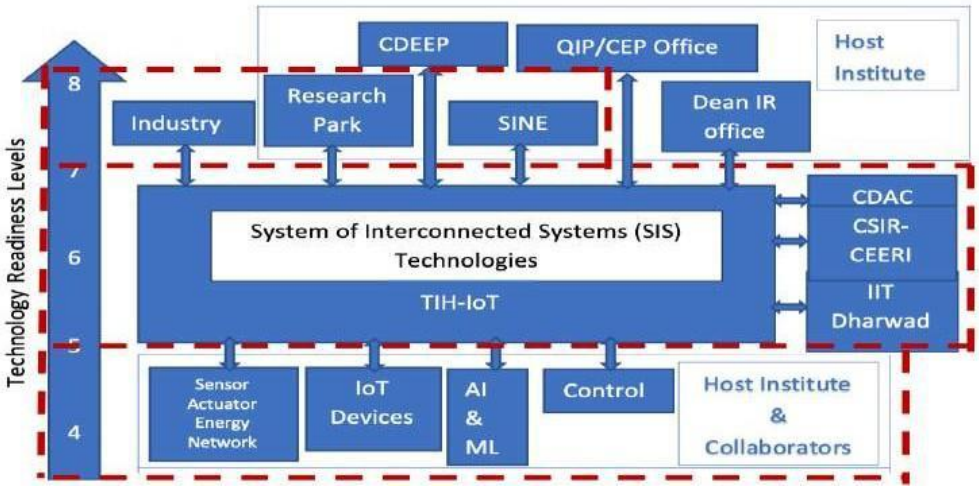


Figure 6: Interface of TIH-IoT with existing entities of Host Institute

Table 1: Summary of various activities at TIH-IoT

Industry	Host Institute
• Streamline thrust areas through specialized laboratory + training environment • Promoting start-up • Idea generation and cultivation through critical analysis and testing • Virtual laboratory access, exclusive use • Industry relevant courses • Skill building workshops	• Industrial problems + consultancy • Availability of skilled personnel (less management load on faculty) • Testing facility • Multi-disciplinary collaboration within/ outside (national & international) the institute • Certified courses + Masters program • Workforce support for organising seminar/conference/workshop/course

• Industry-EndUser workshops • Expert talks • Online courses + short-term lab exposures • Seminars/Conferences/Competitions	• Channelizing IITB's inventions for commercialization
Academic Collaborators	Start-ups
• Student and faculty exchange • Virtual Laboratory access • Sophisticated facility access • Skill building workshops • 50:50 partnership in proposing international projects • Expert talks • Participation in Seminars/Conferences/ Competitions	• New business opportunities • Mentoring by established industry • Facilities to increase TRLs • Skill building workshops • Seed capital for sustenance • Initial support for office space • End User interface • Networking with industry

The hub will bring together various activities happening in pockets in IIT Bombay. Collaborative efforts within multiple disciplines would aim to provide integrated technologies targeting SIS solutions for Industry 4.0 revolution.

Industry Collaboration

Industry-Government-Academia collaboration will be one of the most critical components of achieving the objectives of TIH-IoT and NM-ICPS. We need to identify the key players in the IoT innovation ecosystem and reach out to them for collaboration for translational research and technology development (Figure 7).

We have identified the following stakeholders, based on the role they are playing in the overall IoT ecosystem and based on our technology and domain focus areas:

- Industries using IoT/IoE Technologies: In Security, Healthcare, Education, Industrial IoT, Agriculture domain areas
- Industries developing IoT/IoE Technologies: To leverage their expertise in core IoT Technology development
- Industry Organizations & Groups: For devloping effective network of technology user and provider organizations
- Government, PSUs, R&D Organizations: Contributing for solving issues of national importance and inter-ministerial problems

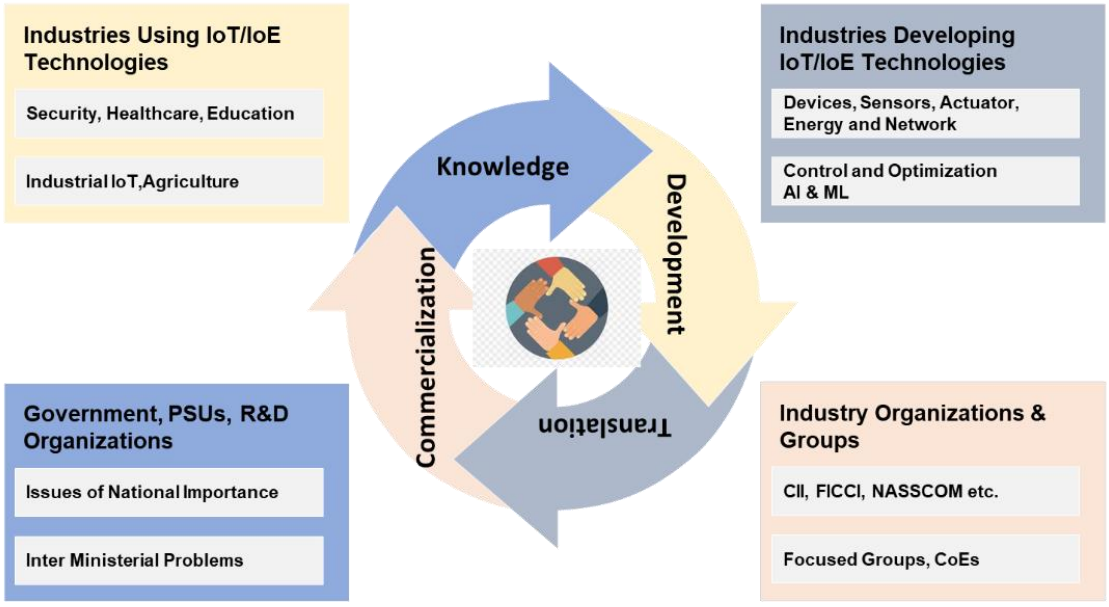
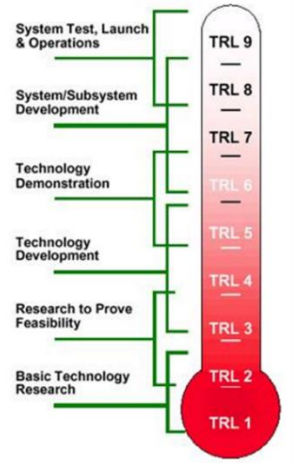


Figure 7: Industry collaboration

TIH Programs mapped to TRLs

Technology readiness levels (TRLs) is a measure of estimating technology maturity of core technologies in a program during the selection process and in subsequent monitoring and evaluation phases until these technologies, or products utilizing them, attain market readiness. Originally introduced by NASA, the TRL scale is a metric with nine technology readiness levels for describing the maturity of a technology from ideation stage (TRL-1) to highest degree of application/commercial readiness (TRL-9) as shown in figure 8 below. Levels in between covers establishment of proof of concepts, prototype developments, functional validations from models to real operational environments and clearances of mandatory regulatory barriers between levels towards market introduction of these technologies/products.

One of the main objectives of TIH-IoT is to raise the TRLs of various research and technology development activities. To fulfil this objective TIH-IoT has proposed various programs targeting at various TRLs. The below table represents the various programs mapped at different Technology Readiness Levels:



Technology Development	Innovation & Entrepreneurship	Human Resource Development	International Collaboration
Technology Products	Dedicated Innovation Accelerator (DIAL) Start-ups & Spin-off	Job Creation	Product Development
Proof of Concept, Test Beds etc.	Prototype: PRAYAS	Skill Development	PoC, Prototype, Test Beds
Technology Development (IP, Licensing, Patents etc)	GCC - Grand Challenges & Competitions	Faculty Fellowships, Chair Professor	Collaborative Research
Publications, IPR and other Intellectual activities	Seed Support System Entrepreneur In Residence (EIR)	Graduate, PG, Doctoral Fellowships	Reseach & Fellowships

Figure 8: Mapping of TIH Programs to TRLs

(Ref: https://en.wikipedia.org/wiki/Technology_readiness_level)

When a technology is at TRL 1, scientific research is beginning and those results are being translated into future research and development. TRL 2 occurs once the basic principles have been studied and practical applications can be applied to those initial findings. TRL 2 technology is very speculative, as there is little to no experimental proof of concept for the technology. The technology development programs aimed at publications, IPR and other intellectual activities, Seed Support and EIR in Innovation and Entrepreneurship programs and Student Fellowship programs can be mapped at these TRL levels.

When active research and design begin, a technology is elevated to TRL 3. Generally, both analytical and laboratory studies are required at this level to see if a technology is viable and ready to proceed further through the development process. Often during TRL 3, a proof-of-concept model is constructed. The technology development programs aimed at IP, Licensing, Patents etc., Grand Challenges and competition in Innovation and Entrepreneurship programs and Faculty Fellowship and Chair Professor programs can be mapped at these TRL levels.

Once the proof-of-concept technology is ready, the technology advances to TRL 4. During TRL 4, multiple component pieces are tested with one another. TRL 5 is a continuation of TRL 4, however, a technology that is at 5 is identified as a breadboard technology and must undergo more rigorous testing than technology that is only at TRL 4. Simulations

should be run in environments that are as close to realistic as possible. Once the testing of TRL 5 is complete, a technology may advance to TRL 6. A TRL 6 technology has a fully functional prototype or representational model. The technology development programs aimed at creating PoC, Prototypes, Test beds etc., prototype development under PRAYAS initiatives in Innovation and Entrepreneurship programs and Skill Development initiatives in HRD programs can be mapped at these TRL levels.

TRL 7 technology requires that the working model or prototype be demonstrated in a operational environment. TRL 8 technology has been tested and "qualified" and it's ready for implementation into an already existing technology or technology system. Once a technology has been "proven" during a successful mission (in operational environment), it can be called TRL 9. The technology development programs aimed at commercialization of technologies, developing new products etc., Accelerator for Startups and creation of spin-offs through Innovation and Entrepreneurship programs and job creation initiatives in HRD programs can be mapped at these TRL levels.

Investment Plan for different components

Taking in consideration the focus areas of TIH-IoT, the expected outcomes and strategy to achieve the same, a high-level investment plan for different components of the hub has been prepared. Following are the key considerations for the preparation of the investment plan:

- Investment plan has been prepared based on the funding being received under NM-ICPS.
- Core technology and application verticals have been identified, based on the current focus areas of the hub. Initially, an approach of uniform distribution of funds for different application verticals has been adopted.
- Based on the requirements and progress made in different application verticals, Hub will re-visit the investment plan, on a periodic basis and will change the allocation for different verticals, if needed.
- The decision on investment in infrastructure facility is finalized by the BoD based on the sustainable plan on operation and maintenance costs.

The below table represents the year-wise budget allocation for different components/programs:

Table 2: Investment plan for different programs

S No	Area	Budgeted Amount (Rs in Lakhs)					
		1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
1	**Technology Development**						
1.1	**Core technologies:**	20.00	20.00	20.00	20.00	20.00	100.00
1.2	**Technologies for new CPS area**	20.00	20.00	20.00	20.00	20.00	100.00
1.3	**Application-oriented technologies**						
1.3.1	Security	22.00	140.00	280.00	120.00	140.00	702.00
1.3.2	Healthcare	22.00	140.00	280.00	120.00	140.00	702.00
1.3.3	Education	22.00	140.00	280.00	120.00	140.00	702.00
1.3.4	Industrial IoT	22.00	140.00	280.00	120.00	140.00	702.00

1.3.5	Agriculture	22.00	140.00	280.00	120.00	140.00	702.00
1.3.6	Other Projects	12.59	52.95	108.79	46.85	50.74	271.92
1.4	Equipment	349.34	0.00	0.00	0.00	0.00	349.34
1.5	CPS Testbeds for Verification and Validation	230.80	1752.64	1285.12	91.73	100.90	3,461.19
	Sub Total	**742.73**	**2545.59**	**2833.91**	**778.58**	**891.64**	**7792.45**
2	**Entrepreneurship Development**						
2.1	Technology Business Incubator (TBI)	50.00	87.50	87.50	87.50	87.50	400.00
2.2	Start-ups & Spin-off companies	100.00	110.00	110.00	100.00	100.00	520.00
2.3	GCC - Grand Challenges & Competitions	50.00	200.00	200.00	200.00	50.00	700.00
2.4	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	20.00	20.00	20.00	20.00	20.00	100.00
2.5	CPS-Entrepreneur In Residence (EIR)	21.60	25.20	21.60	21.60	21.60	111.60
2.6	Dedicated Innovation Accelerator (DIAL)	0.00	75.00	0.00	0.00	0.00	75.00
2.7	CPS-Seed Support System (CPS- SSS)	0.00	50.00	50.00	50.00	50.00	200.00
	Sub Total	**241.60**	**567.70**	**489.10**	**479.10**	**329.10**	**2,106.60**
3	**Human Resource Development**						
3.1	Graduate Fellowships	68.00	68.00	68.00	68.00	68.00	340.00
3.2	Post Graduate Fellowships	44.28	44.28	44.28	47.97	47.97	228.79
3.3	Doctoral Fellowships	124.25	124.25	124.25	124.25	124.25	621.24
3.4	Post Doctoral Fellowships	8.00	20.00	32.00	26.00	14.00	100.00
3.5	Faculty Fellowships	28.80	57.60	28.80	28.80	28.80	172.80
3.6	Chair Professors	35.40	70.80	35.40	35.40	35.40	212.40
3.7	Upgrading PG Program	20.00	30.00	20.00	20.00	10.00	100.00
3.8	HRD - Workshop/ conferences/ seminars/ sponsorships, etc.	20.00	40.00	42.00	44.10	46.31	192.41
	Sub Total	**348.73**	**454.93**	**394.73**	**394.52**	**374.73**	**1967.64**
4	**International Collaboration**	0.00	72.00	75.60	79.38	83.35	**310.33**

5 TARGET BENEFICIARIES

The technology requirements from any government or non-government beneficiary are channelized through the industries. Hence, the primary beneficiaries of TIH-IoT would be the industry partners who are willing to be the first movers in the oncoming revolution of Industry 4.0. Evidently, the government agencies and ministries as well as end users, are another set of major beneficiaries. In the initial phase, the main focus of technology development is the inter-ministerial problems in mainly two application areas: Agriculture and Health. Along with these two focused application verticals, the TIH-IoT will simultaneously work on Security and Industrial verticals.

Agriculture	Healthcare	Smart Education	Industrial IoT	Security Systems
• Farmers • Government agencies • Line Ministries •ICAR •State agiculture universities	•Individual Patients • Doctors • Polyclinics and hospitals • Pharmaceutical companies •Health insurance companies, Governments	• Government • Education department • Educational Institutes • Students	• PSUs • Private Industries	•CRPF, CISF,NSG, RAF, Assam Rifles, etc •SrivisifAI, L&T (Defense), TATA Power SED •PSUs, defence organizations, private sector companies • Smart homes

In particular, the Government agencies and industries in the area of security, agriculture, health, engineering and process are beneficiaries of these technologies. Agriculture IoT would directly benefit large farmers who would be able to deploy such cutting-edge technologies to reduce dependence on manual inspection. Smaller farmers who are often at a disadvantage in regular inspection of farmlands at remote locations with poor road connectivity would also benefit - perhaps by pooling resources with adjacent farms. The labour and resource freed from the drudgery of manual inspection would be able to migrate to higher level tasks through the grassroot level skill development activity envisaged in the hub.

In the area of security, the technology demonstrator (mentioned in more detail later) of Multi-Agent Mobile Systems For Video Surveillance And Mapping would benefit police of all states of India and also paramilitary and internal security forces. The technology demonstrator of unified secure, reliable and intelligent IoE based reconfigurable drone technologies with drone ports for packet delivery, surveillance, trace, inspection and air-traffic management systems in Indian Airspace would have Indian Army, Indian Navy, Ideaforge, Commercial delivery companies, Airport authority, Airbus, Boeing, ADA, ADE, NAL, Dassault Aviation, Collins Aerospace, DGCA, AAI and Drone/Aircraft manufactures as target beneficiaries.

Overall, we anticipate this technology of the future to touch almost all sections of society and industry and bring about a transformation in the way business is conducted in the country in the future. The modes of interactions with industries would be to facilitate time-bound and quality outcomes for technology development for current and future market need. We would explore and analyse following modes of industry interactions:

- Projects with the responsibility of understanding need, identifying stakeholders, technology identification, technology development, prototyping, field trials leading to commercialization
- Independent projects
- Involvement of industry experts in defining the technology problems

The group of faculty members in IIT Bombay involved in the hub has several industrial interactions which are mainly in the form of industry supported research projects, consultancy projects and technology transfers. All these would be continued and be enhanced under the activities of the hub. Each of these projects will reap the benefit of synergies by being in the hub. In addition to these, future modes of collaboration where industries can significantly provide their inputs are:

- Technology support for the development of IoT related products from a comprehensive perspective such that all its challenging technological components like sensors development, interface, embedded systems, communications are well addressed.

- Testing of the developed technologies in real environment and accordingly provide feedback
- Mentorship to students, faculty
- Expert talks, workshops, seminars, training and internships

Many industries have already promised to be a part of these activities. Their letters of support were provided in the initial submission. Now, we approached these industries to provide relevant use-cases to assess the market need.

Weaker sections of the society who might currently be involved in routine inspection jobs would benefit from the personnel training programs of the hub. With appropriate skills, they would be able to migrate to better positions in the industry. This would have a cascading effect on their community as other members get inspired and strive for similar levels of success.

6 LEGAL FRAMEWORK

The TIH will closely work with the IIT Bombay and other entities. Their model of interactions would be exactly the same as the ones in IIT Bombay. The TIH is anticipated to work closely with other TIHs, Tier-II collaborators (who act as bridges and satellite), National and international academic institutions, Industry, and SINE (Technology Business Incubator in IIT Bombay). The IIT Bombay is already interacting with these entities except newly formed TIHs and Tier-II collaborators. The model of interactions with the TIH would be the same as a company while Tier-II collaborator is an academic or research institution / centre, the interaction model with the TIH-IoT would be the IITB model for industry or institution depending on their scope of work.

While interactions of the TIH-IoT to entities external to IIT Bombay is same as existing methodology of IIT Bombay, the interactions with the IIT Bombay facilities and resources would be based on subsidized charging model. The IP sharing rules would also be the same as that followed by the IIT Bombay. Further, procedures for monetizing IP would be established in the benefit of start-ups.

