Detailed Project Report (DPR)

National Mission
on
Interdisciplinary
Cyber-Physical Systems (NM-ICPS)

सत्यमेव जयते

(Interdisciplinary Cyber-Physical Systems Division)
Department of Science & Technology
Ministry of Science & Technology
Govt of India

2018

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"Oneimportant area that needs to be addressed is the rapid global rise of Cyber-Physical Systems. This has the potential to pose unprecedented challenges and stresses to our demographic dividend. But we can turn it into a huge opportunity by research, training and skilling in robotics, artificial intelligence, digital manufacturing, big data analysis, deep learning, quantum communication and Internet-of-Things. There is a need to develop and exploit these technologies in services and manufacturing sectors; in agriculture, water, energy & traffic management; health, environment, infrastructure and Geo Information Systems; security; financial systems and in combating crime. We need to develop an Inter-Ministerial National Mission in the Cyber-Physical Systems to secure our future by creation of basic R&D infrastructure, manpower and skills."

Excerpt from the speech of Hon'ble Prime Minister, delivered at the 104th Indian National Science Congress,S V University, Tirupati(Jan 3-7, 2017)

“ Combining cyber and physical systems have great potential to transform not only innovation ecosystem but also our economies and the way we live. To invest in research, training and skilling in robotics, artificial intelligence, digital manufacturing, big data analysis, quantum communication and internet of things, **Department of Science & Technology will launch a Mission on Cyber-Physical Systems** to support establishment of centers of excellence.”

*Excerpt from the **budget speech** of Hon'ble **Union Finance Minister,** Delivered on **1st February 2018***

डॉ. हर्ष वर्धन
DR. HARSH VARDHAN

मंत्री
विज्ञान और प्रौद्योगिकी एवं पृथ्वी विज्ञान ;
पर्यावरण, वन और जलवायु परिवर्तन
भारत सरकार
नई दिल्ली - 110001

MINISTER
SCIENCE & TECHNOLOGY AND EARTH SCIENCES ;
ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA
NEW DELHI - 110001

MESSAGE

Ever increasing ability to acquire new knowledge and quest for harnessing it for improving the quality of life has been the prime motive of Department of Science & Technology. We have seen in our own lifetime how technologies and particularly, the internet has disrupted almost everything by taking in its folds anything that can be put in digital domains. The change is only going to accelerate as the advances in knowledge and technology are certain to bridge the physical world that we have lived all through and the cyber world that we have created around us. We are all set to be immersed, as the trends suggest, into cyber-physical systems (CPS) forever and as a country we need to prepare ourselves for the imminent change and challenges it poses.

I am happy that a National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS), announced by the Hon'ble Prime Minister has been now fructified by Department of Science & Technology and given a shape. With the Detailed Project Report on the Mission, first step for a long walk has been taken. The five year mission being mounted will fuel development of human resource, new knowledge, technology solutions and entrepreneurship in a mutually implicating manner. This initiative rightfully brings onboard other ministries and departments as partners, as the cyber-physical systems are going to intrude and permeate every walk of human life i.e. as individuals, society or nation.

I am sure that such a broad-based yet focused mission when implemented in full measures will usher in Digital India that the country yearns for. Through this message, I issue a call-to-action to all the direct stakeholders to come forward and go an extra mile. I am confident that his collective effort involving academia, industry, government, students and entrepreneurs can transform and position India in global arena.

(Dr. Harsh Vardhan)

209, अनुसंधान भवन, 2, रफी मार्ग, नई दिल्ली–110001 दूरभाष : +91–11–23316766, 23714230; फैक्स : +91–11–23316745
209, Anusandhan Bhawan, 2, Rafi Marg, New Delhi-110001 Ph.: +91-11-23316766, 23714230; Fax: +91-11-23316745

चतुर्थ तल, आकाश विंग, पर्यावरण भवन, जोर बाग, नई दिल्ली–110003 दूरभाष : +91–11–24695136 फैक्स : +91–11–24695329
4th Floor, Aakash Wing, Paryavaran Bhawan, Jor Bagh, New Delhi-110003 Ph. +91-11-24695136 Fax +91-11-24695329

प्रो. आशुतोष शर्मा
Prof. Ashutosh Sharma

सचिव
भारत सरकार
विज्ञान और प्रौद्योगिकी मंत्रालय
विज्ञान और प्रौद्योगिकी विभाग
Secretary
Government of India
Ministry of Science and Technology
Department of Science and Technology

Message

The global technological trends clearly suggest that we will have more and more of cyber physical systems (CPS) around us in the decades ahead and that all our future is CPS - the systems which can take actions autonomously, efficiently and effectively. The change is already ushering in the developed countries and India cannot afford to be behind in the race. This Mission on ICPS has been conceived to prepare India for leadership position in this area which is considered as next paradigm shift succeeding Internet.

We, however, should have CPS developed, responsive to the needs of our country which has a huge working population that has to be provided jobs. Therefore, it would be necessary to understand the challenges for India, potential for application/intervention of CPS therein and deliver the solutions on ground, to benefit the people. We shall have to reach out to institutions and industry, even those overseas- to develop and implement these systems. We must act swiftly and gain the technological edge in this area, at a global level.

I am pleased that a Detailed Project Report (DPR) on the Mission drawn with all the aforesaid considerations is ready for implementation. It has suggested models/ mechanisms which tend to maximize participation of stakeholders, leverage their strengths and lead to delivery of intended outputs/outcomes, on the ground. I am confident that with the scale, size and width of the Mission, CPS induced formative change will be felt by every citizen in coming years.

(Ashutosh Sharma)

Technology Bhavan, New Mehrauli Road, New Delhi - 110016
Tel: 00 91 11 26511439 / 26510068 • Fax: 00 91 11 26863847 • E-mail: dstsec@nic.in • website: www.dst.gov.in

FOREWORD

In this age when the merger of the physical and cyber world is certain and so is the disruption Cyber-physical systems (CPS) are going to make across all sectors, India cannot afford to be ignorant. It is absolutely important to focus on new knowledge, technology solutions, skilled human resource and salubrious eco-system for entrepreneurship, to make India a top player in the field of CPS. This, by all means, is a huge challenge and requires channelizing of resources in a big way, and the government has rightfully decided to mount a Mission.

I am glad that detailed project report on the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) has been brought out by DST at the crucial phase of technology transformation. It covers not just research & development but also takes education, translational research, skill development, entrepreneurship in the span. I am sure that it will help guide us to create an ecosystem for CPS as it has identified the key elements, principal stakeholders/ actors, model(s), funding mechanisms and an implementation strategy as well.

The report has also highlighted a large number of top challenges and research areas on which different stakeholders can work together upon to create a technology paradigm that will accelerate the growth of thecountry. I am confident that it will excite all the concerned especially the IT inclined youth and ensure agreater level of participation in the quest for India's technology leadership in the domain of cyber-physical systems.

Dr V K Saraswat
Member (S&T), NITI Aayog
Chairman, ICPS-DPR Apex Committee

Executive Summary

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. The interdisciplinary area of Cyber-Physical Systems (CPS) is identified as one such emerging field, progress in which is expected to have asignificant impact on health care, urban transportation, water distribution, energy, urban air quality, manufacturing and governance. This Detailed Project Report (DPR) on a National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) presents an overview of CPS in general, outlining its importance to the modernisation and digitalisation of socio-technical systems and services. The activities envisioned under this Mission will provide a great fillip to Indian manufacturing via theinvention 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."

The DPR describes the underlying technologies, provides a preview of the many research issues, and discusses the national and international state-of-the-art. An assessment of the anticipated skill gapsis contained, besides the expected need for human resources in existing and new job sectors. India has traditional strengths in Information and Communications Technology (ICT), academic and research institutions with deep scientific and analytical skills, and the nation also has extensive experience in core sectors such as energy, transportation, agriculture, and space. These are the ingredients that can be expected to give India, the advantage for achieving leadership in the critical and emerging field of CPS.

The term CPS refers to computer-based inference, decision, and control (the "cyber" aspect) in the context of a "physical"system. The term was coined as recently as 2006. CPSs are, however, as old as the earliest efforts to embed computers in physical systems to control and optimise their performance; a classical example from the 1970s being the embedded computer control of motor vehicle engines. Today, the term CPS is used for systems involving dense embedded sensors and actuators, interconnected by the Internet of Things (IoT), with computing in the network, or at the edge, or in the cloud, for the purpose of observing, controlling, and optimising socio-technical systems such as smart farms, smart energy grids, smart urban water networks, smart homes, smart factories, or smart cities.The term smart states that the corresponding system (or "vertical," e.g., an urban water network) is being enhanced by CPS technology (which depends on the integration of several techniques, or "horizontals," e.g., sensors, wireless communication, cloud computing, hydrology models, and data analytics). With the increasing need for efficient utilization of scarce resources such as water and energy, increasing urbanization, and increasing consciousness of the impact on the climate due to human activities, there is going to be increasing emphasis on "smartening up" our socio-technical systems, thereby requiring us to deploy the technology of CPS. Being inherently interdisciplinary, CPS requires the technologies that includes: sensors and actuators for a variety of modalities depending on the physical domain, e.g., pollution sensors, water quality sensors, soil moisture sensors, machine vibration sensors,etc.; low power electronics;energy harvesters to extract energy from the environment in order to permit extended periods of device operation without battery charging; dense scale wireless communication to interconnect the large number of devices that will be embedded in the physical domain; distributed in-network computing, cloud computing; resilience to a variety of physical and cyber attacks, and data privacy. The development of such technologies requires fundamental scientific advances in materials and devices, communications, distributed computing and control over networks, machine vision, robotics, and brain-machine interfaces, cyber and network security in large distributed, resource-limited systems, and modelling, machine learning, and data analytics for a variety of physical systems.

Although the practical CPS of the near future will be built on standard digital electronics, digital computing, and digital communications, rapid advances are happening in the area of Quantum Computing technologies. To engage the expertise of our scientific community, to generate Human Resources for the future, and to develop our expertise and technologies in the area, the Mission envisages support for national research in Quantum Computing technologies as well.

It is expected that practical CPS will emerge over two-time scales. After over 20 years of research in wireless sensor networks, the Internet of Things (IoT) will be the first to become a reality. International standards are being defined, and IoT devices are now available, though still quite expensive. This technology will soon find widespread deployment in standard applications such as the control of street lighting, monitoring of urban water storage, and electricity metering. Such systems will facilitate more efficient operations of the underlying physical systems, with data visualisation, and simple inference and decision making, often with a human "in the loop."

The vision of CPSs involves dense-sensing, distributed and autonomous decision-making and actuation at large scale, and will require several advances before this visionis fully realised. Several challenges remain to be addressed, to make such a vision a reality. Theoretical frameworks for large-scale, interconnected systems are not well developed. Tools such as distributed optimization and control, stochastic analysis, traffic theory, and decision sciences still need to be fully developed to be able to drive large-scale interconnected systems. Analysis of large and complex datasets consisting of information regarding hundreds of temporal and spatial variables, especially in real-time, also poses a challenge. Most of the systems constitute not only a system-of-systems but also a network of information networks, which raises important questions regarding security. CPS will empower National Critical Infrastructure (NCI) and have the potential to significantly impact daily lives as they form the basis for emerging and future smart services. On the other hand, the increased use of CPS brings to the core potential new cybersecurity threats that could have significant consequences for the country and the society as a whole.

This DPR is the culmination of a countrywide consultative process which was carried out to assess the importance of CPS as a technology, uncover the core R&D issues, assess the national status of the technology, and identify the national strengths and weaknesses. The consultative process also explored methods and structures to connect NM-ICPS with national developmental objectives with particular emphasis on Sustainable Development Goals (SDGs). The DPR captures the aspirations of the citizens, assesses the present status of CPS in terms of research, technology potential and identifies various stakeholders across the sectors. It also carries a SWOT analysis, examines the legal and policy framework, assesses market opportunities and the demand for workforce skills and presents skill deficits.

NM-ICPS and the associated activities will be coordinated under one umbrella. The major sub-missions or Programmes of the mission will be on (i) Technology Development, (ii) Establishment of Centers of Excellence, (iii) HRD& Skill Development, (iv) Innovation, Entrepreneurship & Start-up Ecosystem and (v) International linkages & collaborations; each further split into anumber of components (projects/ schemes).

The Mission will support research and innovation in academic and research institutions, in areas such as those described earlier, leading to the development of CPS technologies and applications. The NM-ICPS will support Centers of Excellence (CoEs) in academic and research institutions across the country; in association with the industry. The CoEs will carry out interdisciplinary, collaborative, andtranslational research to develop core domain knowledge. As per the mandate, they will develop prototypes and proofs-of-concepts (PoC) and translate them into products, in conjunction with industry/ start-ups leading to new jobs creation and economic growth.

Skill development, HRD and nurturing start-ups through entrepreneurship programmes are also one of the goals of the NM-ICPS. Development and deployment of smart systems of systems, enhanced with CPS technology, will require skilled human resources at all levels, in technologies such as the IoT, design and deployment of low power wide area wireless sensor networks, machine learning and data analytics, and security and privacy in CPS. At the deployment level, just as in the 1990s there grew a need for digital communication network deployment technicians, there will emerge the need for the IoT deployment technicians. There is a need to generate advanced skilled HR to meet the emerging demands across the sectors. The NM-ICPS will also develop and establish research collaborations with international academic & research institutions for the advancement of CPS and associated research in the country.

The NM-ICPS is proposed to be implemented over five years. This DPR first provides an overview of CPS as a major emerging technology and then details the objectives of the NM-ICPS programme, the implementation mechanisms, the legal framework, the budgetary requirements of the various sub-programmes, the measurable outcomes and the review mechanisms, and the mission management structure.

DPR Apex Committee

Department of Science & Technology, GoI constituted an Apex Committee to guide, mentor and suggest the development of Detailed Project Report (DPR) on National Mission on ICPS. Composition of the Committee is

1	Dr V K Saraswat, Member (S&T) NITI Aayog, New Delhi	Chairman
2	Secretary Ministry of Electronics & Information Technology, New Delhi	Member
3	Secretary Department of Heavy Industries, Ministry of Heavy Industries & Public Enterprises, New Delhi.	Member
4	Secretary Department of Industrial Policy & Promotion, Ministry of Commerce & Industry, New Delhi.	Member
5	Secretary Department of Scientific & Industrial Research, Ministry of Science & Technology, New Delhi.	Member
6	Prof Anurag Kumar, Director Indian Institute of Science, Bangalore.	Member
7	Prof U B Desai, Director IIT Hyderabad, Telangana	Member
8	Prof Santanu Choudhary, Director Central Electronics Engineering Research Institute (CEERI), Pilani.	Member
9	Prof M Chandrashekar, Director IIM Visakhapatnam, A.P	Member
10	Representative of O/o Principal Scientific Adviser, New Delhi	Member
11	Shri K S Viswanathan, Vice-President NASSCOM, Bangalore	Member
12	Representative of CII, FICCI and other Industry Associations.	Member
13	Dr K R Murali Mohan, Scientist-G & Head ICPS Division, DST, New Delhi	Member-Secretary

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Chapter 1

Mission Introduction

1.1 Context and Background

Hon'ble Prime Minister while addressing 104th Indian National Science Congress stated that "one important area that needs to be addressed is the rapid global rise of Cyber-Physical Systems. This has the potential to pose unprecedented challenges and stresses to our demographic dividend. But we can turn it into a huge opportunity by research, training and skilling in robotics, artificial intelligence, digital manufacturing, big data analysis, deep learning, quantum communication and Internet-of-Things. There is a need to develop and exploit these technologies in services and manufacturing sectors; in agriculture, water, energy & traffic management; health, environment, infrastructure and Geo-Information Systems; security; financial systems and in combating crime. We need to develop an Inter-Ministerial National Mission in the Cyber-Physical Systems to secure our future by creation of basic R&D infrastructure, manpower and skills."

Vigyan 2030 stipulates that Cyber-Physical Systems (CPS) should be taken up as a National Mission and states that "CPS will address the threat to jobs, security and strategic requirements that the new industrial revolution poses. The goal is to ensure opportunity by generating new directions and training. The areas of focus could be in Big Data, Manufacturing, and Quantum Communication. Specific action will be to start Centers of Excellence. Train youth at all levels, develop Incubators and start-ups in these areas and set up Top Level Challenges. Push commercialisation around innovative MSMEs and ensure diffusion Industry 4.0 through Manufacturing and Services. Where necessary, there will be collaborations internationally."

Hon'ble Union Finance Minister in his budget speech on 1st February 2018 stated that "Combining cyber and physical systems have great potential to transform not only innovation ecosystem but also our economies and the way we live. To invest in research, training and skilling in robotics, artificial intelligence, digital manufacturing, big data analysis, quantum communication and internet of things, Department of Science & Technology will launch a Mission on Cyber Physical Systems to support establishment of centers of excellence.**"The National Mission on ICPS (NM-ICPS) is in line with high aspirations and offers a strategy to achieve the stated vision".**

The term CPS was first introduced by Helen Gill in the USA in 2006, but the roots of the term CPS are older and deeper, as reviewed by Lee [1]. It is further explained that the term "cyber," as a prefix, stems from the field of research known as "cybernetics", the scientific study of control and communication in the machine. The term "Cybernetics" was coined by Norbert Wiener, an American mathematician who had a huge impact on the development of control systems theory. During World War II, Wiener pioneered technology for the automatic aiming and firing of anti-aircraft guns. Wiener derived the term from the Greek κυβερνήτης (kubernetes), meaning helmsman, governor, pilot or rudder. The metaphor is apt for control systems. In more recent years, Internet-of-Things has become popular which is a platform for current day CPS. Various other terms used in the past as popular predecessors of CPS are as in Table 1.1.

Table 1.1 - CPS and its predecessors

Year	Term	Coined By
1926	Teleautomation	Nikola Tesla
1948	Cybernetics	Norbert Wiener
1961	Apollo Guidance Computer	Charles Stark Draper
1988	Ubiquitous computing	Mark Weiser
1999	Internet of Things	Kevin Ashton
2006	Cyber-physical systems	Helen Gill

There have been some milestones in the development of computer technology and information technology. Mainframe computers appeared in 1960s-1970s. In 1980s-1990s, Internet and desktop computers were created which can deal with personal and commercial business. Around 2000, appeared pervasive computation to conduct calculation at any time or place. All these events have fundamentally influenced the development of information society and digital economy. At present, many experts from various fields are paying close attention to the emergence of a new engineering system, cyber-physical systems (CPS).

1.1.1 Cyber-Physical Systems

CPS is integrations of computation, communication, cognition, sensing and physical processes. Embedded computers, networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa. A multidimensional and complex system as CPS is, the close integration of the information world and the physical world is realized through the combination of computing, communication and control technology. CPS refers to the deep and seamless integration of computational and physical resources to realize engineered systems that far exceed today's systems in autonomy, functionality, efficiency, usability, safety, and reliability.

The development of smart infrastructures and services for a sustainable society requires extensive interdisciplinary research. The smartness comes through the interconnections between the distributed components which are to be observed and controlled. The entire system with observation, inference and control, being taken care of by advances made in communications, controls and computing etc., is the defining characteristic of a CPS.

The emerging discipline of CPS combines to help in the development of smart infrastructures. CPS connects physical systems through various communication technologies and helps them interact. Such infrastructure would include electric power grids, water and gas networks, health care, transportation and monitoring natural resources. Novel concepts and theories developed in CPS are providing more profound insights into the nature of systems and systems interconnection in a massively networked world involving many intelligent sub-systems coordinating with each other. Such a framework would enable us to analyze dynamics of the control, computation and communication (in some cases human interaction) in a unified way, applicable across several domains.

Three key areas of interest in CPS are embedded sensing, inference and control in a large distributed system with attendant problem of security and privacy. The world is quickly moving towards design and control of large-scale systems like the internet which is the most prominent large-scale engineered system. However, theoretical frameworks for large-scale, interconnected, systems are not well developed. Tools such as optimization and control, stochastic analysis, queuing systems, and decision sciences still need to be fully developed to be able to drive large-scale interconnected systems. Analysis of large and complex datasets consisting of information regarding hundreds of temporal and spatial variables also poses a challenge. Most of the systems constitute not only system-of-systems but also a network of information networks, which raises important questions regarding security. For example, availability, integrity, confidentiality, authentication, authorization, non-repudiation, etc. Each application area will throw up a range of new challenges. (Source: TIFAC Technology Vision 2035, Technology Roadmap Information & Communication Technology).

CPS is multidisciplinary systems to conduct feedback control on widely distributed embedded computing systems by the combination of computation, communication, and control technologies. They are transformation and integration of the existing network systems and traditional embedded systems. CPS offers a new approach to the application of information technology to improve the performance of a system and is realized by having a closely coupled interaction between physical processes, networking, and computational elements. The physical process is monitored and controlled by embedded (cyber) sub-systems via networked systems with feedback loops to change their behaviour when needed [2]. These subsystems work independently of each other with the ability to interact with the external environment [3], [4]. They go beyond traditional systems employed in the industry about their complexity, requiring close networking with the appropriate disciplines which require specific tools for the analysis of the various properties of transportation and have the following characteristics [5].

- Systems of collaborating computational elements controlling physical entities
- Networks of interacting elements with physical inputs and output instead of as standalone devices
- Internet of Things, Data, and Services
- Interconnections between physical and virtual world models
- Ability for autonomous behaviour, such as self-control and/or self-optimization
- Internet-based business models, social networks, and communities
- Systems of systems
- New way of cooperating among distributed and intelligent smart networked devices as well as with humans

The diversity of CPSs applications ranges from the mini-scale to the large scale. Thus, CPS is gaining growing importance in networking of embedded computing systems and components of Information and Communications Technology (ICT). CPS is attracting much attention in recent years and is being considered as an emerging technology. It combines computation and communication capabilities with the physical world. It can add more intelligence to social life. It integrates physical devices, such as sensors and cameras, with cyber components to form an analytical system that responds intelligently to dynamic changes in the real-world scenarios. CPS can have wide-ranging applications, such as smart medical technology, assisted living, environmental control, and traffic management.

CPS consists of coupled intelligent objects that can cooperate and organize themselves and make autonomous decisions. By using sensors, these embedded objects monitor and collect data from physical processes and networked systems and then make data globally available. Then, software applications can directly interact with events in the physical world, notably by merging them with the virtual links of Internet of Things (IoT), data and services.

CPS connects strongly to and encompasses popular technologies- Internet of Things (IoT), Industry 4.0, the Industrial Internet, Machine-to-Machine (M2M), the Internet of Everything, TSensors (trillion sensors), and the fog (like the cloud, but closer to the ground). However, in particular, IoT like a platform on which CPS applications are created, much the same way at the World Wide Web is an application running on the Internet. All of these reflect a vision of a technology that deeply connects the physical world with information world. In broader views, the term CPS is more foundational and durable than all of these, because it does not directly reference either implementation approaches (e.g., the Internet in IoT) or particular applications (e.g., Industry in Industry 4.0). CPS was identified as a key research area in 2008 by the US National Science Foundation (NSF) and was listed as the number one research priority by the US President's Council of Advisors on Science and Technology

1.1.2 Introduction of major technologies involved in CPS

CPS involves transdisciplinary approaches, merging theory of cybernetics, mechatronics, design and embedded systems, IoT, Big Data, AI, and other technologies.

(i) Robotics: Robotic systems are an important class of CPS. The ability of robots to interact intelligently with the world rests upon embedded computation and communication, real-time control, and perception of the world around them. Robotics and cyber-physical systems have emerged as a major commercial technology sector, combining software and hardware to enable products from autonomous vehicles to fitness trackers and smart homes. Specialists in robotics and cyber-physical computing work alongside hardware engineers and generalist application developers, employing specific skills and knowledge to integrate and control diverse hardware devices; collect, communicate and analyse sensor data streams; and develop and employ novel algorithms that allow these systems to act in response to their environment. Common development practices in this field involve rapid prototyping and iterative refinement and demand new skill sets from computing professionals. In the case of Robotic Systems, adoption of CPS principles is a necessity to ensure the integration of such systems with Enterprise Systems and Manufacturing Systems. Robot design, integration and state-of-the-art experimental model should include an emphasis on the dual use of real and virtual environments.

Future robotic systems that will realize the vision of CPS include increasingly intelligent robotic surgery systems, robots for assisted living in smart-homes, and robot teams for exploration and emergency response. To enable advanced robotics and CPS applications, a wide range of issues including visual perception, inference from empirical data, motor learning and control, and the design, implementation, and verification of safe and performant CPS.

(ii) Mechatronics: Mechatronics may be defined as an interdisciplinary field of engineering science which aims to integrate mutually and interconnect mechanical engineering, electrical engineering/electronics and computer science (also often called information technology) such that the interactions constitute the basis for the design of successful products.

Now-a-days mechanical engineering products change from mechatronic systems to CPS. CPS is connected, embedded systems which directly record physical data using sensors and affect physical processes using actuators. They evaluate and save recorded data, use globally available services and interact with operators via multimodal human-machine-interfaces.

(iii) Embedded systems: In embedded systems, the emphasis tends to be more on the computational elements, and less on an intense link between the computational and physical elements. In CPS, embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. CPS is the next generation of embedded ICT systems that are becoming pervasive in every aspect of daily life.

Most modern computing devices are ubiquitous embedded systems employed to monitor and control physical processes: cars, aeroplanes, automotive highway systems, air traffic management, etc. In the past, research on embedded systems tended to focus on the design optimization problems of these computational devices. In recent years, the focus has shifted towards the complex synergy between the computational elements and the physical environment with which they interact. The term CPS was coined to refer to such interactions. In CPS, embedded computation and communication devices, together with sensors and actuators of the physical substratum, are federated in heterogeneous, open system-of-systems.

Based on the communication and collaboration among embedded devices these IoT networks can automatize or improve a lot of tasks and processes. These systems are being applied in areas like smart cities, health systems, smart homes, cities, smart grids, medical devices, production lines, automotive controllers, and robotics etc.

(iv) Internet of Things (IoT): CPS is also similar to the Internet of Things (IoT) sharing the same basic architecture, Nevertheless, CPS presents a higher combination and coordination between physical and cyber space. The concept of enabling interaction between intelligent objects is closely related and supported by the imminent change from the "Internet of Data" to the "Internet of Things". The Internet of Things (IoT, also Cloud of Things or CoT) refers to the interconnection of uniquely identifiable embedded computing like devices within the existing Internet infrastructure. IoT can be understood as the Internet of the future that will be suffused with software, information, data archives, and populated with devices, appliances, and people who are interacting with and through this rich fabric". The Internet of Things domain consists of different research areas: "things on the move", "ubiquitous intelligent devices" and "ambient and assisted living".

IoT can realize the function of object identification, positioning and monitoring through the access to the network. IoT and CPS are designed to support applications that can manage enormous amounts of data and a wide variety of data from the environment.

(v) **Big Data:** CPS covers data from M2M and IoT, communications, heterogeneous data integration from multiple sources, security and privacy, to its integration into the cloud Data platforms. Big data analytics is a rapidly expanding research area spanning the fields of computer science, information management. It has become a ubiquitous term in understanding and solving complex problems in different disciplinary fields. These include engineering, applied mathematics, medicine, computational biology, healthcare, social networks, finance, business, government, education, transportation and telecommunications. To effectively synthesize big data and communicate among devices using IoT, machine learning techniques are employed. Machine learning extracts meaning from big data using various techniques which include regression analysis, clustering, Bayesian methods, decision trees and random forests, support vector machines, reinforcement learning, ensemble learning and deep learning.

(vi) **Artificial Intelligence:** Use of Artificial Intelligence (AI) in the context of cyber-physical presents an intrinsic relationship between data, hardware, software and human participants. Cognitive computing provides a promising solution to the industry that encompasses AI, machine learning, reasoning, natural language processing, speech and vision, and human-computer interaction; it will help improve human decision-making and given advances in speech recognition, computer vision and sensor cognition, it would allow for deeper and broader penetration of digital systems. Rapid development in AI have meant that advances like autonomous cars and systems are around the corner and it has also meant that AI as a term has broader meaning as well.

(vii) **Wireless Sensor Networks (WSN) & Intelligent Sensing:** The CPS has been coming into view and will find applications in daily life and business process management. The emerging CPS must be robust and responsive for its implementation in coordinated, distributed, and connected ways. It is expected that future CPS will far exceed today's systems on a variety of characteristics, for example, capability, adaptability, resiliency, safety, security, and usability. With the rapid development of computing and sensing technologies, such as ubiquitous wireless sensor networks, the amount of data from dissimilar sensors and social media has increased tremendously. Conventional data fusion algorithms such as registration, association, and fusion are not effective for massive datasets.

1.1.3 Advantages of CPS

The advantage of CPS is a promising solution for the integration of physical and cyber world due to several benefits such as the following.

(i) Network Integration

CPS has the interoperability with WSNs and Cloud Computing. It may provide the compliance with networking standards. CPS involves multiple computational platforms interacting over communication networks. CPS provides network integration characteristics such as media access control techniques and their effects on system dynamics, middleware, and software that provide coordination over networks control over the timing of network transactions and fault tolerances.

(ii) Interaction between Human and System

Modelling and measuring situational awareness-human perception of the system and its environmental changes in parameters are critical for decision making. This is an absolute necessity for complex and dynamic systems. Some CPSs include human as an integral part of the system which makes the interaction easier because usually, humans are difficult to model using standalone systems.

(iii) Dealing with Certainty

Certainty is the process of providing proof that design is valid and trustworthy. Evidence can include formal proofs or exhaustive tests in simulations and prototypes. CPS is designed to be able to evolve and operate with the new and unreliable environment. CPS can demonstrate unknown system behaviour to study further and evolve into a better system.

(iv) Better System Performance

With the close interaction of sensors and cyber infrastructure, CPS can provide better system performance in terms of feedback and automatic redesign. Better computational resources and cyber subsystems in CPS ensure the presence of multiple sensing entities, multiple communication mechanisms, high-level programming language, and end-user maintenance which further ensures the better system performance by CPS.

(v) Scalability

CPS can scale the system according to demand utilizing the properties of Cloud Computing. Users can acquire necessary infrastructure without investing additional resources. CPS is inherently heterogeneous as it combines physical dynamics with computational processes. The physical domain may combine mechanical motion control, chemical processes, biological processes, and human involvement. The cyber domain may combine networking infrastructure, programming tools, and software modelling. CPS can provide design methodologies and tools that support those methodologies, which scale to large designs and promote understanding of complex systems.

(vi) Autonomy

CPS can provide autonomy due to having sensor-cloud integration. Typically, CPS is a closed loop system, where sensors make measurements of physical dynamics. These measurements are processed in the cyber subsystems, which then drive actuators and applications that affect the physical processes. The control strategies in the cyber subsystems are adaptive and usually predictive.

(vii) Flexibility

Present systems based on CPS provide much more flexibility compared to the earlier systems.

(viii) Optimization

Present sensors and cloud infrastructure offer large optimizations for a variety of applications. This capability opens the pathway for CPS to optimize the system in wide extent.

(ix) Faster Response Time

CPS can provide faster response time due to faster processing and communication capability of sensors and cloud infrastructure. Fast response time can facilitate the early detection of a remote failure, proper utilization of shared resources such as bandwidth etc.

1.2 General Description of the proposed Mission

1.2.1 NM-ICPS Scope

The CPS and associated streams and on all aspects of ICPS research in India will be coordinated under the umbrella of NM-ICPS with a broader scope of Translational Research, Technology Development, HRD, Start-up development. The Mission would institute research through academic collaborations and foster in-depth investigations to understand the processes and phenomena that are in operation leading to the development of CPS applications. A dedicated group of scientists, in collaboration with several other national academic and research institutions of excellence, associated with industry, would carry out major research programmes under directed research and extramural funding mechanisms to meet the requirements of Ministries/ Departments/ Industry. It will establish links with specialized institutions in the country and abroad for establishment and strengthening of advanced facilities for research. The ICPS would also establish workable research collaborations with International academic institutions for the advancement of CPS and associated research in the country.