The Legal Framework of a Section 8 Company is provided in Annexure-V. Apart from what is conveyed in the Annexure-V, from the purview of the existence, annual filings and maintenance of the Section 8 Company from the internal perspective, there will be additional requirements towards -

1) The Company's relationship vide a contract with the IITB for the place/ building/ location allocated and a MoU for the understanding/arrangement on the nature of relationship inter-se i.e. among IITB and TIH-IoT towards the mutual agreement on way of working, funding mechanisms, exit etc;
2) The Company's internal contractual relationships with its employees, appointed Directors, senior management etc; and
3) Lastly, its contracts with third party vendors/service providers and customers/clients etc who may be hosted at TIH-IoT or given some kind of support.

Pursuant to the aforestated, once established, the Company will have to take the services of a Lawyer (for legal services), CA and CS in order to comply with its tax and ROC compliance statutory and regulatory requirements for e.g. Board Resolutions Minutes of Meetings and Filing of IT Returns, Audit Reports etc.

Confidentiality

TIH undertakes on its behalf and on behalf of its subcontractors/employees to maintain strict confidentiality of the project including, but without limitation to, the R&D work and know-how generated and prevent disclosure thereof, for any purpose, other than in accordance with the Tripartite Agreement. All parties will also ensure confidentiality as required for the project except the disclosure is warranted by operation of law.

Intellectual Property Policy

As per Tripartite agreement, and to fulfill the requirements of Intellectual Property creation and licensing, TIH has created its separate IP policy and will be shared with all the stake holders. The IP policy is formed by taken into consideration the benefit for the innovator as well as TIH and will be win-win situation for both the parties.

Various Standard Operating Procedure are being created for rapid and adoption of CPS applications.

Force Majeure

No parties shall be held responsible for non-fulfillment of their respective obligations under the Tripartite agreement due to exigency of one or more of the force majeure events such as, but not limited to Acts of God, war, flood, earthquake, strike, lock outs, lock downs, epidemics, riots, civil commotions etc. provided on the occurrence and in

cessation of such event, the Party effected thereby shall give a notice in writing to the other Party immediately, after but not later than one month of such occurrence and cessation. The period between the occurrence and cessation of such event will be excluded while calculating the period during which the party has to perform his obligations under this Agreement. If the force majeure conditions continue beyond six months, the parties may mutually decide about the future course of action.

Use of Names and Trademarks

The Parties agrees that they will not use the name of the other Party or its employees in any advertisement, press release or publicity with reference to Tripartite agreement or any product or service resulting from the agreement, without prior written approval of the other parties.

7 ENVIRONMENTAL IMPACT

TIH IIT Bombay look forward to use most efficient technologies for the development of the products and systems, maximize the usage of renewable energy. The sustainable approach to reduce the Carbon footprint will be a focused approach where TIH will ensure in every technology development process. We strive to use technologies and environmental management system that are related to environmental preservation, resource conservation, and energy conservation technologies. TIH IIT Bombay will make efforts to improve and enhance environmental education for employees, disclose environmental information on an adequate and timely basis to remain always trusted and highly appreciated by society, and to actively promote relation activities contributing to environmental management through close exchange with stakeholders.

8 TECHNOLOGY

As per the gap analysis in NM-ICPS DPR, the identified gaps are reiterated briefly as follows:

G1: Lack of collaborative/interdisciplinary approach

G2: Lack of scale for experimental validation

G3: Lack of facilities to support large-scale experimental test-beds

G4: Lack of connections with stakeholders and translators to convert outputs to outcomes

G5: Lack of large-scale mission mode project management capabilities

In order to foster R&D and address challenging problems along with identified gaps in the domain of IoT and IoE, the technology development under TIH is categorized as follows:

T1: Grand challenge and competitions: Grand Challenges are problems which are very difficult and nearly impossible to solve with the current technology or process, however will have significant socio-economic impact. The outcome of this category may or may not exist as of now but if the R&D activities are lined up, the 50% objectives have a possibility of achievement.

T2: Core technologies: These are innovative and distinct technologies that have large impact through its applicability in multiple use-case. Through these technologies, TIH plans to build up core and unique multidisciplinary expertise.

T3: Technologies for new CPS area: These technologies are addressing the challenging scenarios posed by interconnecting “land-air-water”.

T4: Application-oriented technologies: These technology developments are driven by requirements from government and industry mapped to core technologies and user-aware technologies from individual technical verticals. In order to be consistent with the industrial terminology, we further categorize these technologies in Table 3.

T5: CPS Testbeds for Verification and Validation: The technologies required for systematic testing and validation supported by theoretical and practical claims are envisioned under this category. These are augmenting to increase TRLs of core and application-oriented technology objectives.

Table 3: Categorization of New Technology/Product

Sr. No.	Category	Details
A1	New-to-the-world Products/Technology	The alternative expression for new-to-the-world products/technology (really new products/technology) already indicates that this is what most people would define as a new product. These products are inventions that create a whole new market.
A2	New-to-the-firm Products/Technology (new Product Lines)	Products that take a firm into a category new to it. The products are not new to the world, but are new to the firm
A3	Additions to existing Product Lines	These are simple line extensions, designed to flesh out the product line as offered to the firm's current markets
A4	Improvements and Revisions to existing Products	Current products made better.
A5	Repositioning	Repositioning are products that are retargeted for a new use or application
A6	Cost Reductions	Finally, cost reductions complete the six categories of new products. Cost reductions refer to new products that simply replace existing products in the line, providing the customer similar performance but at a lower cost

The TIH-IoT defines R&D focus as to provide technology solutions and eco-systems for commercialization to **"Reliable IoT "**with the concept of **"Fit & Forget".** The concept of "fit and forget" is motivated from addressing integrated approach on addressing challenging problems on the deployable, adaptable, safe, secured and reliable features of IoT. These features enable the end-user to develop trust in the technology. The identified technologies in each category are explained in detail next and connect the challenges and gaps according to the Table 4

Table 4: Mapping of identified technologies with challenges and gaps

	T1 (Grand Challenge)	**T2 (Core technologies)**	**T3 (New CPS area)**	**T4 (Application-oriented)**	**T5 (Testbeds)**
C1: Reliable IoT	X	X		X	
C2: Eco-friendly IoT	X			X	
C3: Hybrid IoT			X	X	X
C4: Easy-to-develop		X		X	
G1: Interdisciplinary	X	X	X	X	X
G2: Experimental Validation		X	X	X	X
G3: Large-scale testbeds					
G4: Stakeholders		X	X	X	X
G5: Large-scale mission mode				X	

- **Grand challenge and competition:** Considering the nature of this category, the TIH-IoT would focus primarily on addressing challenge C2 along with C1 (refer section 2) where carbon consumption conscious technologies with self-diagnostic capabilities are encouraged. The grand challenge is motivated from that a reliable IoT technology itself must have predictive features on its health. Once the IoT is installed, its users and customers must have least botheration on its service and maintenance at the same time have a reliability on its safe operation.

Identification of faults/attacks in the physical devices or network or cyber system or any combination of the possible faults/attacks in the integrated cyber-physical system is important to develop a reliable IoT technology. Furthermore, in order to not attend these identified cyber-physical faults/attacks, the IoT can have auto-triggered self-healing activity that may work at the compromised performance with defined metrics. Hence, under the core technology developments, the challenge is to address

Self-healing Interconnection of eco-friendly Things

A use-case of the grand challenge is to address early detection of plant stress. This use-case not only addresses the predictive analysis of its own but also a plant or a group (network) of plants. In the last decade, advancements in IoT / AI/ML methods have helped farmers improve crop quality and crop yield. Network of sensors used for measuring soil health, weather prediction and hyperspectral imaging methods etc. have been deployed and used successfully for plant health monitoring. Above methods observe some parameters e.g. different wavelengths of the reflected / transmitted light from leaves affected by disease, these symptoms are manifestation of disease. These techniques offer early detection, but there is a need to have much earlier than this stage.

Plants have natural mechanism to counter the pest and disease attack. Natural counter mechanism is in the form of chemical release to defend the attack. Detection of these chemicals at early stage are indicator of initiation of pest / disease attack. Techniques like polymerase chain reaction (PCR), enzyme-linked immunosorbent assay (ELISA), immunofluorescence (IF), flow cytometry (FCM) etc. are used to identify these chemical. These techniques requires sample to be taken, test time may be long, instruments are bulky and expensive.

A plant health monitoring system which can be deployed at point of care i.e. at and with plant, providing real-time information, affordable, care free is desired. Keeping this as an objective following is the grand challenge in a use-case with combined objectives:

"*Develop a system for early detection of pest and disease attack using IoT; Self-identification of physical and cyber faults/attacks; Detection time and accuracy shall be better than imaging techniques; Deployable at farm and affordable to marginal farmers; Cost shall be recoverable in three years; Operation and maintenance cost shall be comparable with other farming tools.*"

- **Core technologies:** These technologies target on addressing challenges C1, C2 and C4 together by giving solutions through edge computing. While solving the problems through edge computing, the carbon footprint is likely to have significant reduction as compared to the cloud computing methods. However, edge computing solutions further pose challenges on data integrity and distributed decision making. The multi-disciplinary technical verticals of IoT are Sensors & sensor network, Low power & energy constrained devices, Communication protocol & security, Data analytics & machine learning and Real-time control, planning & estimation. The challenges arising from integration of these technical verticals along with the challenges posed in section 2 are addressed through the development of core technologies (Figure 9).

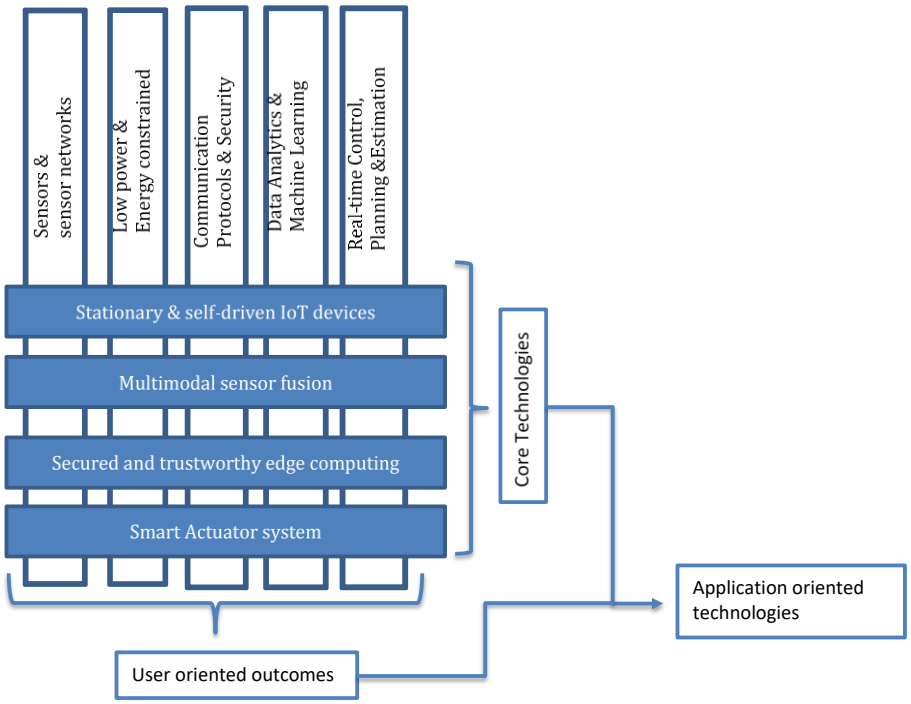


Figure 9: Integration of Technical Verticals and their corresponding objectives

The core technology that is integration of technical verticals and their corresponding objectives are as follows:

- Self-driven IoT device: Be able to reach to a user-defined location, collect data and return autonomously
- Self-powered IoT device: Energy harvesting wireless communication and system design
- Multi sensor fusion: Range of devices (or a single device) that is capable of interfacing variety of sensors and interpretation can be programmed based on state estimation or AI/ML methods
- Smart actuator interface: An interface that provides energy consumption estimates and has self-diagnostic features
- Secured and trustworthy edgy computing solution: A miniature programmable interface that any IoT developer can interface and ensures no potential risk to physical safety and cyber security.

- **Technologies for new CPS area:** This category corresponds to very hard and challenging problem where objectives of connecting "Everything" be partially addressed. The focus in this set of technologies is to interconnect "land-air-water" using ***Hybrid IoT*** concept. Many new use-cases can emerge by providing a solution for interconnecting "land-air-water." These use-cases will open opportunities for further research studies and commercial as well as defense applications, where
  - Reaching to localized areas in water bodies (river, ocean, etc.) are difficult to reach and have remained unexplored.
  - Combination of underwater and aerial interactions have disturbed the ecosystem such as contamination of drinking water bodies/rivers, climate change, aquatic life etc.
  - Safe and secured communication through locally connected devices is to be established for small- or large-scale area coverage.

It is hard to provide a single solution for this focus area due to variety of dependencies on operating conditions. The operating condition administers the communication protocol, device requirement, networking and security solution, etc. Therefore, we approach to investigate this new CPS area using "Hybrid IoT" where requirements from a set of operating conditions are addressed as an IoT technology and the interconnections of heterogeneous operating conditions are addressed at another interconnection layer as shown in Figure 10.

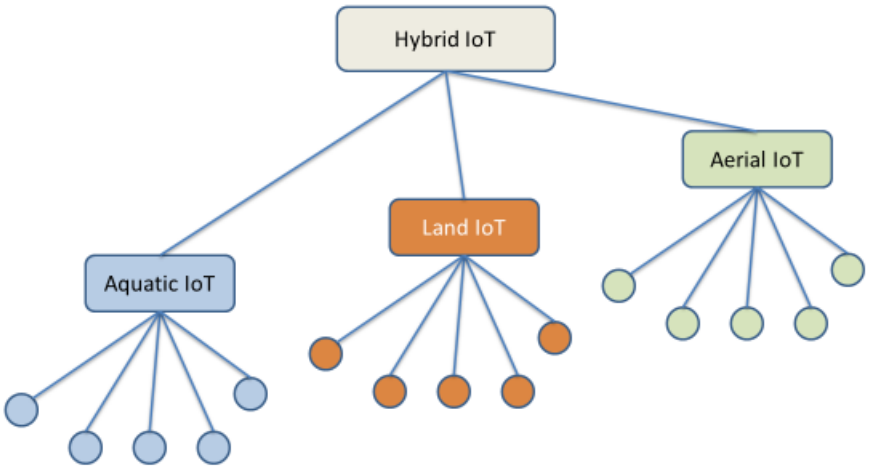


Figure 10: Hybrid IoT and Interconnection Layers

The plan is to address the challenges in the new CPS area in following phases:

Phase 1: Modification of existing systems for interconnection or novel devices for interconnection by fixing operating conditions independently for land, water and aerial IoT devices

Phase 2: Interconnected systems with same operating conditions; Addressing safety critical analysis; Evolving testing and validation methods for land, water and aerial IoT devices independently

Phase 3: Interconnect devices with heterogenous operating conditions to demonstrate communication capability through land, water and aerial IoT devices.

While developing this set of technologies in phase-wise, use-cases would be explored with government, industry and international collaboration to define the operating condition requirements.

- **Application-oriented Technologies**: These set of technologies are driven by the requirements of either Government or Industry or has national importance. Technologies are defined based on the user's requirements and have specific deliverables and further refined by the advises of experts from industry and government. In the initial phase of deliverables from the TIH-IoT, the following application-oriented technologies have been detailed-out.
    - **Agriculture:** End-to-End solution (a large-scale mission mode project) for pest and disease monitoring in specific crops important for Maharashtra region. The sub-projects under this main objective is categorized under A2-New-to-the firm products/technologies. In this work it is aimed at projecting a comprehensive IoT-oriented concept for breaking the challenge of economic viability of solutions for the multi-dimensional requirements of smart farming. The approach and the plan are defined differently from traditional project planning. We envision sustainable end-to-end IoT based technologies. The project will be envisioned of interaction with farmers, scientists, academicians, NGO's, large industries and startups. It will consist of solutions for different stages of growth of plant starting from the soil preparation, plant nutrition management, pest and disease control, pre-harvest management to final storage of the crop.

      Phase 1: Develop drone and sensor network-based solutions to capture data required for pest/disease prediction. Development of smart fertilization and irrigation system and development of smart storage system using renewable energy.

      Phase 2: Develop customizable energy-autonomous smart agri-station with auto-calibration (EAgriS) for flexible farm sensing. Development of ML models for plant health classification and field testing of the solutions which are developed.

      Phase 3: Intelligent calibration-aware sensors with smart maintenance for soil, water and pre-harvest management using developed EAgriS with wireless communication and connected to the

existing data visualization platforms for farmers. Modifications of the systems to adapt for multiple crops.

- **Healthcare:** The focus is on converting medical devices to provide IoT support for telemedicine. A direct application of core technologies is envisioned under this objective and categorized under A3- Additions to existing Product Lines. The healthcare industry and society at every level will benefit from a reliable telemedicine service. A basic component of telemedicine is to provide instantaneous reliable patient data to the doctors and healthcare specialists. This is possible with the conversion of existing medical devices to IoT devices so that healthcare centres or patient themselves can use devices for providing measured data. A secured reception of reliable data ensuring privacy protection to the healthcare experts is an important feature. Monitoring the health of medical IoT used for telemedicine, an added objective of self-diagnostic IoT enhances reliable outcomes. The phase-wise plan in this application vertical is as follows:

  Phase 1: Identify already existing critical needs from healthcare experts and identify if existing medical device(s) be converted to IoT.

  Phase 2: Either convert existing device to IoT using a core technology or develop a new medical device with in-built communication facility. Deploy in real-life scenarios.

  Phase 3: Provide safety – critical analysis with self-diagnostic capabilities for predictive as well as preventive maintenance of medical IoT used for testing.

- Developing scalable and self-sustainable course modules with effective delivery. The sub-projects to satisfy the said objective are categorized under A4- Improvements and Revisions to existing Products. These sub-projects with corresponding brief objectives are as follows:

  - Low-cost device for installing learning material: Develop a low-cost device to reach out to places with low network bandwidth.
  - AI based evaluation, query solving and feedback: Provide a solution for scaling up the course delivery by automating the evaluation and query solving. Incorporating automated feedback for effective delivery is a target for complete automation.
  - Light weight course delivery modules: The lightweight course contents has low bandwidth requirements that can either be pre-loaded in the low-cost device or can be downloaded quickly and stay connected with low bandwidth requirements.
  - Video bots (local character) + Vernacular products for national and international outreach: In order to have same course delivery in local languages and instructor-independent modules, the modules can have course delivery through video bots speaking in multiple languages.
  - Learning modules using games: An effective course delivery can have games for better understanding of critical problems.

  Phase-wise plan under developing technologies for smart education is as follows:

  Phase 1: Define course contents of a skill building course module and prepare its effective delivery with the help of an expert.

  Phase 2: Convert the course module to scale-up to reach out to large community at national and international levels.

  Phase 3: Based on the success of first skill building course module, develop other course modules.

- **Industry-driven problems:** While interacting with industry, CII and NASSCOM centers, there is traction to solve challenging problems in manufacturing and smart cities. The effort from TIH-IoT to build use-cases for core technologies.

- **Testbeds:** For the systematic testing and validation to facilitate standardization for world-wide acceptance to IoT innovative solutions, the TIH-IoT aims to build following novel facilities at small-scale that can be replicated at

large scale at:

- **Hardware-in-Loop Simulator (HILS):**

Systems are becoming more and more connected and System of interconnected systems (SIS) is becoming norm in the industry. SIS is helping in increasing efficiency, making decisions, reducing cost, increasing reliability etc. Connections are between process, sensors, actuators, applications etc. These connections can be wired and wireless, vulnerable to attacks. Cyber Physical System (CPS) consisting of sensors, actuators, applications etc. may not be collocated. One of the major concerns is secured interconnections in CPS and its elements to establish reliable and trustworthy communication. Security aspects are considered during design of the system and implemented during realization at leaf level i.e., at device level. SIS may consist of thousands of devices and may not be co-located, testing such complex system before deployment is a challenge.

Lifecycle of a system can be explained using the Vee diagram as shown below Figure 11. Need is established by exploring new opportunities, which could be deficiency in the existing system. Once the need is established systems engineering team understands the problem by studying critically various stages in the life cycle of the system i.e., design, production, operation, maintenance and disposal from cradle to grave. Considering emphasis on environmental impact current trends is birth to rebirth i.e., reuse / repurpose the components at the end of life. Right hand side of the Vee depicts design phase and left-hand side depicts the synthesis of the realized components designed in the right-hand side. Design is based on the requirements generated during the critical study of problem at hand. To tame the complex system, it is decomposed and solved. During decomposition interfaces between them is established. During decomposition test plans are developed to ensure that test can be conducted on realized of system / sub-system / component to verify / validate requirements.

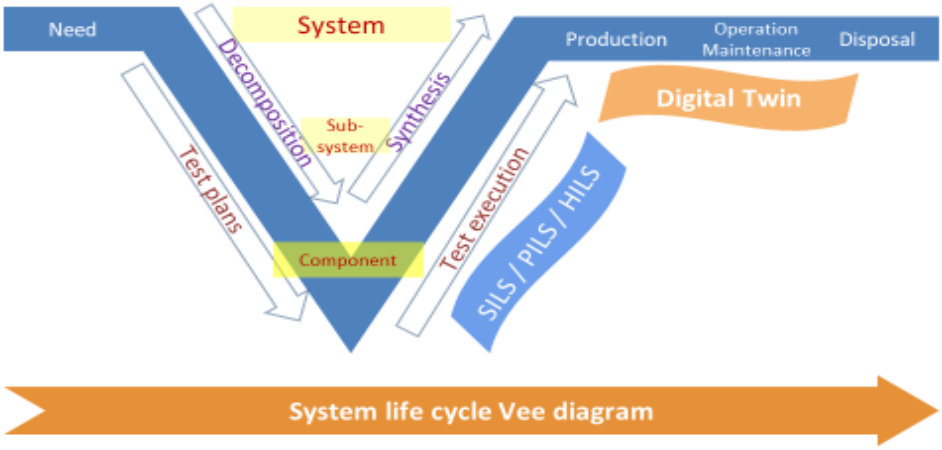


Figure 11: System life cycle Vee diagram

It may be noted that in the right side of Vee diagram system elements are virtual, modelling and simulation is extensively used for designing these elements. In the left-hand side, as the realized elements become available integration takes place. As the integration progresses, tests are conducted to check requirement compliance. Some test may need inputs which are close to real application. In such scenario virtual environment is created to simulate realistic behavior using the models used during the design phase. Complete system will be available at the top of left-hand side.

In the testing phase software in loop simulation (SILS), processor in loop simulation (PILS) and hardware in loop simulation (HILS) is extensively used to reduce number of faults during real implementation (Figure 12). For PILS and HILS real time simulation is important because some of the elements in simulation are real. Typically for HILS process, actuators and sensors are simulated as shown below. Models of process, actuators and sensors used during the design phase can be repurposed for HILS. CPS has large component as software running in real time or non-real time on edge, fog or cloud. It is very critical to test the software and hardware before deployment in real environment. HILS can be an effective tool for system / sub-system / component level testing. HILS is extensively used by aerospace, automobile, power industry. It is used for testing complete

system before deployment. Un-modelled behavior due to delays, asynchronous information can be captured. HILS for CPS poses some challenge, number of connections are large, may need distributed computing to meet the real time criticality, process modelling etc,

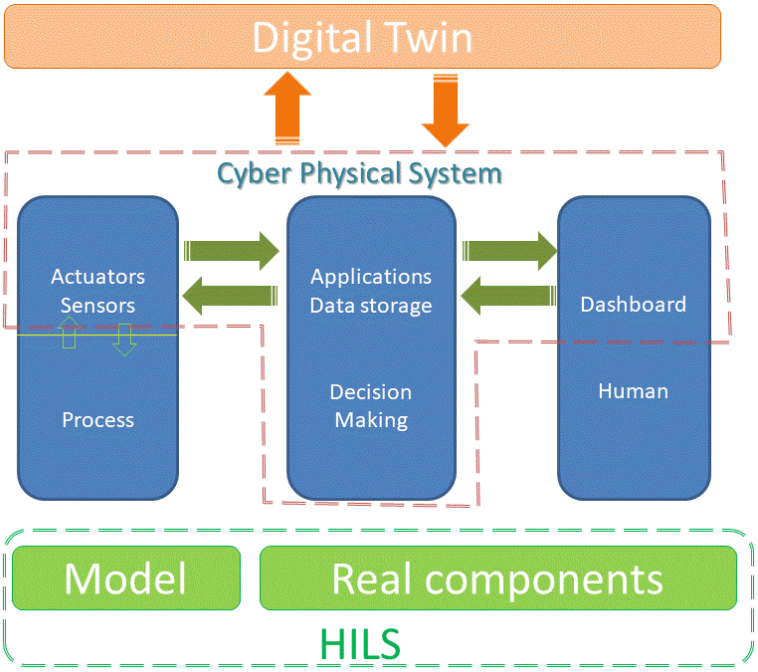


Figure 12: Hardware in loop simulation (HILS) and Digital Twin

Digital twin technology is used by industry to optimize the process, fault detection, maintenance scheduling, fault prediction etc. Models used during HILS can be repurposed for creating digital twin. HILS facility will require good computational power to execute models in real time, interfacing cards for simulating actuators and sensors, high speed switches for networking, Industry certified Real time OS for component certification, graphics card to simulate scenery, touch screen-based input consoles, large screen for out of the window scene visualisation etc.

- **CPS Testbed for Hybrid IoT:** This testbed is a support for technologies developed under T3- New CPS area and one of its kind. We plan to apply Hybrid IoT concept to interconnect "land-air-water" that clearly has distinct operating conditions. Moreover, solutions using edge computing in this domain has benefits on creating local and secure networks. The CPS testbed envisioned enables testing of *reliable IoT* by creating scenarios such as
  - Demonstration of successful Hybrid IoT technology
  - Fault-diagnostic in IoT device or series of IoT devices
  - Self-detection of any cyber attack
  - Propagation possibility of cyber attack
  - Compromised performance with network issues at different levels of Hybrid IoT
  - Possibilities of extending communication range using local and encrypted channels through IoT in land-air-water.

Many more such scenarios are possible to emulate with the proposed testbed comprising of an indoor water-tank with a high ceiling and a small surrounding free area for mounting/floating IoT devices in land-air-water. This has two major parts; one for testing underwater technology and another for testing on land and air. The underwater testing facility has a water tank with a filtering unit. One of its own kind facilities for testing underwater technology will have testing platforms with illumination and temperature control. This facilitates not only testing networked IoT devices which involves testing underwater communication, perception, etc. but

also data collection and IoT device deployment. There are many situations where IoT devices cannot be mounted, hence a network of stationary and moving IoT devices are used to collect the necessary data. The second major part is the testing facility for a network of heterogeneous kinds of IoT devices. The devices can be land or aerial moving platforms collecting IoT relevant data. The facility includes a motion capture system giving feedback for the motion of these moving platforms and testing the control for the independent devices as well as system-level control for networked devices. Figure 13 shows a picturization of testbed concept for hybrid IoT.

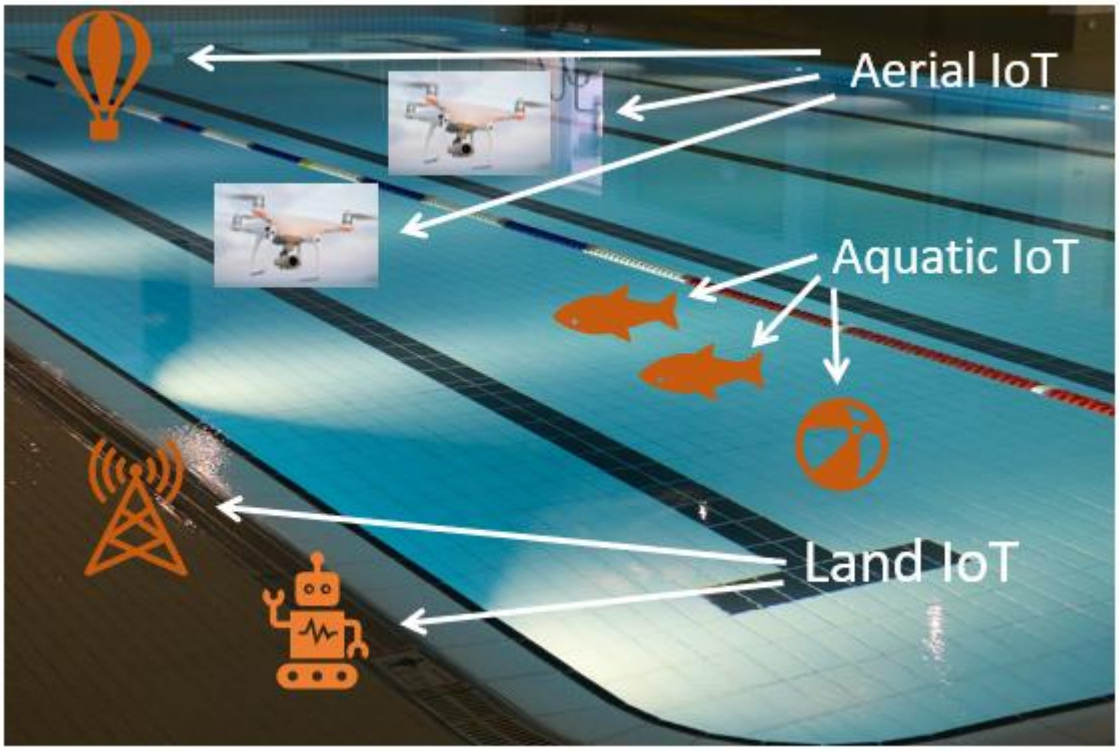


Figure 13: Conceptualization of CPS testbed for Hybrid IoT

The concept of controlled laboratory testing validating the theoretical results and verification in realistic scenario at small scale with limited number of IoT devices can be extended to large scale for testing at R&D centres/DRDO labs.

Technology Roadmap of TIH

Technology Roadmap are essential part of the any organizations strategy to achieve its vision and mission. The technology roadmap provides the details of the critical technologies available, best practices and gaps in the existing technology. Roadmap informs the management and guides where the technology development is progressing and the investments to be done in the R&D (Figure 14).

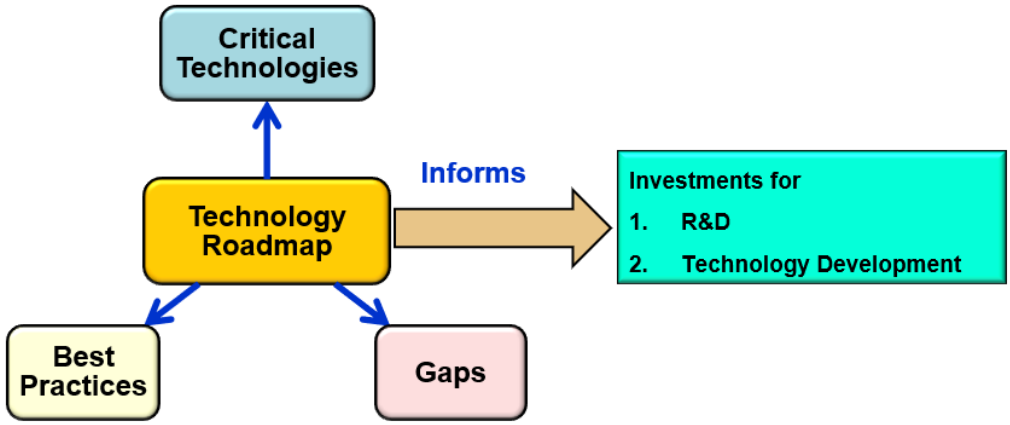


Figure 14: Importance of Technology Roadmap

Figure 15 shows the proposed Technology Roadmap for TIH. The technology roadmap shows the Core Technologies and other technologies and applications. Initially the efforts will be focused on to development of different core technologies which are independent of the applications and thereafter these developed technologies will be deployed across different applications. Hence in the present roadmap the applications part will be lagging behind the technology development. Resources, infrastructure requirement will be mapped based on the above roadmap. The detailed timelines with major milestones will be worked out to achieve the target of the present roadmap. The technology roadmap will be refined as we progress in achieving the milestones. The technologies which will be developed by TIH will be application independent and can be used as “plug and play” and “fit and forget” technology. TIH will also focus on the development of test beds for verification and validation of IoT based technologies which will help in development of standards in these domains. In the later part TIH will also focus on the development of Technologies for New CPS areas and will bring out different applications in these areas.

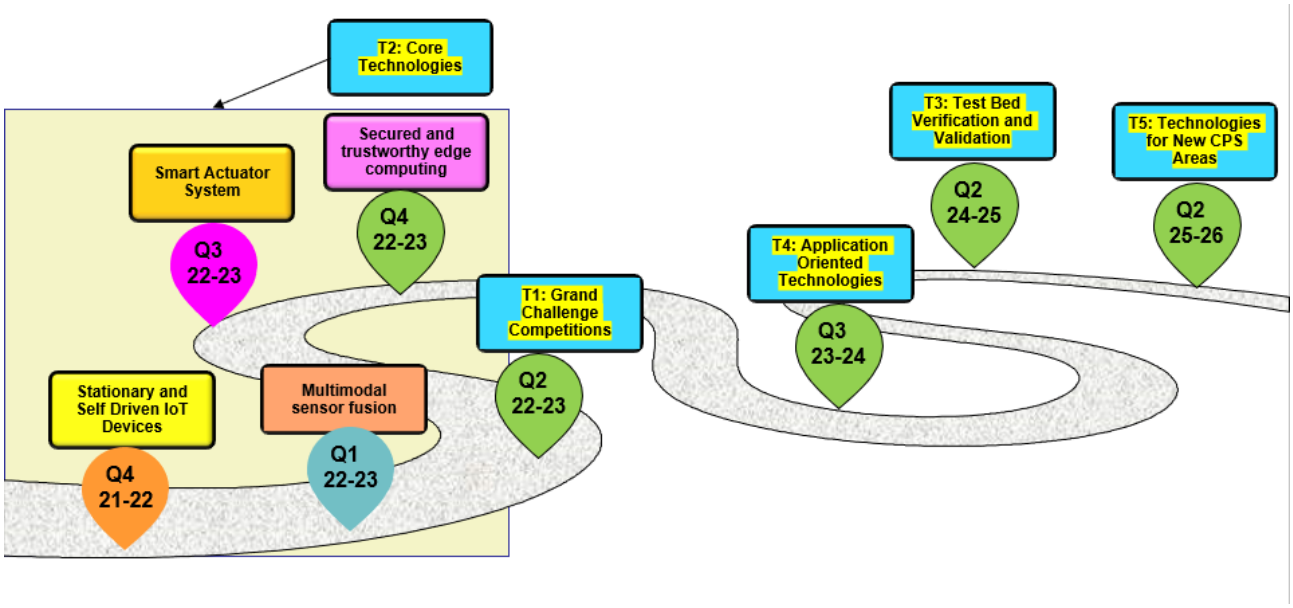


Figure 15: Technology Roadmap of TIH.

CDAC would also provide support for prototyping of technology developed by TIH-IoT. Faculty members of IIT Dharwad are involved in research on various IoT devices and are looking forward to taking them to higher TRL levels by collaborating with TIH-IoT.

We are aware that a system is getting more and more connected to other systems to fulfil its desired goals i.e. operation, efficiency, life cycle objectives etc. The interconnections are between humans, things, processes etc. More connections mean more data from the connected systems. Connections need to be secured; wireless; devices need to be energy efficient for long operations; harsh environment; unattended etc. there is need to optimise resources at

system level to keep long operation, life, energy etc. as objectives. For long operation life, without failure it is also important to continuously monitor and predict system health. System health monitoring and prediction using large data from discrete sources is a niche research area. Modelling and Hardware in Loop Simulation (HILS) can help in development of Human Machine Interface (HMI), system synthesis and system testing before implementation of IOT/IOE system. Furthermore, the TIH-IoT would be involved in various technical aspects of its technology focus on health monitoring, diagnostics, operation and analysis leading to predictive maintenance, safety, etc.

We have considered two types of technology development - (1) core technology and (2) application verticals. In Core technology, we will develop the core/generic technologies that can be used in several applications. We will be using these technologies to develop the projects in different application verticals. In application verticals, we have considered some application domains to demonstrate integrated solutions that can be directly used by the industries. Many of the core technologies will be customized for these application domains. Other technologies required to complete the proposed projects will be developed in collaboration with other TIHs and/or with open calls for proposals. The application verticals are first explained followed by the structure of technology demonstrations for core technologies along with application verticals and their use in customized form.

1. IoT in agricultural applications

India has a wide landscape and diverse geographical parts with many people working in agriculture related sectors. Water resources, climate, water contamination monitoring and treatment for agriculture lands, water storage and irrigation, enhancing productivity of farmland products, improving quality of life for farmers and various aspects of climate and weather conditions are among many domains related to the economical technologies and solutions for the productive and efficient agriculture. The advent of technology has helped multiple sectors in attaining profitability. One such sector is agriculture. IoT in farming, the future of precision implementation, has resulted in the term smart farming (Figure 16). With the use of many smart farming sensors, communication networking, data analysis and prediction, and wearables, the farmers can get real-time updates on their mobile device applications. It will help provide insights and statistics for crops and livestock. Smart Farming systems use modern technology to increase the quantity and quality of agricultural products.