IT systems will be built around machines, storage systems and supplies that adhere to a defined standard and be linked up as CPS. Using these technologies will make it possible to replace machines along the value chain flexibly. This will enable highly efficient manufacturing in which production processes could be changed at short notice and downtime minimized. The level of efficiency, quality and customisation that will be possible through the combination of automation, Data Science, AI and CPS will revolutionize the economy as a whole.

However, CPS being a disruptive technology, there will be issues related to jobs and job market may shrink in the shorter term. In case of India, it will pose a threat at all levels considering the present scenario. The paradigm shift that CPS is bringing needs to be understood holistically. It is a global phenomenon and a paradigm shift, in a paradigm shift everyone comes down to ground zero. Those with required technical skills will be able to resurrect and reposition themselves to meet the new challenges. The same is true for countries and economies.

In the global IT industry, India has a significant advantage in the IT enablement part of the value chain for CPS. As per NASSCOM estimates, while Indian IT exports are likely to grow in the range of 9 percent annum, the domestic market is expected to rise by a modest 9-12 percent. Indian IT companies are now well recognized for delivering quality, have proved their capabilities of timely execution of projects and are best positioned to ride global recovery. This gives India a unique advantage of positioning itself at the forefront of emerging technologies like CPS (Source: CII report on manufacturing excellence). However, a holistic approach encompassing R&D, technology development, human resource development, innovation and start-up ecosystem development and interdisciplinary collaborations shall have to be addressed timely and the proposed ICPS Mission aims towards that.

1.2.2 Mission Aims and Objectives

(a) Aims

(i) Make India a leading player in CPS technologies.

(ii) Achieve translation of CPS technologies for societal and commercial use, nurture start-ups and increase in the job market.

(iii) Produce next generation technocrats in CPS technologies.

(b) Objectives

(i) To promote translational research in Cyber-Physical Systems (CPS) and associated technologies.

(ii) To develop technologies, prototypes and demonstrate associated applications pertaining to national priorities.

(iii) To enhance high-end researchers base, Human Resource Development (HRD) and skill-sets in these emerging areas.

(iv) To enhance core competencies, capacity building and training to nurture innovation and start-up ecosystem.

(v) To establish and strengthen the international collaborative research for cross-fertilization of ideas.

(vi) To set up world-class interdisciplinary centers of excellence in several academic institutions across the country, that can become repositories of core expertise in CPS and related areas and serve as focal points for technology inputs for the industry and policy advice for the government

(vii) To involve Government and Industry R&D labs as partners in the collaboration centers. Incentivise private participation to encourage professional execution and management of pilot scale research projects

(viii) To set mission mode application goals and foundational themes for excellence for different centers. Set up CPS test beds at various centers.

(ix) To tie up with incubation centers and accelerators to foster close collaboration with entrepreneurship eco-system

(x) To address some of the National issues and development of sector-specific solutions.

Expected outputs/ Deliverables

S. No	Objectives	Expected outputs/ Deliverables
1	To promote translational research in Cyber-Physical Systems (CPS) and related technologies.	Increased core researchers base, Start-ups and spin-offs
2	To develop technologies, prototypes and demonstrate associated applications pertaining to national priorities.	A set of technologies, tools, algorithms to feed into some of the national priorities
3	To enhance high-end researchers base, Human Resource Development (HRD) and skill sets in these emerging areas.	Creation of next-generation technocrats, Scientists, Engineers, Skilled and semi-skilled workforce.
4	To establish and strengthen the international collaborative research for cross-fertilization of ideas.	Global standard Collaborative research for some of the India specific issues.
5	To enhance core competencies, capacity building and training to nurture innovation and Start-up ecosystem.	Start-up companies, job creation and economic growth
6	To set up world-class interdisciplinary collaboration centers of excellence in several academic institutions around the country, with a substantial amount of funding to enable them to achieve significant breakthroughs.	Dedicated translational research centers aimed at taking Academic output to Industry/Market

S. No	Objectives	Expected outputs/ Deliverables
7	To involve Government and Industry R&D labs as partners in the collaboration centers. Incentivise private participation to encourage professional execution and management of pilot scale research projects	Enhanced participation of private industry in R&D, PPP model demonstration in technology development
8	To set mission mode application goals and foundational themes for excellence for different centers. Set up CPS test beds at various centers.	Proven prototypes, national test beds for sector-specific solutions
9	To tie up with incubation centers and accelerators to foster close collaboration with entrepreneurship eco-system	Enhanced delivery mechanism
10	To address some of the National issues and development of sector-specific solutions.	Technologies to address some of the national issues.

1.2.3 Sub-Missions or Programmes under NM-ICPS

Towards realization of objectives of the Mission in full measures, the implementation shall be through 5 sub-missions or Programmes

1 **Technology Development** through expert-driven research, consortium-based mission-oriented research through cluster-based network programmes, directed research for the specific requirements of Industry, other Govt verticals and International Collaborative Research Programmes.

2 **Centers of Excellence:** Dedicated Centers to carryoutdomain-specific translational research, training and capacity building, product, process and prototype development.

3 **HRD and Skill Development:** to generate next generation technologists and advanced skill development.

4 **Innovation, Entrepreneurship and Start-up Ecosystem:** To enhance core competencies, capacity building and training to nurture innovation and Start-up ecosystem.

5 **International Collaborations:** To establish and strengthen the international collaborative research for cross-fertilization of ideas.

1.2.4 NM-ICPS and National Priorities

NM-ICPS programme rightly fits into National initiatives like Sustainable Development Goals (SDGs), Digital India, Make-in-India, Industry 4.0, SMART Society 5.0, Skill India and Start-Up India. The ICPS Mission facilitates and caters to these national initiatives by developing sector-specific core technologies, human sources development and develops advanced skill sets and will feed into Innovation and Start-up ecosystem of GoI. The following are some of the national priorities wherein ICPS has a role in their implementation and success.

(1) Sustainable Development Goals (SDG): NITI Aayog has been entrusted with the role to co-ordinate 'Transforming our world: the 2030 Agenda for Sustainable Development' (SDGs). Moving ahead from the Millennium Development Goals (MDGs), SDGs have been evolved through a long, inclusive process for achievement during 2016-2030. The SDGs cover 17 goals and 169 related targets resolved in the UN Summit meet 25-27 September 2015, in which India was represented at the level of Hon'ble Prime Minister. These SDGs will stimulate, align and accomplish action over the 15-year period in areas of critical importance for the humanity and the planet. The NM-ICPS has a role in developing technologies, tools, testbeds, prototypes, algorithms, visualization tools to augment the Ministries/ Departments implementing the SDGs. The technologies range from Data analytics, IoT, CPS testbeds, security, AI, ML, DL and Quantum technologies.

(2) Industry 4.0: The fourth industrial revolution is already on its way. Revolutions are fast, disruptive, destructive and irreversible. India needs to prepare for the inevitable change on the manufacturing front. Industry 4.0 will be a challenge and may also have continued advantage in the global manufacturing industry. The world has already witnessed three industrial revolutions, which gave disruptive leaps in industrial processes resulting in significantly higher productivity. The first improved efficiency through the use of hydropower, increased use of steam power and development of machine tools; second brought electricity and mass production (assembly lines); the third further accelerated automation using electronics and IT and the fourth industrial revolution is rising. While some areas will see fast and disruptive changes, others will change or evolve slowly. This time, physical objects are being seamlessly integrated into the information network. Internet is combining with intelligent machines, production systems and processes to form a sophisticated network. The real world is turning into a giant information system. Industry 4.0 provides relevant answers to the fourth industrial revolution. It emphasizes the idea of consistent digitization and linking all productive units in an economy. Main characteristic of industry 4.0 shall be SMART robots and Machines, robots and humans will work hand in hand, speak on interlinking tasks and using smart censored man-machine interfaces. The use of robots is widening to include various functions like production, logistics, office management and basic customer services. The robots performance requirements are significantly different for each industry/ sector. India should not miss this Fourth Industrial revolution.

(3) New Quality of Connectivity: As of now, the connectivity is a feature of the digital world, in Industry 4.0 the Cyber (digital) world and physical (real world) are connected. Machines, work-pieces, systems and human beings will constantly exchange digital information via Internet. This means physical things will be linked to their data footprints (source: CII Manufacturing Excellence).

(4) Digital India: The Government has estimated an investment of US$ 26 billion in technology in coming years for digitization, infrastructural improvements, and push for manufacturing and technology in healthcare and agriculture. The Indian government's Digital India programme, which aims to transform India into a digitally-empowered society and knowledge economy, will bring forth a numerous opportunities for large number of IT industry players to develop platforms providing government services and information to people in all parts of the country. Security and data accessibility solutions will see increased demand for data scientists from the government.

(5) Smart Cities: The development of 100 smart cities, under 'Smart Cities' GoI initiative, will require companies to build consortium to bag these projects. This will drive investments at all layers of ICT infrastructure, benefiting companies which are into technology consulting, telecommunications, networks, hardware infrastructure, managed services and systems integration. The designing of 'SMART cities' involves convergence of spatial data, census data, crime data, natural resources, transport, energy, education data etc. to arrive at location-specific city models. CPS is the core discipline which will enable in development of technologies.

(6) Society5.0: It is a society in which the different needs of members are distinctly met through the provision of the relevant goods and services in the desired amount to the people who need them, and in which the entire people can be assessable to top-notch services and live a convenient, vibrant life that takes into account their differences such as age, gender, religion or language. This concept is anticipated to introduce transformational change in an expansive scope of industrial solutions such as manufacturing, logistics, sales, transportation, medical care, finance and public services. This eventually will have effect on people's work and lives by giving them encouragement to realize high quality of life. Defining the Smart society and as well support systems are being laid out towards realizing the goal for Smart Society development, adding new value in the society. To develop and realize an environment in which people and robots and artificial intelligence (AI) systems exist together and work to enhance personal satisfaction by offering finely separated services that meet different consumer needs is a challenge. The general public should likewise be capable of foreseeing potential needs and giving services to bolster human activities, determining deficiencies in service due to societal disparities and empowering anybody to be a service provider. Then again, on account of the high level of convergence amongst the Cyberspace (internet) and the physical world in a super brilliant society, the harm that cyber-attacks can exact on this present reality will likewise turned out to be progressively extreme and may truly influence individuals lives, including their financial and social exercises. Ways and means to accomplish a more elevated amount of security is required. Such endeavours will serve as a wellspring of mechanical quality and universal intensity.

(7) Make in India: The government's 'Make in India' campaign aims at spurring a manufacturing-led growth with more focus on the ease of doing business than on an incentive-linked investment climate. The push for manufacturing has two aims, to create jobs and lift growth. According to the

India Electronics and Semiconductor Association (IESA), an industry body, the electronic system design and manufacturing (ESDM) industry will benefit from the government's Make in India campaign and is projected to see investment proposals worth Rs 10,000 crore over the next two years. CPS becomes central theme in Make in India.

(8) Skill India & Stand-up India: Govt focus on enhancing the skill sets both at ground level and high value areas. The efforts facilitates or catalyses initiatives that can potentially have a multiplier effect as opposed to being an actual operator in this space. The approach is to develop skilled workforce in all advanced areas and convert disruptions in to an opportunity.

1.3 Problems to be addressed

Future generations of CPS engineers and scientists must be ready to tackle the increasingly complex problems facing society. While it is possible for researchers to gain some theoretical CPS education from the growing CPS scientific literature, it is believed, that theoretical understanding alone is not sufficient particularly when CPS involve complex interactions between the cyber, physical, and sometimes, human realms. To substantially conclude about the nature and magnitude of problems we ought to inspect CPS and related area both at National and International perspectives and gaps there to.

1.3.1 Application Problems

There are innumerable problems which can be addressed through the CPS Mission. Identification of the application areas for mission mode execution can be made based on prioritized needs of the country, and the interests of the various stakeholders and industry.

(1) Energy Systems and Smart Grids

(2) Water Systems and River Grids

(3) Water grids, energy, agriculture and health

(4) Advanced manufacturing

(5) Non-terra habitat systems (underwater, space, moon, mars systems)

(6) Satellites networks for defence and civilian applications

(7) Autonomous drone systems for farming, surveillance, security, logistics, transport

(8) Large-scale precision agriculture in arid regions

(9) Intelligent & Compassionate Cities

(10) Traffic and Internetworked Mobility Systems

(11) Autonomous Transport Systems

(12) High-quality health diagnostics and prognostics Systems for everyone

(13) High-quality Education Systems for everyone

1.3.2 R&D Problems

There is a broad range of areas for possible future research into foundational aspects of CPS, identified in the sections below.

(a) Multi-Domain Modelling, Simulation and Analytics

(1) Multi-domain modelling

(2) Hardware in the loop simulation/emulation

(3) Real-time/ High-Performance Computing based simulation/emulation

(4) Machine learning techniques for modelling

(5) Artificial Intelligence techniques for inference and understanding

(b) Control, Optimization, Planning and Policy

(1) Distributed and Hierarchical Control

(2) Hybrid Systems Control

(3) Model Predictive Control

(4) Stochastic Control and Reinforcement Learning

(5) Real-time optimizationfor control

(6) Artificial Intelligence techniques for Reasoning and Planning

(7) Distributed and collaborative autonomous systems

(8) Policy-based control for Humans in the loop

(9) Mechanism design and games for large-scale cyber-social systems

(10) Control over Networks

(11) Distributed signal processing and control over a network of resource challenged devices

(12) Signal processing and control over wireless networks (with packet loss, and packet delay)

(c) CPS Science

(1) Complex Systems Science

(2) Stability and Chaos

(3) Emergent Properties

(4) Human and Social Agents

(5) Category theory and its applications for CPS

(6) Mathematics for CPS

(d) CPS Systems engineering

(1) Co-engineering of Hybrid Systems

(2) Safety & Reliability Engineering, Formal techniques for design and validation

(3) CPS Security, device biometrics, information and data security

(4) Distributed Programming Models, Distributed Run-time environments, Software development environments,

(5) Real-time and Embedded Systems,

(6) Low latency, large scale, reliable wireless communication

(7) Sensing and Actuation Systems,

(8) Energy efficiency and low power, low-cost electronics for CPS

(9) Human-Cyber interfaces

(10) Multi-dimensional sensing, Sparse sampling/Actuation, Feature/ Information sensing

(11) Signal Processing Techniques

(12) CPS Experimental Test Beds

These topics are by no means exhaustive and we should tap into the research community for further inputs

1.3.3 HRD and Skill Development

CPS is a disruptive technologies and technology-driven system. It may pose job loss once complete automation is undertaken. At the same time, it provides an opportunity for job seekers to create job avenues in highly skilled areas. CPS is a global phenomenon and it operates on fusion of technologies. Therefore, India should concentrate on an interdisciplinary approach and develop cross-cutting fusion technologies. Thus, the proposed programme aims at providing the state of the art training and capacity building for creation of next-generation technocrats, engineers and scientists. It will address at various segments of education system like graduates, postgraduates, Doctoral, post-doctoral, skilled and semi-skilled segments. NM-ICPS aims at addressing most of the HRD issues in a holistic manner preparing the country for the next technology revolution.

1.3.4 Translational Research

India has the highest number of researchers and developing technologies which have potential in the industry. But it operates on watertight compartments and silos. There is a requirement to bring in a middle order structure which translates the academic R&D into technologies to industry. NM-ICPS mission which proposes the creation of Center of Excellence basically aims at translational research that is converting the academic research into industry oriented technology.

1.3.5 International Collaboration

Now after the advent of the internet, the world has become a global village, innovations happening across the globe are not only affecting the global economy but also the global skill. The concept of leapfrogging has become classic and continuous for some economies. The technology changes are very fast, and at the same time, it becomes obsolete very fast. Therefore, catching the international development is the need of the hour. International collaboration and collaborative research proposed by NM-ICPS aim at bringing the global research paradigms and connecting to the Indian researchers. Some of the issues could be very specific to India and global research community particularly NRI researchers would evolve a valuable solution to address some of the Indian specific problems. NRIs would like to contribute for the development of India at various scales. The best brains in the international research are mostly from India. ICPS will provide a platform for NRIs to contribute the developmental aspect of CPS research.

Systems as a separate phrase for research started about a decade ago in USA. Europe (especially Germany & France) have been at the forefront of CPS research in the form of Systems Engineering, for some years, thanks to their strong background in industrial engineering and manufacturing. Under the Systems Engineering domain, aspects related to safety, reliability, real-time guarantees, robust engineering, formal techniques for design and validation etc have been developed for mission-critical systems. However, the intersection of complex systems science and systems engineering, to engineer large-scale systems, including humans, is only just beginning. Thisis reflected in the agenda of some of the new interdisciplinary centers like the IDSS in MIT and Data Science Institute at Columbia University

TABLE: 1.2 International research institutes

Name	Website	Start Date	Remarks
Netherlands Platform Complex Systems	http://www.npcs.nl/	2015	Coordinates activities across universities in NL
Institute for Data, Systems and Society	https://idss.mit.edu/	2014	Focus on human and social systems
Data Science Institute	http://datascience.columbia.edu/		Data Science across multiple disciplines
Center for CPS and IoT	http://cci.usc.edu/		CPS & IoT
Link Lab, University of Virginia	http://linklab.virginia.edu/	2015	Focus on CPS. Will be a full-fledged academic department
PRECISE, UPenn	http://precise.seas.upenn.edu/about-us/	2008	Interdisciplinary research center
Vermont Complex Systems Center	http://www.uvm.edu/~cmplxsys/	2007	MS in Complex Systems and Data Science
Center for Embedded CPS, UC Irvine	http://www.cecs.uci.edu/ http://www.mecps.uci.edu/	2001	Full academic department. Offers a Masters in Embedded & CPS
Univ. of Michigan Center for Study of Complex Systems	https://www.lsa.umich.edu/cscs/	1999	
Complexity Sciences Center, UC Davis	http://csc.ucdavis.edu/Welcome.html		Focus on physics and basic sciences.
Center for CPS, Cranfield University	https://www.cranfield.ac.uk/About/People-and-Resources/Schools-institutes-and-research-centers/satm-centers/Center-for-Cyberphysical-Systems		Focus on autonomous vehicles (drones)
Department of CPS, German Center for Artificial Intelligence	http://www-cps.hb.dfki.de/home		Focus on correct, secure and safe design,
Allen Institute for AI	allenai.org/		Focus on AGI (Artificial General Intelligence)
Google Brain Research	https://ai.google/brain-team		Focus on AGI (Artificial General Intelligence)
BAIR (Berkeley Artificial Intelligence Research Lab)	bair.berkeley.edu		Focus on Autonomous vehicles, robotics, AGI and computer vision
CSAIL (MIT Computer Science & Artificial Intelligence Lab)	https://www.csail.mit.edu/		Focus on Autonomous vehicles, robotics, AGI and computer vision

Name	Website	Start Date	Remarks
SRI	https://www.sri.com/		Translational research institute with focus on incubation and commercialization
Vector Institute	https://vectorinstitute.ai/		Focus on Autonomous vehicles, robotics, AGI, Speech and computer vision
CMU (Carnegie Mellon University)	https://ai.cs.cmu.edu/		Focus on Autonomous vehicles, robotics, AGI, Speech and computer vision
Open AI	openai.com		OpenAI is a non-profit AI research company, discovering and enacting the path to safe artificial general intelligence.
University of Oxford	http://www.cs.ox.ac.uk/research/ai_ml/		Focus on computer vision and Artificial General Intelligence
Montreal Institute for Learning Algorithms (MILA) and the Institute for Data Valorisation (IVADO)	https://mila.quebec		Focus on fundamentals of Artificial Intelligence, AGI, Speech and vision
Stanford University	http://ai.stanford.edu/		Focus on Autonomous vehicles, robotics, AGI, Speech and computer vision
University of Toronto	https://www.utoronto.ca/news/tags/artificial-intelligence		Focus on Autonomous vehicles, robotics, AGI, Speech and computer vision

CPS Week is an annual marquee event which collocates 5 conferences related to CPS. In addition, ACM and IEEE have also created new journals for CPS. There are numerous IoT conferences worldwide and as we discussed earlier - there is a significant overlap of IoT and CPS. Apart from this, major conferences include NIPS(Neural Information processing systems)ICML (International Conference on Machine Learning) and AAAI(Association for the Advancement of Artificial Intelligence).

1.3.6 Innovation, Entrepreneurship & Start-up Ecosystem

The global innovation paradigm operates in a cycle wherein innovative ideas are funded to generate prototype/ PoC and patents leading to a series of start-ups. Established industry players scout for technologies through Patent portals, start-ups monetize their patents. However, this paradigm is loosely operating in India. An analysis of International Patents data will through the huge problem that India is facing in the area of monetization of innovations.

a) Patent Landscape analysis in Cyber-Physical System and related area

This section provides patent landscape analysis in Cyber-Physical System and related area. The description includes top assignees, CPS key players; CPS patents' top IPCs, and the technology function matrix.

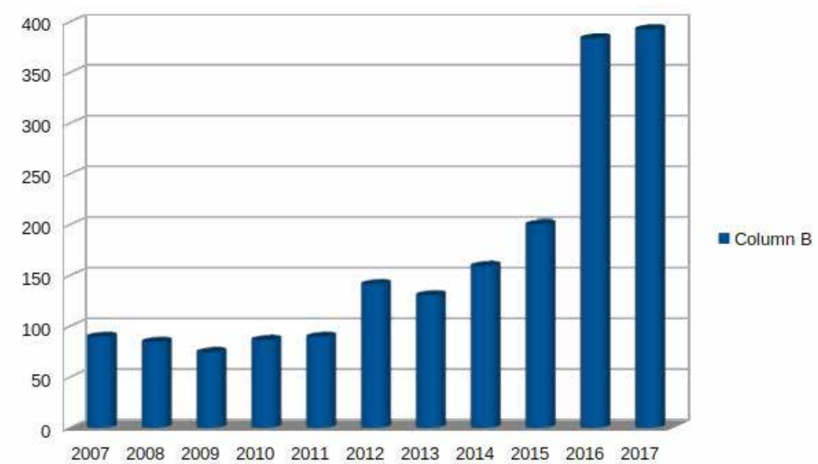


Fig. 1.1: Shows the patent publishing trends from 2006 to 2017.

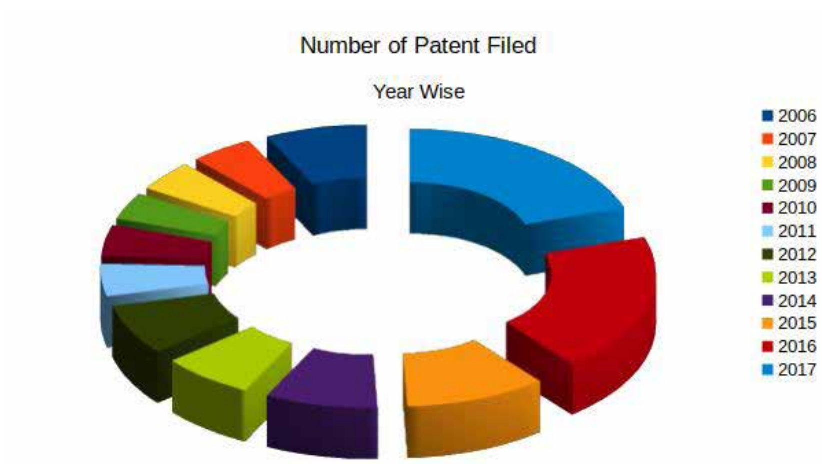


Fig. 1.2: Number of Patents Filed per year in CPS and related area

Top Ten Assignees in CPS and related area

The top 10 assignees are Siemens, Rockwell, ABB, Fisher Rosemount, Honeywell, Mitsubishi, Schneider, General Electric, Invensys, and Fisher controls. The leader is Siemens from Germany with 107 patents followed by Rockwell from the USA with 59 patents.

Rank	Top assignees	Country	Patent count
1	Siemens	Germany	107
2	Rockwell Automation Tech	USA	59
3	ABB	Switzerland	52
4	Fisher Rosemount Systems	USA	38
5	Honeywell International	USA	24
6	Mitsubishi Electric	Japan	23
7	Schneider	France	19
8	General Electric	USA	17
9	Invensys Systems	UK	14
10	Fisher Controls	USA	11

Fig. 1.3 List of Top Assignees

In third place is ABB from Switzerland with 52 patents. Fisher Rose-mount and Honeywell from the USA follow ABB. The former has 38 patents, and the latter has 24 patents. Siemens is a pioneer in the field of electronics. Siemens's patent numbers are approximately equal to the sum of the patents for enterprises ranked 6 to 10. Siemens holds a leading position in this field. The top ten patent assignees account for 1/4 of the total number of CPS patents found in the database. Bosch, Trumpf, SAP, and Festo are four additional German companies holding CPS patents.

The top 10 IPC classes for global CPS utility patents found are depicted in Figure 1.4 of the top 20 technical IPC categories (to be thorough in the IPC category explanation) and the CPS patent counts belonging to these IPC classes. For the leading International Patent Classification (IPC) analysis, the G05B (Control or regulating systems in general; functional elements of such systems; monitoring or testing arrangements for such systems or elements) class dominates the field of CPS. About ⅓ of the patents belong to G05B19/418 (Total factory control, including control of a plurality of machines, direct or distributed numerical control, flexible manufacturing systems, integrated manufacturing systems, and computer integrated manufacturing) with 428 patents.

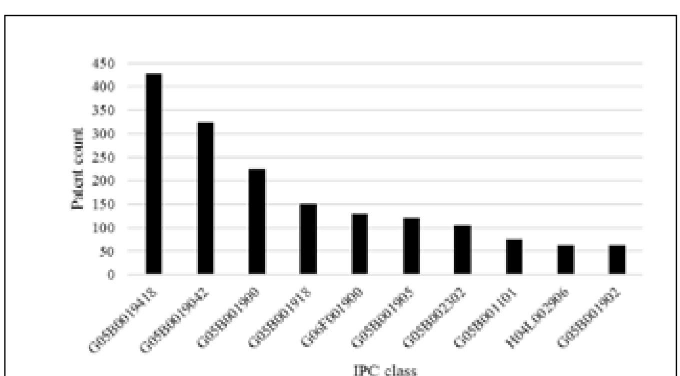


Fig.1.4: Top IPC Categories

The core concept of CPS is to integrate all devices. The G05B19/042 (Using digital processors), G05B19/00 (Programme control systems), and G05B19/18 (Numerical control) belong to the G05B class and are ranked second, third, and fourth with 325, 225, and 150 patents. G06F19/00 (Digital computing or data processing equipment or methods, specially adapted for specific applications) is a classification of data processing and computing and ranked fifth with 130 patents. Similarly, G06F15/16 and G06F07/00 relate to data processing with 48 and 41 patents. H04L29/06 and H04L29/08 relate to data transmission with 64 and 60 patents. Therefore, control, data processing, and data transmission are the three main technologies of this field. CPS requires control technology to achieve optimization and prediction. Likewise, data transmission and processing between different devices are also important to achieve the purpose of CPS.

(b) Current status of CPS in India

Indian Institute of Science, Bangalore has set up a center exclusively focused on Cyber-Physical Systems in 2011, which is an academic center of IISc, and is funded by a philanthropic grant from the Robert Bosch Foundation through Bosch India. IISc Journal brought out a special issue devoted to CPS in 2013 and is holding the first international Symposium on CPS in India. IIT Hyderabad has set up a CPS Innovation hub to develop and prototype ideas for a smarter planet.

CSIR-CEERI has about 40 scientists in the department of Cyber-Physical Systems. This department is organized into following verticals: (i) Cognitive Computing (ii) IoT (iii) Integrated System (iv) Signal Analytics (v) Automation and Control and (vi) Power Electronics. Major technology development initiative of the group are (a) Smart Water Grid (IOT based water quality monitoring system is being deployed in Jaipur); (b) Cyber-Physical Social System for water management in water-scarce agricultural region of Jhunjhunu in Rajasthan (optimizing use of water for both drinking and agriculture); (c) Multi-modal sensor based intelligent surveillance for large installations (a service-oriented product being developed with an industry).

Almost all the IITs, some of Central/ State Universities have been researching in various foundational and applied aspects related to CPS, especially in the areas of controls, hybrid systems, AI, data science and wireless sensor networks. This research is also spread across many different departments - truly reflecting the broad and interdisciplinary character of the field. However, there is a lack of a coherent view on CPS as a discipline distinct from existing research areas and there is a dearth of dedicated interdisciplinary collaboration centers in this space. Hence most of the research is still largely in silos, whereas true progress in CPS, especially on the applications front, will only emerge via interdisciplinary collaborations. Further, a lot of CPS research is either theoretical or is confined to small experimental and system development work at the laboratory level. As CPS as an area is heavily interdisciplinary, satisfactory progress in the area, in terms of developing an understanding of building complete CPS systems, will come not just by individually funded projects, but by supporting multidisciplinary and multi-institutions teams that are given a mission to address a specific problem over a given time frame. Two or three such mission mode projects will need to be supported. There need to be put in place carefully evolved and enabled review mechanisms that will help shepherd the projects towards success.

(c) Gap Analysis

A gap analysis is to establish specific target objectives by looking at the mission statement, strategic goals and improvement objectives. The next step is to analyze current processes by collecting relevant data on performance levels and how resources are presently allocated to these processes. Lastly, after comparison of target goals against current state, it can then draw a comprehensive plan that outlines specific steps to take to fill the gap between its current and future states and reach its target objectives. The analysis provides a basis for predicting research and development future trends and helps policymakers manage technology changes that will result from CPS.

Gap Analysis: Identifying the gap between current situation and the future state specifying uptake tasks.

Gap 1: Lack of collaborative/interdisciplinary approach

While many of the above topics are studied in silos in various departments in academic institutions, there is truly a need to study such systems holistically and hence motivates the need for an interdisciplinary approach.

Gap 2: Lack of scale for experimental validation

CPS as a distinctive area makes sense when the scales of the systems are large. Experimental validation of ideas/theories/technologies at large scales - is a skill to be mastered. Due to various practical and financial reasons, university research is largely restricted to theoretical or laboratory scale. While both still need to be pursued, enabling pilot/large scale testbeds/laboratories will be a critical missing piece and great value addition.

Gap 3: Lack of facilities to support large scale experimental test beds

Large-scale experimental test-beds are difficult to construct, maintain and operate, solely by academic institutions. This will require university-industry partnerships - for example, imagine the Large Hadron Collider experiment. Can we strive for the CPS version of such effort in India to foster fundamental advances?

Gap 4: Lack of connection with stakeholders and translators to convert outputs to outcomes

CPS application projects - in areas of large societal/industrial impact, need to have all the stakeholders on board from the beginning. The views of the stakeholders regarding what application problems to focus on will be of great importance to ensure practical applicability of the research. At the same time, this has to be facilitated in a way which does not constraint/suffocate the academic researchers for them to make foundational advances. Involving "technology translators" at an early stage, i.e. entrepreneurs/agencies/companies which can convert the research technologies to commercial products should also be looked into. Again this needs to be done keeping in mind the timescales and limitations of academic research. Thus a truly hybrid approach, via collaboration centers, might need to be evolved.

Gap 5: Lack of large-scale mission mode project management capabilities

Academic researchers usually work best individually (with a small team of students and research project staff). Large-scale experimental projects, especially those who are mission mode, will necessarily involve large teams and multiple interdependent tasks. Effective project management of these will be critical to ensure a good chance of success. The lack of a unified theoretical framework of network and physical resources to be used are the main obstacles in developing a CPS.

Chapter 2

Mission Beneficiaries

2.1 Stakeholders Consultations

Indian business, research institutions and enterprises are sitting on a goldmine of opportunities. CPS has become one of the more talked about topics and has tremendous potential in India. With social media usage on the rise and increased adoption of technology by all most all sectors, CPS is on the agenda of boardrooms across Indian enterprises. However, most Indian enterprises are still coming to terms with this concept. Apart from the business & industry, the Government through its various Ministries and arms, research organizations and institutes of higher learning are yet another source of CPS technology development and consumption. While everybody realizes the importance and the potential of CPS not much has been done and achieved by way of a structured and concerted approach to channelize the resources and efforts to exploit and leverage the possibilities of using CPS in the country. In addition, the CPS domain of the country has a very large number of stakeholders having their stakes very divergent fields. To handle the enormous task of preparing a strategic roadmap for this Mission, consultative approach resortedand same was adopted with an objective.