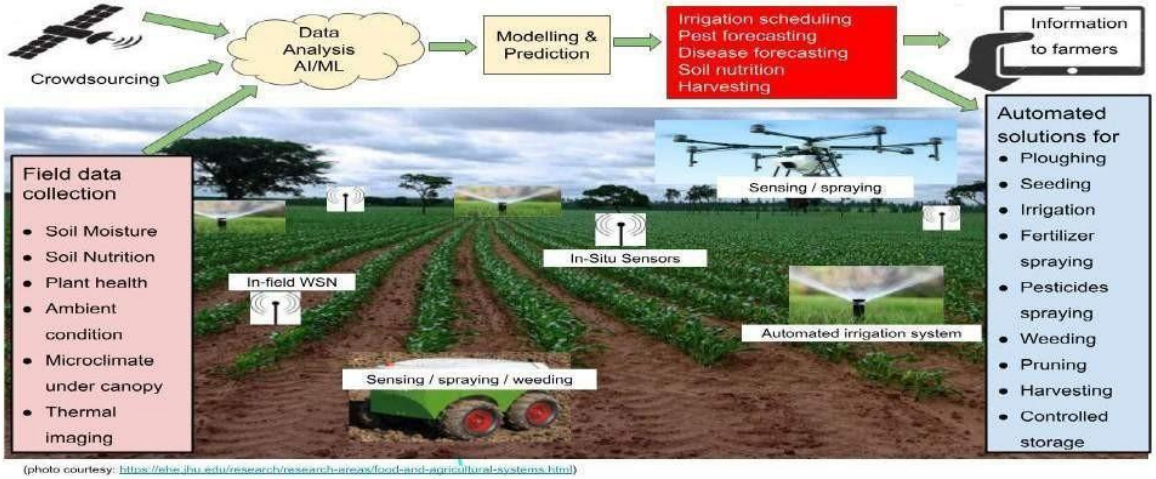
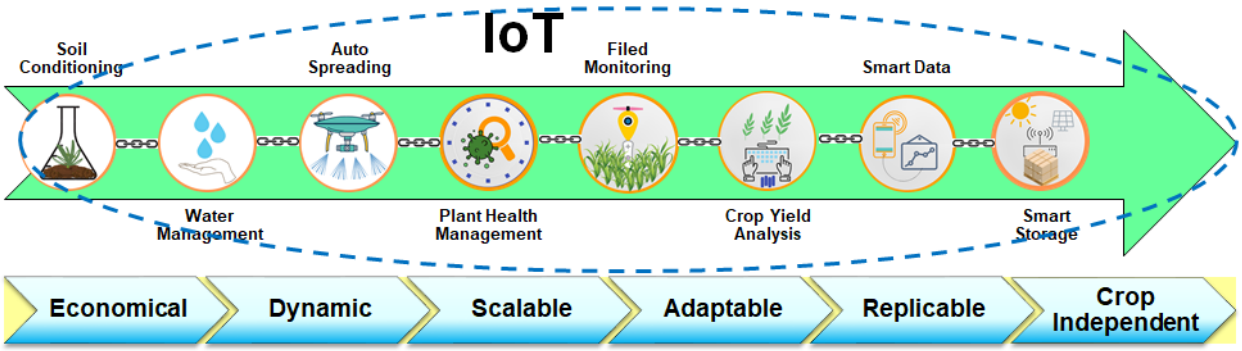


Figure 16: IoT in Agriculture

(photo courtesy: https://ehe.jhu.edu/research/research-areas/food-and-agricultural-systems.html)

IoT Based Economically Viable Indigenous Smart Agriculture (IoT_EVISAgri) TIH IIT Bombay

This concept note aims at projecting a comprehensive IoT-oriented concept for breaking the challenge of economic viability of solutions for the multi-dimensional requirements of smart farming. This brief writeup is the outcome of interaction with farmers, scientists, academicians, NGO's, large industries and startups. The approach and the plan are defined differently from traditional project planning. We envision sustainable end-to-end IoT based technologies.



The diagram, shown above, conceptualizes our vision of linked technologies to provide a comprehensive model encompassing key stages of cultivation as summarized below.

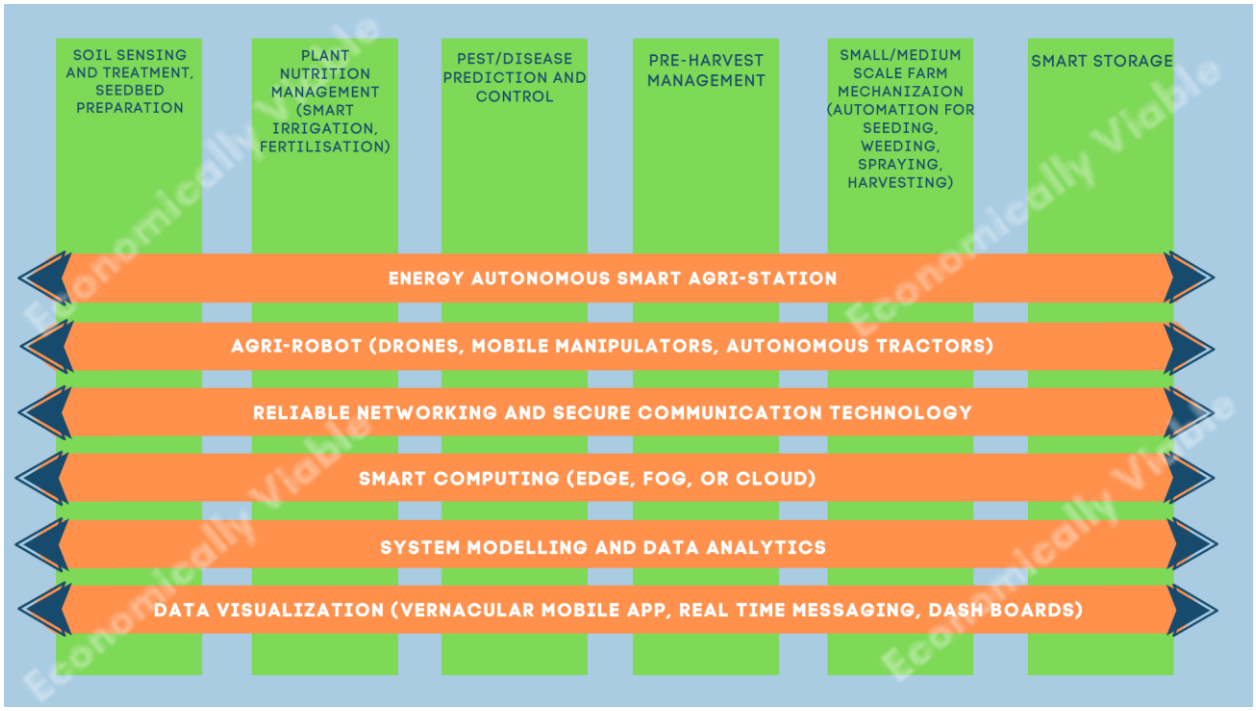
- Soil preparation and profiling
- Plant health monitoring
- Harvesting
- Preservation and transportation

Team combination: Representative from state governments and ministry, Farmers, Agriculture scientists and faculty, Engineering faculty members, Industries (large, medium and small-scale entities), NGO's, TIH IIT-Bombay ExeCom members associated with the Agri-Tech vertical and other TIH's

Targets and objectives for the ambitious goal of comprehensive linked solutions

(1) Solutions for efficient farmers' supervision
(2) Solutions with short-term development and long-term use for reducing manual tasks in farms
(3) Reliable wireless networking solutions for the equipment/devices in 3 different milestones
(4) Seamless economically viable IoT based small farm mechanization (less than 1-acre area)
(5) Seamless economically viable IoT based medium/large farm mechanization
(6) Concurrent crop-independent and crop-dependent technology deployment/design, development & deployment *(D/DDD approach)*
(7) Maximum in-field operation strategy
(8) Connecting farms
(9) IoT-based price prediction
(10) Plan-B strategies for risk reduction and failure management

Target technologies and applications



Milestones -

	Milestone 1 (T0+2 YEARS)	Milestone 2 (T0+3 years)	Milestone 3 (T0+5years)
Soil sensing and treatment, seedbed preparation	● Development of multi-parameter and remote-controlled energy-autonomous smart agri-station (EAgriS) with wireless communication connected to the existing data visualization platforms for farmers with one field testing (model A)	● Development of customizable energy-autonomous smart agri-station with auto-calibration (EAgriS) for flexible farm sensing with wireless communication and connected to the existing data visualization platforms for farmers (model B)	● Intelligent calibration-aware sensors with smart maintenance for soil, water and pre-harvest management using developed EAgriS with wireless communication and connected to the existing data visualization platforms for farmers (model C)
Plant nutrition management	For a selected crop, develop ● Smart fertilization system ● Smart irrigation system using data visualization techniques/tools.	● Field testing of systems developed in milestone 1 and its improvement ● Development of ML models for plant health classification.	● Modifications of the system to adapt to multiple crops, field testing and improvement of the modified systems
Pest/disease prediction and control	● Develop drone and sensor network-based solutions to capture data required for pest/disease prediction in flat crops. ● Development based on	● Develop solutions for crops which have non-uniform canopy. ● Propose improved and relevant/specific system and machine learning	● Solution for very early prediction of disease ● Micro delivery of pesticides and fertilizers

	existing ML models for pest/disease prediction and detection.	models/architectures.	
Pre-harvest management	• Development of sensors to check the readiness level of selected crop/fruit with lab testing • Field testing and evaluation of the sensors	• Develop AI/ML based algorithms for smart irrigation and smart fertilization • Field testing and evaluation of the parameters and sensors.	• Develop solutions to predict the time for harvesting for the selected crops/fruits.
Small/medium scale farm mechanization	• Development of semi-automated solutions for harvesting a selected crop	• Field testing of the developed solution. • Development of mechanized transport of the selected crop to the storage space.	
Smart storage	• Deployment of sensors for assessing the crop damage and climate control. • Development of Smart Storage System for Onions • Use of renewable energy for climate control and sensing	• Modification in the Smart Storage System for other crops	
Data visualization	• Develop data visualization techniques/tools for a few selected languages.	• Modification of app based on feedback and extension to other languages for different states.	• Iterate and improve the AI models with possibly human-in-the-loop.

2. IoT in healthcare applications

Human civilization in order to ensure its continued existence has been finding newer ways to improve the longevity of the human body. Three distinct pieces to this entire endeavor have existed right from stone-age to modern times – Collection of information, processing/analyzing the information and finally devising an innovative solution once the problem statement has been identified. Healthcare professionals have invested time and effort in figuring out how the human body functions and how it is affected by internal and external factors, both favorable and adverse. If the information collection process had the scalability and speed that exists today, medical science would have been light years ahead of where it stands today. Today, technology has made possible what was inconceivable a few decades ago. There are ways and means to capture massive amount of real-time data at reasonable costs and analyze it meaningfully to arrive at more accurate and effective decisions. Internet of things (IoT) is what has made this possible by rendering intelligence (however limited) to objects.

Indian healthcare landscape is suffering from a mixed bag of problems ranging from a huge gap between the number of medical practitioners/facilities and the patients, skewed distribution of doctors towards large metros, poor quality of healthcare services, poor accessibility in rural and remote areas, inadequate healthcare infrastructure and overburdened healthcare staff. Over the years, Indian healthcare scenario has seen a limited growth even though the world's second populous country accounts for 20% of the global disease burden with a high infant and maternal mortality rate. The healthcare system becomes more vulnerable in the disease outbreaks, as in the present case of

COVID-19 pandemic. These call for a dedicated action plan to improve the healthcare scenario in the country and it is realized that innovating thinking and adoption of smart technologies is the only way to significantly improve the healthcare infrastructure and its quality. In this context, the Internet of Things (IoT) enabled healthcare infrastructure has high potential to create an efficient, low-cost, accessible, integrated and patient caring system. The right solutions will also be able to maximise the usage existing resources/infrastructure and significantly impact the way healthcare services are provided.

Today's world has been involved with many challenges related to public health issues. The rise in health problems along with high healthcare costs encourage everyone, especially elderly and differently abled people, to use remote health management. Technology can move the routines of medical checks from a hospital (hospital-centric) to the patient's home (home-centric). The right diagnosis will also lessen the need of hospitalization.

A new paradigm, known as the Internet of Things (IoT), has an extensive applicability in numerous areas, including healthcare (Figure 17). Internet of Things (IoT) is a developing ecosystem that integrates software, hardware, physical objects, and computing devices to communicate, collect, and exchange data. Lack of access to medical resources, growth of the elderly population with chronic diseases and their needs for remote monitoring, an increase in medical costs, and the desire for telemedicine in developing countries, make the IoT an promising technology for healthcare systems. New IoT solutions for healthcare are smarter and, more importantly, tailored to the needs and requirements of healthcare organizations. With 5G being rolled out, now is the time for healthcare providers to set their IoT roadmaps.

In the initial phase, TIH will focus on the Telemedicine applications and in the coming years will extend the focus on other application areas of IoT for the healthcare. Details of other application areas in the Healthcare is provided in Annexure – I.

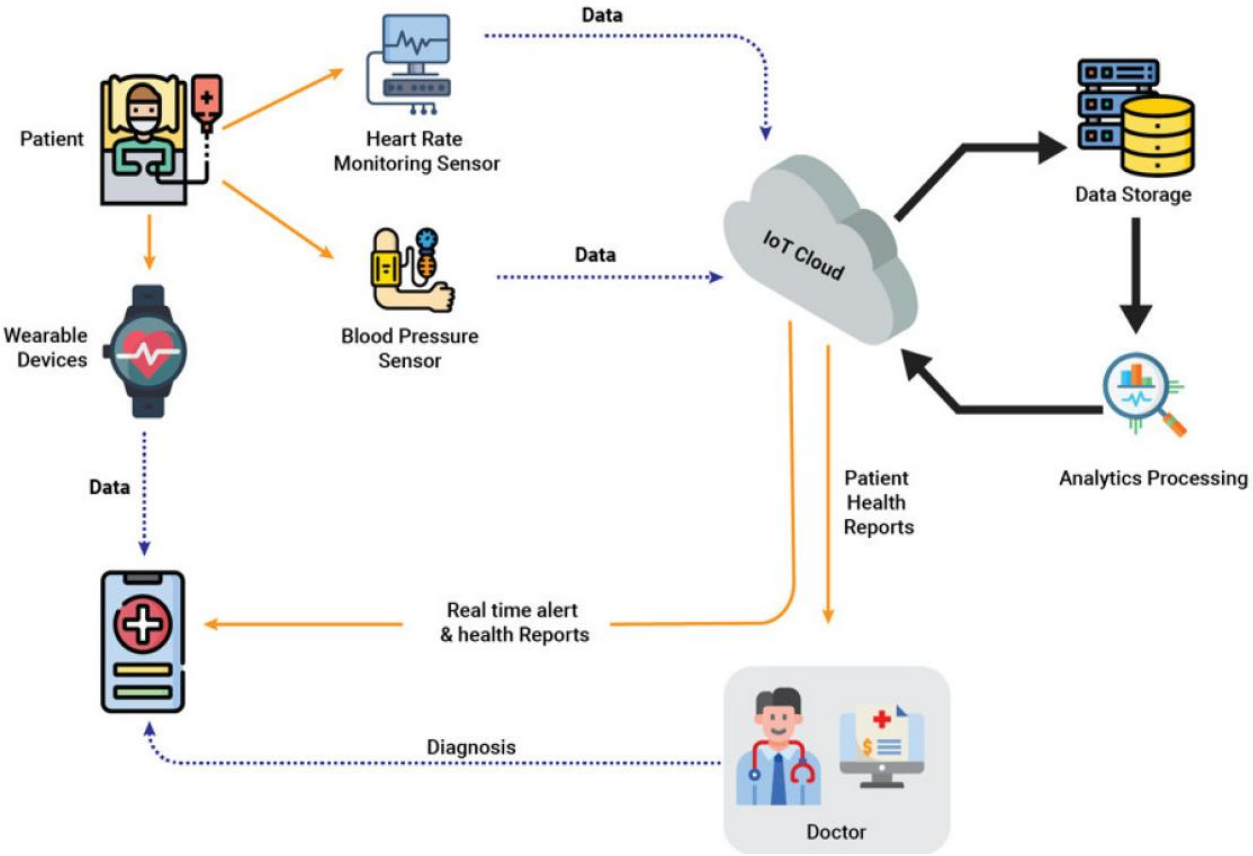


Figure 17: IOT Healthcare

([1]OpenSystems Media, 2020)

3. IoT in security applications

Several crowded public spaces, important locations, vital installations, and zones of potential conflict in our country need to be under a constant watch to monitor movements of people and vehicles in order to prevent destructive events. Manual surveillance of sensors such as CCTV, thermal, and seismic sensors, places a huge burden on those manning the screens, as most of the time there is nothing alarming going on. This leads to loss of alertness of the personnel manning the observation stations due to fatigue and ennui at those rare times when such alertness is most required. These scenarios warrant the development of an ever-learning system that models normal activities based on the sensors that are hooked into it, and alerts the concerned security personnel when rare or interesting activities happen. Audio surveillance is also gaining importance globally. While video is arguably the best-known technology in security and surveillance, dio can add significant value to form the most effective system. In absence of installed video or audio surveillance setups, autonomous vehicles are the natural choice for ad hoc surveillance of a building or structure under threat (Figure 18).

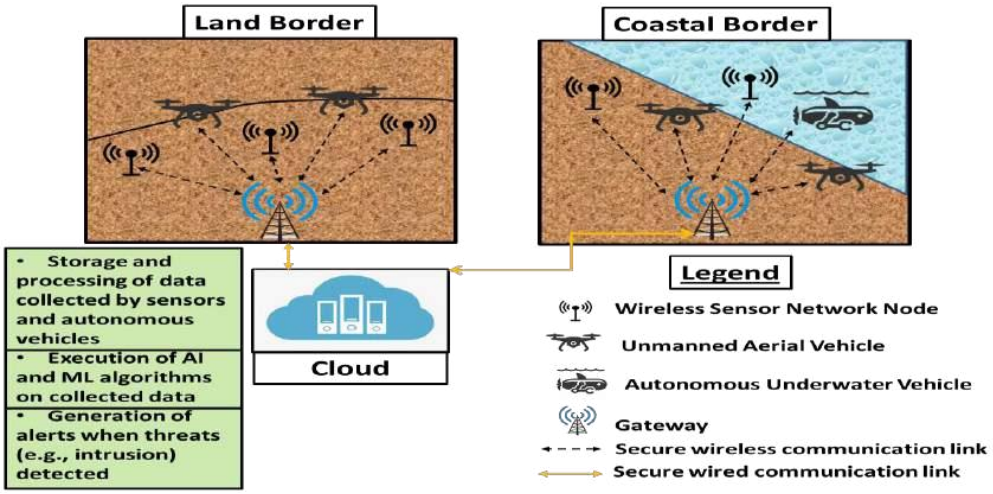


Figure 18: IOT in Security

4. IoT in Industrial applications

The adoption of emerging technological trends and applications of the Internet of Things (IoT) in the industrial systems is leading towards the development of Industrial IoT (IIoT). IIoT serves as a new vision of IoT in the industrial sector by automating smart objects for sensing, collecting, processing and communicating the real-time events in industrial systems. The major objective of IIoT is to achieve high operational efficiency, increased productivity, and better management of industrial assets and processes through product customization, intelligent monitoring applications for production floor shops and machine health, and predictive and preventive maintenance of industrial equipment. “Industrial IoT (IIoT)” is the network of intelligent and highly connected industrial components that are deployed to achieve high production rate with reduced operational costs through real-time monitoring, efficient management and controlling of industrial processes, assets and operational time.