(1) To evolve models for promoting and fostering CPS and applications in the country.

(2) Assess the present status of the industry in terms of market size, different players providing services across sectors/ functions, opportunities, SWOT analysis, policy framework, present skill levels available etc.

(3) Market landscape survey to assess the future opportunities and demand for skill levels.

(4) Gap analysis in terms of HRD.

(5) Evolve a strategic roadmap and micro-level action plan clearly defining roles of various stakeholders- government, industry, academia, industry associations and others with clear timelines and outcomes.

(6) The international scenario examined while evolving strategic roadmap.

2.1.1 Stakeholders Engagement

Tomake this Detailed Project Report (DPR) comprehensive so that the Mission objectives are realized in full measures, it was decided to anchor it in the aspirations of stakeholders, champions and enthusiasts of CPS in the country, who would be the key drivers of the new revolution. Accordingly, a consultative framework was conceived- both through face-to-face interactions and over the internet. A series of interactions with experts from academic, R&D, industry and government institutions was organized at geographically spread-out places, details of which are given in Table 2.1.

(a) METHODOLOGY

The methodology adopted for the study was two folds that are primary research and secondary research.

(a.1) PRIMARY RESEARCH

The primary research consisted of obtaining feedback from the national consultative meetings/ workshops, feedback through a set of questionnaire to Stakeholders. An open-ended questionnaire was evolved to collect insights/ foresight/ ideas and integrate them into this DPR. In all nine questions were posed, seeking inputs on areas for research and development, human resource development, innovation, entrepreneurship, start-ups, Centers of Excellence, international collaborations etc. The list of participants is provided in Annexure-A.

TABLE 2.1: CONSULTATIVE MEETINGS

S No	DATE	Place	No of Participants
1	22& 23/06/17	IISc, Bengaluru	56
2	28/06/17	IIT Delhi, New Delhi	31
3	06/07/17	ASCI, Hyderabad	34
4	19/9/17	DA-IICT, Gandhinagar	43
5	24/9/17	BAMETI, Patna	45
6	27/9/17	C-DAC, Pune	28
7	06/10/2017	Inter-Ministerial Meet, New Delhi	55

TABLE 2.2: RESPONSES RECEIVED FROM THE STAKEHOLDERS

S. No.	CATEGORY OF STAKEHOLDER	NUMBER OF SUGGESTIONS/ RESPONSES RECEIVED
1	Academics and Researchers	1000+
2	Ministries/ Departments/ End Users	
3	Industry associations, Industry/ Service Providers (SP)	

Suggestions and feedback received from the stakeholders during the consultative meetings are presented in following sections:

I. National Mission on ICPS

- We should have CPS developed, responsive to the needs of our country which has a huge working population that has to be provided jobs. Therefore, it would be necessary to understand the challenges for India, the potential for application/intervention of CPS therein and deliver the solutions on the ground, to benefit the people.
- We shall have to reach out institutions and industry in a big way, even those overseas- to develop and implement these systems. We must act swiftly and gain the technological edge in this area, at a global level.
- Linkage of R&D with entities who work for technology commercialization is needed to be included in this mission. For sustainability of CoE in long-term (for further operation), there should be the key criterion before selection. This is possible only if there is a substantial contribution from industry which must gradually increase over a period.
- Instead of creating a new CoE, upgradation of an existing CoE set up earlier by different ministerial departments relevant to ICPS mission must be considered. Industry partnerships in CoEs (involve Industries who want to integrate with CoEs is on 50:50 basis to solve the problems identified by industry by CoEs).
- As this mission is hugely interdisciplinary, multidisciplinary, to bring different stakeholders together for deep R&D in CoEs, three approaches can be used such as problem-centric approach, tool-centric approach and mixed approach (using other two approaches simultaneously). In the tool-centricapproach, R&D is driven by developing multiple tools for the problem domain, whereas the problem-centric approach is driven by developing one tool for many application areas. In this CPS mission, it is best suited to ensure a mixed approach, because of the interdisciplinary nature of the Cyber-Physical Systems.
- It is not possible for solving all problems of India like poverty, water, unemployment, health, etc., and the focus should be sharply on selected technology areas that provide solutions which have mass impact on the society.
- Standardization of CPS related technologies is needed covering three aspects- Hardware, Communication, and Human. DPR should also cover related human standards in addition to the other two, already included in DPR. We have to couple the already existing standardizations such as Machine to Machine which are in public domain, in the mission.
- The aim of Mission should also be to create more human resource trained in CPS in

consultation with industryso that industry will accept it and make both side gains.

- Basic needs of the society be formulated as real-time problems and treated as objectives in CPS. Example: Smart Meters for prediction of failures, consumer behaviours etc. in Power, Water, Gas supply systems, etc.
- There is a need to facilitate collaboration and extend financial support to individual researchers and small industry R&D groups to bring them into mainstream research
- Establish sub-centers for R&D in remote tier-II & tier-II institutions without proper resources, to give opportunities to students and faculty there.
- Demonstration Centers should be established under the Mission that can provide hands-on-training to students, entrepreneurs, start-ups, and MSMEs, on core CPS technology. They can also be used as common prototyping and testing facilities.
- R&D areas identified should be aligned with the National Mission and mandatorily be output driven.
- Programmes that promote cross-disciplinary collaborations, like Engineering & Medical fields must be launched
- Some prize money/ reward/ incentive should be introduced for excellence in competitive R&D. Competition in R&D will drive towards a high quality of deliverable outputs (product or idea).
- CPS is not new, and alot of technologies already there on the shelf should be used to develop further applications. The approach could be to identify the readiness level (or maturity) of different technologies in CPS and support them rather than support initiatives start from scratch.
- India will be a deficient country in next twenty years in term of water, mass transport, education, energy, security, etc. These deficiencies should be overcome through CPS based solutions.
- India will be a job and experience deficient country on the one hand due to automation and on the other due to many smaller countries doing the jobs at much more cheaper costs. CPS must be judiciously used to overcome this deficiency.
- In ICPS mission one research area is in the field of quantum computing. As many developed countries have already started research in the quantum computing area and India is lagging behind in this particular research area, so to fill the gap our country must start research work in Quantum computing area.

- Department of Space suggested taking up Proof of Concept (PoC) with all stakeholding central ministries/ departments.

II. Technology Development

- Open source platforms should be created for testing of prototypes, to drive the research on CPS, towards translation. Data (Repository) sharing policies should be formulated for rudimentary data gathering, sharing and fair usage from every possible source (agencies, industry, government, etc) example: retail data from telecom services. A cloud-based platform/ repository of data should be developed that can be used freely by different agencies working on CPS based products/ services. Example of such repository is NEON-2016. An open platform should be extended to researchers working in this area to communicate with each other to overcome the hardships in the process of research. It will also help to find a solution to the common problem in the ICPS and related area because there is a chance that the hurdles in one research can be a strong pillar for others research. Open information portal for UG/PG students for technologies open for research/project by the government. A portal/platform for industry-academia-Government to share the problems faced by each other.

- Assurance is a performance metric of a system that includes safety and reliability (to give correct results) and is very much needed from CPS system, as they work on the core. Towards this, investment in STQC (Standardization, Testing and Quality Certification) is required.

- System security is of utmost importance for the technologies deployed. Suitable protocols and standards should be formulated for secure CPS implementation and functionality.

- Major thrust areas of (horizontal or platform) R&D can be Sensing Technology, Human Machine Interaction, IoT on large Scale, Security anomalies. Thrust areas with a focus on translational research could be: Agriculture, Healthcare, Urban Infrastructure, Smart Manufacturing, etc. At least top 3 industries should be identified for end-to-end research and deployment (not stopping at development). CPS is well suited for predictive as well as preventive maintenance and will find huge application in railways, power systems, etc. Drainage system monitoring and waste management should be one important issue that should be taken up in this CPS mission.

- There should be approaches/ incentives identified to catch the students young and train them on CPS skills based on industry needs.

III. Centers of Excellence (CoEs)

- CoEs should focus on research covering all aspects of technology life-cycle-research, technology development, translation, and management. CoEs should be funded to excel in verticals (application areas) to be useful to the society; in the process, they will also develop the horizontals (core areas) too. CoEs should be interacting with each other; there should be an over-arching Meta CoE that can oversee their functions and integrate them.

- Full-time managers/faculty should manage CoEs. In a CoE, the academia, industries, government and user agencies should be working together side by side. CoEs should have a hub-and-spoke architecture- that allows other academic institutions, research institutions, industry, industry associations, SMEs to plug in.

- Some suggestion on areas for CoEs to focus on: Public Distribution services, Healthcare analytics/ management, Networked automated systems, CPS security, Manufacturing (including manufacturing of biopharmaceuticals), Dependable predictive/ warning systems, Disaster monitoring and prediction. CPS should be aggressively used to solve water problems, energy problems, and sanitization that can impact a large segment of the population. 3-D Electronic printing is a huge prompt for CPS technology. 3-D Electronic printing, required for customizing solution should be facilitated through CoEs. Some suggested areas are- safe and energy efficient logistics, driverless cars.

- CoE must be based on cluster model approach with all stakeholders participating and benefitting from it. Tier II and Tier III colleges and polytechnics should be allowed to be the part of the CoEs, as spokes that reach out remote locations and address local problems.

- Line ministries should also participate financially in the CoEs focussing on the verticals. DST should be providing funds to run the CoEs for five years, to ensure sustenance.

- Intellectual Property rights are often contentious issues which the industry would like to clarify before they are asked to participate in CoEs. Ownership of IP should be given to the hosting Institute of CoE. A mechanism is, however, is required if multiple institutes are participating. The DPR should provide a basic minimum guideline on IP sharing which can be modified as per the needs of industry. IPR sharing is a big stumbling block in projects involving industry; these need to be addressed in the DPR itself and should not be left to CoEs. Institutions being considered for the support that lead to IP generation must also be funded for international patents.

- Test-bed facilities for testing solutions/prototypes must be created, a large number of innovative ideas die in the absence of business models that can be the pull-factor.

- Conclave for CoEs once in a year should be organized to discuss the problems faced, future challenges and possible solutions by each, to benefit collectively.
- Central Government should contact State government for the execution of CoEs objectives that are relatedto regional issues.
- There must be an awareness/training programmes in CPS and related areas for government officials and working personnel who are not able to understand the jargon in the context of ICPS national mission.

IV. HRD & Skill Development

- Introduce a scheme on the lines of "Visvesvaraya Ph.D. Scheme for Electronics & IT" of MiETY, exclusively for research in CPS. Under this programme, Industrial Organizations of the country get an opportunity to collaborate with academic institutes of their choice for Research & Development and to produce skilled Ph.D. candidates in the areas of their interest with generous support from DeitY. The fellowship amount could be on a higher side than other schemes and kept highly competitive. High-value PG and Doctoral fellowship jointly with Industry (like Microsoft, Ericsson, and Siemens) should be started. Special fellowships for M.Tech. students, specializing in CPS should be introduced. A fixed number of fellowships per year under ICPS project for PG/ Ph.D./JRF/SRF/PDF level.
- International/ national level symposium focusing on CPS should be conducted every year.
- Tier II & tier III engineering colleges should be considered for a role in the Mission. They could be considered for funding joint projects and setting up common facilities that can enhance the learning experience of the students. Thematic Faculty Development Programmes for tier II & tier III institutions must be introduced, so that students in these institutions can be encouraged to take up projects and research in CPS.
- Organization of Summer schools on CPS, for faculty and researchers, should be considered.
- Curriculum development should be taken up by focussed groups and involving industry. A balanced content with fundamentals and modern paradigms of CPS should be takeninto consideration. Workshops must be supported for curriculum development. M.Tech. Courses in CPS and allied areas it encompasses is the immediate need. The courses may have a focus on device networks, machine learning, data analytics etc. with a compulsory field-oriented project.
- The dearth of qualified people to teach topics/subjects in an evolving area like CPS is imminent. To tide over the shortage, finishing schools should be introduced and funded.

Industry person can develop faculty & curriculum inputs; Faculty from industry can be involved in teaching courses.

- The training programmes in CPS should be of high quality and rigorous and lead to high-value certification.
- Industry must be involved in designing courses or modifying the existing programmes. Incentives to industry for participation in internships and training of students in Institutions, through taxes. The industries must be asked to give projections on the requirement of human resources that are specialized and skilled in CPS.
- Engineering colleges should be equipped with laboratory (simulation and prototype) kits that make CPS exciting to the students. Every academic institute must have a student activity center with basic instruments, tinkering labs, toolkits, etc. to develop prototypes. CPS labs can be used to promote do-it-yourself (DIY) culture among engineering students, who get deprived of such opportunities because their focus gets shifted to entrance exams. DIY should get formally integrated into the curriculum if the quality of engineers has to be improved.
- There should be a scheme to support/upgrade existing PG programmes into full-fledged PG programme in CPS with minimal funding. Through this, they can quickly produce human resource (engineers, researchers, teachers, entrepreneurs) in the domain of CPS is a need for more case studies on CPS, a repository of which needs to be created. Under the Mission, institutions at the level of polytechnics, diploma, it is should also be considered, as there will be need of skilled workforce for filed implementation, operation, and maintenance of CPS-based products/services. For example, Diploma in Internet technologies, sample verification. The ITIs/Polytechnics can be equipped with trainer kits, gadgets associated with IoT etc. Quality of courses at these levels must be ensured.
- Online contests and hackathons for students (individual/group) should be organized as part of the Mission, to bring forth innovative ideas/ approaches/ models. Start innovation clubs in schools/ colleges challenge the students and offer incentives to encourage their participation in large numbers.
- Certification Courses of appropriate level should be initiated by entities which will be considered for imparting training, skilling and entrepreneurship programmes, whether by academia, institutes or industry. Institutions should initiate certificate programmes for skills; certificate could be jointly awardedwith Industry/industries Association and DST.
- A scheme should be designed to support small projects from Govt. /Academic Institutions for 2nd/3rd year UG students. UG students should be given some credits/certifications, with

fellowships for spending their time on the project under CoEs. Industry supported 6 months internship 4th year of UG courses under the CoE.

- Capacity building at tier I institution in association with industries should be considered. At least 25% lectures/ training from industry under this capacity building, using modern tools/ technologies for education. This will help in creating a workforce according to industry needs.

V. Innovation, Entrepreneurship& Start-up ecosystem

- Start-up funding should also be encouraged from the project funding agency itself. Funded projects should have the plans for the deliverables from the project. At the end of the project, there should be at least 1 or 2 major global level startups coming out of the project. Industry-academia- Government (DST) collaborative incubation center should be set up. Also leverage existing industry/ government/ NASSCOM programmes. For example, Nvidia runs the inspection programmes for start-ups. Set up "CPS focused fund" as the seed stage incubation.

- Create ecosystem along with start-ups, hardware facilities, cloud platforms. Establishing perfect Synergy between academics, R&D institutes, industry and finally the end user with appropriate feedback and corrective mechanisms.

- Requirements to the society should be defined so that the start-ups could confidently venture into those areas. The commercial viability of an application should be checked. This is to be identified by an interactive discussion with industry and line ministry by involving the industry in specification development and its implementation. After the successful development of product and it's testing with the help of industry, hand holding the industry technically.

- Creating appropriate workforce at different levels [ITI, diplomas, Engineering, M.Tech./Ph.D. and skilling existing workforce].Internship for engineering students as teaching assistants for "tinkering labs" for High Schools. Skill development through internship/ training for the large duration on practical problems which will have social impacts. Incorporate entrepreneurship education/ training into the curriculum. Education ecosystem requires introduction of new courseware and faculty development

- Current manufacturing systems require hand holding to introduce new technologies within their current facilities, especially Indian MSMEs

- Government funding should be for buying the end products for the masses. The development funding should come from venture capitalists, Funding schemes for social Enterprises (capital investment).Identify Industries who might be interested. Funding by DST to set up the infrastructure and meet the personal needs of entrepreneurs (basic). Incentive programmes that bring the right teams together and to focus on a product over a 1-2 year horizon and innovation challenges for it verticals with substantive funding.

- Define end use cases/ pain areas and invite start-ups to develop solutions
- Throwing open challenges with decent funding would be good idea to boost start-up culture in India. Challenges need not be for a new solution but could be for making existing technologies faster/ efficient manifolds or cheaper than a target cost. Create competition among start-ups to deploy and demonstrate solutions on a test bed/ track/ village so that different cost-effective and deployable Solutions come out. Access to testbeds/sandboxes to qualify competing Technologies (network tech, protocol, middleware) etc, for example, setting up of Smart City testbed to test the efficacy of solutions. Conduct competition for new ideas/ products on CPS among students- give incentives to convert them into entrepreneurs. Some examples of challenges: Portable ICUs (Portable), Drones for critical supplies (medicines, blood etc), Vehicle that could go to outer space and return safely defined by ISRO.
- Connect and facilitate the start of with developed ecosystem through some common forums. Recognize the best contributor; this will bring in massive value. Tie up with MNC's like IBM which provides variety of infrastructure/ ecosystem. Also including some easy access to start-ups.
- Pre-incubators to facilitate professional teams to work with the university faculty on executing pilot-scale research projects. Technologies from these pilot projects could get commercialized by these teams at start-ups. Free incubation support from industry to candidates. Invite the participation of interested people to start the start-up, and take advantage of all incubation center from different industries under some scheme by Government.
- School of Business/ Management must be involved in promotion of entrepreneurship, designing appropriate training programmes
- A special initiative should be for sensors that energy efficient, as they are critical for any CPS. Simulation of sensors for various applications or solving problems like: water pollution, Preventive mechanism for collisions, Detecting and monitoring waste, Early warning systems for disaster management., Precision agriculture, Traffic violation, Surveillance, Health of rails, Health of water bodies from ponds to rivers to oceans, Early warning systems in buildings, CPS has a huge role to play in Water recycling, Hydroponics, Soil-less farming, Renewable energy challenges, networking healthcare system, Intelligent transportation systems, Assistive technologies etc.

VI. International collaborations

- Some Indian origin scientists and researchers are ready to collaborate with their Indian counterparts. A mechanism that facilitates win-win interaction and does not delay would be required to take advantage of overseas experience and expertise.
- Some of the suggested international institutes are:
  - Bilateral and trilateral international collaborations are needed to tackle international challenges based on CPS.
  - MIT IDSS (MIT alumni network which has an enterprise forum could be tapped. A similar forum in India, in CPS area, would be useful)
  - Purdue University, West Lafayette, Indiana, USA.
  - University of Iowa, Iowa City, Iowa, USA (for smart cities solution)
  - Oklahoma University
  - Association of Swiss Universities of Applied Science (Swiss delegation scouting opportunities in South Asia to help with smart cities solution)
  - University of Illinois, Chicago (Healthcare)
  - Duke University (Energy Data Analysis, a brain research center)
  - KTH University, Sweden
  - EPFL, Lausanne, Switzerland (Energy Data analytics)
  - Missouri University of Science and Technology, Rolla, Missouri, USA
  - NTU, Singapore
  - Melbourne Institute of Technology, Melbourne, Victoria, Australia
  - Florida International University, Miami, Florida, USA
  - Manufacturing Enterprise Solution Association, USA
  - University College London
  - Cranfield University, UK (3 D- Printing)
  - Fraunhofer Institute for Systems and Innovation Research, Munich, Germany.

- Berkeley Artificial Intelligence Lab
- Carnegie Mellon University
- CSAIL , MIT
- University of Oxford
- University of Toronto
- MILA

(a.2) SECONDARY RESEARCH

Secondary research involved capturing relevant information from public domain through research articles, published documents on CPS, Net Search, etc. A very large number of research papers, reports, books, other public domain documents, and presentations; also information collected during participation in some CPS related conferences/seminars held recently. A list of the materials referred has been included in the Bibliography given in the report. An organized and structured thought process, as given in the Table 2.3 below was deployed to cull relevant information.

TABLE 2.3: STRATEGIC THOUGHT PROCESS

Major Strategic Thought	Contributing Factors	Mapping with the Objectives of the Study
CPS and its supporting areas	Understanding CPS Defining CPS Driving value from CPS How to approach a CPS project	Assess the present status of CPS and its role & potential in R&D, the business & industry
Assessment of the current status	Major stakeholders, Availability of technologies The current and future technologies to be used, Adequacy of the available infrastructure, Quality & quantity of manpower available, Available Technologies & Providers	New computation Paradigm, Assessing the present status
Opportunities, threats, Gaps and questions	Where and how do we start? How do we create a business case for a pilot? SWOT Analysis What data is relevant?	SWOT Analysis, Market landscape survey to assess the future opportunities and demand
CPS and The Global Scenario	Successful applications of CPS CPS for Development CPS Market	The international scenario for evolving strategy for India.

Major Strategic Thought	Contributing Factors	Mapping with the Objectives of the Study
Identification of the Pillars of Information Driven R&D, Governance and Business Transformation	Identification of the Business Drivers Doing more with the data – using CPS and Business opportunities The aims of deploying an enterprise hubs	CPS Applications Evolve a strategy and micro level action plan defining roles of various stakeholders
Maturity Stages on Road to CPS	Initiate – Kickstart& build first success Scale up - Build confidence in sustainable success	Training & Capacity Building CPS Road Map Entrepreneurship
Leveraging CPS for Scientific Research & Development	Applications in R&D projects Establishment of Center for Excellence in CPS Dissemination of CPS knowledge Capacity Building through Training programme	Indian Perspective Identify Gap Areas Challenges in R&D for S&T Gap analysis in terms of skills levels and policy framework
Digital India	Provisions under Digital India Initiative Leveraging provisions under 'Digital India' Leveraging CPS Synergy with e-Governance initiatives	Evolve a strategy and micro level action plan defining roles of various stakeholders Integrating Government Ministries
Data Demand Trends	Identify Gaps in roles and skills Gap Closing – Center of Excellence, Skilling/ Upskilling, Training Programmes, Workshops at various levels of stakeholders	Gap analysis in terms of skills levels and policy framework
Managing the governance issues of CPS	The regulatory context Privacy law as applied to CPS Responsible CPS business practices R & D Projects	CPS Policy Perspective Evolve a strategy and micro level action plan defining roles of various stakeholders Integrating Government Ministries
Detailed Project Report and Future Outlook	Formulation of the Project, its Objectives & Targets, Cost Benefits & Outcomes, Monitoring mechanisms and Action Plan including technology, cybersecurityand other relevant issues	Justification of the Project Project Objectives & Targets Project Design & Costs Envisaged Benefits & Outcomes Evaluation parameters {Measurable Indicators} Project Monitoring and MIS Roles of various Stakeholders Evolve a strategy and micro level action plan clearly defining roles of various stakeholders to

India Strengths, Weakness, Opportunities and Threats (SWOT)

A SWOT analysis helps in understanding the strengths and weaknesses and helps in identification of open opportunities and the threat that can come along. It provides with a vision to differentiate between marginal and valuable opportunities. It also helps in deciding what to exploit and what to ignore. SWOT analysis gives a taste of what are the threats and their intensity. It facilitates with options to keep an eye on the unlikely to cause damage and beware of increasingly dangerous threats. Finally provides it an opportunity to identify the gaps that will lead to the preparation of a strong and structured Strategic Roadmap for CPS. Below is the SWOT analysis of CPS in India.

Strengths

- There is broad and detailed domain know-how as well as process know-how available.
- Many domains have innovative technology and skilled people.
- There are many universities/institutions with high capacity where state of art research being carried out.
- Avenues where good science/engineering /domain specific education can be obtained.
- Immense growth opportunity in CPS: Indian product firms have shown a growth rate of 20-40 percent in the last few years; several emerging players have witnessed over 100 percent growth within the first year of launch. (NASSCOM)
- Growing start-up base accelerating the growth: Four-fold increase in start-ups in the last four years. (NASSCOM)
- Innovative offeringsfocusing on end-to-end customer business needs. (NASSCOM)

Weaknesses

- There are no established cooperation networks between academia and industry.
- Computer clusters and cloud resources are readily not available and accessible to the users/ stakeholders such as Researchers in the Institutes and Research Labs.
- There are not many SMEs that are dynamic and flexible and can react quickly to technology changes.
- There is no existing and strong technology-driven market in India.
- There is a lack of a solid start-up culture because of risk aversion and fear of failure.
- There are few large companies to lead the market and many small-sized companies that

need nurturing.

- There is no visibility of ecosystem service offerings.
- Lack of seamless data access and inter-connectivity, and low levels of interoperability: data is often in silos and data sharing is difficult due to an ineffective Data Sharing Policy as well as standardse.g. formats and semantics.
- Migration of data between systems, versions or partners is challenging.
- Access and processing of dataset those are too big to be given to the end user.
- The different languages within the country create a barrier (multilingualism).
- Poor and inconsistent use or management of technologies.
- There is a lack of specialized education programmes for CPS.
- There are not enough skilled people to participate in advanced manufacturing fields.
- Rules and regulations are fragmented across the country/industry/domain.
- There are high security/sensitivity/confidentiality demands that can be difficult to address.

Opportunities

- Being a multicultural society, various cultures/practices/strengths/approaches can result in creative thinking if they are mixed.
- The proposed mission and best practice examples in other initiatives can lead to synergies.
- Strengthening the Indian market, e.g. by fusing the emerging start-up nucleus.
- Create lots of SMEs for the low hanging fruits of CPS for which agility is required.
- Investment in the entire innovation chain, beyond basic research.
- Investment support mechanisms for SMEs/Research/ Institutions/ Students/ Scholars/ Entrepreneurs.
- Collaboration within Industry/ Academia/ Service Providers.
- Improve and encourage innovation & creativity to create cost-effective solutions.
- There is the opportunity to open up completely new and different business areas and services.

- New applications can be created throughout the CPS ecosystem, ranging over acquisition, extraction, analysis, visualization and utilization.
- Wearable sensors and sensor technologies become mainstream generating more data. Analytics is an opportunity.
- The explosion of device types opens up access to any data from any device for greater and more varied applications.
- Development of APIs for access becoming standardized and available.
- Interoperability tools and standardized APIs to facilitate exchange.
- Greater visibility and increased use of directory services for technology sources.
- Contextualization and personalization of CPS.
- The evolution of different sectors and the increased volume of themes enable innovative applications to be developed.
- Use and exploration of CPS to be ubiquitous in education and training.
- User-generated and crowd-sourced content increasingly available that will help a variety of recurring problems solved once for all.
- Shift from technology push to end-user engagement.
- Create technology driven rich and complex value chains.
- Develop strong and workable policies for technology access in the country across private and public to help build comprehensive capabilities.
- As the presence of the Internet of Things (IoT) — such as connected devices, sensors and smart machines — grows the ability of things to generate new types of real-time information and to actively participate in an industry's value stream will also grow, (GARTNER), it is an opportunity for India.
- Fuelled by the Nexus of Forces (mobile, social, cloud and information), customers now demand a lot more information from their service providers. The rapid dissemination of the IoT will create a new style of customer-facing analytics — product tracking — where increasingly less expensive sensors will be embedded into all types of products. (GARTNER)

Threats

- Many skilled professionals leave the country to work in other regions; adding to the risk of a "Brain Drain".

- Acute lack of skilled professionals and graduates to the requirement of industry.
- Non-standardization of the 'contents', 'duration', 'mode of delivery' and 'certification' of the skilling and or up-skilling efforts made by the education/training ecosystem of the society.
- There are no existing start-up ecosystems in CPS areas.
- Policies are often too connected to the legacy technologies/processes.
- Complete analysis of ethical and privacy issues is needed.
- Risk of over-regulation and protectionism in the country as compared to elsewhere in the developed world.
- Technology & Techniques: To capture value from CPS the organizations will have to deploy new technologies e.g. storage, computing and analytical software. The range of technology and technique challenges and priorities set for tackling them will differ depending on the technical maturity of the institution.
- Organizational Change and Talent: Organizational leaders may not fully understand and appreciate the value in CPS as well as how to unlock this value.
- Shortage of Skills: There are a wide range of skills relevant for CPS, including knowledge of robotics, the ability to programme and use software, market-specific knowledge and communication. These skills may not be available in required quantity and quality.
- Business-Education Collaboration: One way to provide the multi-disciplinary skills required for CPS is for students to work closely with a company during their studies. Collaboration between a university/institution with expertise and business with real-world problems can be beneficial for both parties.

2.2 Target Beneficiaries

ICPS is a system of systems, and thus it operates at sector/system level. The following are some of the target beneficiary sectors:

Healthcare

The recent advances in wireless sensor networks (WSN), medical sensors, and Cloud Computing are making CPS a powerful candidate for healthcare applications including in-hospital and in-home patient care [10]. These advances promise to provide CPS with the ability to observe patient conditions remotely and take actions regardless of the patient's location [11]. These sensors can collect vital patient information containing health data. Collected data are sent to a gateway via the wireless communication medium. Wired sensors can also be used; however, wireless sensors provide more flexibility and comfort to both the caregiver and the patients [12]. The data collected by the sensors can be stored in a server and made accessible to clinicians. Security is a vital concern here as patient data is confidential from legal and ethical perspectives. So, while designing CPS architecture for healthcare applications, special attentionneeds to be paid to ensure data security. Other issues to consider are like the database management systems should be efficient and reliable. Healthcare applications require huge computing resources for intelligent decision making based on the massive patient data. The network of wireless sensors collecting patient data is constrained in energy, processing and storage capacity. So, cloud computing can provide solutions for such issues [13]. The combination of active user input such as smart feedback system, digital records of patient data, and passive user input such as biosensors and/or smart devices in healthcare environments can support the data acquisition for efficient decision making. The challenges of CPS in healthcare [14] are 1) Software reliability 2) Medical device interoperability 3) Data extraction 4) Security and privacy 5) System feedback 6) Complex query processing. Some work has been carried out on the CPS for healthcare applications [15], [16], [17]. The CPS architectures proposed by Rajkumar et al. [18] and Xia et al. [19] investigated different applications, such as assisted living and monitoring network. Although many CPS architectures have been proposed in the literature, their number for healthcare applications [14], [13] is very few. Hu et al. [20] proposed service-oriented architecture (SOA) based medical CPS concept; however, it lacks the complete architectural framework. Wang et al. [15] presented a secured CPS architecture for healthcare, which utilizes WSN-cloud integrated framework. Banerjee [21] proposed modelling and analysis of medical CPS. Managing CPS architecture for healthcare requires handling different types of data such as input data, historical data, and output data. In healthcare, based on the type of biosensors, the data size can be different. There can be simple data such as temperature, whereas large image data such as magnetic resonance imaging (MRI) is also required to be processed. Yilmaz [22] stated that depending on applications, the data acquisition and transmission might vary. Biomedical sensors are responsible for collecting important physiological data, and these data are fed to the processing and communication system for further use. Present biosensors can collect vital patient information efficiently [23]. It is important to specify the sensing method for better efficiency for CPS in healthcare [24]. The data collected by sensors must represent the current state of the environment; for this reason, they are subject to logic and time constraints [23].The elements to consider in designing real-time data processing for CPS in healthcare are data response time and data arrival update. Kang [25] proposed a mechanism to make systematic trade-offs between transaction timeliness. CPS in healthcare involves monitoring of patients and older adults. Designing an emergency medical system using patient health record in aloud environment has been proposed by the authors in [26]. Recent developments in image communication over wireless multimedia sensor networks (WMSN) [27] have the potential to extend the capabilities of CPS by allowing extracted and/or compressed images to be communicated in an energy efficient manner. Healthcare applications require huge computing resources for intelligent decision making based on the massive patient data [28].

Transport

The transportation sector is the most important part of any modern economic infrastructure in today's world. The CPS can be effectively applied to transportation system processes and the information technology requirements for applying CPS to on-road transport systems. Traffic flow simulation studies consisting of vehicles and roads can be conductedto understand real-world transportation system dynamics. The transportation system requires interaction between objects such as information and communication technology (ICT), the required transportation infrastructure, vehicles and drivers, interfaces for the multiple modes of transportation etc. Mathematical models of transportation systems and mobility management, incorporating both real and hypothetical scenarios, have to be embedded into transportation systems analysis. So, methods and techniques for the application of information to improve traffic control systems performance, guaranteeing real-time properties when designing CPS in the transportation sector. The CPS-based traffic control analyzes the information flow amongst computer systems, traffic sign systems and travellers in the traffic control system. The CPS approach in transportation is not only about the application of methods of advanced information and communication theory, it is also about the theory of building new systems by integration of information and communication processes, physical processes, and the cyber-physical which can be introduced as smart transportation systems. Smart transportation systems are focusing on guaranteeing crash avoidance of autonomous cars, efficient algorithms for collision avoidance at traffic intersections, and real-time motion planning for autonomous urban mobility, an important issue in smart cities. Therefore, the CPS approach in transportation is not only about the application of methods of advanced information and communication theory, it is also about the theory of building new systems by integration of information and communication processes, physical processes, and the cyber-physical which can be introduced as smart transportation systems. The development of smart Cyber-Physical transportation control systems has to start from their reanalysis, which requires an approach introduced in [29]. All information needed to achieve cyber-physical transportation control objectives, whatever it takes, such as materials, energy, and the ways they are presented, obtained, stored, transmitted, and processed, is important for achieving the objective [5]. Smart transportation systems [30] are envisioned to address the numerous challenges faced by the transportation sector. One category of solutions envisioned in intelligent transportation systems pertains to the real-time, reliable delivery of traffic-related information to drivers. This consists of both safety-critical applications (such as blind spot warnings during lane changing) and applications that improve the driving experience and help the environment (such as notification of congestion and rerouting advice that can help to alleviate traffic congestion and lost productivity) [31]. Supporting these applications requires a thorough understanding of the smart transportation systems problem space about its types of communication networks. Timely and reliable dissemination of information via vehicle-to-vehicle and road-side infrastructure communication is a difficult problem due to multiple challenges, as described in [31]. Some challenges are imposed by the physics of the system, including the wireless radio transceiver power, shared nature of the wireless channel, mobility of the vehicles, and density of the vehicles. Other challenges arise from the vagaries of the cyberinfrastructure, including behaviour of protocols like IEEE 802.11 Media Access Layer (MAC), Address Resolution Protocol (ARP), Internet Protocol (IP) addressing and routing, and the Transmission Communication Protocol (TCP). The smart transportation applications based on CPS are diverse: Car merging assistants [32], Cyber-Physical traffic control systems [29], Smart traffic lights for traffic flow control [33], Traffic delay estimation [34], Traffic flow dynamics [35], Vehicle tracking systems [33].

Smart Manufacturing

The manufacturing industry is now transforming into the fourth industrial revolution, called Industry 4.0. This transformation has the meaning of embracing some contemporary automation, data exchange and manufacturing technologies such as CPS, IoT, Big Data [36]. In the context of manufacturing, CPS is defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities [37]. With recent developments that have resulted in higher availability and affordability of sensors, data acquisition systems and computer networks, the competitive nature of today's industry forces more factories to move toward implementing high-tech methodologies. Consequently, the ever-growing use of sensors and networked machines has resulted in the continuous generation of high volume data which is known as Big Data [38], [17]. In such an environment, CPS can be further developed for managing Big Data and leveraging the interconnectivity of machines to reach the goal of intelligent, resilient and self-adaptable machines [39], [40]. Furthermore, by integrating CPS with production, logistics and services in the current industrial practices, it would transform today's factories into an Industry 4.0 factory with significant economic potential [41]. Since CPS is in the initial stage of development, it is essential to clearly define the structure and methodology of CPS as guidelines for its implementation in industry. To meet such a demand, a unified system framework is required to design for general applications. Nowadays, the assembly of these new technologies has led to the new concept, "Smart Factory", in the field of manufacturing and the entire value chain from product design to delivery is digitalized and integrated. The manufacturing industry is currently changing to a new paradigm, targeting innovation, lower costs, better responses to customer needs, and alternatives towards on-demand production [42]. Along with the change, the German government has been promoting "High-Tech Strategy 2020 Action Plan" since 2013 and mentioned, "4th industrial revolution" or "Industry 4.0" [43]. The "Industrial Internet" is first introduced by General Electric in the US in its visionary paper [44]. Even though both nations use different terms, several key challenges are addressed in common:

(i) Flexibility: flexible adaptation of the production chain to changing requirements,

(ii) Optimization: production optimization due to IoT, CPS, and Big Data

(iii) Interoperability: interoperable data exchange between cyber and physical entities

A manufacturer's sustainable competitiveness depends on its capabilities concerning cost, delivery, flexibility, and quality [45]. Smart Manufacturing Systems (SMS) attempt to maximize those capabilities by using advanced technologies that promote rapid flow and widespread use of digital information within and between manufacturing systems [46], [47], [48]. SMS are driving unprecedented gains in production agility, quality, and efficiency across U.S. manufacturers, improving long-term competitiveness. Specifically, SMS use information and communication technologies along with intelligent software applications to optimize the use of labour, material, and energy to produce customized, high-quality products for on-time delivery and quickly respond to changes in market demands and supply chains. Smart manufacturing, different from other technology-based manufacturing paradigms, defines a vision of next-generation manufacturing with enhanced capabilities. It is built on emerging information and communication technologies and enabled by combining features of earlier manufacturing paradigms [49].

Energy

The CPS for energy sector has large-scale impact for both primary energy consumption reduction as well as grid stability problems. The term Cyber-Physical Energy Systems (CPES) has been coined when discussing the integration of computing, communication and control in the energy domain. It includes generation, both conventional and renewable, transport and distribution, energy storage, as well as the consumer side. The key issue to be solved is that of increasing adoption of variable renewable energy sources in connection with energy storage and demand-side strategies. To adapt the future energy systems to the new challenges, the Conventional energy systems should exhibit adaptive performance such as flexibility, efficiency, sustainability, reliability, and security. This performance can be obtained through a systematic embedding of cyber technologies capable of monitoring, communicating, and controlling the evolving physical system. In general, the main features that a CPES must have are 1) Reliability 2) Autonomies 3) Close integration 4) Distributive Networking. The research focus areas include improving the sustainability of energy system by better resource utilization and management, modelling of complex interactions between electric grids (physical), and monitoring (cyber) infrastructure and security of the power system against cyber threats. Security-related aspects can be further classified into detection, prevention, mitigation, and restoration. Currently, most of the cybersecurity research in power system deals with vulnerability/attack detection and prevention. An approach for improving the sustainability of the energy system using CPS theory has been provided in [50]. In this paper, an integrated electricity and transportation infrastructure for promoting the use of RESs had been discussed. They modelled the energy system as a cyber-physical energy system, where RESs, Gridable Vehicles, and thermal power plants constitute physical resources. An onboard system in a GV acts as a cyber-resource, which communicates with utility and vehicle owner's preferences, etc. for proper function. The authors studied the effectiveness of RESs and GVs for a sustainable cyber-physical energy system. They also suggested techniques for maximizingutilization of distributed RESs to reduce emission and cost of operation. An example of better resource utilization using CPS approach has been discussed in [51]. This work presents a dynamic model of the battery to describe the variations in the capacity of a battery under time-varying discharge current. In CPSs, the current drawn from the batteries is decided by the control laws and online scheduling algorithms, according to the state of the plant and the processor. For this reason, the life of a battery cannot be determined at the design stage. Hence, using the battery model provided in [51], the optimal discharge profile for a square wave current can be determined. The white paper on CPS security for smart grid [52] identifies a set of cybersecurity challenges at various levels, such as information-level security, infrastructure-level security, and application-level security. In this white paper, the research issues in modelling, detection and prevention algorithms, trust management, and attack attributions have been outlined.

Environmental

A class of effective CPS can be developed that monitors the environmental conditions or the ambient conditions in indoor spaces at remote locations. The National Weather Study Project is a large-scale community-based environmental initiative in Singapore that aims to promote the awareness of weather patterns, climate change, global warming and the environment. We are designing and building the National Weather Sensor Grid (NWSG) as the key infrastructure for this environmental monitoring initiative. The NWSG is built upon the SPRING framework and has several important features. First, it connects mini weather stations geographically distributed across Singapore to automatically collect and aggregate weather data in real-time. Second, the weather data are stored in a large-scale data archive that uses distributed data storage resources. Third, the NWSG integrates computational resources for the compute-intensive processing of weather data. Fourth, the weather data can be conveniently accessible and shared via the web through mash-ups, blogs, and other user applications. We are developing techniques and tools to efficiently publish, query, process, visualize, archive and search the vast amount of weather data. Finally, the NWSG provides a scalable platform to handle hundreds of weather stations, and it can also integrate different types of sensors besides weather stations. The NWSG has been implemented with user level, middleware and core services following a grid-based architecture. A proxy-based architecture is used to integrate the weather sensors with the grid infrastructure. To facilitate seamless integration of heterogeneous sensor resources and grid environments, the

NWSG uses an ontology-based design with the resource brokerage and meta scheduler services implemented at the middleware level to help in resource discovery and job planning. Since the NWSG is targeted at a wide range of users ranging from the scientific community to the public, it implements user authentication, job management, and load balancing services to minimize job execution response time and maximize throughput [53].

Infrastructure

The CPS can be used to analyze the communication between the distributed sensors and actuators of a building. The designed system can use measured information from the sensors to control the components of the building via its actuators. To interpret the information received from several sensors and react with a suitable action, the system uses complex event processing (CEP). The sensors of the building producing information, they come into the system as a stream of events, each event containing the current state of one sensor. This stream of events has to be processed as fast as possible to react in real time to events which happened in the physical world, like the falling rain on an open skylight. To do so, the CPS must have the capability to process events fast and recognize complex events. Li et al. [54] discussed a smart community architecture, which is modelled as a CPS with cooperating objects, namely, networked homes. In smart homes, the sensors and actuators are configured such that they can be remotely controlled through the Internet. Through this, the activities of the users can be monitored. Smart community takes the concept of smart homes further by using networking among a group of smart homes. The individual homes are modelled as multifunctional sensors, and whenever necessary, automatic or human-controlled physical feedback is given to improve community safety, healthcare quality, and home security. The authors also discussed the communication and networking in the smart community. [55] modelled a smart community as the convergence of social world, cyber world, and physical world. It consists of humans and smart, physical entities that interact with each other. They also discussed the technical challenges in the development of a smart community, which involves ubiquitous sensing, autonomous networking, collaborative reasoning, and community management. Kleissl and Agarwal et al [56] modelled modern buildings as CPSs and examined the possibility of joint optimization of energy use by its occupants and IT equipment. Their work aims at designing zero net energy buildings, i.e., buildings with zero net annual energy consumption. The authors viewed the information and communication infrastructure of the building as energy consumption and energy/operations optimizers. All public infrastructures have to be monitored to assess their condition. Even if these infrastructures are monitored by personnel through scheduled visits, a visual inspection is often not sufficient, as anomalies may still go undetected. A more efficient approach to monitoring is to install a variety of sensors across the structure to monitor its state continuously and determine its health [57].

Agriculture

It will play an important role in the field of precision agriculture, and it is expected to improve productivity to feed the world and prevent starvation. To expedite and accelerate the realization of CPS in the field of precision agriculture, it is necessary to develop methods, tools, hardware and software components based upon transdisciplinary approaches, along with validation of the principles via prototypes and testbeds [58]. The main purpose of such an integrated system is to provide an innovative solution for monitoring of crop based on mechatronic systems, to improve precision agricultural management, a solution that will lead to overcoming bottlenecks identified in this area. Thus, these systems can substantially increase efficiency and quality once again.

Security

CPS is present at the core of the modern society. The attackers on both physical and cyber systems can cause harm to these infrastructures from multiple directions, such that their identity remains hidden. Due to latest advancements such as sophisticated threat matrices, industrial network automation, lack of knowledge about threat patterns, big data management, and privacy, the upcoming attacks and threats have made these CPS highly insecure. As these infrastructures are heavily connected, this, as a result, makes the attack more sophisticated and targeted. Also, such attacks can easily be triggered with minimum human involvement from remote locations, thus making the infrastructure more vulnerable to cyber-attacks. Large-scale data centers, used for CPS protection and monitoring are also vulnerable to malicious user behaviours, such as cyber-attacks, compromise of credentials or unforeseen behavioural patterns. There is a need for deploying such security solutions that follow a defence-in-depth mechanism. Security analytics and intelligence can play an important role in this regard. It works mainly by collecting enormous amounts of data and uses it for creating threat patterns, such that preventive measures could be takenpromptly. The proper analysis provides in-depth knowledge about the causeof an identified vulnerability or threat. Security and military applications have been the primary motivation in developing Intelligent Video Systems (IVS) as a part of CPS [59]. From small outposts to military cities with thousands of people, everything is a potential target. Security systems are ready to adapt as needed. IVS can offer customized, mission-critical security applications and systems that can adjust quickly to changing needs and government regulations. A basic security application of IVS is for people detection and tracking in an environment [60], [61]. Based on this, the system may be employed to estimate the number of accesses in public buildings as well as the preferred followed routes [62]. Such an automatic surveillance system is developed in [63] to detect several dangerous situations in subway stations. Intrusion detection is often required for perimeter protection.

2.3 ICPS and National Initiatives

ICPS programme rightly fits into National initiatives like SDGs, Digital India, Swachh Bharat, Make-in-India, Industry 4.0, SMART Society 5.0, Skill India and Start-Up India. The ICPS Programme facilitates and caters to these national initiatives by developing India specific core technologies, human sources development and develops advanced skill sets and will feed into Innovation and Start-up ecosystem of GoI. The following are some of the national priorities wherein ICPS can play a role in their implementation and success.

(a) INDUSTRY 4.0: The fourth industrial revolution is already on its way. Revolutions are fast, disruptive, destructive and irreversible. India needs to prepare itself for the inevitable change. Industry 4.0 will be a challenge and may also have continued advantage in the global manufacturing industry. The world has already witnessed three industrial revolutions, which could also be described as disruptive leaps in industrial processes resulting in significantly higher productivity. The first improved efficiency through the use of hydropower, increased use of steam power and development of machine tools, second brought electricity and mass production (assembly lines) and the third further accelerated automation using electronics and IT. The fourth industrial revolution is already on its way. However, while some areas will see fast and disruptive changes, others will change slowly and steadily a more "evolutionary" pace. This time, physical objects are being seamlessly integrated into the information network. Internet is combining with intelligent machines, production systems and processes to form a sophisticated network. The real world is turning into a giant information system. Industry 4.0 provides relevant answers to the fourth industrial revolution. It emphasizes the idea of consistent digitization and linking all productive units in an economy. The main characteristic of industry 4.0 shall be:

SMART robots and Machines, robots and humans will work hand-in-hand, speak, on interlinking tasks and use smart censored man-machine interfaces. The use of robots is widening to include various functions like production, logistics, office management and basic customer services. The robot's performance requirements are significantly different for each industry/ sector.

IT systems today are already at the core of the production systems. In Industry 4.0, those systems will be far more connected to all sub-systems, processes, internal and external objects and the supplier and customer networks. Complexity will be much higher and will require sophisticated offerings to consumers. IT systems will be built around machines, storage systems, and supplies that adhere to a defined standard and be linked up as CPS. The level of efficiency, quality, and customization that will be possible through the combination of IoT, Data Science and CPS will revolutionize the manufacturing industry.

New Quality of Connectivity: As of now, the connectivity is a feature of the digital world, in Industry 4.0 the Cyber (digital) world and physical (real world) are connected. Machines, work-pieces, systems and human beings will constantly exchange digital information via the Internet. This means physical things will be linked to their data footprints (source: CII Manufacturing Excellence). Quantum communication will be a new paradigm on which the future communication will be built.

(b) DIGITAL INDIA: The Government has estimated an investment of US$ 26 billion in technology in coming years for digitization, infrastructural improvements, and push for manufacturing and technology in healthcare and agriculture. The Indian government's Digital India programme, which aims to transform India into a digitally-empowered society and knowledge economy, will bring forth a lot of opportunities for large number of IT industry players to develop platforms providing government services and information to people in all parts of the country. Security and data accessibility solutions will see increased demand for data scientists from the government.

(c) SMART CITIES: The development of 100 smart cities, under 'Smart Cities' GoI initiative, will require companies to build consortium to bag these projects. This will drive investments at all layers of ICT infrastructure, benefiting companies which are into technology consulting, telecommunications, networks, hardware infrastructure, managed services and systems integration. The designing of 'SMART cities' involves convergence of spatial data, census data, crime data, natural resources, transport, energy, education data etc. to arrive at location-specific city models. Data Science is the core discipline which will enable in arriving solutions.

(d) SOCIETY 5.0: It is a society in which the different needs of members are distinctly met through the provision of the relevant goods and services in the desired amount to the people who need them, and in which the entire people can be assessable to top-notch services and live a convenient, vibrant life that takes into account their differences such as age, gender, religion or language. This concept is anticipated to introduce transformational change in an expansive scope of industrial solutions such as manufacturing, logistics, sales, transportation, medical care, finance and public services. This eventually will have effect on people's work and lives by giving them encouragement to realize high quality of life. Defining the Smart society and as well support systems are being laid out towards realizing the goal for Smart Society development, adding new value in the society.

To develop and realize an environment in which people and robots and artificial intelligence (AI) exist together and work to enhance personal satisfaction by offering finely separated services that meet different consumer needs. The general public should likewise be capable of foreseeing potential needs and giving services to bolster human activities, determining deficiencies in service due to societal disparities and empowering anybody to be a service provider. Then again, on account of the high level of convergence amongst the cyberspace (internet) and the physical world in a super brilliant society, the harm that cyber-attacks can exact on this present reality will likewise turn out to be progressively extreme and may truly influence individuals lives, including their financial and social exercises. Ways and means to accomplish a more elevated amount of security are required. Such endeavours will serve as a wellspring of mechanical quality and universal intensity.

(e) MAKE IN INDIA: The government's 'Make in India' campaign aims at spurring a manufacturing-led growth with more focus on the ease of doing business than on an incentive-linked investment climate. The push for manufacturing has two aims, to create jobs and lift growth. According to the India Electronics and Semiconductor Association (IESA), an industry body, the electronic system design and manufacturing (ESDM) industry will benefit from the government's Make in India campaign and is projected to see investment proposals worth Rs 10,000 crore over the next two years.

(f) SKILL INDIA: Govt focus on enhancing the skill sets both at ground level and high-value areas. The efforts facilitate or catalyses initiatives that can potentially have a multiplier effect as opposed to being an actual operator in this space. The approach is to develop partnerships with multiple stakeholders and build on current efforts, rather than undertaking too many initiatives directly, or duplicating efforts currently underway. To scale up efforts necessary to achieve the objective of skilling / up-skilling 150 million people.

2.4 Sustainable Development Goals (SDG) and NM-ICPS

TABLE 2.4: Sustainable Development Goals (SDG)

S No	Sustainable Development Goals (SDG)	Nodal Ministries/ Departments	NM-ICPS contribution and linkages
1	Goal 1: End poverty in all its forms everywhere	Rural Development	Provide data analytics framework, algorithms, visualisation tools and data fusion methodologies.
2	Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Agriculture & Farmers Welfare	A CPS testbed and demonstrable prototype for precision agriculture will work with nodal Ministry for scale up and development of operational systems
3	Goal 3: Ensure healthy lives and promote well-being for all at all ages	Health & Family Welfare	Cyber systems-based health delivery for rural areas, IoT based remote testing, consultancy and monitoring
4	Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Human Resources Development	Skill and semi-skilled HR Development, UG/PG/Doctoral/ Post-doc in high-end CPS technical resources development
5	Goal 5: Achieve gender equality and empower all women and girls	Women & Child Development	Provide data analytics framework, algorithms, visualisation tools and data fusion methodologies.
6	Goal 6: Ensure availability and sustainable management of water and sanitation for all	Water Resources, River Development & Ganga Rejuvenation	A CPS testbed and demonstrable prototype for water distribution, surface water optimisation, will work with nodal Ministry for scale-up and development of operational systems

S No	Sustainable Development Goals (SDG)	Nodal Ministries/ Departments	NM-ICPS contribution and linkages
7	Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all	Power	Grid optimization, distribution models, demands forecast, predictive analytics and development of SMART Grids.
8	Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Labour & Employment	Generate high skilled and next-generation workforce.
9	Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Commerce & Industry	Robotics, SMART manufacturing, AI-based autonomous systems and catering to Industry 4.0. Start-up development and employment generation
10	Goal 10: Reduce inequality within and among countries	Social Justice & Empowerment	Provide data analytics framework, algorithms, visualisation tools and data fusion methodologies.
11	Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable	Urban Development	Enabling sustainable management of basic resources – energy, water, food, health, sanitation etc for SMART Cities development
12	Goal 12: Ensure sustainable consumption and production patterns	Environment & Climate Change	Provide data analytics framework, algorithms, visualisation tools and data fusion methodologies.
13	Goal 13: Take urgent action to combat climate change and its impacts	Environment & Climate Change	Sensor-based systems development for pollution estimation, modelling and systems approach for climate change data analytics
14	Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Earth Sciences	Development of marine CPS, e-Navigation and port management
15	Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss	Environment & Climate Change	Provide data analytics framework, algorithms, visualisation tools and data fusion methodologies.
16	Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Home Affairs	Provide data analytics framework, algorithms, visualisation tools and data fusion methodologies.

S No	Sustainable Development Goals (SDG)	Nodal Ministries/ Departments	NM-ICPS contribution and linkages
17	Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development	Finance, Science & Technology, External Affairs, Commerce & Industry, Environment & Climate Change, Statistics & Programme Implementation	Development of International collaborations in CPS and related areas.

2.5 Outcomes

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

TABLE 2.5: PHYSICAL (NUMBER OF UNITS) AND EXPENDITURE INRS. CRORE (FINANCIAL) FOR EACH COMPONENT

Components	Year 1		Year 2		Year 3		Year 4		Year 5		Total	
	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial	Physical	Financial
I. Technology Development	29	42.50	6	100.00	140	350.00	140	375.00	46	182.50	361	1050.00
II. HRD & Skill Development	1123	70.15	1609	132.65	3838	214.75	3067	112.45	2398	78.00	12035	608.00
III. Center of Excellences	2	150.00	4	250.00	11	650.00	6	300.00	2	100.00	25	1450.00
IV. Innovation and Start-up ecosystem	80	75.20	85	96.60	245	114.80	233	87.30	182	76.10	825	450.00
V. International collaborations	0	0.00	1	5.00	2	10.00	2	10.00	3	15.00	8	40.00
VI. Mission management Unit	1	62.00	0	0.00	0	0.00	0	0.00	0	0.00	1	62.00
Grand Total	**1235**	**399.85**	**1705**	**584.25**	**4236**	**1339.55**	**3448**	**884.75**	**2631**	**451.60**	**13255**	**3660.00**

TABLE 2.6: Measureable Deliverables

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
1	To promote and foster R&D in Cyber-Physical Systems (CPS) and related areas like Data Science (DS), Internet of Things (IoT), Cyber Security and quantum communication.	Increased core researchers base in advanced and cutting technologies	No of researchers in CPS	100	1000
2	To develop technologies, prototypes and demonstrate associated applications pertaining to national priorities.	A set of technologies, tools, algorithms to feed into some of the national priorities	No of technologies	0	360
3	To enhance high-end researchers base, Human Resource Development (HRD) in these emerging areas.	Delivery of next-generation technocrats, Scientists, Engineers, Skilled and semi-skilled workforce.	No of students	200	12000
4	To establish and strengthen the international collaborative research for cross-fertilization of ideas.	Global standard Collaborative research for some of the India specific issues.	No of collaborations	0	40
5	To enhance core competencies, capacity building and training to nurture innovation and Start-up ecosystem.	Start-up companies, job creation and economic growth	No of start-ups	3	800
6	To set up world-class interdisciplinary collaboration centers of excellence in several academic institutions around the country, with a substantial amount of funding to enable them to achieve significant breakthroughs.	Dedicated translational research centers aimed at Academic to Industry	No of CoEs	1	25
7	To involve Government and Industry R&D labs as partners in the collaboration centers. Incentivise private participation to encourage professional execution and management of pilot scale research projects	Enhanced participation of private industry in R&D, PPP model demonstration in technology development	No of partnerships developed	0	12
8	To set mission mode application goals and foundational themes for excellence for different centers. Set up CPS test beds at various centers.	Proven prototypes, national test beds for sector-specific solutions	No of prototypes/ testbeds	0	50

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
9	To tie up with incubation centers and accelerators to foster close collaboration with entrepreneurship eco-system	Enhanced delivery mechanism	No of incubation centers	0	15
10	To address some of the National issues and development of sector-specific solutions.	Technologies to address some of national issues.	No of domain-specific solutions	0	50
11	No of Research Papers published	New knowledge generation	Number	20	1000
12	No of start-ups in CPS		Number	3	800
13	Number of Center of Excellence established	Dedicated translational centers	No of centers	1	25
14	Number of new tools created	New processes developed	Number	2	50
15	Number of Solutions created for Govt Departments/ Organizations	New solutions	Number	0	100
16	Number of Best Practices developed	Best practices	Number	0	200
17	Number of UG/PG fellowships awarded	Preparation of next-generation technocrats	No of fellowships	0	10000
18	Number of Ph Ds/ Post-Docs	Delivery of next generation researchers	No of fellowships	10	2000
19	Number of faculty Trainers Trained	Generation of pool of trainers	No of trainers	30	500
20	Number of implementing agency selected	Scaling up of CPS activity	Number	10	100
21	Requests received from Govts etc	Acceptability of CPS	Number	0	50
22	No of student training programmes organized	Delivery of skilled human resource	Number	2	100
23	Number of entrepreneurship development programmes organised	Start-up culture enhancement	Number	0	100
24	No of the new CPS application areas identified	Scaling up of CPS in various areas	No of areas/ Sectors	0	50
25	Number of tie-ups with industry	Academic-Industry interactions	No of tie-ups	0	12
26	Number of proposal received for Venture capital/seed money etc.	Start-ups	No of start-ups	0	800

S No	Objectives/ Indicators	Expected outputs/ Deliverables	Unit name	Baseline data	Measurable Outputs/ Deliverables
27	Number of international collaborative research projects started/completed	Cross-fertilization of ideas	Number	1	20
28	No of cluster-based network projects started	Directed research	Number	2	50
29	Number of awarenessprogrammes launched	Development of scope of CPS	Number	0	25
30	Number of participants benefited throughawarenessprogrammes	Scale and volume	Number	0	2500
31	No of national workshops/ conferences organized	Development of intellectual networks and interactions	Number	5	25
32	Number of collaborative international conferences organized	Development of international networks	Number	2	8
33	No of CPS Infrastructure projects started/implemented	Technology platforms	Number	0	12
34	Number of international experts participation in CPS	Attracting attention of experts from abroad	Number	0	50

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

Chapter 3

CPS Technologies and Mission Strategy

3.1 Technology

CPS is an emerging and fusion of various technologies from across disciplines. Some of them are maturedand some under development. Technology choices are wide and based on application domain; a set of technologies will be converged to deliver a CPS. The following are some of the generic technologies that will play a crucial role in CPS.

Taxonomy of CPS

CPS represents the integration of physical and embedded systems with communication and IT systems. In describing CPS, the characteristics help to clarify what type of system is considered, also with regard to different stakeholders and viewpoints. The characteristics also serve to set the ambition in CPS design, e.g., regarding the desired level of automation. The characteristics are applicable to both small and large CPS. The taxonomy of the CPS is shown below in Figure 3.1 and explained in the following sections.

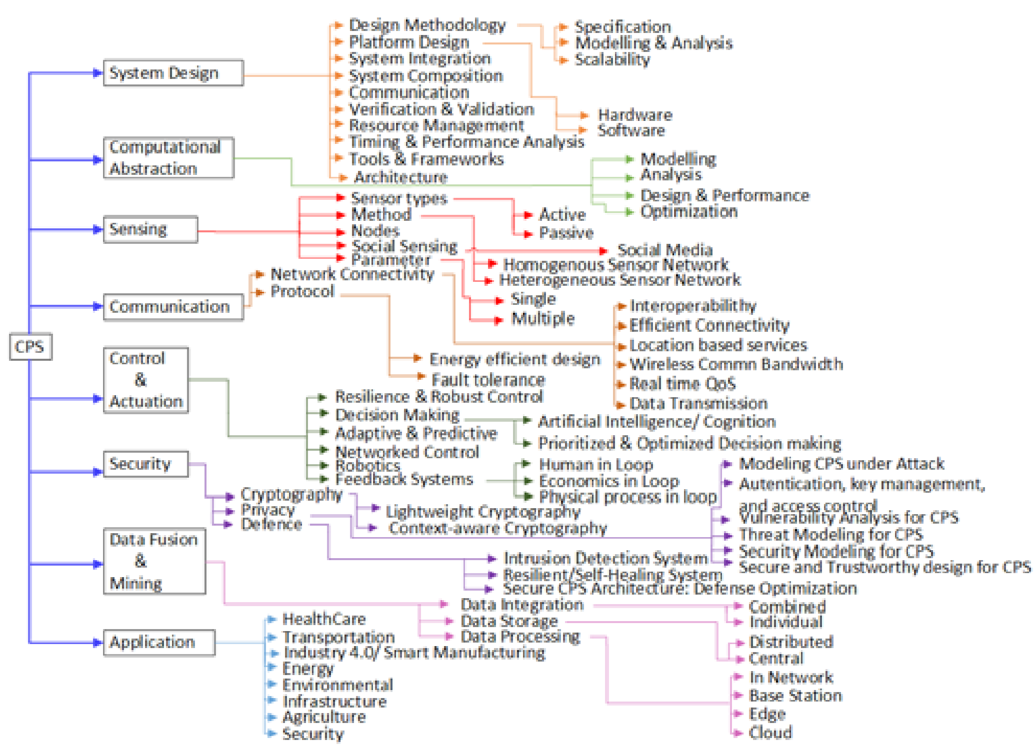


Figure 3.1: Taxonomy of CPS

3.1.1 System Design

CPS Design involves the integration of computations, networking, and physical processes. Traditional methods of system design need to be looked from altogether different perspectives to realize a CPS. The perspectives may be incremental or a contradictory change. CPS design will integrate the best practices of all the multidimensional and application systems like real-time embedded systems and distributed sensor, control and actuation. CPS design involves a set of architectural and composable alternatives (a 'design space') that must be systematically explored and evaluated [64]. The System design can be looked into as:

1. Design Methodology

A system design methodology is often iterative process between analyzing the behaviour, structure, and geometry of the system. The development steps for CPS are requirements specification, CPS design, and implementation.

a. Specification

Specifications of a CPS design need to capture the control, computing, and communication requirements. The challenges include requirements to address the complexity of the continuous domain, the precise scope of the system, interactions and system behaviour during mode transitions at a minimal. Specification of CPS should not only exhibit the expected behaviour of a CPS, but it should also exclude undesired or dangerous behaviours. Specifications of a system can also be captured mathematically and are known as a formal specification. Specifications can also be provided graphically [65]. [66] proposes an approach for specifying real-time CPS based on the aspect-oriented formal specification, which exploits the diversity and power of existing formal specification languages. It provides an aspect-oriented specification approach based on the combination of Object-Z and Time-CSP. Aspect-oriented formal specification method simplifies the requirement analysis process of real-time CPS.

b. Modelling and Analysis

CPS is an engineered system. Model of CPS gives an abstraction to provide an understanding of the functionality, component interactions and other designing aspects of that system; making modelling of CPS inherently significant. A model of a CPS comprises models of physical processes as well as models of the software, computation platforms, and networks [67]. Models of concurrency in the physical world (coexisting physical dynamics in a time continuum) are very different from models of concurrency in software (arbitrary interleaving of sequences of atomic actions), and very different from models of concurrency in networks (asynchronous, partially-ordered discrete actions or clock-driven time slots). Reconciling these divergent models of concurrency, ensuring interoperability and communication between components that have divergent models of concurrency, is a central problem in CPS. Also, Design Space Exploration for complex CPS cannot be realized as a closed form analytical search procedure, and requires multiple techniques, with multiple abstractions and fidelity, and involves complex iterations. It can be said with confidence that CPS will be next class of system where specifications can never be 100% frozen. The specifications will keep on evolving from the usage of the system in different environments it is deployed.

c. Scalability

The challenge is to provide design methodologies and tools that scale to large designs, facilitate analysis, and promote understanding of complex systems.