IIoT is a subset of IoT which requires higher levels of safety, security and reliable communication without the disruption of real-time industrial operations due to mission-critical industrial environments. The focus of IIoT is efficient management of industrial assets and operations along with predictive maintenance (Figure 19).

The true potential of IoT is unveiled when it is used in the manufacturing and industrial section. Industrial Internet of Things (IIoT) combines the most powerful technologies that have been used in the industrial sector for ages. The collaboration of Machine Learning, Big Data, Sensors, Machine to Machine (M2M) communication, automation, Artificial Intelligence and IoT gives us a promising Formula for near perfect Industrial Operations. The Gigantic Industrial Machines will not just be powerful but also be smart. The massive data set from machines when captured consistently and accurately can help businesses to identify problems and inefficiencies sooner, helping them save time, money and some critical blunders. It could leverage quality control, sustainability, optimal utilization, green practices, supply chain traceability and efficiency.

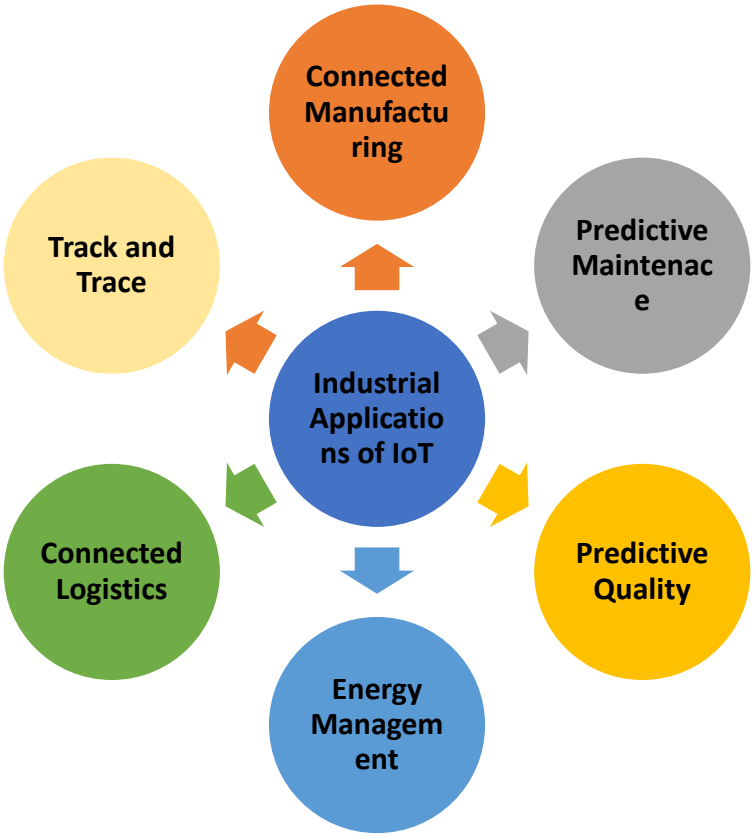


Figure 19: IoT in Industrial Application

9 MANAGEMENT

Hub Governing Body (HGB)
HGB will have a connect between the Mission, HI and TIH and to provide scientific, technical, administrative directions and to act as an advisory body. A generic structure for HGB has been given below:

Director/Vice Chancellor of Host Institute	: Chairman
Academic Representatives	: 1/3rd of total members
Industry Representative	: 1/3rd of total members
Government Representative	: 1/3rd of total members
CEO/Project Director, Hub	: Member-Secretary

The HGB could co-opt eminent people (India & Abroad) as members.
The HGB would meet as often as required and at-least once in six months.

Board of Directors (BoD)
Once TIH is registered as section-8 company and BoD constituted, the companies are run as per the directions of respective BoDs. All decisions regarding running of a Company including decisions regarding procurement, recruitment, support of projects, fellowships and other financial aspects are vested with BoD only as per Companies Act.

The HGB and BoD are two different and independent Bodies with clearly defined roles and responsibilities. Chairman is common between HGB and BoD and some Members could also be common but not necessary. Invariably 1/3 from Industry, 1/3rd from
Academia (from other than HI) and 1/3rd from Govt. Project Director from HI will be also be a Member.

Executive Committee (Exe Com)

Executive Committee (Exe Com) is constituted to frame guidelines, plan and implement, interact with expert council and industry/academia partners with the approval of Board of Directors.

Major roles and responsibilities of Executive Committee members are:

1. Framing guidelines
    a. Laying down guidelines and helping in creating roadmap from start to end for the initiatives mandated by NM-ICPS.
    b. Owning/responsible (by overseeing) for start to end procedure of the initiative.
    c. Ensuring that all the initiatives have a closure with a complete committee report in place
2. Planning and implementation
    a. Planning the stages of various activities
    b. Laying down the time-lines implementation of each stage of each activity.
    c. Giving directions and guidance for implementation and/or improvement of the initiatives
3. Interaction with Expert Council:
    a. Helping in formation of Expert Council
    b. Being a part of the review committee as per requirement
    c. Direction and suggestion in formation of a review committee (RC) based on the domain expertise
    d. Guiding the EC/RC to ensure the NM-ICPS mandates during review and selection processes

4. Interaction with industry/academic partners
    a. Supporting interactions with industry/academic partners
    b. Guidance in developing network of experts.

Expert Council

Creating a database of experts is one of the mandates of The National Mission on Interdisciplinary Cyber Physical Systems (NM-ICPS). Formation of Expert Council is aimed at creating a pool of experts in the field of IoT and IoE by bringing together the individuals from industry, academia, government, R and D units and, startups, who might be interested in contributing to the knowledge and research opportunities in the field of IoT and IoE.

Roles and responsibilities of Expert Council:

- Consultancy/advisory role in knowledge development, project implementation
- Participation in the review, evaluation and selection of the technical proposals in the relevant areas of expertise driven by project requirements
- Evaluation/review of training courses.
- Advising/Mentoring Startups, industries, Governments and Regulatory bodies.

Participation in exchange of ideas between various stakeholders (academia, industry, government etc) to come up with solutions.

Organization Structure

The organization structure of the hub is shown in Figure 20 and Figure 21. The hub is headed by the Project Director or Professor-in-Charge appointed by the Host Institute. The hub has Technical and Administrative teams, headed by Chief Executive Officer (CEO). The technical team is further divided into 6 teams. The concept of having technical teams hired under TIH-IoT is motivated to obtain following main benefits:

- Cost cutting on individual project
- Collaborative work without duplication
- Sustained quality technical staff

Each technical team is advised by a group of IITB faculty signing up for giving significant time to the TIH and has a hierarchy of technical group staff headed by a Team Lead. Each Team Lead is supported by a group of technical staff at various levels, PhD / MTech students and Industry experts working on future technology and industry specific R&D projects.

The technical group staff comprises various levels; Sr. Technical Officer, Technical Officer, Sr. Engineer, Engineer and Technician. It is important to have levels in each technical team to provide options for career growth within the

hub. The number of technical teams and structure of each team (with defined hierarchy) would be based on various factors such as workload, revenue generation, infrastructure being developed, etc. We believe that the sustainability of experienced human resources is the key for long- term sustainability of the hub.

Each technical team would be responsible for demonstrating a technology or multiple technologies along with other annual goals (Industry relations, training, organizing events, etc.). These technology demonstrations are among the ones listed in Annexure-I in the initial phase. Each team would work independently using the outcomes of other teams making a distributed but a coherent system.

The Administrative team structure as shown in Figure 21 has further sub-teams for handling Human Resource (HR), Accounts, Legal, Marketing and Operations. The structure for sub-teams has two layers, Director and Manager with corresponding responsibilities.

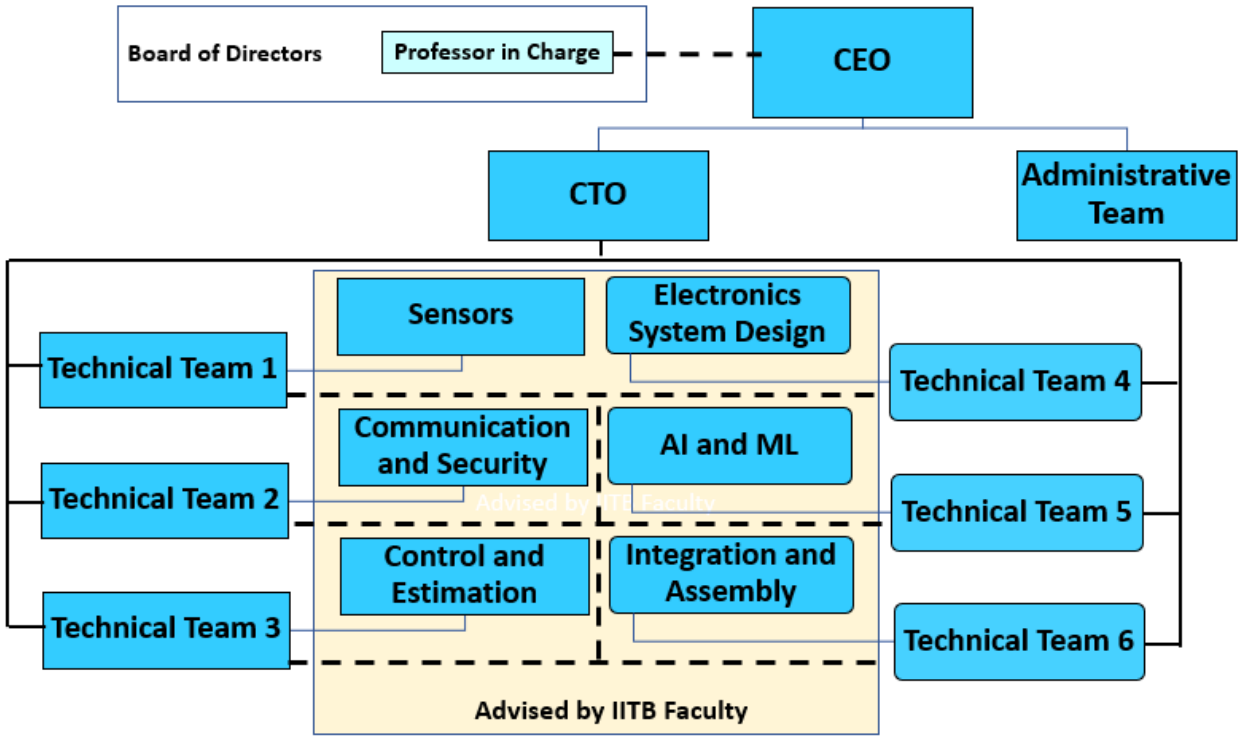


Figure 20: Organization structure of TIH-IoT

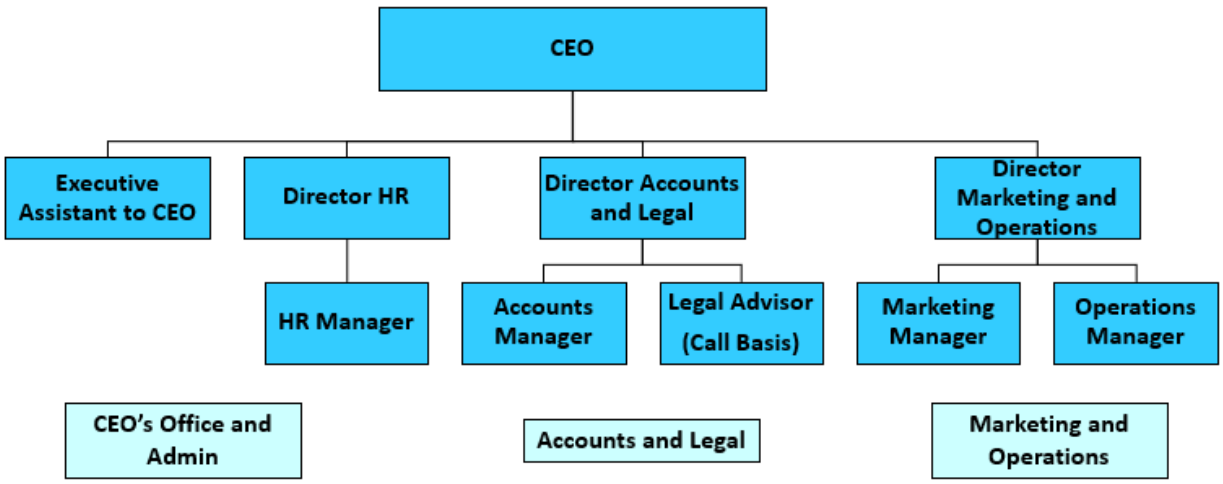


Figure 21: Organization structure for Administrative Teams

10 FINANCE

The cost estimates have been projected on the basis of discussions/ deliberations with stakeholders, existing government schemes and tacit knowledge available with the Department.

We have prepared 2 cost estimates:

- First plan takes into account the funding provided under NMICPS and also the projected revenues, which would be generated during the course of the implementation of the Hub activities. This is in-line with the self-sustainability objectives of the Hub.
- Second Plan is based on the funding provided under NMICPS.

For year 1, both the plans are similar. Based on the progress made, the plan will be further refined with the approval of BoD.

Plan with Revenue Generation:

The cost estimates are mainly in three major heads:

- Operating Expenses
- Capital Expenditure
- Investments

1. **Operating Expenses (Recurring Expenses):** In the project all expenses which the business will incur through its normal business operations are considered as operating expenses. Operating expenses include rent, equipment maintenance, salary etc. The major head of the operating expenditure and the overall cost that is projected to be incurred in a 5-year period will be as follows:

Table 5: Operating Expenses

Major Operating Expenses	Operating Expenses Head	Total Cost Incurred in 5 Years (Rs in Lakhs)
Salary	Salary-Man power (Administrative)	948.71
	Salary-Man power (Technical)	2751.04
Utilities and Overhead	Overhead	846.40
	Utility Bill	182.41
	Consumables –Laboratory	264.61
	Consumables – Office	29.86
International Collaboration	International Collaboration	310.33
Admin and General Expense	Travel	235.51
	Equipment AMC	640.50
HRD & Skill Development	Fellowships	1575.23
	HRD - Workshops/ conferences/ seminars/ sponsorships, etc.	192.41
Technology Development	Technology Development (TIH-IoT – 50% + collaborative projects 50%)	4773.00
Contingency	Contingency	584.30
Total		13334.29

The Operating assumptions for the various cost heads and the rationale for the same is provided below as follows:

1.1. ***Salaries:*** The payroll (with 10% annual increment) for the firm will be having 2 major sub heads i.e. Administrative and Technical.

- The Administrative team will comprise the following personnel:

Table 6: Salaries of Administrative Staff

Salary-Man power (Administrative)	Nos	Salary/month (Rs in Lakh)
CEO	1	2.50
CTO	1	2.50
Sr. Manager (Marketing + Account + HR)	3	1.50
Jr. Manager (Marketing + Accounts + Operations + HR) + Executive Assistant to CEO	5	0.75
Total		13.25

Key functionalities that will be undertaken by the team:

1. *Chief Executive officer (CEO)* will be the highest-ranking executive in the company, whose primary responsibilities will include making major corporate decisions, managing the overall operations and resources of the company, acting as the main point of communication between the board of directors (the board) and corporate operations. He will be appointed immediately and will be in the payrolls from Day 1.
2. *Vice President (VP) Projects* will make all the executive decisions with regards to the technological interests of the company. VP Projects will be responsible for outlining the company's technological vision, implementing technology strategies, and ensuring that the technological resources are aligned with the company's business needs. He will be appointed immediately and will be in the payrolls from Day 1.
3. *Senior and Junior Manager (Accounts)* - Accounts team will look into the roles and responsibilities, including accounts receivable, accounts payable, payroll, financial reporting, budgeting and maintaining financial controls. In the Year 1, both of them will be recruited.
4. *Senior and Junior Manager (Marketing/Operations)* Marketing Department's job is to reach out to prospects, customers, technology community, while creating an overarching image that represents our company in a positive light and also to provide the logistics support for the various projects, courses undertaken. All the three members will be recruited from Year 2 onwards.
5. *Senior and Junior Manager (Human Resources)*- The department is responsible for hiring and firing employees, training workers, maintaining interoffice relationships and interpreting employment laws. In the Year 1, both of them will be recruited.
6. *Executive Assistant to CEO:* The responsibilities of the person will be to complete a broad variety of administrative tasks for the CEO including: managing an extremely active calendar of appointments; completing expense reports; composing and preparing confidential correspondence arranging complex and detailed travel plans, itineraries, and agendas; and compiling documents for travel-related meetings. He will be appointed immediately and will be in the payrolls from Day 1.

The structure of the Administrative Department is given in Figure 21:

- Technical Team- The technical team will consist of 6 teams comprising Project Lead, one Senior technical officer with eight team members having subject matter expertise. The subject matter selected for the company will be Sensors, Communication and Security (C&S), Control and Estimation (C&E), Electronic System Design (ESD), Artificial Intelligence and Machine Learning (AI & ML) and Integration and Assembly (I &A). In Year 1, Project Lead, one Senior Technical Officer and one Tech Officer for each team will be recruited and the balance team will be in the payrolls from Year 2 onwards. The total salary expenses projected for the full team are as follows:

Table 7: Salaries of Technical Team

Salary-Man power (Technical)	Nos	Salary/month (Rs in Lakh)
Sr. Tech. Officer (Theme/Sub-theme)	6	1.25
Tech. Officer	12	1.00
Sr. Engineer	12	0.80
Jr. Engineer	12	0.60

Technician	12	0.40
Total		41.10

The structure of the Technology Department is given in Figure 20. Key functionalities that will be undertaken by the technology team will be as follows:

1. Prepare indigenous projects that can be commercially used in various industries
2. Planning, executing, monitoring, controlling and closing projects with complete adherence to the deadlines.
3. Preparing course materials and teaching material for the various courses to be offered under the project
4. Organize Industry collaborations, workshops and technology upgradation courses
5. Building of world class labs and conducting courses for Industry
6. Building up a network of both domestic and international collaborations with Industry and Universities.