2. Platform design

A platform is the implemented hardware or software for realizing a system. Platforms are a deciding factor in ranking a CPS. Platform specifications may again come from the physical domain of CPS or its application area. It also provides the necessary interface & computational abstraction for CPS. As of now, most of the platforms available for CPS are application specific. Because of the cross-domain nature of CPS, there will always be a specificity and somewhat exclusivity in CPS but an approach to build a generic CPS platform can always be looked into. Platforms are available at the system as well as component levels. [67] Discusses the model-based design techniques that have sufficiently well-defined semantics to provide an effective basis for platform-based design and engineering. Components can be designed to operate with a model, and when deployed, will operate in predictable ways with the deployed system. The rigorous foundations of the models provide a foundation for integration across design domains, design adaptation and evolution, and analysis and verification. Their work has been demonstrated in the open-source software frameworks Ptolemy Classic, Ptolemy II, Polis, Metropolis, and MetroII. Many of the techniques developed have been deployed in a wide range of domain-specific applications, including hardware and field-programmable gate array (FPGA) synthesis, signal processing, automotive system design, computer architecture design and evaluation, instrumentation, wireless system design, mixed-signal circuit design, network simulation and design, building system simulation and design, financial. Platform design can be classifiedfurther as Hardware and Software.

a. Hardware

Physical components of a CPS decide the hardware platform. Its efficiency can be judged by operations per time unit. It will include the controller, interface circuits, sensors, and actuators. The controller or computational part is usually called a node and has processor. A variety of platform nodes are available to be considered for CPS system design ranging from small scale to large scale. For example, Structural Health Monitoring using IoT, MSP430 to Xbee based have been used. Companies are coming up with new architectures & devices to cater the need of future CPS in their domain. Nvidia boasts of Jetson TX series as power efficient and computationally competitive. Intel too has come up with power efficient & portable single board computers. Arduino and Raspberry are well-known community platforms, and there exist many more. All of these platforms play a significant role in development today. But they have to be put on to use in CPS to validate their usability in CPS. As per [69] CPS platforms are composed of devices, most times smart devices, with embedded sensors that continuously acquire information from the physical environment, which is stored as historical data and/or is processed often in real time to make decisions and act on the physical world through actuators software.

b. Software

The programming aspects of a CPS are called a Software platform. It includes the abstract representation of functionality and control required to produce a desirable output. It will include the functions, programmes and other GUI components. The main objective of efficient software design is to extract the maximum possible synergistic output from hardware components and system. Simulink & eclipse are preferred platforms for simulation and integrated development environment. CPS also can be a System-of-systems as in Smart Grids and Smart Cities. [69] discusses the requirement of CPSoS for managing massive amounts of data, being aware of their emerging behavior, and scaling out to progressively evolve and add new systems. It presents the architectural foundations of a cloud-centric framework for automating the development and deployment of CPSoS service applications to converge towards a common open service platform for CPSoS applications.

3. System Integration

CPS is diminishing the domain boundaries and thus making system integration an obvious challenge for component interactions. Objective is to achieve a stable CPS. It requires extensive research in interfaces and tool support. These challenges are both at Hardware & Software level. A modular approach may help in defining stable interfaces to interconnect the components whereas a layered architecture is good for achieving protocol simplicity. [70] argues systematic development of a science for integrating CPSs that is based on investigating compositionality in heterogeneous systems. Authors have attempted to identify the challenges associated with CPS Integration. The paper suggests the research directions to solve these challenges by extending the passivity-based approach from continuous dynamics to discrete event system models. Other challenges include stability and preserving compositionality in other properties, such as safety, and performance requirements are also an important and essential design goal. Tool support for integration of CPS should be researched as well. Integration of CPS is considered as a major challenge. This is largely because of either the theoretical understanding about the physical object is missing or because the integration is usually the last phase of a system development. So, incorporating the modifications to support integration in the last phase becomes almost impossible.

4. System Composition

CPS is a composition of Physical and computational objects. CPS compositional elements include monolithic design, object orientation, application modules, component-based software engineering and service orientation. Effective component-based system design depends on two properties: compositionality and composability. Preserving compositionality in other properties, such as safety, and performance requirements are also an important and essential design goal. [71] surveys the current state-of-the-art in composition mechanisms for CPS and reviews each approach in terms of its support for composition analysis, re-use and adaptation. Key composition mechanisms for CPS include monolithic design, object orientation, application modules, component-based software engineering and service orientation. A number of different compositionality models have been proposed for CPS. The best known include Multi-Mode Automata (MMA), Timed Process Algebras and Hybrid Automation. CPS development must be supported from the design phase by process algebras to achieve strong results on correctness, performance, cost and efficiency. A short talk [72] briefly discusses the design challenges in terms of compositionality in the design process. Research directions, such as Model Integrated Computing (MIC), Model Driven Architecture (MDA), Model Driven Design (MDD), Business Process Modelling (BPM) and others made model-based approaches in software engineering practical and led to the appearance of a new generation of CASE tools. [73] Discusses the CPS system composition in terms of QoS properties and functional correctness. Current compositional frameworks have been developed with limited heterogeneity, such as real-time resource management, automata and differential equations. The new theory of system composition must provide a comprehensive treatment of system integration concerns. The theory of system composition must also address the interaction of protocols.

5. Communication

Communication networks are an essential part of any CPS as they interconnect the CPS subsystems and components. Communication can be one of the classifiers for system based on the type of communication, protocol and/or topology followed. CPS needs to communicate for data sharing and synchronization of processes within itself as well as wit surroundings. CPS communication ranges from IoT to M2M. [74] Evaluates different existing communication protocols in the scope of Service-oriented Architecture (SoA) and loosely coupled systems, extracts common tasks and implementations, and identifies common communication patterns. Some of the protocols are Web services, Universal Description, Discovery, and Integration (UDDI), OPC Unified Architecture (OPC-UA), and the data-centric approach Data Distribution Service (DDS). These protocols follow a pattern of Discovery, Request-Response or Publish-Subscribe. [75] have proposed a solution to CPS communication consisting of different wireless sensor nodes communicating through UDP messages using the existing IEEE 802.11 b/g infrastructure. This is a simple Wi-Fi based solution for monitoring of environmental parameters as Humidity and Temperature. They have also discussed the other common wireless network protocols in CPS like Bluetooth (IEEE 802.15.1), ZigBee (IEEE 802.15.4), ISA100.11a, Wireless HART. [76] Defines the communication modes and fit CPS into the framework of hybrid systems targeting a Smart Grid application. This approach takes a viewpoint that the operation of communication network can change the mode of the physical dynamics in CPS. It further discusses Mode Provisioning and Scheduling as major challenges within the framework of hybrid systems. It also provides examples for mode provisioning and scheduling in different layers of communication networks. In addition to these, some papers have attempted to modify the existing protocols at a specified layer to improve the efficiency of communication system [49], [77].

6. Verification & Validation

CPS systems are largely verified using trial-and-error approach as of now because of cross-domain expertise requirements. A developed CPS should be verifiable and its functionality should be validated beforehand. This takes us back to the simulation & synthesis tools for realizing CPS from specs. The simulation tools need to be integrated with fuzzy models for validating the CPS. [78] Have defended that verification and validation of CPS is not a onetime event but a life-cycle process that produces an explicit body of evidence for the certification of safety-critical services which is a specific requirement of CPS. This will corroborate the trust in CPS and evolve the process of Certification for such systems. Trust is a combination of a many characteristics, mainly reliability, safety, security, privacy and usability. The paper expects that a new CPS science will define new mathematical foundations with formalisms to specify, analyze, verify and validate systems that monitor and control physical objects and entities. [79] Expresses that verification of CPS at full detail is not possible due to the state explosion problem. This paper presents an automatic abstraction methodology that simplifies the model accordingly. They have presented an automatic abstraction technique for simplifying their labelled hybrid Petri net (LHPN) models. The basic idea is to apply LHPN transformations to remove details from the model that are irrelevant to the property of interest. [80] Presents a specification framework based on natural language queries that are automatically converted to a deterministic class of timed automata used for runtime monitoring called as Brace Assertion. This paper brings Behavior-Driven Development (BDD) into runtime verification of CPS applications and describes them by work on runtime monitors based on temporal logics and other runtime monitors mainly designed for efficiency. [81] Suggests that component-level verification alone isn't sufficient to guarantee safety. They have used hybrid I/O automaton (HIOA) framework to find out the Inductive Invariants. They agree that simulation models can be leveraged for obtaining bounded time safety guarantees for high-dimensional nonlinear models for CPS systems. [80] Identifies significant research gaps in addressing verification and validation of CPS ranging from developers perspective to availability and limitation of tools.

7. **Resource Management**

CPS possesses a new challenge of efficient management of Resources. Hyping on a cross-domain nature, resources related to node, subsystems and computational requirements need to be handled efficiently. This offers opportunity to discover new scheduling algorithms to optimize the resource utilization for CPS generation systems. Always changing nature of Physical processes further complicates the resource management. Resource management policies can be opportunistic, adaptive, competitive or cooperative. [82] Discusses resource management and availability in terms of dependability of CPS. They have reviewed the application of current maintenance principles to the CPSs by categorizing the principles as non-applicable, exportable and adaptive. [83] Sees the CPS as not lacking in resources but the auto-management techniques are required to ensure that a system will address resource management issues in an autonomous mode. [84] Refers data as major resource and cloud computing as a solution to manage it. They have denied a cloud-centric framework which relies on the well-known qualities of the microservices architecture style, the autonomic computing paradigm, and the model-driven software development approach.

8. **Timing & Performance Analysis**

Timing synchronization is another important factor for realizing the CPS. Synchronizing the clocks & processes across the (distributed) system brings assures a number of design & implementation challenges. Performance of CPS is another dimension to be looked for analyzing CPS. It ensures the faith and usability of the CPS in a particular domain. A CPS should be deterministic.

9. **Tools & Frameworks**

Tools are software components for specifying requirements or designs, simulating systems, and analyzing designs. CPS design involves the tools from across the domains. Type of tools may depend on the domain/ application. Selection of tools & integrating them to work for sustainable systems will be a challenge as well as opportunity. One of the major challenges will be to connect these tool components in a whole design process. This will again require a call to choose a universal language like UML or SysML. Frameworks will provide a conceptual view for conceding a stable CPS design. It may include designing a system from available systems. The components of a framework should be scalable and configurable. The same framework should work for all of CPS ranging from small & simple to very large & complex distributed systems. Framework elements may include domains, facets & aspects to further classify the systems.

10. Architecture

Architecture of CPS is a deciding factor while deciding a CPS design. Different architecture styles can be used based on their merits & demerits like layered or tiered. The main benefits of the layered architectural style are: Abstraction, Isolation, Manageability, Performance, Reusability, and Testability. The main benefits of tier architecture styles include Maintainability, Scalability, Flexibility and Availability. Maintainability: Because each tier is independent of the other tiers, updates or changes can be carried out without affecting the application as a whole. Scalability: Because tiers are based on the deployment of layers, scaling out an application is reasonably straightforward. Flexibility: Because each tier can be managed or scaled independently, flexibility is increased. Availability: Applications can exploit the modular architecture of enabling systems using easily scalable components, which increases availability. [85] Has done initial work in providing an integrated definition of CPS based on its attributes. [20] has reviewed the status of CPS architectures and analyzed three main features for them as design, real-time control, security assurance and integration mechanisms. The paper also explains & proposes a Service Oriented Architecture (SOA) for CPS. [86] States that Trustworthy CPS architecture must be based on a detailed understanding of the physical properties and constraints of the system. So, the architecture should cater to the need of proactive, real-time, autonomic and data interoperability to defend dynamically against changing adversary models.

3.1.2 Computational Abstraction

Computational abstraction is the process of identifying and representing mathematically the salient features of the system and interactions of real system. Computational abstraction deals with the physical properties of the system such as safety, real-time, resources, robustness, power constraints and security characteristics etc. [78]. It is model specification based abstraction and plays important role in CPS for various applications to identify the necessary mathematical models and methods to implement. Distributed or cloud computing performs the large-scale complex computation and communication to collect application's sensory and remote centers data. Computational abstraction increases the system efficiency by applying the appropriate algorithms. It is the process to reduce and factor out details to focus on few concepts at a time. Computational abstraction in CPS is performed by the modelling, analysis, optimization, design and performance.

1. Modelling

Designing and modelling of CPS requires vast computation, large network, large data and multiple domains such as control, communication, feedback, and response. To validate the design, static and dynamic models based computations are used. In which user-defined values and simulation environment are used to design the static models whereas complex computation, prediction and design involves in dynamic models. Modelling of the computational system provides the proof of concept based idea before implementation so the model shapes with more perfection and efficiency. For the modelling framework, single-threaded imperative programmes and discrete-event models uses for the cyber side, and physical system operates with ordinary and partial differential equations [88]. For example, CyPhySim is an open source simulator and supports mixed continuous and discrete dynamics using model of time, modal model and hybrid systems [88]. The combination of physical and computational process explains the deterministic models for physical dynamics and for computation is nearly always nondeterministic in CPS [1]. On the other hand, nondeterministic and probabilistic models are necessary for systematically handling unknown and behaviours [1]. Physical dynamics is classified into the ordinary differential equation (ODE) and actor model. The ODE is venerable tool for engineers whereas actor model is derived by the software modelling and simulation tools [87]. In recent years, some researchers follow the following aspects such as event model, physical model, reliability, and real-time assurance, among others and software design methods include model-driven development (MDD) (e.g., UML), model-integrated computing (MIC), and domain-specific modelling (DSM) for embedded system design in CPS model base design [89],[17].

2. Analysis

Computational analysis combines database technology, programming, sensing data, designing visualization, computational geometry, numerical analysis, modelling and simulation, imaging, signal processing, computational data processing and analysis techniques. The computational analysis based on the statistical analysis, specialized algorithms and machine learning algorithms at the node level and/or cloud level. It is essential for visualization of that data, interpretation and information extraction, construction of user-focused applications, analysis of textual and sensor-derived information. For example, machine learning applied to recognition of postures and activities of Smart Shoe therefore Support Vectore Machine

(SVM), Multi-Layered Perceptron (MLP) algorithm, both the algorithm produced the results with the accuracy which is actual performance achieved in physical activity recognition by Smart Shoe [91]. After that Deep Learning classification applied to the raw data for feature extraction from the sensor signals [91]. When applying the analysis to the model and design, the safety conditions can be analyzed through the models and timing behaviour of software can be analyzed through the designs [87]. According to the researcher, real-time system analysis is proposed fuzzy genetic algorithms to boost the computing efficiency. The example explained to overcome the problems of object masking, separation and occlusion within a vehicle parking scenario by using adaptive background learning algorithm and intelligence [90]. The author works on the analytic methods for Intelligent Video Systems (IVS) such as intelligence, cooperative view selection, integration and statistics, network analysis, learning and classification and 3-D sensing [90]. Intelligent Video Analytics (IVA) has been applied using adaptive and intelligent methods of neural network, genetic algorithm, knowledge-based approaches, particle filtering, particle swarm optimization, finite state automation, reasoning, self-organizing maps (SOMs), support vector regression (SVR), Kalman filtering, semantic analysis, Markov models and decision tree and clustering [90].

3. Design and Performance

Computational design and performance focuses on design process, production and the resulting forms, products, geometric study, parametric, scripting and automation. Computation design works on simulation, analysis, synthesis, tangible interaction, and people-centered as well as building-centered design algorithms. Computation design method is used to formulate and enhance the performance of application-specific architecture and system. The design tools used in the computation design based on the mathematical modelling, algorithms, simulation and design automation. The design includes the data mining, pattern recognition, artificial intelligence and their structure logics etc. Model-based design is the approach to design a primarily system with the help of specified model (virtual system) rather than physical prototype [92]. Testing of the developed model relies on the powerful automated implementation techniques and the synthesized implementation preserves the properties of the original model [92]. The researcher works on the model based design for emphasizing the mathematical modelling, model physical processes, characterize and derive a control algorithm, computation, simulation, construct, synthesize software and verify and validate system [68].

4. Optimization

Computation optimization is an important paradigm with real-time applications of CPS. Optimization techniques are used for design architectures, mathematical modelling, computer simulation and computation-intensive numerical optimization. High efficient optimization methodologies in design, algorithms and large computational resources requires modern and high- speed computers. The computational design optimization can be defined by the transforming an application's design problem into a mathematical optimization, features of the systems to optimization process and expressing the modifications as functions of the optimization variables and prediction the optimized values. The computational optimization is used to determine the fine-tune features and conceptual layout of the system. Optimization is challenging task in terms of high computational cost of evaluating objectives, nonlinearity, multimodality, discontinuity, uncertainty and problem-solving time of the problem functions in the real-world systems.

3.1.3 Sensing

Physical entities of CPS are performed by the sensing devices and systems. Raja Waseem Anwar et. al proposed that sensors are used to monitor and measure various physical phenomenon and convert it into useful information which contains the attributes, sampling, time and space stamp etc.[95]. The sensors and actuators play a bridge role between physical and cyber world [96]. Different types of sensors (wired and wireless) and actuators are used for richer measurement and control of physical processes [78]. The sensing entities are responsible for collecting important sensor's data and these data are fed to the processing and communication system for further use. Sensing is the key concern for several applications like HealthCare, Transportation, Energy, Environmental, Infrastructure, Communication and Defence System etc. and these sensing values are used as input parameters to the CPS [96], [78]. The elements from Sensing perspective depends upon the localization (positioning in space) of sensors, time synchronization, sensor networks and sensor nodes etc. For example, sensing is the heart of smart infrastructure to collect information from the sensors and monitor public infrastructures, such as bridges, roads and buildings, provides awareness [57].

1. Sensor Types

Sensing element is the key feature of sensing data from physical environment. So, the performance of the control system depends on the performance of the sensing element. The sensing element converts physical entity into the electrical signal and fed into an autonomous system [57]. The sensors have the ability to collect the entire target unit's information efficiently. The collected information (data) is forwarded to the controller unit that can use data locally or transmit to server, cloud or distributed network through a gateway [57]. The sensors can be a part of wireless sensor network with the attachment of sensor node. To acquiring or sending the data/ information through the sensor, the sensing information can be obtained with the help of active or passive sensors. The sensors are broadly classified into acoustic, sound and vibration, automotive and transportation, chemical, electric, magnetic, radio, environment, weather, moisture, humidity, flow and fluid velocity, ionizing radiation and subatomic particles, navigation instruments, position, angle, displacement, distance, speed, acceleration, optical, light, imaging, pressure, force, density, level, thermal, heat, temperature, proximity and presence sensors [57]. The other type of sensors are smart sensors, they are capable of processing, manipulation, and computation of the sensor-derived data. These types of sensors require interfacing circuit, logic functions, two-way communication device, and decision-making device [57]. The sensor type depends on the application and it's principle of operation. So, it is important to specify the application specific sensors for better visibility and data.

2. Method

The sensory data largely depends on the sensor network whether the sensing system is equipped with single sensor or multiple sensors. The complexity of the system depends upon the type of sensing strategy. The CPS mainly consists of large number of sensors in the form of homogeneous and heterogeneous sensor network to collect the sensing data. The homogeneous sensor networks are static and consist of all identical sensor nodes with battery efficiency and hardware complexity. In the case of homogeneous sensor network, sensors present in the network communicate with each other via wireless nodes in single or multiple hops to form ad hoc network [92]. This communication channel collects data from the sensor nodes, analyze and communicate to the server or cloud [92]. In the case of heterogeneous sensor network, two or more different types of sensor nodes are used with the battery energy, functionality and efficiency. These type of sensor networks implements extra battery energy and complex hardware at their end so the rest of the hardware network cost reduces. Sometimes, the sensors observed the unusual data from the sensors therefore the system's performance and user's decision making plays important role to analyze the sensed multidimensional information in an efficient manner. So, it is important to specify the sensing method for better efficiency and hardware complexity for CPS.

3. Nodes

Sensing node plays a critical role in the CPS. The sensing node is capable of performing gathering sensory information, data processing and communication with the other nodes connected to the network. The sensor nodes are equipped with low power processor, memory, mobility, communication, ADC, sensors, and power [57]. In the CPS wired and wireless both type of sensing nodes used for different applications such as defence, medical devices and systems, traffic control and safety, advanced automotive systems, distributed robotics (telepresence, telemedicine) and agriculture, etc. [1]. The wireless sensing nodes along with Bluetooth device, ad-hoc and stationed nodes etc., are self-organizing and having long battery life. In wireless sensor network (WSN), the sensor nodes interfaced with the number of sensors at a platform and collecting data, pre-processing, processing and transmit information to sink-node via other sensor nodes [57], [97]. These nodes are having functional and processing capabilities. The wired sensor nodes are Ethernet connected or cable connected nodes. They are used for the constant and infrastructural environment. The wired sensor networks are a traditional method that consists of a small number of sensor nodes and they are wired with central processing station [98]. Examples of some classified sensor nodes are Mica, Mica2, Mica2dot, IMotes, Telos B, Stragate, etc, Apart from these nodes EYE nodes (Energy-efficient Sensor Networks) and BTnodes (uses Bluetooth) [98]. But the sensing node's challenges are energy, power consumption, scalability and lifetime of sensing node etc.

4. Social Sensing

Due to the advancement in Mobile & Internet technology, there are sensors spread across and throughout the society. Man is a social animal and now he holds the Mobile which gives him an omnipresent status by communicating & sharing information as and when he wants. [99] identifies social sensing as an act of sharing the information regarding the physical environment. They also analyses that extracting useful information from social sensing is must for further action. Presence of social networking sites and applications like Facebook, Google+, LinkedIn, WhatsApp, Snapchat etc. have helped in distributing and social sensing. Media & other broadcasting mechanism also serve as platforms for social sensing. Success of CPS proliferation largely depends upon the data collected, analyzed and system response to that analysis. [100] discusses the social sensing systems using social networking sites and sensors embedded in mobiles like Biketastic, BikeNet, CarTel and Pier and doing context-aware computing. Social networks, in a sensor-rich world, have become inherently multi-modal data sources, because of the richness of the data collection process in the context of the network structure. Social sensing plays a role in almost all the applications as are discussed in this report but still need data analysis to make efficient use of this. Low power, precise and well connected sensors act as technology enablers for this paradigm shift. Google Maps can be cited as an obvious example of social sensing to find out the fastest route to your destination in traffic.

5. Parameter Sensing

Parameter specification is important for the better computation and communication strategy. It improves the performance of the entire system. A single parameter system is useful for the simple applications like temperature monitoring, but for the complex or bigger applications like air traffic control, healthcare; multiple parameter systems requires for detailed monitoring and controlling [97]. The wired and wireless sensors information gathering and input this information to the multi-parameter system plays a key role in monitoring the complex applications. The wide range of sensor parameters depends upon the sensor properties. The sensor's parameter consists of device configuration, device specifications, event, power consumption, resolution, sensitivity, metrics, schemes, and techniques.

3.1.4 Communication

Communication networks are an essential part of any CPS as they interconnect the CPS subsystems and components. The taxonomy classification of communication for CPS is as follows:

1. Interoperability

CPS ecosystem requires interoperability to create the "seamless" programmability of the various physical components that enables the full potential of a connected experience. This means CPS physical components require standards to enable horizontal platforms that are communicable, operable, and programmable across devices, regardless of make, model, manufacturer, or industry. Standardized abstractions and architectures are urgently needed to fully support integration and interoperability and spur similar innovations in CPS [101]. A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network [102]. For a spatially distributed remote nodes setup (e.g. robotic control, industrial automation), wherein the processing capacities are low and power is a premium, the 6LowPAN is the preferred approach. These nodes, which are all homogeneous, will talk through a gateway, which in turns opens up these devices for accessibility from external world. In the CPS scenario, the physical components such as sensors, control system are all digital things connected to the web. They are monitored and controlled through service frameworks and various applications — custom as well as generic. Thus there is a strong need for standardization, that enables the semantics being conveyed and understood, and also for interoperability of devices from multiple vendors. The researchers in past have studied the state-of-the-art interoperability issues and challenges and proposed the semantic interoperability standard [103].

2. Efficient Connectivity

The heterogeneity in CPS exposes several problems that cannot be easily solved through current control, communications, and software theory. As an example, today's network research often deals with coverage and connectivity issues assuming homogeneous network components [53]. However, coverage and connectivity should clearly be redefined in Cyber-Physical control network systems. Such systems will consist of wired and wireless networks with different capacities and reliability. In particular, a generic framework for the design of CPS architecture can be developed that has heterogeneous communication capabilities of each component, and real-time guarantees [107]. The researchers have proposed sleep-awake protocol to reduce energy demand of communication through dynamically switching radio between the sleeping mode and active mode. Considering a radio component as main source of energy depletion, the energy-preserving medium access control protocols become popular approaches [108]. As the industrial CPS involves thousands of connected sensors communicating through the wireless network, the power consumption of sensors is a big concern and limitation for the widespread of IoT. Saving energy should become a critical design goal for IoT devices, such as wireless sensors [109]. There is a need to develop energy-efficient techniques or approaches that can reduce the consumed power by sensors [110]. The online pattern clearly costs a great extra amount of energy for broadcasting temporal solutions. In order to save energy, the concept of self-triggered control [111] is adopted in this paper, in which the controller dynamically determines the next tasks execution time including sampling, command broadcasting, and changing of action. A joint optimization framework is presented, which combines the objective of control as well as other relevant system objectives and constraints such as communication errors, delays and the limited capabilities (e.g. energy capacities) of devices. The problem is solved by an online optimization approach, which consists of a communication protocol and a simulated annealing based control algorithm. Meanwhile, by taking into account the communication cost, the author has optimize the control intervals by integrating two kinds of acceptance, i.e., cyber and physical acceptances, into the control algorithm [94].

3. Location-based Services (LBS)

A location-based service is a software-level service that uses location data to control features. As such location-based services is an information service and has a number of uses in social networking today as information, in entertainment or security, which is accessible with mobile devices through the mobile network and which uses information on the geographical position of the mobile device. Location is the most obvious context attribute, but not the only one- also identity, status or activity, and time characterizes a situation. An integrated system based on Wireless Sensor Networks for patient monitoring, localization and tracking has been proposed in [112]. The system can be rapidly deployed in any indoor environment, due to adopted self-calibration method. They developed both a distributed solution entirely running on a low-cost mobile sensor node and a centralized solution that minimize the target node energy consumption. A similar analysis is carried out in [113], together with a prototype of MEDiSN, a WSN-based system capable of monitoring vital signs of unattended patients. However, patients' localization is only presented as broadly useful, according to the indications of many staff members, depicting this topic as a future feature that can be added as soon as researchers will be able to provide efficient and effective ways to perform it. In [114], the author has presented the indoor location-based smart factory (iLSF) platform, a service model for collaboration among factory workers, facilities, manufacturing materials, and factory control system. The iLSF collects the information from the factory through a protocol that supports self-collaboration among wearable devices, tags of machines, and anchor nodes. The proposed platform enables a worker to automatically configure a machine with their personally preferred value, and receives the working history from a machine. Finally, we suggest various specific service scenarios such as a safety notification to workers in a dangerous environment and a guide to workers informing them of the proper manufacturing process.

4. Wireless Communication Bandwidth

In CPS, the major communication happens through wireless medium. The wireless communication bandwidth plays a crucial role while using wireless media. Many efforts have been put by researcher to effectively utilize the wireless bandwidth for CPS application. A joint power and bandwidth allocation with QoS support algorithm is proposed using convex optimization method is proposed in [115]. The algorithm achieves the goal of the total system capacity maximization, while efficiently satisfying the minimum rate constraint of delay-constraint service traffic and proportional fairness of best-effort service traffic. In [116], the author has proposed a new framework, which is called dynamic QoS-based bandwidth allocation (DQBA), to support heterogeneous traffic with different QoS requirements in WiMAX networks. The design of CPS with wireless control systems must deal with interdependencies between control and communication. For example, while it is well known in digital control that a low sampling rate usually degrades control performance, a high sampling rate may increase resource contention in bandwidth-constrained WSANs leading to long communication delays, which again may lead to degraded control performance. The coupling between wireless communication and control therefore motivates a Cyber-Physical code-sign approach that integrates wireless networks and control designs.

5. Real-time Quality of Service (QoS)

Network QoS management in this new realm is among those issues that deserve extensive research efforts. It is envisioned that wireless sensor/actuator networks (WSANs) will play an essential role in CPS. From an end user's perspective, real-world WSAN applications have their specific requirements on the QoS of the underlying network infrastructure. The researchers have put the significant efforts over the past few decades on real-timeQoS for wireless network. CPS by nature is application-oriented. Therefore, WSANs have to provide QoS support so as to satisfy the service requirements of target applications. In [88], the author proposed a three-layer QoS scheduling model for service-oriented IoT. At application layer, the QoS schedule scheme explores optimal QoS-aware services composition by using the knowledge of each component service. The proposed QoS-aware scheduling for service-oriented IoT architecture is able to optimize the scheduling performance of IoT network and minimize the resource costs. Another work on a QoS architecture based on IoT layered structure has been proposed in [117]. This architecture sets QoS agent in lower layers then transmits QoS requirements, trying to guarantee the consistency as well as effectively use the existing QoS mechanisms in every layer. In [118], the author has proposed the QoS requirements for the smart grid applications. To meet the QoS requirements of diverse smart grid applications, it differentiates the traffic flows into different priority classes according to their QoS needs and maintains three dimensional service queues attributing delay, bandwidth and reliability of data. The problem is formulated as a drift optimization with the objective of maximizing the weighted service of the traffic flows belonging to different classes. A suboptimal distributed control algorithm (DCA) is presented to efficiently support QoS through channel control, flow control, scheduling and routing decisions.

6. Data Transmission

In CPS, the connectivity among various physical components emphasize the perception of information and provides data support for a variety of specific application through data collection, processing, integration and routing. IoT interconnects Internet information sensing devices like wireless sensor and radio frequency identification (RFID) through wireless network and Internet technology, and it is a new type of network to realize the overall perception, reliable transmission and intelligent processing of information. The research direction is required to realize rapid exchange of data transmission by optimizing existing routing algorithms. In particular, the change of existing network system structure with the "best effort" is needed provide real-time network transmission services for the system. As a burgeoning technique for signal processing, compressed sensing (CS) is being increasingly applied to data transmission in wireless communications. In [119], the author has investigated the application of CS to data collection in wireless sensor networks, and aimed at minimizing the network energy consumption through joint routing and compressed aggregation. The authors in [120] have been investigated how CS can provide new insights into data sampling and acquisition in wireless sensor networks and IoT. In this research, the author briefly introduces the CS theory with respect to the sampling and transmission coordination during the network lifetime through providing a compressed sampling process with low computation costs. The network and data transmission architecture for the long-range sensor networks has been proposed in [121]. The proposed network architecture is based on oneM2M IoT standard. It has Infrastructure Node (IN), Middle Node (MN) and Application Service Node (ASN) as network elements. In this method, IN employs cloned MNs to reduce the traffic load at the MN, which is the gateway. ASN delivers data through MN or cloned MNs to the IN. Through the load balancing by the proposed method at the MN, the efficient data transmission for IoT services in long-range sensor networks can be provided.

7. Protocols for Energy Efficient Design:

In modern CPS, new dimensions of freedom are enabled to energy efficient solutions. adopt a control and optimization approach for energy efficient design in CPS. Energy is most important factor for designing communication protocols for CPS. The WSN protocols are widely used for communication between the various physical components must be an energy efficient protocol. The research work in [122] presents the challenges in the design of the energy-efficient Medium Access Control (MAC) protocols for the WSNs. Moreover, it describes few MAC protocols (12 in total) for the WSNs emphasizing their strengths and weaknesses, wherever possible. There are a few attempts to propose and discuss models for energy efficiency WSNs. Most of them are based on the sensor node power consumption model. In particular, the authors in [123] present a realistic power consumption model for WSN devices by incorporating the characteristics of a typical low power transceiver. This work proves that for typical hardware configurations and radio frequency environments, whenever single hop routing is possible it should be preferred as it is more power efficient than multi-hop routing. On the other hand, in [124] the authors present an energy model divided into a set of finite state machines that represent the states and transitions of a sensor node's hardware. In addition, in [125] a general energy consumption model of WSNs devices based on the actual hardware architecture is proposed. In order to achieve this, the authors utilize the measured energy consumption performance of the actual hardware components and implement a realistic CSESM (Communication Subsystem Energy Consumption Model) of WSNs devices.

8. Fault tolerance:

In CPS, the requirement of safety-critical real-time applications relies on basic fault-tolerant communication protocols. The communication backbone of such a system has to be equally reliable and must work fail-operationally that is, it must stay operational even in the presence of faults as long as they meet a predefined fault-hypothesis. A fault-tolerant communication controller is a typical example of an embedded, fault-tolerant system. In

[53] proposed an efficient fault-tolerant and energy-efficient clustering protocol for an IoT system. The performance of the proposed protocol was tested by means of a simulation and compared against the low energy adaptive clustering hierarchy and dynamic static clustering protocols. The results showed that the fault-tolerant and energy-efficient clustering protocol has better performance than both the low energy adaptive clustering hierarchy and dynamic static clustering protocols in terms of energy efficiency and reliability. Similar work has been proposed in [126]. In this, the author introduces a fault tolerant, energy efficient and secure clustering scheme for M2M (FESM) area networks that minimise the number of cluster heads (CHs) and active nodes to reduce network energy consumption. The machine type communication gateway and CHs transmit beacon messages to discover the failure of CHs and member nodes, respectively. In [127], the author has developed the fault tolerance mechanism for IoT, which is distributed and takes into account the dynamics within IoT. Strip is introduced to store a list of duplicated services, and, each service peer maintains a consistent view of duplicated services in the strip. In combination with the heartbeat protocol, recovery from failure can be achieved by manipulating strips in a distributed manner.

3.1.5 Control & Actuation

Cyber components in a CPS application often include algorithms that react to sensor data by issuing control signals via actuators to the physical components of the CPS. Such closed-loop feedback systems are the domain of the classic field of control theory, which studies stability and dynamics of such interactions. CPS, however, requires extending control theory to embrace the dynamics of software and networks, which can have profound effects on stability and dynamics of the physical subsystems [40].

1. Decision making based on Prioritized and Optimized control

Task prioritization and optimized decision in CPS maximizes its efficiency, capability and safety. Various works that has been done in this area are as follows. Event-triggered control, also known as Lebesgue sampling [128], provides an efficient means of achieving acceptable physical system feedback regulation with minimal computational resource overhead. Event-triggered control contrasts with time-triggered or periodic control in that control tasks are triggered and subsequently executed when the system state deviates a certain threshold from a predetermined value [129]. This approach results in more efficient allocation of cyber resources due to "as-needed" or "on-demand" physical system control task execution. Researchers have begun to advance Lebesgue sampling or hybrid approaches to CPS control [130], [131], [132], [133]. The CPS community has also investigated how to best optimize Cyber-Physical Vehicle Systems (CPVS) team physical trajectories (CPVS positions, motions) to best support networking and to optimize information acquired by a sensor CPVS team.

Song et al. [134] propose use of the Fisher information matrix to optimize observations Sensors over a wireless sensor network (static or mobile). In Bradley et al [135] and Coloe et al [136], a UAS(Unmanned Aircraft Systems) trajectory is itself optimized over Cyber-Physical terms, including the energy used and heat generated by propulsion and computing systems as a function of physical state and processor utilization trajectories. Feedback scheduling adjusts cyber resources based on the needs of the cyber system [137]. It accomplishes this by adapting traditional control theory to regulate the task schedule in the RTS. This, in turn, contributes to regulating the CPS as a whole. In this scheme, sampling periods of various control tasks are adjusted, and subtasks (parts of a task) are scheduled using feedback from execution time measurements and feed forward from workload changes [138].

2. Artificial Intelligence

These systems are ones that emulate human capacities for learning, understanding, or perception. In the context of CPS, there are particular opportunities and challenges associated with controlling or predicting the behaviour of such systems and how their behaviour affects overall system behaviour. Various works that has been done in this area are as follows. [107] presents a solution for the CPS domain of intelligent water distribution networks, using EPANET and Matlab to represent the physical water distribution network and the decision support algorithms used to control the allocation of water, respectively. [50] focuses mainly on smart charging-discharging operations of Gradable Vehicles (GVs) and maximum utilization of Renewable Energy Sources (RESs) in Cyber-Physical energy system (CPES). On the cyber-side, intelligent computations and decisions are carried out on the dynamic data of the physical resources of the CPES for the maximum utilization of renewable sources using GVs to reduce both cost and emission in CPES. Here it presents the overall approach and briefly describes their works and results over the past decade in the application of concepts and methods developed in complex systems and intelligence sciences for intelligent transportation, particularly parallel control and management systems. This paper has incorporated their most recent progress on the development and applications of Parallel Transportation Management Systems (PTMS); it is closely related to emerging technologies in cyber-physical-social systems. [139] describes reported results within the International Academy for Production Engineering CIRP, which can be considered as roots of CPPSs (Cyber-Physical production systems). One of the reported root is Intelligent manufacturing systems (IMS), which were expected to solve, within certain limits, unprecedented, unforeseen problems on the basis even of incomplete and imprecise information [140], [141]. Artificial intelligence and machine learning methods play a significant role here [142], [143].

3. Resilient and Robust control

Robustness refers to the operation of a system under a given range of perturbations or disturbances whereas resilience refers to the restoration of a system under unexpected extreme and rare events [144]. Various works that has been done in this area are as follows. [144] provides a combined approach to resilient and robust control by introducing a hierarchical layered viewpoint of CPS along with application to power systems. [145] established a coupled design framework which incorporates the cyber configuration policy of Intrusion Detection Systems (IDSs) and the robust control of dynamical system. Algorithms designed were based on value iteration methods and linear matrix inequalities for computing the optimal cybersecurity policy and control laws. [146] considers a CPS consisting of two interacting networks, i.e. a cyber network overlaying a physical network. It is envisioned that these systems are more vulnerable to attacks since node failures in one network may result in (due to the interdependence) failures in the other network, causing a cascade of failures that would potentially lead to the collapse of the entire infrastructure. The robustness of interdependent systems against this sort of catastrophic failure hinges heavily on the allocation of the (interconnecting) links that connect nodes in one network to nodes in the other network. This work characterizes the optimum inter-link allocation strategy against random attacks in the case where the topology of each individual network is unknown. [147] is a position paper which investigates the security of CPS. Here, it identifies and defines the problem of secure control, investigate the defences that information security and control theory can provide, and proposes a set of challenges that need to be addressed to improve the survivability of CPS.

4. Networked control

In a typical CPS architecture, the signalling is mediated by software and networks that do not have continuous or periodic behaviour. Adapting control theory to handle the realities of software and networks is an important CPS problem. Works done in this area are as follows. A team in Delft Center for Systems and Control (DCSC) [148], whose research efforts are aimed at improving understanding and control of CPS composed of a large number of interconnected and embedded components. Such networks of systems contain a huge number of sensors and actuators that generate a tremendous amount of data to be processed in real-time in order to increase the autonomy of the participating entities, or accomplish a high level of automation. The scientific challenges currently pursued by the team are of multidisciplinary nature, and include the following topics and applications: Distributed decision-making, control, estimation, and optimization for large-scale systems and Control over wireless sensor/actuator networks Networked CPS are fundamentally constrained by the tight coupling and closed-loop control of physical processes. To address actuation in such closed-loop wireless control systems there is a strong need to rethink the communication architectures and protocols for reliability, coordination, and control. [149] introduces the Embedded Virtual Machine (EVM), a programming abstraction where controller tasks with their control and timing properties are maintained across physical node boundaries and functionality is capable of migrating to the most competent set of physical controllers. [150] provides a mathematical framework for modelling and analyzing multi-hop control networks designed for systems consisting of multiple control loops closed over a multi-hop (wireless) communication network. [151] presents a method to stabilize a plant with a network of resource constrained wireless nodes. As opposed to traditional networked control schemes where the nodes simply route information to and from a dedicated controller (perhaps performing some encoding along the way), their approach treats the network itself as the controller.

5. Adaptive and Predictive control

CPS systems are typically closed-loop systems, where sensors make measurements of physical processes, the measurements are processed in the cyber subsystems, which then drive actuators that affect the physical processes. The control strategies implemented in the cyber subsystems need to be adaptive (responding to changing conditions) and predictive (anticipating changes in the physical processes). Several works done in this field are as follows. [152] provides presentation and analysis of design aspects of dynamic control software in the context of an autonomous train experiment. This is achieved through a self-adaptation software framework intended for autonomous trains and built on a demonstrator. The autonomous train can be seen as an intelligent transport system (a CPS essentially). [153] introduce Neural Programming (NP), which can be used for writing adaptive controllers for CPS. In NP, if and while statements, whose discontinuity is responsible for frailness in CPS design and implementation, are replaced with their smooth (probabilistic) neural if and while counterparts. This allows one to write robust and adaptive CPS controllers as dynamic neural networks (DNN). [154] provides a limited perspective towards predictive control of interconnected systems of systems and CPS, focusing on results related to their expertise and on three aspects which can have significant impact on the CPS. Model predictive control (MPC) has been used in many industrial applications because of its ability to produce optimal performance while accommodating constraints. However, its application on plants with fast time constants is difficult because of its computationally expensive algorithm. In [155], a parallelized MPC that makes use of the structure of the computations and the matrices in the MPC. It has been shown that the computational time of MPC with prediction horizon N can be reduced to O(log(N)) using parallel computing, which is significantly less than that with other available algorithms with similar accuracy, thus providing a Parallelized Model Predictive Control for Distributed Networked Systems.

6. Feedback systems

a. Human-in-Loop

Many CPS include humans as an integral component. Humans are very difficult to model, so understanding and validating such systems becomes particularly challenging. Works that have been done in this field are as follows. In [156], a class of intelligent CPS, a form of next-generation networked systems that involve humans (particularly, human perception) in the control loop. Here intelligent lighting has been taken as a representative case to explore the issues that conventional machine learning faces in human-centric CPSs. This can help in addressing the general problem of how to handle CPSs characterized by non-deterministic, multiple-output problems. Here an intelligent lighting system that can learn the users' preferences to provide a suitable light condition for a given observed context has been taken. [157] provides a Human-in-the-Loop Cyber-Physical Production Systems Control (HilCP2sC) concept, which can be largely conceived as a natural evolution of distributed manufacturing control paradigms which exploits recent technological progresses in embedded systems, ICT and networking and communication infrastructure, and where Human-System interactive dimension of CPS plays a significant role as an enabler for intelligent decisional framework bringing human into the cybernetic loop of the manufacturing control system. The reported research concerns an on-going effort toward the introduction and the development of this concept.

b. Economics-in-Loop

Modern CPS is given expanded scope and greater flexibility by including dynamic pricing signals, financial information, and economic attributes as integral feedback components. The integration of such dynamic value-based parameters provides a wealth of new computationally intelligent behaviour dynamics and dimensions of control that enriches the cyber-physical eco-system. Work done in this field is as follows. With regard to smart buildings (which can be considered as a CPS) parameters such as Weather data, time-of-use energy prices, and energy load forecasts could be used to better tune its control systems increasing energy efficiency and reducing operating costs thereby considering economics in loop. [56] quantify energy use due to lighting, ventilation, and office equipment in a modern mixed-use office building and explore opportunities for energy conservation and renewable energy production.

7. Robotics

Robotic systems are an important class of CPS. The ability of robots to interact intelligently with the world rests upon embedded computation and communication, real-time control, and perception of the world around them. Future robotic systems that will realize the vision of CPS include increasingly intelligent robotic surgery systems, robots for assisted living in smart-homes, and robot teams for exploration and emergency response [39]. Works done in this field are as follows. [135] considers small unmanned aircraft system surveillance mission, the visual inspection of a pipeline, has been done to investigate specifics of cyber–physical cost terms and their tradeoffs. A multidisciplinary cost function minimizes energy and maximizes mission efficiency and effectiveness has been done in this work. [158] provides a Robotic Development Platform architecture that integrates principles of CPS. The proposed architecture is scalable, by facilitating the integration of different existing development and simulation tools and will allow robot systems to be tested in different environments, with different characteristics, and facilitate the integration of real world simulation with virtual environment simulation. [159] provides a different approach to the problem of building a CPS for mobile robots control is presented. It is based on Erlang language and technology, which support lightweight processes, fault tolerance mechanisms and uses message passing concurrency model with built-in inter-process communication. Created system used a new, open-source robotic platform, which had been designed for scientific and educational purposes. The paper presents the interaction process between several physical devices through the Smart-M3-based smart space. These devices are robots that are modelling the vacuum cleaner behaviour. For this purpose, the scenario of robot's interaction in smart space is described in the paper. One of the examples of CPS is a "smart home" system, in et al., this concept has been used,and a simple scenario has been taken where two or more robots receive a task to execute actions, e.g., find an object and bring it to storage. This work presents the interaction between several robots through the Smart-M3-based smart space. The interaction is based on the scenario presented above. Robots can move through the physical space, manipulate objects, read and interpret data from sensors, interoperate through the smart space using ontologies and make simple decisions about future actions.

3.1.6 Security

The integration of computation, communication, and control units has led to the birth and rapid development of a new generation of engineering systems. These are CPS which have been increasingly used in fields ranging from aerospace, automobile, industrial process control, to energy, healthcare, manufacturing and transportation, where secure operation is one of the key concerns. By exploiting the sensing, networking, control and computation capabilities, the new generation CPS is able to connect the cyberspace and the physical space. However, such connections have also provided an attacker the rich opportunities to perform potential malicious attacks. Security of CPS is becoming a significant area of research drawing enormous attention in the control, computation, sensing and communication communities. The sophisticated attackers can design strategies specifically to exploit vulnerabilities of the CPS resulting in system abnormalities that are far from random. The taxonomy classification of CPS security is as follows:

1. **Cryptography**

   a. **Lightweight Cryptography**

Cryptographic technologies are advancing: new techniques on attack, design, and implementation are extensively studied. One of the state-of-the-art techniques is "Lightweight Cryptography (LWC)". Security solutions for ICS must be lightweight, and a natural solution is to use cryptographic primitives which provide fundamental security features, such as confidentiality, authenticity, and non-repudiation. Considerable research efforts have gone in designing lightweight cryptographic primitives, both symmetric [160], [161], [162] and asymmetric [163], [164], suitable to be deployed in systems, such as ICS. The design of lightweight cryptographic primitives typically involves tradeoffs among security, cost, and performance [165]. A good design would strike a fine balance among these three metrics, and at the same time fulfil the needs of the underlying application. In [166], the author proposes to investigate lightweight security enforcement in ICS from a broader perspective. More specifically, rather than solely focusing on individual cryptographic primitives, we posit that it is also important to achieve system collective lightweightness without compromising on either security or efficiency. Numbers of lightweight cryptographic primitives suitable for resource-constrained wireless sensors have also been presented, such as the block ciphers. Lightweight cryptography is a cryptographic algorithm or protocol tailored for implementation in constrained environments including RFID tags, sensors, ICS, SCADA and so on. Lightweight cryptography also delivers adequate security. Lightweight cryptography does not always exploit the security-efficiency trade-offs. CPS forms the core of industrial control systems (ICS), which is the backbone of many aspects of the critical infrastructure sectors, particularly in technologically advanced countries. Security solutions for ICS must be lightweight, and a natural solution is to use cryptographic primitives which provide fundamental security features, such as confidentiality, authenticity, and non-repudiation.

b. **Context-Aware Cryptography**

Designing of context-aware security Framework for CPS is indeed a major requirement. The security-relevant context information incorporated into multiple security measurements such as authentication, encryption, key agreement protocol, access control and so on. In [167] discussed the approach to building security services for context-aware environments. Specifically, the research focus on the design of security services that incorporate the use of security-relevant "context" to provide flexible access control and policy enforcement. The author presented a generalized access control model that makes significant use of contextual information in policy definition. Extensible context-aware access control enables administrators to specify more precise, and fine-grain authorization policies for any application. Dynamic authorization enforcement scheme is presented in [168], which makes authorization decisions based upon runtime parameters rather than simply the role of the user.

2. Privacy

a. Threat Modelling for CPS

The attack models derived from the attacker model are used to generate parameterized attack procedures and functions that target a specific CPS. The models have been used extensively in understanding the impact of cyber-attacks on any CPS and in the design and assessment of detection mechanisms. The Modelling of CPS under threat models both physical and cyber-attacks and unifies number of existing attack models into a common framework useful for researchers in the experimental assessment of attack detection techniques. A good amount of the security work on CPS centers on attack detection. An approach to detect attacks monitors inputs based on a model of the system and tries to find anomalies [169]. The papers apply system modelling to detect attacks by detecting behaviour anomalies; the author defines a framework where the way to conduct specific attacks can be described in relation to the system architecture. In [170], the author analyzes the effects of attacks with Markov models. In [171], the author model threats using data flow graphs related to hardware units, while we use patterns and relate threats to architectural units, which we believe are more precise. In [172], they introduce a language (using UML and BNF) to describe CPS attacks. The model emphasizes the mechanics of the attacks and does not consider the attacker goals. There is no relative timing representation for the attack either. [159] uses a reference architecture to trace propagation of attacks. Another interesting approach to threat modelling uses aspects [173]. Aspects model crosscutting functionality and improve reusability; we think that patterns are more powerful to describe attacks than these models. Stuxnet has been modelled using Boolean Logic Driven Markov Processes (BDMP), a combination of attack trees and Markov processes. Other attack models include attack trees, where the root node denotes the goal of an attacker and a path from leaf nodes to the root node denotes an attack instance, i.e., the steps for completing the attack [174]. A model using graph theory to express control system failures and attacks is also presented in [175]. In [176], a language for modelling multistep attack scenarios on process control systems is proposed, enabling correlation engines to use the models to recognize attack scenarios.

b. Authentication, Key Management, and Access Control

The task of providing security services for the CPS heavily depends on authentication, authorization and message integrity of CPS devices and systems. In addition to encryption and authentication procedures, key management processes are also part of cryptographic methods. In particular, computing and communication process for the CPS, it is necessary to ensure that the data, transactions, communications are genuine. It is also important for authenticity to validate that both parties involved are who they claim they are [177]. Authentication schemes can offer strong protection against attacks targeting data integrity, but cannot by themselves provide all the necessary security in an operational environment [178] especially under the circumstance of DoS attacks. Hence, authentication schemes are required to detect malicious attacks, collaborate with attack detection and response systems, and even designed to be robust to DoS attacks in the Smart Grid applications. The fundamental requirement for authentication design is to provide efficient multicast authentication schemes for the Smart Grid applications. Therefore, few recent works [179], [180] are directed toward this objective, i.e. fast multicast authentication protocols for power control systems. The most straightforward multicast authentication scheme is to use public key based authentication. For example, Public Key Infrastructure (PKI) can contribute towards establishing trust between different identities using digital signatures. The access control for CPS depends on the Trustworthiness of entities play an important role in CPS security. NIST (National Institute of Standards and Technology) has published the guidelines for smart grid cybersecurity [181] that includes the description of cryptography and key management issues. Informatively, NIST recommends the usage of standard symmetric ciphers such as AES (Advanced Encryption Standard) for message encryption and CMAC (Cipher-based Message Authentication Code) for message integrity on which most security schemes including REMP rely today. It relies on an external key management protocol, ZRTP [182], to establish one master key for deriving session keys. Moreover, it needs additional time-synchronization for key derivation. We notice that the per-group key management property of conventional group security schemes is well-aligned with the Publish-Subscribe (hereafter caller pub-sub) communication [183] property as the first property of the CPS communications.

c. Vulnerability Analysis of CPS

The prevalence and vulnerabilities of CPS draw the attention of both researchers and attackers. As the interaction between the physical and cyber systems increases, the physical systems become increasingly more susceptible to the security vulnerabilities in the cyber system. Hence, the vulnerability assessment is a requirement of cybersecurity standards for any CPS [174]. In [184], the author presents CPINDEX, a security-oriented stochastic risk management technique that calculates Cyber-Physical security indices to measure the security level of the underlying Cyber-Physical setting. CPINDEX installs appropriate cyber-side instrumentation probes on individual host systems to dynamically capture and profile low-level system activities such as interprocess communications among operating system assets. Probabilistic Risk Assessment provides a foundation for the calculation of risk reduction when applied to SCADA security. In [185], the author described a new risk modelling tool, augmented vulnerability trees, and two new indices for quantifying the risk. OCTAVE (Operationally Critical Threat, Asset, and Vulnerability Evaluation) [89], is a framework for identifying and managing information security risks developed at Carnegie Mellon University's CERT Coordination Center. It is a self-directed activity by a team that draws on the knowledge of many employees to define the current state of security, identify risks to critical assets, and set a security strategy. It also uses event/fault tree analyses to model threats to critical assets.

d. Secure and Trustworthy design of CPS

CPS is in most cases safety- and mission-critical. Standard design techniques used for securing embedded systems are not suitable for CPS due to the restricted computation and communication standards. Integrity refers to the trustworthiness of data or resources [71]. A lack of integrity results in deception: when an authorized party receives false data and believes it to be true. Integrity in CPS can therefore be viewed as the ability to maintain the operational goals by preventing, detecting, or surviving deception attacks in the information sent and received by the sensors, the controllers, and the actuators. The sensitivity of sensed data and the presence of actuation components further increase the security requirements of CPS. To address these issues, it is necessary to provide new design methods in which security is considered from the beginning of the whole design and addressed in a holistic way. In addition, the CPS is a cross-layer design - starting from models of physical systems, to software, to architecture, and finally to reliability of circuits and devices. Thus, the requirement of certified and trustworthy CPS design is must for which end-to-end guarantees may be offered.

e. Intrusion Detection System

CPS intrusion detection addresses the embedded physical components and physical environment in a CPS, which under attacks, manifest physical properties and normally require a closed control loop to react to physical manifestation of attacks. A reckless adversary can enter the network and immediately disrupt the concerned processes to cause a catastrophe. On the other hand, a more sophisticated adversary may take care to not disrupt normal system operation in order to propagate and set up a distributed attack launched at one point in time. This is the brand of attack that Stuxnet. For this reason, speed of detection (detection latency) is the key challenge in CPS Intrusion Detection System (IDS) design. The

IDS can be of three types. i) Misuse/signature-based intrusion detection is based on a process that compares the signatures with observed events to identify possible incidents, where each signature is a pattern that corresponds to a known threat. ii) Anomaly-based intrusion detection is defined as the process that compares normal behaviours' definitions with observed events in order to identify significant deviations. iii) A stateful protocol analysis is the process that compares predetermined genuine activities of each protocol state with the observed events to identify deviations. Knowledge-based intrusion detection approaches look for runtime features that match a specific pattern of misbehaviour [186]. Some sources refer to this approach as pattern-based detection [187], Behaviour-based intrusion detection approaches look for runtime features that are out of the ordinary [186]. The key advantage of behaviour-based approaches is they do not look for something specific. This eliminates the need to fully specify all known attack vectors and keep this attack dictionary current. [188] studied an IDS for smart utility (water) applications that uses a three-stage back propagation artificial neural network based on Modbus features. [189] studied a behaviour-based IDS for a medical CPS. The authors propose a distributed design where mobile devices collect data that they forward to a centralized audit server. The study of semi-supervised IDS for smart utility (power) applications called Intrusion Detection System using Neural Network–based Modelling (IDS-NNM) is presented in [108]. IDS-NNM uses error-back propagation and Levenberg-Marquardt approaches with window-based feature extraction. In [190] authors propose a multi-trust IDS called Multi-Agent System (MAS) for SCADA applications. Their analysis function, Ant Colony Clustering Model (ACCM), is biologically inspired by its namesake—the ant colony. Multi trust [191] is unexplored in CPS IDS research. This is the concept of using hearsay/reported information (data from witnesses or third parties).

f. Resilient/Self-Healing System

The malicious entities could take charge of CPS control by exploiting cyber insecurities or physical faults, or their combination. Therefore, to improve CPS resilience, we need diagnostic tools and automatic control algorithms that ensure survivability in the presence of both security attacks and random faults and include models of the incentives of human decision makers in the design process. The resilient system framework will enable designers and operators to build a self-healing capability into CPSs by maintaining synergistic integrations of human-centric elements with automated diagnostic and control processes. In [192], the author proposes a hybrid theoretical framework for robust and resilient control design in which the stochastic switching between structure states models unanticipated events and deterministic uncertainties in each structure represent the known range of disturbances. The author proposes a set of coupled optimality criteria for a holistic robust and resilient design for CPS. The authors in [193] have described a general technique: passivity and a particular controller structure involving the resilient power junction. In [194], the author gave a new simple characterization of the maximum number of attacks that can be detected and corrected as a function of the pair (A, C) of the system and we show in particular that it is impossible to accurately reconstruct the state of a system if more than half the sensors are attacked. In addition, the author has shown how the design of a secure local control loop can improve the resilience of the system. When the number of attacks is smaller than a threshold, the author proposed an efficient algorithm inspired from techniques in compressed sensing to estimate the state of the plant despite attacks. In [195], design a resilient end-to-end message protection framework, REMP, exploiting the notion of the long-term key that is given on per node basis. This long-term key is assigned during the node authentication phase and is subsequently used to derive encryption keys from a random number per-message sent. Compared with conventional schemes, REMP improves privacy, message authentication, and key exposure, and without compromising scalability and end-to-end security. In [145], the author has designed resilient controllers for Cyber-Physical control systems under DoS attacks. We establish a coupled design framework which incorporates the cyber configuration policy of Intrusion Detection Systems (IDSs) and the robust control of dynamical system.

g. Secure CPS Architecture

Defence Optimization: In the recent years, the CPS have paid much attention to some security issues, such as safety, security, reliability, resilience, dependability, etc. In particular, the need for combining security theories with the attacks which CPS is facing, and provides recommendations and defences. The CPS security architecture we put forward successfully addresses these issues. The CPS security architecture can be designed from three aspects. One of them is CPS security theories, which contains security objectives and basic theories. Security objectives provide a sort of goals which CPS should achieve. Without security objectives, such as safety, security, reliability and resilience, we could not know in which conditions CPS cannot operate healthily and in a stable manner. Basic theories usually contain information theory, control theory and game theory, which provide theoretical support for CPS research. In past the researcher had attempted various methods to build the secure architecture for CPS. In [192], the author adopted a hierarchical viewpoint to these security issues, addressing security concerns at each level and emphasizing a holistic cross-layer philosophy for developing security solutions. The work proposes a bottom-up framework that establishes a model from the physical and control levels to the supervisory level, incorporating concerns from network and communication levels. The [196] proposed a novel adaptive control architecture for addressing security and safety in CPS. Specifically, the author developed an adaptive controller that guarantees uniform ultimate boundedness of the closed-loop dynamical system in the face of adversarial sensor and actuator attacks that are time-varying and partial asymptotic stability when the sensor and actuator attacks are time-invariant.

3.1.7 Data Fusion & Mining

The Key issue for CPS is the collection and acquisition of data such as parallel data collection (via sensors), data fusion, processing of physical data from the environment, locally, globally and in real time. Data from sensors combined with data fusion, data mining, and interpretation enable physical awareness of systems. The integration of Data into CPS solutions presents several challenges and opportunities. Data integration for CPS is not suitable for conventional solutions based on the offline or batch processing. The interconnection with the real-world, in industrial and critical environments, requires reaction in real-time. Therefore, real-time will be a vertical requirement from communication to Big Data analytics. Big Data for CPS requires, on the one hand, real-time streams processing for real-time control, and on the other hand, batch processing for modelling and behaviours learning. The researchers have proposed several techniques for data management and integration for CPS. Such approach targets health-care application to present the data management [197]. This system consists of a data collection layer with a unified standard, a data management layer for distributed storage and parallel computing, and a data-oriented service layer. The results of this study show that the technologies of cloud and big data can be used to enhance the performance of the healthcare system so that humans can then enjoy various smart healthcare applications and services. In [198], the author discussed the problem of aggregating the sensor readings in a CPS. These readings are obtained from a large number of sensors that are densely located and communicate over the single broadcast domain (i.e., at any time, at most one sensor can communicate). The authors proposed an efficient method for data acquisition based on interpolation of all readings. Their method also models the dynamics of the physical system, which enables it to perform data acquisition at a time that is independent of the number of nodes. Lots of research organizations and companies have devoted themselves to this new research topic, and most of them focus on social or commercial mining. This includes sales prediction, user relationship mining, and clustering, recommendation systems, opinion mining, etc. [199], [200]. However, this research focuses on 'human-generated or human-related data' instead of 'machine-generated data or industrial data', which may include machine controllers, sensors, manufacturing systems, etc. Some applications of CPS that involves data analytics may need to store large volumes of data. Conventional WAN based transport methods cannot move terabytes of data at the speed required for applications. It uses a portion of available bandwidth and does transfer at speeds that are unsuitable for such huge volumes, introducing unacceptable delays in storing retrieving and processing data. Methods and algorithms focusing on data-based aspects like statistical analyses in business, management, and biomedicine [199], [201], data-driven process monitoring/prognostics [201], [120], and system control and optimization [202] have been widely investigated in recent years but still on the starting line. Many enterprises, however, regard their big data as confidential information, which hinders the development of novel approaches to academic research. Therefore, enterprises should consider a greater cooperation with researchers and engineers by making their specially processed data public for improvements of the existing techniques and for fostering new ideas. Presently, the challenges of industrial big data are still associated with their properties related to data measurement, detection, and processing. CPS applications not only have to find and analyze the relevant data they need; they must find it quickly. Visualization helps applications perform analyses and make decisions much faster, but the challenge is at high speed the application has to go through the large volumes of data and access the level of detail needed. As the degree of granularity increases the challenge grows. One possible solution is hardware. Some vendors are using powerful parallel processing and increased memory to crunch large volumes of data extremely quickly. Another method is putting data in memory but using a grid computing approach, which involves many machines to solve a problem. Both approaches allow the applications to explore huge data. It is well-known that the CPS usually generates large amounts of data that should be processed properly to get valuable and on-time information. In [203], the author presents a novel data mining approach to mine the inherent regularity of several body sensor parameter readings related to vital sign data of a patient. This mechanism allows systems to monitor health conditions and generates valuable information to support the decision making process of patients and medical personnel. In particular, the authors present the design and implementation of an efficient and scalable regular pattern mining technique that can mine the complete set of periodically/regularly occurring patterns in body sensor data streams. A work related to the previous one is presented in the [204] in which the authors present a nearest neighbour approach for classifying real-time data streams based on statistical summaries. Particularly the article proposes a classifier that adapts to concept drifts and is robust to noise. The classification algorithm is competitive with its alternatives and naturally parallel. The article also reports the development of a parallel version of the classifier that was implemented using open source technologies. Such a version was evaluated empirically and the obtained results show that the proposal is scalable with respect to the workload and number of used processing nodes. It also includes a discussion on the use of open source technologies for data stream processing.

The above broad technology streams are core in CPS. Some of them are evolving and new streams may emerge like Quantum Computing, Communication, and Cryptography. CPS is inclusive of all and provides a system level performance and delivery.

3.2 Mission Strategy

With the Mission cut-out and its objectives defined, its success in terms of delivery lies on the strategy chalked out and of course, execution of the plan. The inherent complexity of the CPS and the Mission to place India in a leadership position in this domain requires range of actions to be taken across the technology landscape, besides defining the instruments/ intervention that can be used to deliver. For this Mission, the technological landscape corresponds to the life-cycle of technology idea in the mind to the product in hand; spanning basic research, applied research, translational research, product development and commercialization. The knowledge/technology generation goes entwined with human resource development at multiple levels; at Under Graduate (UG) levels to tinker with the ideas, at Post Graduate (PG) and doctoral level to work further on these ideas often to prototypes, at faculty level to teach the basics and oversee ideas converting into prototype; the experts in the translational research carry those prototypes further into a market-ready product. After technology valorisation and weighing the economics, entrepreneurs carry them further through their established enterprises or start-ups. There are gaps that innovations confront in the journey that sees them pitted with competing technologies or those existing and waiting for the ecosystem to favour them. The stage leading to commercialization and subsequent incremental innovations, also take human resource development alongside.