1.2. ***Overheads:*** Overhead consists of rent and the cost for providing infrastructural facilities, benefits to the staff employed in the projects, etc.

The infrastructure plan is the following:

Table 8: Infrastructure Details

	Year 1	Year 2	Year 3	Year 4	Year 5
Indoor Space (sq ft)	2000	12000	12000	20000	20000
Outdoor space (sq ft)	2000	3000	3000	3000	3000
Manpower	Admin (80) % Technical (25%)	Full	Full	Full	Full
Key activities	Admin, Technology demo,	Admin, Technology demo, HRD, incubation	Admin, Technology demo, HRD, incubation	Admin, Technology demo, HRD, incubation,	Admin, Technology demo, HRD, incubation
Facility develop-	DTF (outdoor), transferable indoor facility	DTF (Under-water)	-	All facilities	All facilities

Space allocation plan that maps with activity plan is further explained

First-year:

- Initial activities in Monash Academy building in around 2000 sq ft
- Outdoor activities in about 2000 sq ft

Second and third year:

- Office and administrative activities in Monash Academy building in about 2000 sq ft
- Technology development space of approximately 10,000 sq ft or an appropriate area either in Research Park building (under construction) or in some other suitable place
- Outdoor activities at the hillside in around 2000 sq ft and near the central library in about 1000 sq ft.

Beyond the third year:

- All indoor activities in about 20,000 sq ft on the top two floors of CoPT building (under construction)
- Outdoor activities as in the second and third year

1.3. ***Utility Bills:*** The utility bills are conservatively assumed at Rs. 10.00 lakhs in Year 1 and Rs. 40.00 lakhs per year in Year 2-5 with 5% annual increment covering electricity, telephones, broadband, auditors, consultants, company secretary, office boys, legal etc.

1.4. ***International Collaboration:*** International collaboration will be based on existing International co-operation modalities. The team will be responsible to explore opportunities in the fields of expertise to ensure augmentation of the existing technology as well as build new systems. Generally, in collaboration work, the investments get shared on a 50:50 basis between the partners. We expect the cost will be annually around Rs.0.72 crore with 5% increment for atleast one international collaboration.

1.5. ***Travel:*** As the project envisages international and national collaboration with industry leaders, universities and also setting up similar setups in other institutes in India will involve a lot of travelling and conveyance expenses for the company. The same is conservatively assumed at Rs. 20 lakh in Year 1 and Rs. 50 lakh per year in Year 2-5 with 5% annual increment.

1.6. ***Consumables-***Laboratory and Office- The consumables are conservatively assumed at Rs. 6 lakhs in Year 1 and 60 lakhs per year in Year 2-5 for laboratory, as well as Rs. 4 lakhs in Year 1 and Rs. 6 lakhs in Year 2-5 for office per year, with 5% annual increment.

1.7. ***Equipment AMC***- The equipment AMC cost will be negotiated with either the service providers or the original equipment manufacturers to ensure the equipment's work in its 100% efficiency with minimum downturn time. The costs are assumed at Rs.10 lakhs in second year, and Rs. 200 lakhs per year in third, fourth and fifth year, with 5% annual increment commencing from fourth year.

1.8. ***HRD and Skill Development*** - The following fellowship program, which is calculated for TIH-IoT, is projected:

Table 9: Fellowship Details

Particulars	Number	Fellowship per Month (Rs)	Total for 5 years (Rs in Lakhs)
Graduate Fellowships	340	10000	340
Post-Graduation Fellowships	62	12400	228.80
Doctoral Fellowships	25	31000 + HRA for first 2 years & 35000 + HRA for 3rd-5th year	621.24
Faculty Fellowships	6	80000	172.8
Chair Professors	6	80000+ 120000 (for annual contingencies/ Travel/ Miscellaneous costs) + 100000 (or annual institutional overhead)	212.4
Total			1575.23

Further for conducting and sponsoring various workshops, conferences, seminars, sponsorships, etc. in order to have a greater visibility among the technology community within the overall aegis of the project goals will require outlay of funds of annually around Rs. 0.20 crore in Year 1 and Rs. 0.40 crore per year in Year 2-5 with 5% increment. Considering these programs as well as the Niche Industrial Relevant Training and Skill Building Certified Courses proposed in the Revenue Generation Models, we are targeting atleast 630 numbers, as a part of Skill Development.

1.9. ***Technology Development***- One of the key aims of the project is to have a focused approach in Research & Development in the selected fields of IOT and IOE so as to align with the national goal in achieving technological self-reliance. A total corpus of Rs. 47.73 crores will be required which will be divided by 50:50

i. for collaborative projects (with other Hubs, CDAC and IIT Dharwad) and
ii. for catering to deliverables in the technology focus of TIH-IoT.

The company will identify 5 to 6 key Research projects which will have the potential being used commercially across multiple industries. The funding will be required over the period of 5 years. It will be required for achieving at least 32 nos. of technologies (IP, licensing, patents etc.), 30 nos. of technology products, 90 nos. of publications, IPR and other intellectual activities, 105 nos. of increase in CPS research base, as well as specific skill set, consumables, partnerships/tie-ups, royalty payments, etc., which are more of recurring in nature.

2. **Capital Expenditure (Non-Recurring Expenses):** The project enlists upfront set up of office premise, laboratory, classes etc. and therefore will require a considerable outlay of Rs.74.80 crores approximately. Out of the expenditure the maintenance expenditure of Rs.6.46 crores for the full 5 year is only recurring in nature as the company needs to make the necessary periodic upgradation of the equipment's and facilities.

Table 10: Capital Expenditure

Capital Expenses	Rs In Lakhs
Equipment (Major and Minor)	2890.00
Infrastructure – Refurbishment	1913.48
Infrastructure – Facility Development	2030.00
Maintenance Capex (Recurring in Nature)	646.52
Total	7480.00

Equipment: The equipment required for setting up the world class IoT lab will have to be bought upfront for the Lab. Most of the major equipment is IoT related equipment to setup the Laboratory. Both minor (software) equipment, amounting to Rs. 5.00 crores, and major equipment are considered here.

Infrastructure Facilities: Infrastructure is divided into following main sub heads:

- **Refurbishment:** The refurbishment cost will be used for the space mentioned in the Rent related detailed information above and will also entail the completion work of the façade and flooring, HVAC, False ceiling, windows, walls, Electrical Panels, Electrical wiring, CCTV cabling (no CCTVs), LAN cabling, architect and consultant fees.
- **Facility development including Lab Setup:** Facility development will require alteration and modification of certain existing infrastructure in indoor and outdoor as the following:

➢ **DTF (underwater testing)**

Water tank dimension - 5 m x 10 m x 1.5 m with 2.7 m headroom (i.e. distance between floor level and basement slab bottom). Cost - 11 Cr

Justification - The cost of this alteration and design of the slab without columns costs Rs. 11 Cr. It includes the part fee to the architect and 12% GST for construction.

➢ **DTF (Outdoor facility) Open area dimension - 10 m x 20 m Cost - Rs 8 Cr**

Justification - The cost involves the expenditure of reconstruction to the institute and development of ground with concrete, without any roof cover. This also includes the resettlement of labor hutments in a new location*. With roof cover structure may cost about Rs. 5 Cr (additional).

Further specific infrastructure for the Lab facilities needs to be created which will amount to an additional around Rs. 1.31 crores.

Maintenance Capex- The standard maintenance capex on the building facilities and equipment needs to be done from year 2 onwards and is expected to be an annual cost of Rs.1.50 crores.

3. ***Investments*** - Innovation, Entrepreneurship and Start-ups Ecosystem: As part of creation of innovation, entrepreneurship and start- ups ecosystem, the company would periodically perform various activities which can help to do advanced work in the area of the company's interest and would invest venture capital into the company. The investment will be done after thorough study by an internal investment team headed by the CEO and VP (Projects) and will entail the investments projected in the following activities.

Table 11: Projected Investments

Particular	Number	Amount per project (Rs in Lakhs)	Total for 5 years (Rs in Lakhs)
CPS- Technology Business Incubator (TBI)	1	400	400
CPS- Start-ups & Spin-off companies	52	10	520
CPS-GCC- Grand Challenges and Competitions	1	55	55
CPS-Promotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS- PRAYAS)	1	100	100
CPS-Entrepreneur In Residence (CPS-EIR)	31	0.3 per month	111.6
CPS - Dedicated Innovation Accelerator (CPS-DIAL)	1	75	75
CPS - Seed Support System (CPS- SSS)	1	200	200
Total			1461.6

CPS-Technology Business Incubator (TBI) will work in coordination with IITB's existing Incubator SINE. Considering the activities proposed above and in the revenue generation model, we are targeting to create a large number of jobs.

Comprehensive table for expenses taking into account operating expense, capital expense and investment.

Table 12: Comprehensive details of the expenses

Major Expense Head	Expense Item	Type of Expense	Rs in Lakhs
Salary	Salary-Manpower (Administrative)	Operating	948.71
	Salary-Manpower (Technical)	Operating	2751.04
Utilities and Overhead	Overhead	Operating	846.40
	Utility Bill	Operating	182.41
	Consumables –Laboratory	Operating	264.61
	Consumables –Office	Operating	29.86
International Collaboration	International Collaboration	Operating	310.33
Innovation, Entrepreneurship, and Start-ups Ecosystem	Innovation, Entrepreneurship, and Start-ups Ecosystem	Investments	1461.6
Admin and General Expense	Travel	Operating	235.51
	Equipment AMC	Operating	640.50
HRD & Skill Development	Fellowships	Operating	1575.23
	HRD -Workshops/ conferences/ seminars/ sponsorships, etc.	Operating	192.41

Technology Development	Technology Development	Operating	4773.00
Contingency	Contingency	Operating	584.30
Capex	Equipment (Major and Minor)	Capital	2890.00
	Infrastructure –Refurbishment	Capital	1913.48
	Infrastructure - Facility Development	Capital	2030.00
	Maintenance Capex (Recurring in Nature)	Capital	646.52
Total			22275.89

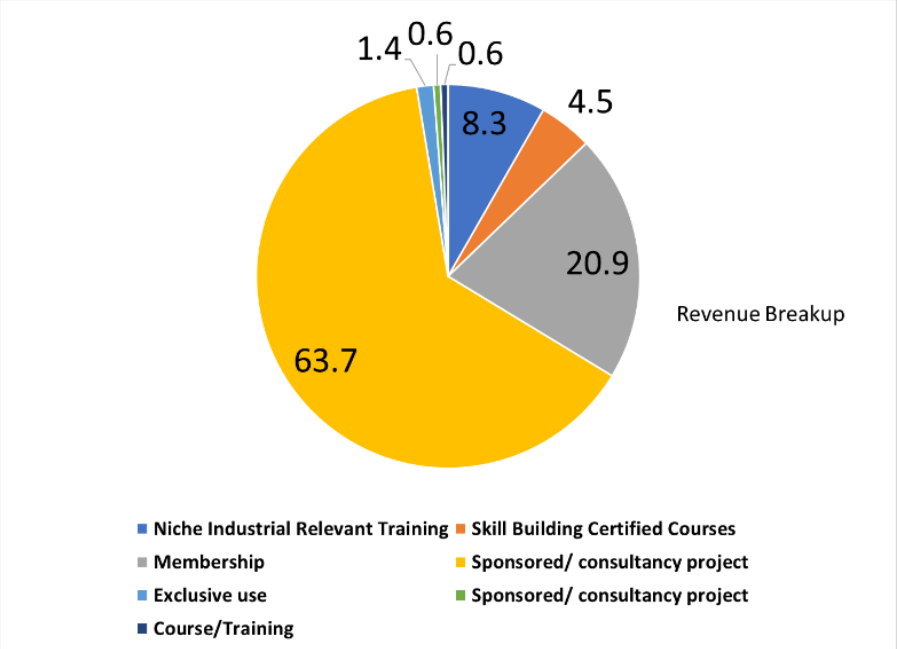
Revenue Estimates:

One of the typical responsibilities that the management must contend with is determining how to ensure the project becomes self- sustainable over the period of projection to take care of the operating expenses without significantly affecting its ability to produce the desired goals set out at the beginning of the project. The revenue streams are projected on the basis of the attainable goals over the period of projection. The project envisages the following main streams of revenue from year 2 onwards:

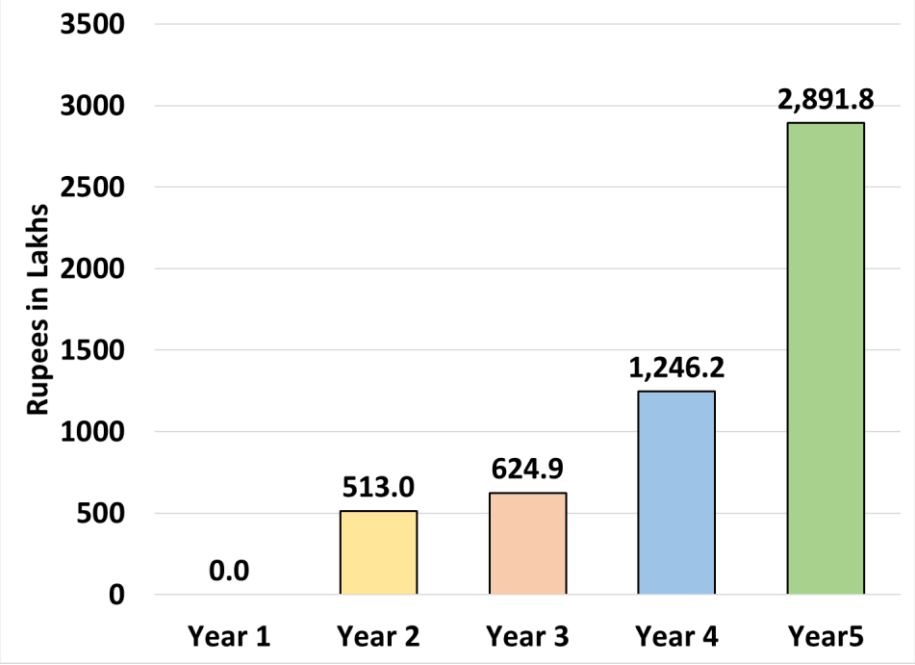
Table 13: Mainstream Revenue

Particulars	Year 1	Year 2	Year 3	Year 4	Year5	Total (Rs in Lakhs)
Human Resource Development						
Niche Industrial Relevant Training	0.00	36.00	75.60	158.76	166.70	437.06
Skill Building Certified Courses	0.00	24.00	50.40	52.92	111.13	238.45
Sub Total	0.00	60.00	126.00	211.68	277.83	675.51
Industry Interactions						
Membership	0.00	150.00	157.50	330.75	463.05	1101.30
Sponsored/ consultancy project	0.00	300.00	315.00	661.50	2083.73	3360.23
Sub Total	0.00	450.00	472.50	992.25	2546.78	4461.53
Laboratory Usage						
Exclusive use	0.00	0.00	15.00	30.00	30.00	75.00
Sponsored/ consultancy project	0.00	0.00	4.80	5.04	21.17	31.01
Course/Training	0.00	3.00	6.60	7.26	15.97	32.83
Sub Total	0.00	3.00	26.40	42.30	67.14	138.84
Total Revenues	0.00	513.00	624.90	1246.23	2891.75	5275.88

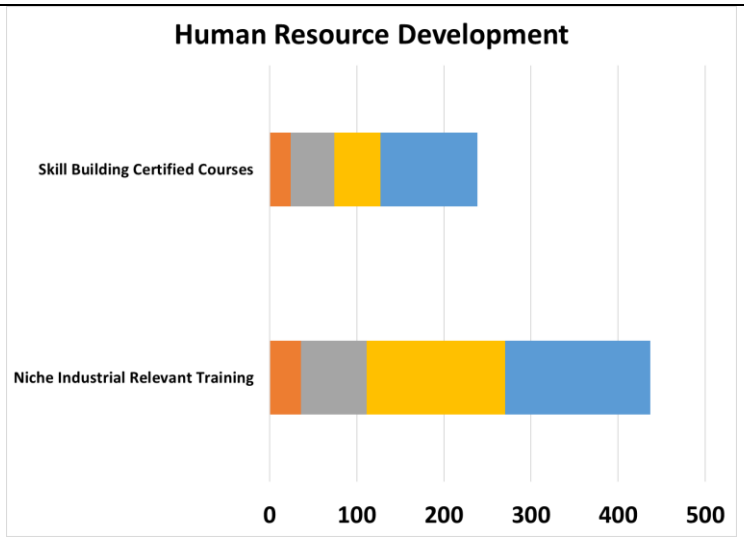
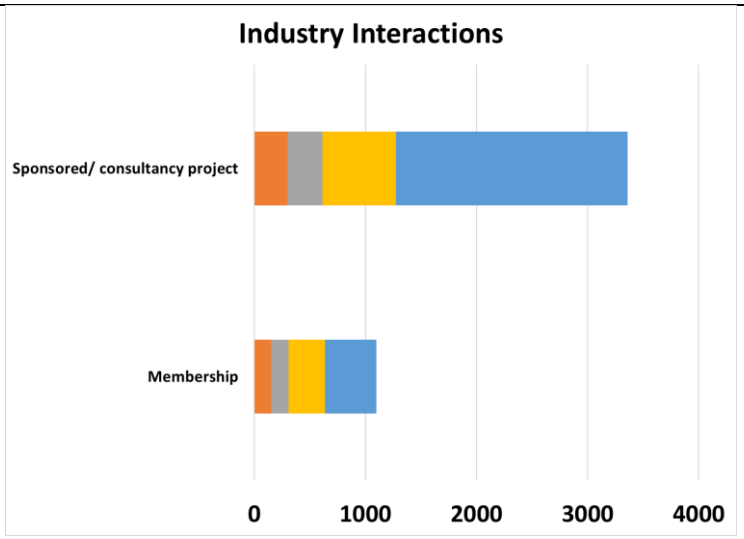
Revenue Breakup Category Wise as % of Total revenue

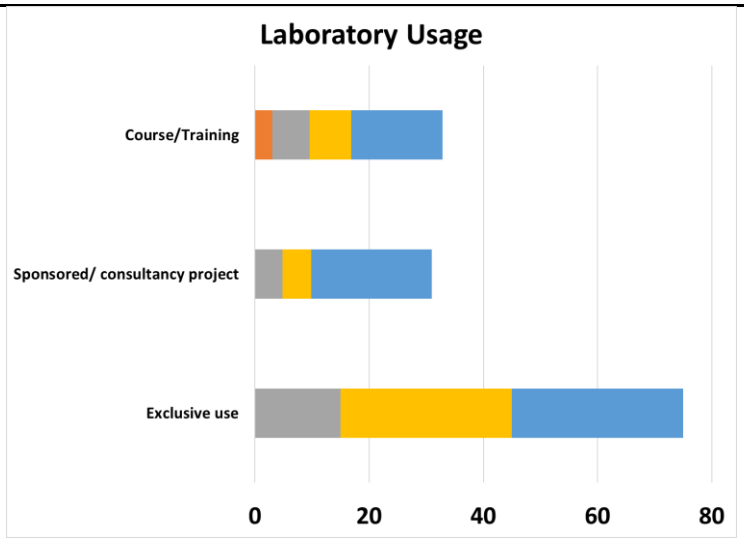


Revenue Breakup Year Wise vis-à-vis Total revenue



The key assumptions of the revenue generation under the subheads is as follows:

	
Niche Industrial Relevant training	The organization is expected to become a pioneer centre for Industrial Training in its field of expertise in India as it will have all the required infrastructure and excellent facilities for industry personnel/ students to pursue their courses. The primary goal of the industrial training program is to provide the respondents with necessary skills to improve employability. Industrial training will be short term in nature and have Rs.30000 per participant as fees with 5% annual increment. The training will be commenced from Q3 of Year 2 to Year 3 with one event per team per half-year, one industrial training event per team per quarter in Year 4 and Year 5.
Skill Building Certified courses	In addition to the above certified courses is envisaged to provide to students. Certified Courses will be short term in nature and have Rs. 20000 per participant as fees. The courses will be commenced from Q3 of Year 2 to Year 4 with one event per team per half-year, with one course event per team per quarter in Year 5.
	