The interventions that can be deployed to deliver on these spaces could be in the form of Centers of excellence- which concentrate their efforts and resources in a chosen field, to maximize the return. Their delivery goes notches up, if they can leverage existing knowledge and expertise available anywhere in the world; it is here that intervention of International Collaborations, mostly facilitated through Science diplomacy, work the best by saving resources and time. The development of new knowledge or leveraging the existing one requires the involvement of the right type of motivated human resource, attracted through internship/ fellowship opportunities. It has been a common experience that only a fraction of technologies see the light of the day, most falling into the valley of death often due to last techno-managerial glitches. A push is needed at the last mile for a technology to get commercialized, through Innovation Accelerators. Further, the development and delivery of technology gets accelerated when challenged by a need; Top Level Challenges posed before the world and the competition induced by them often bring multiple technology solutions for the world at large. The strategy proposed shall be a multipronged, holistic and long-term one, to realize the emerging technologies like CPS in the country. To realize the strategy, the sub-missions or Programme under NM-ICPS will include:

(1) **TECHNOLOGY DEVELOPMENT:** through expert-driven research, Consortium based Research through Cluster-Based Network Programmes, directed research for the specific requirements of Industry, other Govt. verticals and International Collaborative Research Programmes

(2) **CENTERS OF EXCELLENCE:** Dedicated Centers to carry out domain-specific research, translational research, Innovation, Entrepreneurship development, start-up, training, and capacity building.

(3) **HRD AND SKILL DEVELOPMENT:** through Fellowship Based UG/ PG, Ph.D., Post-Doctoral, Short Term Training for Faculty and National Workshops & Conferences etc.

(4) **INNOVATION, ENTREPRENEURSHIP AND START-UPS:** To enhance core competencies, capacity building and training to nurture innovation and Start-up ecosystem.

(5) **INTERNATIONAL COLLABORATIONS:** To establish and strengthen the international collaborative research for cross-fertilization of ideas.

Further each sub-mission or Programmes comprises of major components given in the table below

Sub-mission/ Programme	Major components
Technology Development	1. Expert Driven New Knowledge Generation /Discovery(TRL 1-3)
	2. Development of products/ prototypes from existing Knowledge (By experts or teams) (TRL4-6)
	3. Technology /product delivery in specific sectors(By experts or teams) (TRL7-10)
Center of Excellence	1. International Centers Of New knowledge (ICONs)
	2. Center for Research On Sub-Systems (CROSS)
	3. Center for Advanced Studies, Translational research & Leadership (CASTLE)
	4. Center of Excellence in Technology Integration & Transfer (CETIT)
HRD & Skill Development	1. CHANAKYA Schemes for UG courses (i) Graduate Internships (ii) Development Fund (For Projects done under Graduate Internships) (iii) CPS Infrastructure development fund
	2. CHANAKYA Schemes for PG courses (i) Post Graduate Fellowships (ii) Development Fund (For Projects done under PG Fellowships) (iii) CPS Infrastructure development fund
	3. CHANAKYA-DF (CHANAKYA Doctoral Fellowships)
	4. CHANAKYA-PDF (CHANAKYA Post-Doctoral Fellowships)
	5. CHANAKYA-Faculty Fellowship
	6. CHANAKYA-Chair Professor
	7. CPS- PSDW (Professional Skill Development Workshop)
	8. CPS-Upgrading PG Programme
	9. CPS-Advanced Skill Training School (ASTS)

Sub-mission/ Programme	Major components
Innovation, Entrepreneurship & Start-ups	1. CPS-GCC - Grand Challenges and Competitions
	2. CPS-PRomotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS)
	3. CPS-Enterpreneur In Residence (CPS-EIR)
	4. CPS- Start-up
	5. CPS-Technology Business Incubator (TBI)
	6. CPS-Dedicated Innovation Accelerator (DIAL)
	7. CPS-Seed Support System (CPS-SSS)
	8. CPS-SISE (Strategic Information Services for Entrepreneurship)
International collaborations	International Collaborations with countries ahead in CPS technologies
Mission Management	1. Mission Management Unit (MMU)
	2. Mission Apex Council

3.2.1 Technology Development

Mission has wide-ranging activities ranging from promoting high-end basic research and development of cutting-edge technologies, on one hand, to service the technological requirements of the common man through the development of appropriate skills and technologies on the other. The mission supports research and developments activities through a large number of schemes/ programmes/ missions, most of which see human resource development also happening.

Major components under Technology Development sub-mission is classified into three categories depending upon Technology Readiness Level (TRL):

1. Expert-driven new knowledge generation /Discovery (TRL 1-3)
2. Development of products /prototypes from existing knowledge (by experts or teams) (TRL 4-6)
3. Technology /product delivery in specific sectors, i.e., projects that involve knowledge generation and also conversion to technology, demonstration of full working technology (by experts or teams) (TRL 7-10)

Areas for Directed Research

The CPS and associated streams and on all aspects of ICPS research in India will be coordinated under the umbrella of NM-ICPS. Thus, the ICPS programme would institute research through academic collaborations and foster in-depth investigations to understand the processes and phenomena that are in operation leading to the development of CPS applications. A dedicated group of scientists, in collaboration with several other national academic and research institutions of excellence, associated with Industry, would carryout major research programmes under directed research and extramural funding mechanisms. It will establish links with specialized institutions in the country and abroad for establishment and strengthening of advanced facilities for research. The ICPS would also establish workable research collaborations with international academic institutions for the advancement of CPS and associated research in the country. The innovations associated with distribution, processing, and accumulation of data on the internet are the key advances in framing world-leading super smart society. Consequently, solidification of the accompanying central innovations is required, especially, Cyber security: innovation that backs up safe data and communication, considering the qualities of the IoT, for example, the long life cycles from configuration to transfer. IoT system architecture technology: technology that empowers the displaying of equipment and programming as segments and the building and working of expansive scale systems. Data Science & Predictive Analytics: innovation associated with getting knowledge and value from a lot of a wide assortment of information, including unstructured information. Artificial Intelligence (AI) and Machine learning (ML): technology that backs IoT, enormous information examination and advanced communication. Device technology: innovation that empowers fast, real-time preparation of extensive measures of information with low power utilization. Network innovation: technology that appropriates large measures of data at high limit and rapid speed. Quantum Communication, Information and Computing: innovation that empowers expanding speed and enhancement of real-time processing at the real system area, which is fundamental for expanding the usefulness of IoT. CPS is an area that circumscribes several technological areas which are continuously evolving and there will be a need for new knowledge to stay competitive and acquire leadership position. At the same time, CPS being an application-oriented, there would be a need to focus efforts.

CPS manifests currently in popular terms like the Internet of Things (IoT), Industry 4.0, Industrial Internet, Machine-to-Machine (M2M), the Internet of Everything, T-Sensors (trillion sensors), Web of Things, the Fog (like the cloud, but closer to the ground). All of these reflect a vision of a technology that deeply connects the physical world with the information world. In a broader view, the term "CPS" is more foundational and durable than all of these, because it does not directly reference either implementation approaches (e.g., the "Internet" in IoT) nor particular applications (e.g., "Industry" in Industry 4.0). It focuses instead on the fundamental intellectual problem of conjoining the engineering traditions of the cyber and the physical worlds. One can talk about a "cyber-physical systems theory" like "linear systems theory."

At present, CPS research mainly focuses on studies of system architecture, information processing, and software design.

A. Research on Architecture of CPS

CPS has strict requirements on real-time capability and abstraction of physical awareness. A global reference time is fundamental for all CPS components to communicate and work properly. CPS must have unified time, trust quantification and communication mechanisms at the system level.

A.1) Sensor Network Challenges

(1) Use a variety of sensors and real-time embedded systems for real-time data acquisition.

(2) Conduct analog-to-digital conversion of collected data and other processes including data encryption and data integration through collection nodes.

(3) Protect the security of data transmission (privacy, integrity, and non-repudiation).

(4) Reduce the network energy consumption by energy management.

(5) Apply real-time data protection technology to real-time processing.

A.2) Next Generation Network Systems

(1) Use anti-hacking and defence technology against a variety of network attacks.

(2) Use high-performance encryption algorithm and CA authentication technology to ensure the safety of data transmission.

(3) Realize rapid exchange of data transmission by optimizing existing routing algorithms.

(4) Change the existing network system structure with the "best effort" to provide real-time network transmission services for the system.

A.3) Data Center

(1) Sensor network transmits data to the data center for storage through next generation network systems.

(2) Regular emergency treatments are also needed to prevent the database from collapse.

A.4) Control Center

(1) Control center configuration policy can be dynamically adjusted according to users' needs.

(2) Conduct forecast analysis and performance analysis of CPS behaviour through data mining technology and uncertainty processing technology.

(3) Detect the network and node failure through fault diagnosis technology and conduct

corresponding processing.

(4) Ensure the real-time control processing of CPS through real-time control technology.

B. Research on Information/Data Processing of CPS

Information processing includes the collection, transmission, and processing of perception data, feedback of control information as well as the response of physical system after receiving commands.

B.1) Data Processing: Research on Data Acquisition Technology

(1) Acquisition of perception data plays a key role in CPS; IT can be chosen low-precision sensors or high-precision sensing devices according to specific application requirements.

(2) After necessary processing, perceived information is integrated into the gathering center and then is sent to the data center, to provide important data support for the decision.

B.2) Data Processing: Research on Data Transmission Technology

(1) Self-organization and mobility of Ad-hoc network enable high viability and flexibility, which can be integrated with the Internet to extend the application range of the CPS greatly.

(2) The research of CPS data transmission is focused on putting forward practical converged network data transmission scheme and its strategy according to the demands of the specific application.

B.3) Data Processing: Research on Safety Control

(1) Current safety control mainly includes password management, identity recognition, etc.

(2) A self-adaptive health monitoring and management system model and defined fault diagnosis quality measures based on the special requirements of fault diagnosis.

(3) Solutions from the perspective of verifying the worst-case execution time and preventing and correcting software errors.

B.4) Data Processing: Research on Real-time Capability

(1) CPS data processing must meet real-time requirements to ensure that proper results are given within a limited time.

(2) Real-time capability can hugely influence the design and demand in CPS application systems from soft real-time and hard real-time perspective.

(3) In CPS, heterogeneity leads to the main challenges of the network in large-scale system design, including time-varying delay, time jitter, data rate limitation, packet loss, etc.

B.5) Data Processing: Research on Reliability

(1) To automatically obtain reliable real-time data. The automatic optimization problem is designing and highly reliable real-time embedded systems.

B.6) Data Processing: Research on Uncertainty Processing

Practical problems in CPS, such as

(1) Complex environmental interference in distributed systems,

(2) Wireless network transmission errors,

(3) Network node failure,

(4) Data pre-processing

(5) Errors introduced by storage raise problems of noise, outliers, loss of data (or properties),

(6) Data dispersion, concreteness, and randomness and other uncertainties,

(7) Non-deterministic testing data that exist in the networked test systems.

(8) A self-learning uncertainty reasoning model in the automotive control system, solving the problems of automatic sensing, rapid response and control of vehicles in multiple scenarios.

B.7) Data Processing: Research on the Robustness of the System

(1) For the energy management problem of large-scale data in CPS, to minimize the energy cost by optimizing the task allocation in network nodes.

(2) End-to-end delay in control performance in the collaborative design of control and scheduling, and improved the robustness of the system through end-to-end delay optimization based on resource access analysis.

(3) The fault-tolerant control (FTC) problem increases the redundancy of sensor and actuator in the design stage can enhance the fault tolerance performance of the network

and minimize the adverse effect caused by a fault.

B.8) Problem of Control

(1) Using the event model to deal with the problem of control plays a key role in the CPS study.

(2) A bridge between differential equation model in the field of control and the finite state machine model in computational domain is required.

C. Research of CPS Software System

C.1) Research on Software Architecture

(1) Coordination of semantic abstraction and the real-time capability.

(2) A method for constructing generic middleware in CPS, including adding, cutting and optimizing the basic needs.

(3) The problems of operating characteristics and processing function in different stages of the software lifecycle.

(4) Low efficiency of network transmission and the software operation.

(5) A method of realizing software specification, system modelling, testing and code generation, and hence improved the efficiency of software development.

C.2) Research on Middleware Technology

(1) Middleware can be used to save 50 % time and cost of software development. Different distributed cyber-physical systems must process cyclic or noncyclic event with different needs.

(2) A configurable and reusable middleware framework for the hybrid real-time test, which can detect the problem of communication efficiency of heterogeneous components, is required.

(3) The impact of some factors such as a sequential variation in real-time hybrid testing system, which may bring errors in middleware testing.

C.3) Research on Scheduling Algorithm

(1) A scheduling strategy based on time optimization for a non-interrupted, random running CPS, to improve the existing heuristic scheduling strategy.

(2) Predictable CPS realization and energy consumption.

(3) Task scheduling of CPS based on feedback control, to reach a balance among energy consumption, scheduling robustness, etc.

(4) Discreteness and continuity need to be combined when establishing models of CPS.

(5) CPS needs to find ways to integrate the two; otherwise the computing, communication and control capability in physical equipment cannot be realized.

(6) Behaviour modelling in continuous domain and discrete event domain is required so that developers can conduct integrated modelling and simulation of CPS system.

C.4) Research on Service Model

Develop and design the "vertical integration" framework of CPS (the modelling, analysis, planning, communications, operating systems, networks, etc.), providing comprehensive design and implementation of the CPS through the integration of a variety of techniques.

C.4.1) Security Architecture

Self-configuring and self-healing capabilities and to provide appropriate feedback mechanisms.

C.4.2) Security Control

The current problems in CPS are:

(1) Message integrity

(2) Availability

(3) Confidentiality issues

(4) The limitation of existing active defence

(5) Passive response mechanism

In dealing with the information security of CPS, and problems of automatic control theory in CPS safety control, such as -

- The problem of the traditional filter in predicting the status for a network with uncertain packet loss. elaborated the challenges and directions in CPS safety control
- Elastic control of system under malicious attacks

C.4.3) Attack Defence

Established security mechanisms that are suitable for CPS including

(1) prevention

(2) detection

(3) recovery

(4) dynamic guard against attacks

C.5) Research on CPS System Testbeds

(1) Simulation and modelling on the flexible hardware platform of CPS.

(2) But the present system testbeds are still in the primary stage, with unperfected comparison and many other problems, which need further research.

Cybersecurity is not just a computer science issue but a national security issue also. National critical infrastructures are ripe targets for cyber-attacks. A comprehensive cybersecurity research and technology transfer programme is urgently needed for India, particularly in the context of CPS. All target systems require protection via detection of ongoing cyber-attacks, attribution to sources, and prevention through pre-emption. Offensive cyber measures are also required. Cyber human resource development is a national imperative. Critical infrastructures of a nation include the national power grid, the financial infrastructure, various transportation infrastructures, and localized infrastructures such as gas/oil production and transportation, manufacturing, etc. These are subject to possible cyber-attacks due to the increasing usage of data networks, sensors/actuators, computer-based supervisory monitoring and control and exposure to the Internet caused by IP-convergence. As multiple reports point out, attacks on critical control systems are likely to increase in number and sophistication as the business network and the control network are being merged. This is due to the IP-convergence by virtue of which the business functions and manufacturing or other critical functions are being controlled, and monitored via a convergence of traditionally two air-gapped networks.

As a result, there is an urgent need for (i) research in cyber threat modelling, security policy and technologies, and cyber-defence mechanisms to protect the critical infrastructure on which the national security and national economy depends heavily; (ii) development of manpower educated, and trained to serve in operational roles for cyber security and defence, as well as for future research; (iii) awareness and training of private and public sector businesses involved in creating, managing, and maintaining critical infrastructure such as electric power companies, state electricity boards, the various regulatory agencies, the industries with high level of industrial automation, railways, air traffic control, nuclear power and other power station owning businesses etc., (iv) development of expertise in critical infrastructure cyber defence to help the government in creating policy and small business entrepreneurship incentives to develop indigenous cybersecurity industry; (v) creation of standards and best practices documents for the government and industry; (vi) train college and university faculty at engineering colleges throughout India on cybersecurity education, research, and manpower development; and finally (vii) creating center of excellence in the area of critical infrastructure cybersecurity and defence.

Given this possibility of vulnerabilities of critical national infrastructure, there is a need to not only invest more into the research on cybersecurity of such systems, it is also required to enhance the educational emphasis on this topic. Not only it is needed trained workforce among engineers, it is also required to make every engineer aware of various possibilities through which cyber threats might materialize, and even those who are not working directly in protecting the infrastructure from cyber-attacks, should be adequately trained.

Mission emphasizes that there is an urgent need for (i) research in cyber threat modelling, security policy and technologies, and cyber-defence mechanisms to protect the critical infrastructure on which the national security and national economy depends heavily; (ii) development of manpower educated, and trained to serve in operational roles for cybersecurity and defence, as well as for future research; (iii) awareness and training of private and public sector businesses involved in creating, managing, and maintaining critical infrastructure such as electric power companies, state electricity boards, the various regulatory agencies, the industries with high level of industrial automation, railways, air traffic control, nuclear power and other power station owning businesses etc., (iv) development of expertise in critical infrastructure cyber-defence to help the government in creating policy and small business entrepreneurship incentives to develop indigenous cybersecurity industry; (v) creation of standards and best practices documents for the government and industry; (vi) train college and university faculty at engineering colleges throughout India on cybersecurity education, research, and manpower development; and finally (vii) creating centers of excellence in the area of critical infrastructure cybersecurity and defence.

Table 3.1 provides a framework in which research can be funded to cover various aspects of cybersecurity in critical infrastructure sector. Explanation of various layers of such systems and corresponding methodology in which research needs to be carried out follows the table.

Table 3.1: An Interdisciplinary Research Agenda for Critical Infrastructure Cyber-Security

Layers/Research	Analytical Methods	Simulation/ Co-Simulation	Laboratory Emulation	Cryptography theory and Engineering	Software and System Security	Program Analysis	Machine Learning and Data Analytics	Network Security
Physical Dynamics of the System	X	X	X				X	
The Electro-Mechanical Equipment/sensors/ actuators	X	X	X					
Industrial Automation and control	X	X	X	X			X	
Firmware			X	X		X		
Electronics/ Hardware	X		X	X				
Networking	X	X	X	X		X	X	X
Middleware and System Software	X	X	X	X	X	X		X
Application Software	X	X	X	X	X	X		
Cloud Layer			X	X	X	X		X

It is evident that critical infrastructures are distributedand cyber-physical systems – often spanning the vast geographical region, networked through a dedicated network or the Internet, and have many control centers, substations, and embedded equipment. Such distributed networked cyber-physical systems have many layers of the system stack –starting from the physical elements of the cyber-physical system going all the way up to application software, and even cloud-based software for monitoring, control, and visualization. Therefore, any research agenda for cyber-security and defence of critical infrastructures need to be comprehensive, must span all layers of the system stack, and require an arsenal of different techniques, and methods.

The matrix above shows the various layers and the various research areas that researchers need to engage in. All these research areas are cross-cutting, and interdisciplinary in the sense that they involve multiple layers of the system stack, and individual research activities can either focus on a specific layer or be cross-layer.

Blockchain technology research

Another area of research that is of interest is the use of blockchain technology for the integrity of information such as medical data, customer data, and Aadhaar database. Also blockchain based public key cryptosystem, authentication schemes are of interest to allow immutability of transactional information, public key databases, DNS entries, etc.

So the areas that are not covered by the matrices described in Table 1 and 2 but need research investment are as follows:

(1) Resilient System Design methodology, techniques, and principles

(2) Block Chain Technology for providing incontrovertible transactional information recording

(3) IoT security

(4) Deep/Dark Web monitoring for threat intelligence

(5) Threat Intelligence and mining actionable information from that intelligence

(6) Cyber-security of India Stack a la Digital India

(7) Cyber-security of Machine Learning (as opposed to usage of machine learning in cyber-security through anomaly detection)

(8) Honey pots/ Honey Net systems

(9) Cyber Range as testbed for network security

(10) Malware Analysis and classification and creation of national malware repository

(11) Ransomware protection mechanisms, continuous surveillance mechanisms

(12) Immune system inspired protection against cyber-attacks, worms, APTs, and Trojans.

Data Science Research

Data science starts with a strong set of foundations adapted from several fields including statistics, mathematics, social science, natural sciences, and computer science. Big Data power lies in the analytical realm. It can certainly help us to solve many fundamental problems. Major innovations in Big Data are still to take place; but, it is believed that emergence of such novel analytics is to come shortly. Data is evolving much more rapidly than humans. It is not very wrong to say that such a Big Data surge will transform lives in possibly the next five to ten years. In order to unlock the full potential of big data, it is required to pair it with technologies like Hadoop, Cloud computing, HPC (high-performance computing), GPUs (graphics processing units), etc. Now, CPS being a recent hype has also envisioned smart service platform for users based on big data perspective. For instance, the joint polar satellite mission launching in 2018 will use sensor technology and data to forecast the path of hurricanes and storms. To some extent, this may seem to mean degrading privacy, but it will surely be used in future to serve the humanity more smartly.

(1) From a data management point of view, data science in CPS scenario requires a significantly more profound portrayal of how data is obtained, stored and accessed. Data quality, quality assurance, data integration, storage, protection, and security all should be re-examined. The conventional approach of acquisition, followed by storage, and processing often does not work for high velocity or sensitive data. Data visualization techniques should also be developed in this scenario.

(2) From a computational perspective, huge volumes of data, high data rates, and a huge number of users request new frameworks and new algorithms. New distributed system architectures that can handle the heterogeneity and unpredictable structure in the data access and communication are required. From an algorithmic point of view, there is a requirement for sub-linear algorithms, online processing abilities that can support real-time data streams, and probabilistic and stochastic ways to deal with both scale and noise in the data.

(3) From the security point of view, data security tools need to be developed that will allow us to have central and fine-grained control over access to the data. Big data security has become a topic in own right, and data scientists are usually only confronted with it as data consumers; seldom will they implement the security themselves. Furthermore, as more data gets aggregated, privacy concerns need to be strengthened in parallel, and thus, protocols and conventions will be created as a result.

(4) Furthermore, many classic statistical assumptions and machine learning techniques do not fit current data science needs. Often derived from natural sources, data is increasingly likely to be biased, incomplete and highly heterogeneous. Systematic errors arising in automated data collection and semantic inconsistencies that result from stitching data together from multiple sources across longer time horizons present profound modelling challenges and opportunities for the development of new statistical methods and machine learning algorithms. Even in the small data settings, new techniques that can cope with heterogeneity and biased sampling are needed. While predictive modelling is important, many data science problems involve decision making, and the ability to reason about alternative courses of action is needed. Also, understanding the curse of dimensionality, overfitting, and causality in these complex settings is critical.

(5) Besides, numerous classical statistics assumptions and machine learning methods do not fit into what the current data science needs. Frequently derived from natural sources,

data is progressively prone to be biased, fragmented and profoundly heterogeneous. Systematic errors emerging in automatic data collection and semantic inconsistencies that come about because of integrating data together from different sources pose great challenges, and thus open doors for the improvement of new techniques and new machine learning models. Indeed, even in the 'little' big data setting, where a huge number of small chunks of data will be distributed globally, new systems need to be developed that can adapt to this heterogeneity and fragmentation.

(6) The challenges in scale and heterogeneity also fundamentally change how users interact with data and models, how the data is visualized, what algorithms are needed to support understanding and interpretation of the results of data science models, how decisions are made, and how user feedback is acquired and incorporated. Human-computer interaction and visual analytics will need to integrated more tightly with data science models and algorithms. New use cases for natural language processing, text mining, speech recognition, social network analysis, and computer vision will emerge. This will significantly give rise to "smart" human-things, things-machines, humans-machines, machine-machine and even things-things communication modes.

(7) Because data science systems are often embedded in operational systems with changing demands and distributions, supporting the entire data science lifecycle is important. Ensuring the robustness of all aspects of the pipeline is important. New software engineering and computer programming best practices will need to be developed. Additionally, data artefacts will often persist beyond their initially planned usage, so longer-term duration and management must also be addressed.

(8) Data Science can surely help us unravel numerous solutions in ICPS scenario. Significant advancements, however, are still to happen. Many challenges, both system and data related, need to be handled for such a venture. It is trusted that such novel advances will have a huge impact on devising smart CPSs in India. Data is advancing substantially more quickly than people. Distributed and scalable algorithms need to be devised to handle them. To some degree advancement of data science may appear to mean breaching security; however, it will most likely be utilized as a part of future to serve the humanity smartly. In any case, before that, it is necessary to determine some ethical issues like intellectual property rights, data privacy, cybersecurity, exploitation risks and a huge set of protocols.

Quantum Computation, Information, Communications and Cryptography Research

The field of Quantum Computation, Information, Communications, and Cryptography has made explosive progress in recent years. It is an intensely pursued research area worldwide, because of its relevance to basic scientific research as well as its tremendous technological potential in general and in specific to CPS. The subject is interdisciplinary; its theoretical foundations are well established, and it is poised to develop revolutionary quantum devices in state-of-the-art facilities. Dedicated research centers in the field have been established worldwide, in leading universities as well as in top-notch IT companies. Some examples are: MIT (USA), YQI (Yale, USA), Princeton (USA), IQIM (Caltech, USA), Simons Institute (Berkeley, USA), Station Q (Santa Barbara, USA), ETH (Switzerland), QuTech (Delft, The Netherlands), CQIF (Oxford, UK), CQT (Singapore), IQC (Waterloo, Canada), NII (Tokyo, Japan), CQC2T (Australia). There are dedicated research laboratories in China and Russia too; and they have reached the top level in quantum computing and communication technology. Major IT companies, such as IBM, Google, Microsoft, and Intel, heavily support some of these centers; and also carry out in-house research. Of course, research efforts in various defence laboratories are hidden. For many of these centers, the financial investment is hundreds of millions of dollars; and a major part of that goes towards the installation of high-technology laboratories (electronics, cryogenics, lasers, clean rooms, atomic scale lithography, sensors and detectors with high accuracy, and so on). The Indian research effort in this field is limited on the theoretical side, and severely lacking on the experimental side.

Summary of present status in the field of Quantum Computation, Information, Communications, and Cryptography

Theoretical aspect

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

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

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

their protection against environmental disturbances etc.

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

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

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

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

Experimental aspects

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

(2) Quantum dots and atomic impurities: These can act as individual qubits, and can be realized

with semiconductor technology and careful lithography. Heterostructures, phosphorous impurities in silicon, nitrogen vacancy centers in diamond, are some of the possibilities being explored. Studies are so far at the two-qubit level. Keeping the errors below a threshold is the major challenge.

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

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

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

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

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

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

1. Obtain a worldwide overview of these research areas, from top Indian as well as foreign experts.
2. Assess the research base in India, and devise an umbrella programme to boost the existing Indian research activity in the field.
3. Select the topics to support, particularly on the experimental side, in which Indian researchers

can make significant contributions.

4. Formulate a hiring/training policy to acquire experienced researchers in this subject, covering both positions and timely start-up grants.

5. Suggest a creation of a dedicated center of excellence in this field, as a national effort, with appropriate budget, infrastructure, and scientists and engineers.

6. A strategy and roadmap to foster R&D, international collaborations in this field.

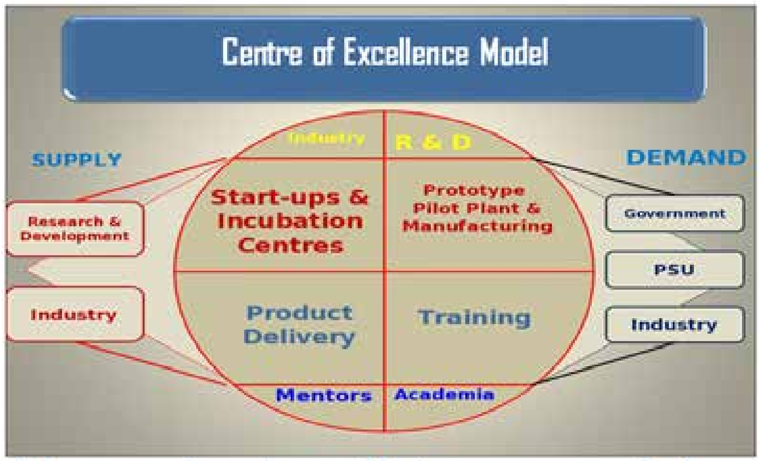
Outcome driven R&D- Top Level Challenges

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

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

3.2.2 Centers of Excellence (CoEs)

Centers of Excellence are emerging as a vital strategic asset to serve as the primary vehicle for managing complex change initiatives. In academic institutions, a center of excellence often refers to a team mandated to focus on a particular area of research; such an entity may bring together faculty members from different disciplines and provide shared facilities. In technology companies or institutions, the center of excellence concept is often associated with technologies or associated business, often human resource development is also in its folds. For an area like Cyber-Physical Systems, that bridges two distinct worlds- cyber and physical, is embedded in several technologies, feeds on ever-evolving technological advancements and finds application across the socio-economic as well as strategic sectors, CoEs are befitting instrument.



The objectives are to carryout translational research and establish world-class Center of Excellence in specific subjects of Interdisciplinary Cyber-Physical Systems in India. These CoEs would support and encourage innovative technology-based start-ups, industries, PSU that have an application and/or impact in the core sectors of the economy in our country. The Center of Excellence would also provide the incubation centers for start-ups with necessary guidance, tech support, infrastructure, access to investors, networking, and facilitating a host of other resources that may be required for the start-up to survive and scale.

Government and industry/ industry associations will be encouraged to participate. It shall be joint collaborative mechanisms that CoEs shall manage, contributed and monitored. Value addition and service provision shall be the driving force for CoEs. The existing and successful models and best practices shall be adopted while establishing CoEs. For India, there are few vertical focus areas that would be followed as guidance in terms of priority, such as

i. **Healthcare for all :** With current ratio of doctor to patient ratio of 1:1681, accessible & economical healthcare for all is almost impossible, unless we leverage AI for creating the technology middle layer that can leverage well trained doctors' expertise to all the remote corners of India

ii. **Smart city, Logistics & Mobility:** With autonomous and connected vehicles on the ground or in air mobility is going to redefine our cities, villages and connectivity within for people as well as businesses. Smart cities in future may not correspond to big cities, but with small cities connected seamlessly. Key policies needs to be enabled to have this revolution.

iii. **Education & Future of Work:** CPS will fundamentally disrupt the current skill driven employment cycle and education workflow, changing our perspective to creating lifelong learners. We would need to overhaul our people development plan to enable the next level of growth.

iv. **Financial Inclusion & Fraud prevention:** India still has 200m+ who are unbanked. With AI enabled speech and AR interfaces, they can access banking & credit anywhere with much lower amount of fraud. Specific policies adopting AI for banking will unlock this adoption.

v. **Precision Agriculture:** Our productivity of agriculture is lowest among our peers except in wheat. Along with a major component of cost is excessive use of pesticides and fertilizers. Leveraging AI & computer vision can accelerate the technology edge that can bring in precision agriculture at low cost, raising productivity. For that a cohesive policy directives might be required.