Membership	The Project envisages to find membership from Industry from Year 2 onwards at an average annual fee of Rs.50 lakh per team. We have projected 3 industrial memberships in Year 2 and Year 3 for 3 technical teams per year, 6 memberships in Year 4 for 6 technical teams, and 3 in each quarter of Year 5 for 3 technical teams. As the total number of technical teams will be 6, we expect the teams to gradually enhance its reputation as pioneers in their field across different industries and build the membership base.

Sponsored/consultancy project	This is the key revenue earner envisaged for this company as the world class setup with experts on the field will ensure lot of collaborative projects from the industries and other funding agencies from India and abroad. Starting from 3 sponsored/ consulting projects in Year 2 and Year 3, the 6 teams will be able to increase it to 6 to year 4 and 18 for Year 5.
	
Exclusive use	Exclusive usage of laboratory for research requirements can be provided and we have assumed an annual income of Rs.15.00 lakhs in Year 3 and Rs. 30 lakhs from Year 4 onwards.
Sponsored/consultancy project	There will be Lab utilization for the sponsored/ consultancy projects which will be charged additionally. There will be 6 lab usage for Year 3 and Year 4, and 24 lab Usage for Year 5 comparable to the projects.
Course/Training	The usage of laboratories will be additional for the different courses provided and has been projected on conservative basis be 6 lab usage for Year 2, 12 Lab Usage for Year 3 and Year 4, and 24 lab Usage for Year 5 comparable to the projects. .

Net Effective of Recurring and Non-Recurring Expenditure and Revenue:

The table below provides the effective yearly deficit on account of Recurring Expenditure and Non-recurring expenditure netted off against the revenue (revenue is recurring in nature).

Table 14: Effective yearly deficit

Budget Head/ Year	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Recurring	13.25	27.00	37.00	16.30	1.65	95.20
Non-Recurring	9.00	30.00	31.00	2.70	2.10	74.80
Total in Rs Crores	22.25	57.00	68.00	19.00	3.75	170.00

Recurring expenditure: Operating Expenses and Investments Non-Recurring Expenditure: Capital Expenditure.
Rationale of Funding Amount:
The cash flow statement for the full period of 60 months has been provided on a quarterly basis with near to accurate projections. The summary of the cash flow statement is provided below:

Particulars	Rs in Crores
Peak Level Cash Requirement (Q4Y5)	Rs. 170 crores
Period from self-sustainable of the project	Q4Y5

Total Cash Inflow for the period of 5 years	Rs.52.76 crores
Total Cash Outflow for the period of 5 years	Rs. 222.76 crores
Shortfall for the Period	Rs.170 crores
Funding Required is avg of Peak Level and cash shortfall	= Rs. 170.00 crores Funding required is Rs. 170.00 crores

To meet the cashflow deficit on a quarterly basis the drawdown schedule is also provided on a quarterly basis. The yearly drawdown of the cash flows is as follows:

Table 15: Yearly drawdown of cashflow

Funding Pattern	Rs in Crores	%
Year-1	22.25	13.09%
Year-2	57.00	33.53%
Year-3	68.00	40.00%
Year-4	19.00	11.18%
Year-5	3.75	2.21%
Total	170.00	100.00%

1. ***Year 1:*** 13.09% of the grants is required in Year 1 on account of the cost proposed to be incurred in the project setup including equipment, infrastructure, technology development for TIH-IoT and collaborative projects (with other Hubs, CDAC and IIT Dharwad) etc.
2. ***Year 2:*** 33.53% of the grants is required in Year 2 on account of the cost proposed to be incurred majorly to meet operating expenses and technology development for TIH-IoT and collaborative projects (with other Hubs, CDAC and IIT Dharwad) etc.
3. ***Year 3:*** 40.0% of the grants is required in Year 3 on account of the cost proposed to be incurred majorly to meet operating expenses and ongoing technology development for TIH-IoT and collaborative projects (with other Hubs, CDAC and IIT Dharwad).
4. ***Year 4:*** 11.18% of the grants is required in Year 4 on account of the cost proposed to be incurred majorly to meet operating expenses. The revenues are expected to be generated with a fair degree of estimation from year 4 onwards and therefore the project reliance on grants is expected to come down.
5. ***Year 5:*** 2.21% of the grants is required in Year 5 on account of the cost proposed to be incurred majorly to meet operating expenses. The revenues generated from the project will stabilize and are near about sufficient to meet the expenses and therefore the grant required as low. Further the peak level cash requirement is reached in Q4.

Table 16: The quarterly drawdown schedule (Rs in Crores) for 5 years

Year	Particulars	Cash Inflow	Cash Outflow	Cumulative Surplus/Deficit	Grant/Sponsorship (Rs in crores)	Cumulative Cash Surplus/Deficit Post Grant
1	Q1	0	12.26	-12.26	22.25	9.99
	Q2	0	3.29	-15.55	0	6.7
	Q3	0	3.21	-18.76	0	3.49
	Q4	0	3.49	-22.25	0	0
	Total	**0**	**22.25**	**-22.25**	**22.25**	**0**
2	Q1	0	40.28	-62.53	57	16.72
	Q2	0	5.32	-67.84	0	11.41
	Q3	0.32	10.12	-77.64	0	1.61

	Q4	4.82	6.42	-79.24	0	0.01
	Total	**5.13**	**62.13**	**-79.24**	**57**	**0.01**
3	Q1	0.33	46.87	-125.79	68	21.46
	Q2	0.38	5.53	-130.93	0	16.32
	Q3	0.38	16.08	-146.63	0	0.62
	Q4	5.15	5.77	-147.25	0	0
	Total	**6.25**	**74.25**	**-147.25**	**68**	**0**
4	Q1	0.62	11.37	-157.99	19	8.26
	Q2	5.61	5.43	-157.82	0	8.43
	Q3	0.62	8.53	-165.72	0	0.53
	Q4	5.61	6.13	-166.25	0	0
	Total	**12.46**	**31.46**	**-166.25**	**19**	**0**
5	Q1	6.65	10.07	-169.66	3.75	0.34
	Q2	6.65	6.06	-169.07	0	0.93
	Q3	6.65	7.57	-169.98	0	0.02
	Q4	8.97	8.98	-170	0	0
	Total	**28.92**	**32.67**	**-170**	**3.75**	**0**

Contingency fund: Contingency fund is considered around INR 5.843 Crores which is less than 5% of the full government project fund for the following purpose:

- If the budgeted expenses enhances due to increased activity as well as projects and other requirements related to fellowships
- Purchase of additional equipment which has not been accounted for in the projections Ø Higher deficit on account of revenue shortfall

The contingency fund may vary based on the requirements.
We have projected revenue from three main sources – Human Resource Development, Industry Interactions and Laboratory Usage. All the three sources of income have a fair degree of estimation possible as the same will construe the core activity of the project. However, one of the objectives of the project is also to get in collaborations with International and national reputed universities and industry leaders in developing new technologies or augment the existing ones.
Any positive development emanating from such collaborations could result in following streams of revenue:

- Development of prototypes/patents which then can be later used for commercialization and thus income generated through royalty or license fees.
- Research grants from collaborators on successful pilot of prototypes
- Increase the scope of work to other industries and therefore higher project intake in our Industry interactions source of revenues
- Further as part of the expense outlay we have projected investment in promising start-ups which are complementary to our field of R&D. Any success in the start-up being able to raise future funds at higher valuation will ensure multiple times returns on our investments.

The above estimates have not been taken in the cashflow as it is exactly difficult to predict such outcome. However, the company's focus is extensive on research and development ensures we have a better than average chance of converting the research-oriented projects into stream of incomes as explained earlier.

Plan with NM-ICPS Fund:

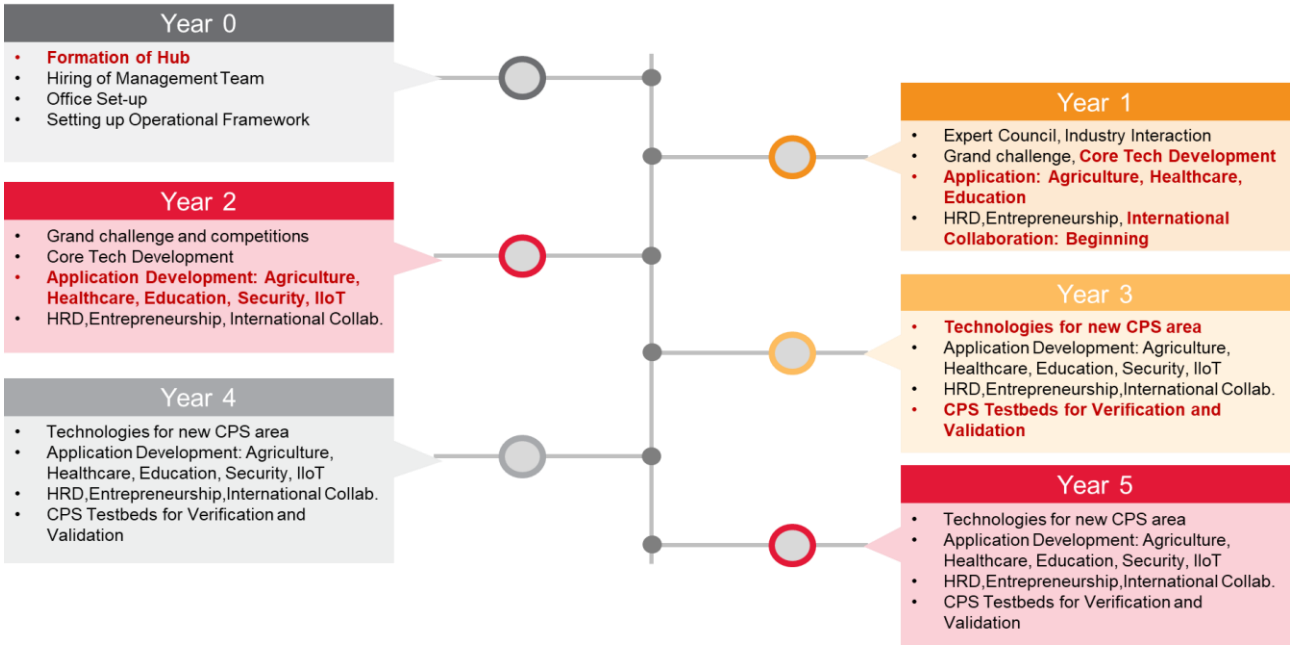
Comprehensive table for expenses taking into account operating expense, capital expense and investment. The expenses are computed based on the details provided earlier.

Table 17: Comprehensive details of the expenses

Major Expense Head	Expense Item	Type of Expense	Rs in Lakhs
Salary	Salary-Manpower (Administrative)	Operating	902.36
	Salary-Manpower (Technical)	Operating	1865.14
Utilities and Overhead	Overhead	Operating	
	Utility Bill	Operating	182.41
	Consumables –Laboratory	Operating	264.61
	Consumables –Office	Operating	29.86
International Collaboration	International Collaboration	Operating	310.33
Innovation, Entrepreneurship, and Start-ups Ecosystem	Innovation, Entrepreneurship, and Start-ups Ecosystem	Investments	2106.6
Admin and General Expense	Travel	Operating	235.51
	Equipment AMC	Operating	640.5
HRD & Skill Development	Fellowships	Operating	1775.23
	HRD -Workshops/ conferences/ seminars/ sponsorships, etc.	Operating	192.41
Technology Development	Technology Development	Operating	2489.8
Contingency	Contingency	Operating	584.3
Capex	Equipment (Major and Minor)	Capital	2019.19
	Infrastructure –Refurbishment	Capital	1336.91
	Infrastructure - Facility Development	Capital	1418.32
	Maintenance Capex (Recurring in Nature)	Capital	646.52
Total			17000

11 TIMEFRAME

High Level Plan



12 COST BENEFIT ANALYSIS

A cost benefit analysis (also known as a benefit cost analysis) is a process by which organizations can analyze decisions, systems or projects, or determine a value for intangibles. The model is built by identifying the benefits of an action as well as the associated costs, and subtracting the costs from benefits. The cost benefit analysis will yield concrete results that can be used to develop reasonable conclusions around the feasibility and/or advisability of a decision or situation.

In the extant case the government invests in order to realise 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. 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.

The project has certain objectives which are tangible in nature but also there are lot of intangibles are also associated with the project wherein the benefits cannot be measured in monetary terms.

a) Cost Benefit Analysis on the Projectable Revenues and costs: In the cash flow projected earlier we have estimated that the project is self-sustainable from Year 5 onwards (to be more specific Q4Y5) and will be in a position to meet its expense obligations from its source of revenues. Taking this thing into account the project will be generating around Rs. 10.54 crores per year from year 6 onwards (netting off the technical development cost but adding maintenance capex and investments). This is on the basis of the projectable revenue and no consideration has been made on the benefits arising out of the R&D activity done by the team.

b) Analysis of the Benefits accrued due to Intangibles: 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. However, some of the benefits that can be clearly stated as follows:

   i. 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.
   ii. Recognition and awards from various prestigious institutes and organizations will ensure a huge name for not only the Institute but also Government of India for providing such world class infrastructure for R&D purpose.

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.

iii. The technology developed out of R&D efforts may not always see the light of the day as its fate depends on market environment, cost effectiveness, competing technologies, cheaper imported products and a host of other factors. If successful, benefits of technology to consumers may also derive from the practical application of a research effort.

iv. This fulfils the Government aspiration of "Make In India" and "Atma Nirbhar" concepts as one of the primary aim of the company will be to work one developing technologies indigenously and therefore the need of the hour is to provide to support the institution.

v. One of the other mission is establishing a ecosystem of start-ups and international collaborations can help in generating multiple revenue streams through dividend income, Capital gains and license fees.

Therefore from the above fact it is clear that even though the project becomes sustainable and has fairly even period of recuperating the Principal investment amount and at the same time achieve the other primary goal of setting up of a world calls R&D facility.

13 RISK ANALYSIS

The ability of TIH-IoT to become self-sustainable in five years depends on its ability to nurture all its revenue generation streams so that the income from them matches the recurring expenditures. Though we feel confident enough of the viability of the revenue generation streams proposed in section 10 (Finance), there is always some risk of failure. The uncertainty in each of the revenue generation streams will now be analyzed and mitigation strategies will be discussed.

A. Collaborative projects with industry:

We have assumed a steady stream of requirements from industries for IoT enabling their processes in their march towards Industry 4.0. We have assumed a lack of in-house experts and research teams in these industries who can provide them end-to-end solutions. However, some large industries may have a significant portion of their IoT requirement already worked out by in-house research teams. They may choose to hire an external expert for the remaining part for developing the system level solution instead of approaching the hub. This will reduce the number of industries who are expected to approach the hub.

However, this scenario is expected to happen with only a few select companies. We expect the majority of Indian companies to realize the benefit of approaching the hub for conceptualizing IoT based solutions, developing them and finally implementing them. The synergy of working in close collaboration with a large number of experts from different domains can hardly be matched by the research team of any single company and we expect most companies to realize it. The initial response of the companies who have been approached for collaboration indicate that all of them appreciate the benefit of working with the hub. Additionally, a dedicated team of TIH-IoT will proactively scout for potential industry collaboration and we expect this risk mitigation strategy to suffice.

B. Waning interest of faculty members:

About 35 faculty members from various departments of IIT Bombay have signed up to be a part of TIH-IoT. There is a small possibility that the number of people with a sustained interest will be lower. This is likely to happen if there is less interest from industry to seek IoT based solutions. The current trend of moving towards Industry 4.0 may be overshadowed by more urgent needs.

However, given the technology trends of an ever-connected world, we expect the push towards Industry 4.0 to be sustained as a long-term trend. With a steady stream of industries approaching the hub for IoT solutions, we expect the number of faculty members associated with the hub's activity to grow and not shrink. Our interaction with the limited group of faculty members with whom we have interacted so far justifies our optimistic outlook and we do not foresee sustenance of interest of a significant number of faculty members to pose a significant risk.

C. Recession in industry:

Till now, all industries who have been approached for being a part of TIH-IoT have shown their eagerness and many of them have already signed a document indicating their willingness. However, investment in a push towards Industry 4.0 requires a long-term vision of higher management. Business cycles are inherently unpredictable. It is possible that in the time of a downturn in business, the push towards a futuristic technology would seem untimely. This may slow down the revenue stream expected from collaboration with industry as they scale back on their research budget.

However, we expect most industries to realize the long-term benefits of moving towards Industry 4.0. We have not seen significant concerns being raised about this risk factor in our interaction with industry so far. Moreover, the level and pace of development of IoT solutions in the Hub can always be tuned to the industry's capability to absorb them. TIH-IoT will be flexible enough to work within the constraints suggested by the industry - both financial as well as technical - and we expect this mitigation strategy to be enough to tide over business cycles.

D. Competition from others for imparting IoT skills:

Currently, very few centres exist in India for imparting the skills needed for developing, implementing and maintaining IoT solutions in the industry. We have budgeted for a steady stream of personnel who would seek to upgrade their skills and become proficient in IoT device development and maintenance. We expect such people to approach TIH-IoT and their skill upgradation has been budgeted as a revenue stream. However, it is possible that other organizations or institutes may try to emulate our success and offer similar promises. It is possible that many would get lured by those promises and not approach the hub.

This scenario, though possible, and perhaps expected in the long term, is not expected to pose a serious threat to the existence of the hub. We are confident of remaining at the forefront of technical excellence and would continue to impart that knowledge through our courses. We do not expect other smaller entities to be able to give a holistic view of IoT design and development. We expect middle and lower level industry personnel to understand the benefit of approaching the hub as the only place where experts from a wide range of domains would be involved in delivery of the IoT certificate courses. We have faith in an informed group of people to be able to separate the wheat from the chaff and look forward to a steady stream of requests for skill development in IoT.

E. Not enough requests for use of our state-of-the-art laboratories:

It is possible that there are a smaller number of requests for use of the state-of-the-art laboratories that will be set up as a part of the activities of TIH-IoT. It is possible that other organizations or institutions may offer similar facilities. However, our experience with the current advanced testing facilities in IIT Bombay allows us to discount this risk factor. These facilities are always overbooked and we usually struggle to accommodate urgent requests. Some of these test facilities are unique in India and others are present in very few other places which limit their access. We expect the demand of our high-end testing facilities to remain at the expected levels and the users to appreciate the benefit of approaching the hub for this purpose. Here, they will also be able to interact with experts who can analyze the results from a broader perspective - something that cannot be expected from an organization offering only testing services.

14 OUTCOMES

The target outcomes of the TIH-IoT is listed in Table 18.

Table 18: Year-wise Target Outcomes

S No	Target Area	Targets					
		1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
1	**Technology Development**						
(a)	No of Technologies (IP, Licensing, Patents etc)	2	4	6	10	10	32
(b)	Technology Products	2	4	6	8	10	30
(c)	Publications, IPR and other Intellectual activities	5	10	20	25	30	90
(d)	Increase in CPS Research Base	5	15	25	30	30	105

2.	**Entrepreneurship Development**						
(a)	Technology Business Incubator (TBI)	1	-	-	-	-	1
(b)	Start-ups & Spin-off companies	10	11	11	10	10	52
(c)	GCC - Grand Challenges & Competitions	0	1	0	0	0	1
(d)	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	1	-	-	-		1
(e)	CPS-Entrepreneur In Residence (EIR)	6	7	6	6	6	31
(f)	Dedicated Innovation Accelerator (DIAL)	0	1	0	0	0	1
(g)	CPS-Seed Support System (CPS- SSS)	0	1	0	0	0	1
(h)	Job Creation	100	1025	4000	4000	4000	13125
3.	**Human Resource Development**						
(a)	Graduate Fellowships	68	68	68	68	68	340
(b)	Post Graduate Fellowships	12	12	12	13	13	62
(c)	Doctoral Fellowships	5	5	5	5	5	25
(d)	Faculty Fellowships	1	2	1	1	1	6
(e)	Chair Professors	1	2	1	1	1	6
(f)	Skill Development	50	100	150	160	170	630
4.	**International Collaboration**	**1**	**0**	**0**	**0**	**0**	**1**

The deliverables are presented in terms of immediate, short-term, and long-term as follows:

Immediate Deliverables (~1 to 3 years):

The immediate goal of TIH-IoT is to launch skill building as well as niche structured courses on IoT engineering along with modules on innovation, entrepreneurship and industry standards, and demonstrating the identified IoT technology with commercial benefits.

The technologies for demonstration in the initial phase of TIH-IoT are identified based on their generic outcomes. These technologies are further integrated to provide a technology with an objective. The integrated technologies are also generic and can be applied to various applications with minimal changes specific to the corresponding application. The technology development through collaborations with academic collaborators and other hubs would be the main focus in the initial phase. Additionally, the TIH-IoT aims to work on formulating Indian standards for IoT and repository for IoT devices for the benefit of Indian industry and security.

To judge whether we are proceeding in the right direction and whether our activity is really making a difference, it is necessary to collect data about the current state of IoT exposure in the industry. Such a survey will be conducted as one of the first exercises after setting up of the hub and will continue to be conducted at regular intervals thereafter. The results will be the basis of taking up additional activity or course correction in deliverables, if needed.

Short-term Deliverables (~ 3 to 5 years):
The short-term deliverables of the TIH-IoT is to provide services in the focused area such that if any industry is looking for developing SIS technology, then either it hires certified IoT engineers to develop the technology or it approaches the TIH-IoT for innovative solutions. The focus of TIH-IoT is in providing integrated physical and cyber solutions. The emphasis would be to develop generic technologies requiring small modifications for corresponding use-case. In particular, the SIS technologies would aim to develop products ready for Industry 4.0 or the fourth industrial revolution.

Long-term Deliverables
Become self-reliant to address growing industry requirements and maintain commercialization ecosystems. Significant expansion by developing and standardizing newer technologies in newer applications.

15 EVALUATION

In the short term, the success of every collaborative effort with a company would be judged by the improvement in the company. This improvement can be quantified in many ways and depends on the specific process employed by the industry. Some common quantifiable parameters are:

- Lower number of product defects
- Lower product delivery time
- Less number of process disruptions
- Less dependence on human error
- Lower machine downtime

We would evaluate the success of every IoT technology implementation activity with the most appropriate metric. The results will inspire fence sitters to take the plunge into this technology of the future.
Further, TIH Foundation for IoT and IoE has come up with a methodology to evaluate/scrutinize projects. The project proposals are initiated from two channels: internal and external.
Figure 22 shows the project proposal evaluation process followed at TIH. Each project proposal is evaluated according to the criteria mentioned along with their scoring guideline. The Reviewers are assigned proposals along with a brief summary to get a feel of the project and to form an opinion about any conflict of interest. Those experts who have No conflict of interest with the applicant and/or the proposals are then given full access to the proposal.
The proposals are evaluated based on following major criteria:
a. Scientific Merit
b. Innovation Level
c. Level of Risk
d. National / Social Relevance
e. Commercial Potential
The scoring guideline consists of following major sections and there are questions in each of these sections. Reviewer has to go through the proposal and provide the score as well as justification for these scores on the rating of 1 to 5.

- Technical Merit of the Proposal
- Industrial relevance and potential for innovation impact
- Industrial participation and plan for technology transfer
- Research competence/Budget Justification
- Category of New Technology/Product
- Rating of the Project
- Confidence level as a reviewer
- Recommendations
-

Following are the details of the rating used for the project proposal evaluation

- Excellent (5) – The present work deals with well-known challenges faced by industries or it identifies new trends or opportunities with strong relevance to IoT and IoE. There are clear evidences that the specific subject of this work is significant and stimulating. A successful solution could have a large impact to industry applications or research communities.
- Very Good (4) - This work presents industry experiences, real-world findings, or standards that are timely and meaningful. The potential impact is evident. They are of good interest to IoT and IoE application areas and have a strong potential interest to them. The project is clearly suitable for consideration.
- Good (3) - The present work subject is of some interest to IoT and IoE community, as demonstrated by a limited number of cases, or industry practices. The findings may have some use to industry but are not broad enough to attract reasonably wide interest from industry or academia. The subject is marginally meaningful and suitable for consideration.
- Fair (2) – The work is related to the industry experiences or cases that are well-known, are of routine nature or are of limited interest to IoT and IoE. Alternatively, the work addresses issues that are case-specific, cannot be generalized or are not substantiated.
- Poor (1) - This work presents a subject that may potentially mislead because of misrepresentation or misconception of the study subject; Alternatively, the work is not related to the scope of IoT and IoE application areas.

Recommendation by referees are taken into consideration and the project is finalized for the funding.

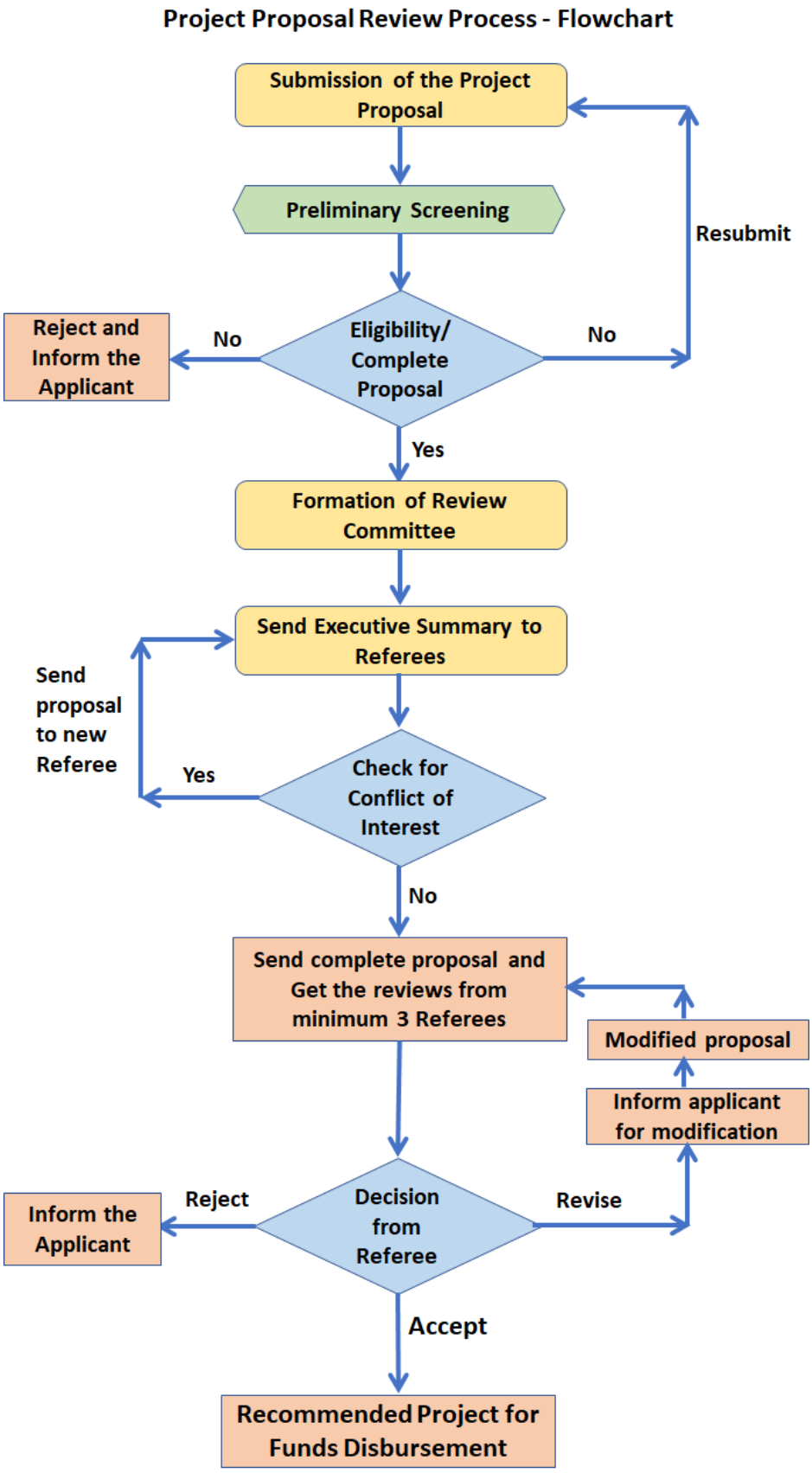


Figure 22: TIH - Project proposal review process

16 ANNEXURE I – Details of Application Areas of IoT

16.1 Application-oriented Technologies under Healthcare

How IoT will help healthcare

Let's dig into an IoT healthcare workflow example:

- A sensor or node collects data from a patient or a doctor inputs data.
- An IoT device analyses the collected data with the help of AI-driven algorithms like machine learning (ML).
- The device decides whether to act or send the information to the cloud.
- Doctors or even robots are connected over the IoT cloud to make actionable and informed decisions based on the data provided by the IoT device.

How will IoT benefits healthcare

- Real-time, remote monitoring of patient health at the comfort at their home and 24x7 emergency notifications to the health professionals.
- No ques or waiting faster response times
- Less overcrowding in hospitals/space freed for the critically ill
- Hospitals or providers will be able to see more patients each day

Tracking Hardware Performance

A great part of the healthcare industry uses complicated and expensive machinery and hardwares. They are prone to lots of risk such as power outages, short circuits, malfunctions, etc. Due to the cost, availability and need of these machines, they need to be protected from such risks. IoT can take care of these expensive healthcare machines.

For example a sensor or a node connected to these machines, it sends the status of the machines to the cloud in real time and alerts hospitals of potential damage to any equipment.

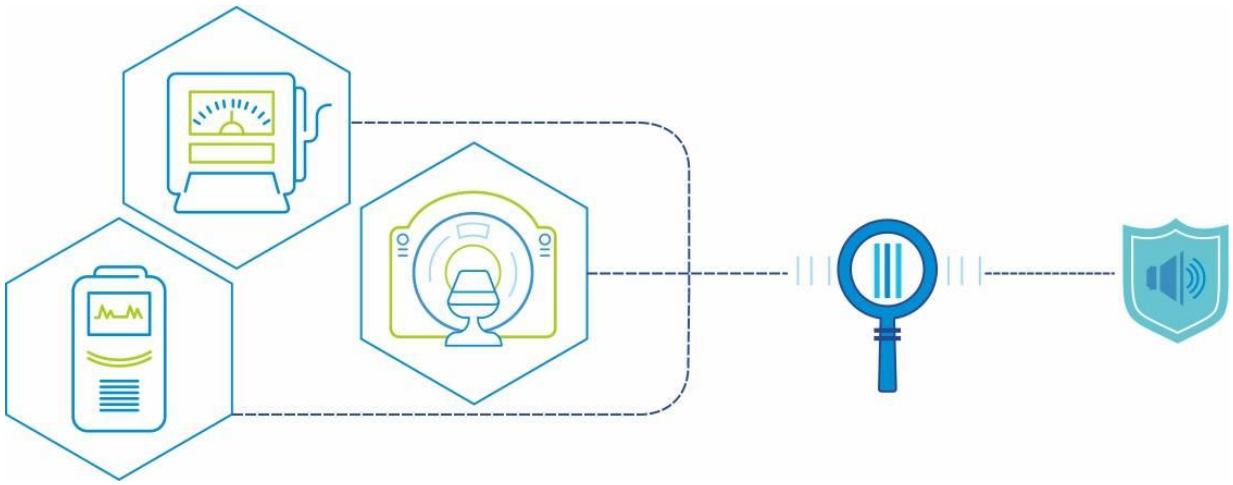


Figure 1: Tracking Devices in Healthcare [(2"IoT for Healthcare | Mobifilia in Healthcare," 2018)]

Personal Health Devices / Wearables

IoT provides a seamless platform to facilitate interactions between humans and a variety of sensors and virtual things, for monitoring personal health. IoT-enabled wearables are smart devices that can be worn as external accessories,

embedded in clothing and garments, implanted in the body, or even adhered to or tattooed on the skin. These devices can connect to the Internet to collect, send data, and receive the information that can be used for smart decision making. These wearables are becoming an increasingly important part of IoT technology, and their development is moving from being simple accessories to more specialized and practical applications.

Figure 2: Personal Health Devices ([3]"Wearable Technology: The Coming Revolution in Digital Health," 2018)

Telemedicine

IoT telemedicine technology can cater to people located in remote areas or those who are unable to visit the doctors and hospitals due to factors like distance, age, or busy lifestyle. It provides remote care and virtual healthcare assistance, which is more affordable and convenient for healthcare professionals and patients. For example- an AI enabled virtual healthcare assistant can keep a track of your basic health data and book an online cloud-based appointment with a doctor when necessary.

The most important application of telemedicine is immediate remote access to medication in life-threatening situations. For example, a drug dispensing solution with audio-video conferencing capabilities. Telemedicine is also efficient for people suffering from serious diseases such as kidney issues, heart ailment, respiratory diseases like chronic obstructive pulmonary disease, diabetes that requires constant monitoring by their doctors. It will save rushing to the hospital at the last moment, high expenses of readmission in the hospitals, and in some cases save the patient from death by giving treatment through telemedicine at the right moment.

Figure 3: Telemedicine ([4]"Doctor, Will I Need Surgery?' Ensuring Telemedicine is Delivered to You Safely and Securely - Entrust Blog," 2019)

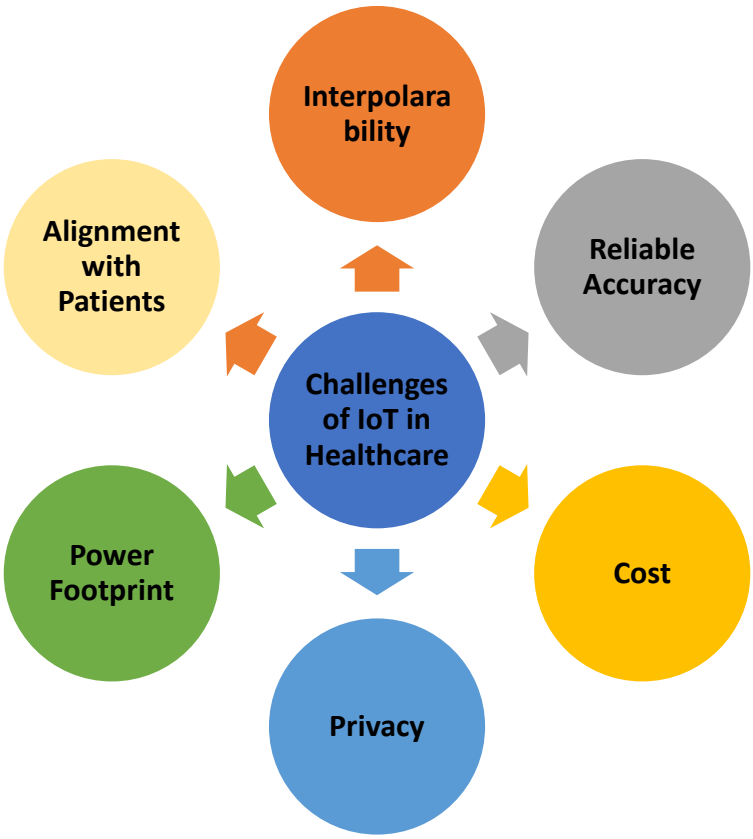


Figure 4: Challenges faced by IoT in Healthcare

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