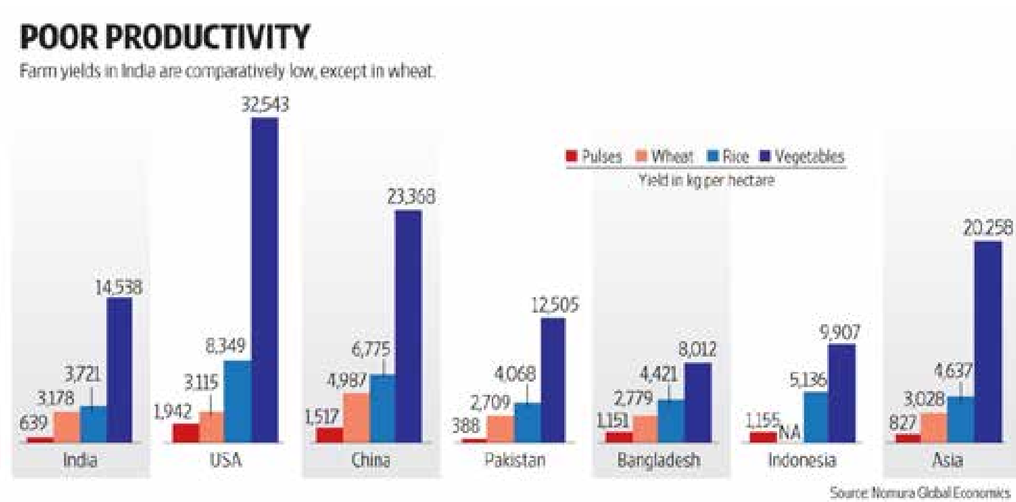


Fig 3.2. Poor productivity levels in agriculture

vi. **Smart Manufacturing & Retail :** 3D Manufacturing tightly driven by data driven retail can bring in efficiency and make it globally competitive. This could drive new kinds of jobs with hyper connected small industries.

vii. **Cyber security & Defence :** Core aspect of centralized command and control is getting flipped with AI, allowing edge intelligence to enable faster response for cyber security & defence with 4 major objectives (detailed out in fig. 10),

a. Enabling intelligent warfare

b. Enabling remote warfare

c. Enabling cyber warfare

Enabling AI driven defence capability with predictive response

Under ICPS Mission, it is proposed to follow a technology life cycle approach, addressing all stages viz. Knowledge-Development-Translation-Commercialization, even at the macro-level. Therefore, it is proposed to create or set-up four-tiered Centers of Excellence (CoEs) as given in the figure. These are: International Centers Of New knowledge (ICON) focussing on generation of new knowledge and intellectual property; Centers for Research On Sub-Systems (CROSS) with focus on creating platform technologies with applications in diverse sectors; Center for Applied Studies, Translational research and LEadership (CASTLE) with focus on development and translation of technologies that are ready for deployment/ commercialization/ operationalization and benefit the end-users; and Center of Excellence in Technology Innovation and Transfer (CETIT) with focus on delivering products/technology ready for deployment or commercialization building up from an idea or concept.

As they are part of technology life-cycle continuum in the Mission, these centers will not have sharp boundaries of functions; overlapping of their operations will be encouraged to address the complete technology lifecycle, if the delivery and commercialization of technology is promising.

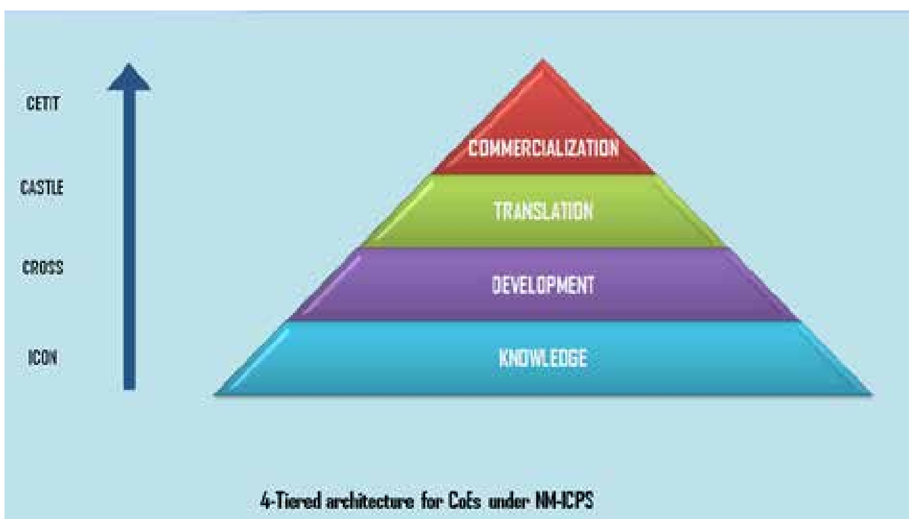


Fig 3.3: Proposed Centers of Excellence under the Mission

With this design, each such Center will, on one hand have forward and/or backward linkage with each other; on the other, they will work in tandem with experts/ institutions outside- the Mission funded projects, other initiatives of government and international institutions. In the highly networked mode as each center would be, they will be equipped and funded sufficiently to function independently as stand-alone entity, however they would leverage each other's strengths and the power of collaboration to produce synergistic outcomes (See Fig 3.4). This would ensure that there is a dynamic functional model where technologies being focused are driven by market demands and are well synchronized

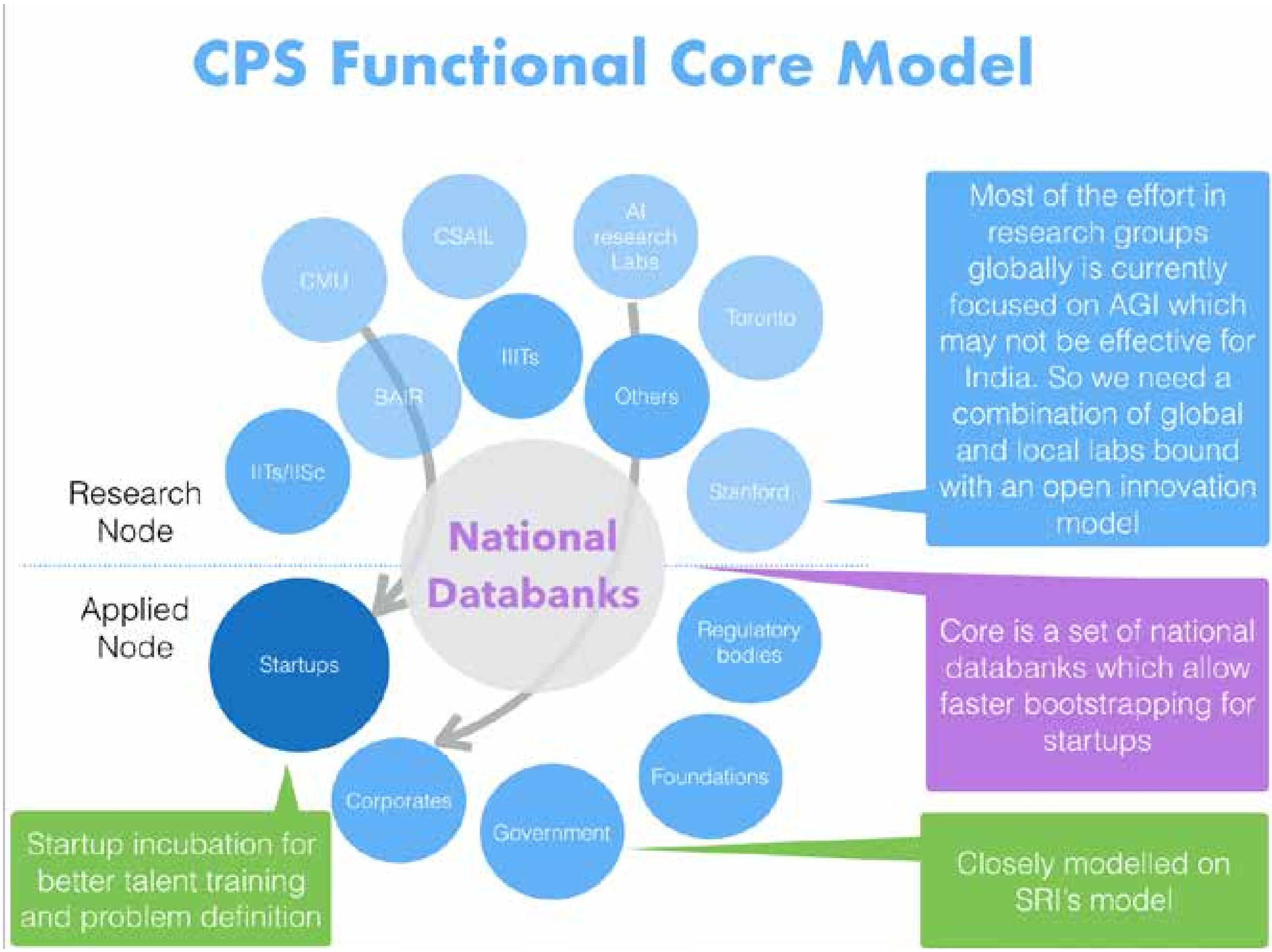


Fig 3.4: Proposed Functional Model under the Mission

Public Private Model & Revenue Model

CoEs funding would be prioritized with those having a public private model in place especially for CETIT. This would ensure that research output have Industry buy in and thus are relevant to some extent.

However it is difficult to attract private capital without proof of pilot in place, especially in a country like India, even for cutting edge areas of research such as CPS. Thus initial pilot phase would be driven by Govt. funding and in later years for Scale and growth phase, it is suggested to bring in 20-30% capital from private pools, with majority of that capital coming in post 3 years, where enough output would be visible to private capital. .

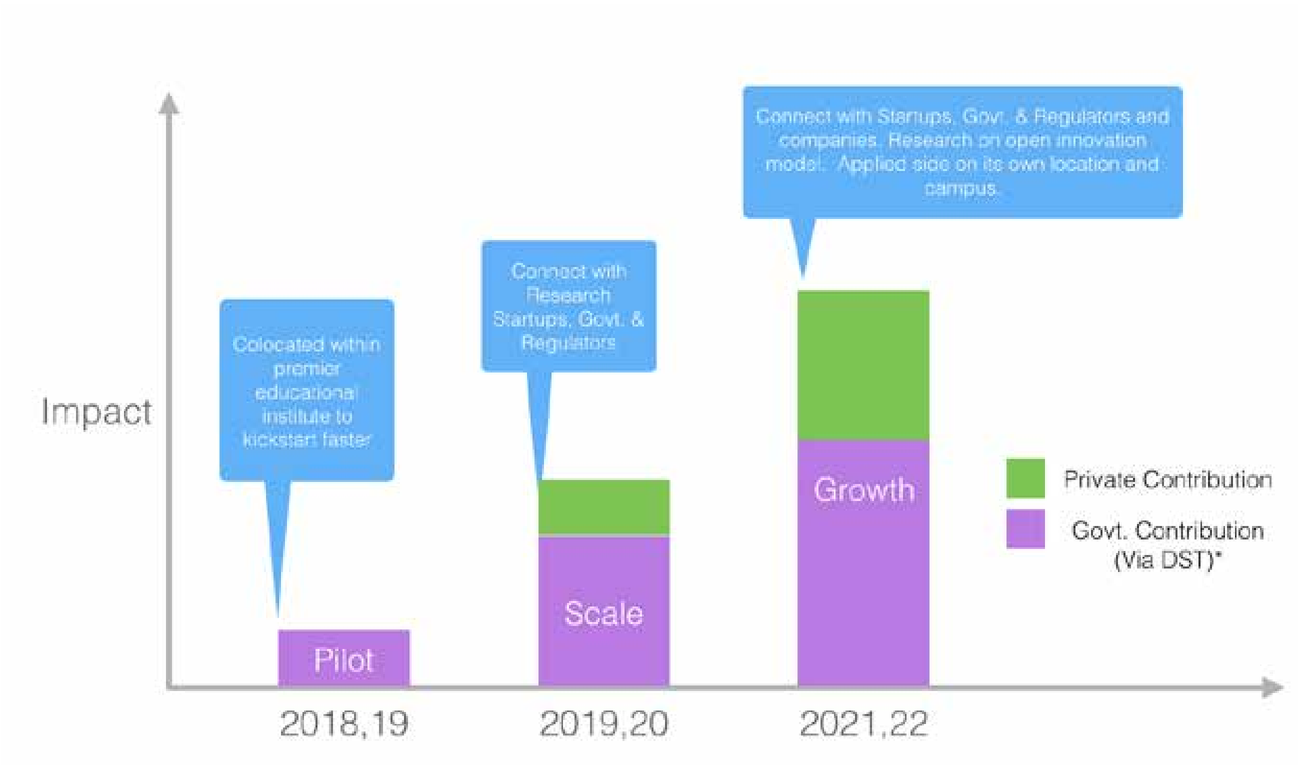


Fig 3.5: Proposed Public-Private Model

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

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

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

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

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

e. **Databank creation across strategic areas of focus** - Aggregating Data banks across verticals from Govt., Industry for offering data as a service for bootstrapping AI applications

Each of the CoE in the four-tiered architecture, IV being the bottom-most (knowledge) and I being the top-most (commercialization) but they will be able to take up the task of CoEs at the layer(s) below is described in the sections below.

Tier I: Center of Excellence in Technology Innovation& Transfer (CETIT)

CETIT will be the CoE responsible for delivering technology ready for commercilization, picking up from any of the previous technology readiness levels (TRL). This could be from taking ideas/ concepts or prototypes and turning them into marketable products by way of proactive coordination, communication, and interfacing for technology transfer. While working as a standalone entity, the mandate of CETIT would include networking with CASTLEs (at immediate lower tier), with industry and government agencies, to facilitate the transfer of technology developed at (CASTLE) and other projects funded under the Mission to the industry. It will showcase ready-to-deploy technology to target beneficiaries. CETIT will be linked with Technology Commercialization Fund and also activities in the entrepreneurial domain. CETIT will have linkages as shown in the table

CETIT	Backward Linkages	Forward Linkages
Within Mission	Linkages with CASTLEs for new technology solutions Human Resource (specializing in technology incubation, valorisation, commercialization, and transfer) Linkages with line ministries (to assess their technology needs)	Industry/ Industry Associations partnering in projects Line ministries (to showcase technology solutions)
Outside Mission	Business Schools Industry Associations	Other Industry/ Industry Associations Start-up Industry Technology Think tanks (for future technology trends)

The financial model for CETIT will include 100% funding for Non Recurring expenses from Government, gradually increasing investment from industry (0%-100%) in recurring expenditures with funding of recurring expenditures from DST/ Line ministries (decreasing over the years) where the industry is to pay for technologies. Each CETIT will provide state-of-the-art facilities for translational work, prototyping, testing and demonstration, institutions of translational research for technology solutions for India, and hence, it is expected that industry participation in financial terms will increase which is necessary to keep these centers functional beyond the Mission. Equipped wuith facilities to incubate technologies, CETIT will provide accelerated Technology commercialization, besides giving market/Business intelligence to CASTLEs/ CROSS. It will also showcase proven technology before the end user and turnout manpower trained in different stages of TRLs.

Scheme		Center of Excellence in Technology Innovation & Transfer (CETIT)
Objective		To commercialize technologies developed under the Mission
Intended/ Targeted Beneficiary	Category	Existing academic and R&D institutions with 10 years of standing, experience and basic infrastructure in CPS related areas
	Numbers	4
Support Amount (per project) Maximum		Rs. 100 crore
Project Duration		5 years
Funding (Nature/ Pattern)		100% Non Recurring expenses from Government Gradually increasing investment from industry (0%-100%) in recurring expenditures Funding of recurring expenditures from DST/ Line ministries (decreasing over years) Industry to pay for technologies
Site/ Workplace		Existing academic and R&D institutions
Expected Outcomes		New deployable products/technology Technology commercialization Institution Technology commercialization Exposure of Entrepreneurship to students in the Center
Performance Metrics		Technologies commercialized, Start-ups, Revenue Generated, Transactions with industry

Tier II: CASTLE (Center for Applied Studies, Translational research and LEadership)

CASTLE provides the eco-system for application based technology development and deployment. As the name suggests, the activities here will be with a pull from user industry/organization. These centers will be expected to takeon the top level challenges identified or inter-ministerial projects calling for CPS based solutions. Translational work will ensure that country acquires leadership in markets through these centers, by actually delivering technologies or technology solutions on the ground. Each CASTLE will, thus, primarily focus on translational research for technology development but also work on lower TRLs. Along with this, focus on human resource development and serve as repository of proven concepts/ prototypes. CASTLE will have Linkages as shown in the table:

CASTLE	Backward Linkages	Forward Linkages
Within Mission	CROSS Linkages with R&D institutions or industry for translational work, under the Mission Institutions funded for top-level challenges identified under the Mission CHANAKYA schemes	CETIT, for valorisation, commercialization, and transfer of technology CPS- Dedicated Innovation Accelerators (DIAL) created under the Mission Entrepreneurship Development schemes
Outside Mission	Linkages with existing (Translational) institutions, R&D labs Linkages with international institutions	Technology Business Incubators Start-ups Industry& Industry Associations Department/ Ministries

Each CASTLE will be supported fully funded for meeting non-recurring expenses by the Government, However, for recurring expenditures, it will be expected that industry contribution will increase gradually (0%-100%) and funding of recurring expenditures from DST/ Line ministries (decreasing over the years). Each CASTLE will provide state-of-the-art facilities for translational work, prototyping, testing and demonstration, institutions of translational research for technology solutions for India, and hence, it is expected that industry participation in financial terms will increase which is necessary to keep these centers functional beyond the Mission. In addition, development of new products/ processes in the process of technology development for application areas, it will reduce the gap between Industry and R&D laboratories. Such technologies that are generated during the process will give early exposure to entrepreneursfor startups or off-take by industry at this layer. Technologies developed in these centers and requiring incubation support can be taken up by CETITs or to existing TBIs.

Scheme		Center for Applied Studies, Translational research and LEadership (CASTLE)
Objective		Create a cluster of dynamic centers excelling in translational research & developing technologies, for application in areas of socio-economic and strategic sectors
Intended/ Targeted Beneficiary	Category	Existing academic and R&D institutions with 10 years of standing, experience and basic infrastructure in CPS related areas
	Numbers	9
Support Amount (per project) Maximum		Rs. 50 crore
Project Duration		5 years

Funding (Nature/ Pattern)	Non-recurring expenditure to be borne by Government; Recurring expenditure reducing from 100% to 0% in five years from Govt. and increasing contribution from Industry from 0% to 100% over the project period of five years.
Site/ Workplace	Existing academic and R&D institutions
Expected Outcomes	Institutions of translational research Technology solutions for India New products/ processes Manpower of high order skills Intellectual property Exposure of Entrepreneurship to students in the Centre
Performance Metrics	Market-ready technology, IP, Transactions with industry

Tier-III: CROSS (Center for Research On Sub-Systems of CPS)

Each CROSS will work as the intermediate layer that will connect the basic research layer (Tier IV ICON) to higher layers. The basic objective of this tier is to develop and integrate core knowledge developed at ICON layer and also from any other source, into a working tool to be used in the higher layers. The primary activity of CROSS includes tool development for direct application, but IP generation and human resource development will also go along. Development of platforms/ architecture by integrating knowledge/ technologies developed will pave the way for taking up the challenges at the next tier. Basic work for solutions will be conducted here. The primary activity will also be undertaken to address the critical sub-system level needs of the identified top-level challenges. CROSS will have linkages as shown in the table:

CROSS	Backward Linkages	Forward Linkages
Within Mission	ICONs and institutions- funded under the Mission for knowledge development CHANAKYA schemes	CASTLEs Institutions which will take-on top-level challenges/ inter-ministerial projects International Collaborations under the Mission
Outside Mission	Linkages with existing institutions, developing CPS sub-systems Linkages with international institutions	R&D institutions, focussed on translational work Organizations looking for CPS Sub-systems

CROSS will be funded through the Mission, but industry contribution in the development of Sub-systems, because of their application-oriented nature, will be encouraged. Each CROSS will see a gradual increase in industry participation, and here industries can be encouraged to fund research and solving problem

Scheme		Center for Research On Sub-Systems of CPS (CROSS)
Objective		To develop and integrate core knowledge developed at ICON layer and also from any other source, into working tool to be used in the higher layers
Intended/ Targeted Beneficiary	Category	Existing academic and R&D institutions with 10 years of standing, experience and basic infrastructure in CPS related areas
	Numbers	6
Support Amount (per project) Maximum		Rs. 50 crore
Project Duration		5 years
Funding (Nature/ Pattern)		100% Non Recurring expenses from Government Gradually increasing investment from industry (0%-100%) in recurring expenditures in development of sub-systems Funding of recurring expenditures from DST/ Line ministries (decreasing over years)
Site/ Workplace		Existing academic and R&D institutions
Expected Outcomes		Centers for research on Sub-systems Development of platforms/architecture New tools Manpower of high order skills Intellectual property
Performance Metrics		New tools developed, new platforms/architecture developed, IP Generated, HR

Tier- IV: ICON (International Centers of New Knowledge in CPS)

ICONs will be the centers of excellence creating new knowledge through basic research in areas that is shared by most of CPS technologies. ICON will be source for fundamental knowledge/ technologies that will be needed to keep India prepared for the next generation of technologies. Thus, the primary activity of ICON includes the development of new knowledge (intellectual property) and highly knowledgeable human resource with top-order skills, besides serving as a repository of papers and patents. It will also engage in International Collaboration to prepare India in its quest to be a leader in the domain. ICON will have linkages as shown in the table:

ICON	Backward Linkages	Forward Linkages
Within Mission	Experts/ institutions funded for R&D under the Mission CHANAKYA schemes	CASTLEs CROSS
Outside Mission	Existing knowledge institutions/ experts International institutions Technology Think tanks	Academic Institutions R&D labs

The deliverable for ICON includes state-of-the-art basic research facilities, besides new knowledge and Intellectual property (sharedthrough common repository maintained by ICON), the manpower of high order skills specialized in CPS technology, knowledge networks connecting to all the components working under the model and connected via input and output linkages. For taking benefit of new knowledge generated by ICONs, membership or formal involvement of industries will be encouraged. The industry participation in ICON will be among things in the form of visiting faculty, co-organization of conferences and industry visits of faculty, student.

Scheme		ICON (International Centers of New Knowledge in CPS)
Objective		Set up a constellation of ICONs, mandated to prepare country for next-generation CPS, through knowledge and human resource development, to position India as a global CPS leader
Intended/ Targeted Beneficiary	Category	Academic and R&D institutions of 15 years of standing, experience of working in the domains of CPS
	Numbers	6
Support Amount (per project) Maximum		Rs. 50 Crore
Project Duration		5 years
Funding (Nature/ Pattern)		100% Non Recurring expenses from Government
Site/ Workplace		Existing academic and R&D institutions
Expected Outcomes		Institutions of international standing New knowledge and Intellectual Property Manpower of high order skills
Performance Metrics		IP, HR, International collaborations

ICON will focus on creation of new knowledge through basic research. CROSSwill focus on developing and integrating core technologies based on knowledge generated in ICONs or any other sources, CASTLE will focus on the development of and deployment of technologies/ solutions. CETIT will focus idea onwards to commercialization of technologies developed under this Mission. They are, thus, four different streams under one umbrella for growth and deployment of CPS that will work in lockstep, in close coordination, sharing of resources and meaningful overlap of activities that allows upward movement on TRL. For the sake of imparting clarity, these four have been compared in Table 3.2.

Table 3.2: ICON, CROSS, CASTLE& CETIT compared

Attribute/ parameter	ICON	CROSS	CASTLE	CETIT
Core mandate	Basic research & Human resource development Prepare India for next-generation CPS	Development and integration of core knowledge developed at ICON layer and also from any other source, into working tool to be used in the higher layers	Applied Studies, Translational Research & Technology Development HRD	Developing and delivering Commercializable technologies, developed under the Mission
Distinctive features	Linkages with international & national institutions of repute Linkages with other Centers of excellence IP generation Knowledge Dissemination (Online Material, Summer Schools)	Linkages with industry Linkages with institutions of repute Linkages with other Centers of excellence IP generation	Linkages with industry Linkages with institutions of repute Linkages with other Centers of excellence Advanced Prototyping Facility (Commercial Model) Market ready technologies/ solutions IP sharing with industry	Linkages with industry Linkages with other Centers of excellence Market ready technologies/ solutions Technology transfer
Funding pattern	100% Non Recurring expenses from Mission	100% Non Recurring expenses from Mission Gradually increasing investment from industry (0%-100%) in recurring expenditures Funding of recurring expenditures from DST/ Line ministries (decreasing over years)	100% Non Recurring expenses from Mission Gradually increasing investment from industry (0%-100%) in recurring expenditures Funding of recurring expenditures from DST/ Line ministries (decreasing over years)	100% Non Recurring expenses from Mission Gradually increasing investment from industry (0%-100%) in recurring expenditures Funding of recurring expenditures from DST/ Line ministries (decreasing over years) Industry to pay for HRD and Technologies

Attribute/ parameter	ICON	CROSS	CASTLE	CETIT
Performance Metrics	Linkages IP generated HRD	New tools developed New platforms/ architecture developed IP Generated HR	Technologies pushed into commercial space Linkages IP generated HRD	Technologies commercialized Start-up Revenue generated
Areas of Excellence	Actuator Development CPS Wireless communication CPS Data Analytics CPS Cyber Security Processing Sensor-based intelligent Devices Photonics Sensor Chip Fabrication(to be associated with Nanotech Center) Quantum Technologies	Development and integration of core knowledge developed at ICON layer	Manufacturing Energy Transportation Health Logistics Entertainment Agriculture Space Exploration Deep Ocean Education Smart City Smart Home Smart Offices Defence	An area for complete Technology Development & Deployment

Innovative ideas from the students/faculty, emerging out of their work need support for generating prototypes and testing them. In the absence of facilities for the same, the ideas get lost. It is proposed to set-up prototyping and testing facilities in CoEs and other Engineering Colleges where students and faculty collaborate on innovative designs—and then turn their ideas into tangible, real-world working products. The engineering colleges selected for a scheme under the Mission must be having basic facilities and the support through this Mission will be for adding to the facilities. Students will also be developing the experiential skills needed in their professional career- as researcher, teacher or entrepreneur.

3.2.3 HRD& Skill Development

In order to firmly root CPS in India, harness its full potential and extend its benefits to compatriots, HRD has to be at the heart of the Mission. It is humans who will be at work creating new knowledge, converting knowledge into technology, technology into products, diffusing products as a consumer good/service, and also, as knowledge seekers. Development of human resource in a focused area requires infrastructure, learning platforms, knowledge/ information resources, teachers, capital, policy framework, etc. However, the key players are the learners/ researchers and teachers across all level who need to be focused through special schemes for them.

Focus on HRD under the ICPS Mission will be ensured under the Programme **Comprehensive and Holistic Advancement of National Knowledge Yield and Analytics (CHANAKYA)**. It will have the following categories of internships/ fellowships/schemes.

1. For UG (Undergraduate) Programme:

(i) CHANAKYA-GI (Graduate Internships): Engineering colleges/ Technical institutes in India are a huge pool of human resource in the form of students, but they are not sufficiently oriented towards reaching out to industry or solving problems that can benefit society. To overcome this gap and produce graduates trained in CPS who can be problem-solvers or turn entrepreneurs, CHANAKYA Graduate Internship of 10months is proposed. It will be encouraging enhanced and continued involvement of students and also, faculty of technical institutions with industries (including technology challenged MSMEs)

Scheme		CHANAKYA-GI (CHANAKYA Graduate Internships) [on the pattern of TIFAC MSME Internship Programme]
Objective		To create a pool of trained professionals in CPS domain to be problem-solvers or turn entrepreneurs
Intended/ Targeted Beneficiary	Category	Undergraduate Students
	Number	6000 in 5 yrs
Support Amount (per project) Maximum		As per Norms
Project Duration		10 months
Funding (Nature/ Pattern)		Grant
Site/ Workplace		Industries (including technology challenged MSMEs)
Expected Outcomes		IP, Technology, Trained Professionals
Performance Metrics		No. of IP Generated Contribution of UG students in solving issues of industries
Any other information		Rules of host institutes where the fellowship is tenable will be applicable; research grants/ overheads to be paid to host institute;

(ii) Development Fund:- For UG Students, who are doing projects in CPS and allied areas under CHANAKYA-GI Programme will be supported by development fund for the project, which will be Rs. 1 Lakh per project (Each project would be typical of 2 Students.

(iii) Common CPS Infrastructure Support: Under the Mission, it is proposed to initiate curriculum in CPS and allied areas (Data Science, Artificial Intelligence, Robotics, IoT, Sensors/

Actuators, and Embedded Systems, etc.) for Undergraduate Students. Proposals from academic institutions having infrastructure, laboratories and faculty in the areas of CPS will be considered. The institutions offering the courses will be provided support for augmenting their infrastructure, supplementing the faculty, industry interaction (visits, student projects), etc

Scheme		Common CPS Infrastructure Support
Objective		Initiate Curriculum for UG Students in CPS and allied areas
Intended/ Targeted Beneficiary	Category	Academic institutions having infrastructure, laboratories and faculty in the areas of CPS
	Numbers	30
Support Amount		Rs. 1 Crore per institute (to supplement the existing infrastructure, Guest/Visiting faculty, industry linkages/visits)
Duration		1year
Funding Pattern		Grant to institution
Workplace		Academic Institution
Expected Outcomes		Trained professionals, Prototypes
Performance Metrics		Students passed out Industry projects done, prototypes developed

2. For PG (Postgraduate) Programme:

(i) CHANAKYA Post-Graduation Fellowships (CHANAKYA-PGF) (24 months):

This fellowship will be offered to students admitted to PG programmes in CPS or related areas and having a valid GATE, at different technical institutions like IITs, NITs and other AICTE approved engineering institutions. The students would be expected to work on a real problem of industry and solve it using CPS. They could also have an opportunity to take part in global ecosystem as well.

Scheme		CHANAKYA-PGF (CHANAKYA Post-Graduation Fellowships) [on the pattern of GATE]
Objective		To provide a platform for PG students to work on a real problem of industry and solve it using CPS
Intended/ Targeted Beneficiary	Category	Students admitted to PG Programmes in CPS or related areas
	Numbers	1000 in 5 yrs
Support Amount (per project) Maximum		As per norms
Project Duration		24 months

Funding (Nature/ Pattern)	Grant
Workplace	Industry/ Academic Institution/R&D Institution
Expected Outcomes	IP, Technology,
Performance Metrics	IP Generation Different approaches to solving real problem of industries Skill-set of PG students under this scheme
Any other information	Rules of host institutes where the fellowship is tenable will be applicable; research grants/ overheads to be paid to host institute;

(ii) Development Fund:- For PG Students, who are doing projects in CPS and allied areas under CHANAKYA-PGF Programme will be supported by development fund for project, which will be Rs. 2 Lakh per project (Each project would be typical of 1 Student).

(iii) Common CPS Infrastructure Support: Under the Mission, it is proposed to upgrade/initiate PG programmes (2 year, 4semester) in CPS and allied areas (Data Science, Artificial Intelligence, Robotics, IoT, Sensors/Actuators, Embedded Systems etc.) Proposals from academic institutions having infrastructure, laboratories, and faculty in the areas of CPS will be considered. Students will be selected based on the scores in a common exam and allotted institutions to pursue the programme. The institutions offering the courses will be provided support for augmenting their infrastructure, supplementing the faculty, industry interaction (visits, student projects), etc. This Programme will be as per the Postgraduate Teaching Programme, run by the Department of Biotechnology.

Scheme		Common CPS Infrastructure Support [on the pattern of PG Teaching Programme of DBT]
Objective		Initiate PG programmes in CPS and allied areas
Intended/ Targeted Beneficiary	Category	Academic institutions having infrastructure, laboratories and faculty in the areas of CPS
	Numbers	15
Support Amount		Rs. 1 Crore per institute (to supplement the existing infrastructure, Guest/Visiting faculty, industry linkages/visits)
Duration		1 year
Funding Pattern		Grant to institution
Workplace		Academic Institution
Expected Outcomes		Trained professionals, Prototypes
Performance Metrics		Students passed out Industry projects done, prototypes developed

3. CHANAKYA Doctoral Fellowships (CHANAKYA-DF) (36 months extendable by another 12 months)

Primarily aimed to encourage in-depth analysis and enrich knowledge in CPS, the Doctoral candidates would be expected to apply independent methodologies of scientific research as well as to create new scientific knowledge/ technology solutions. The fellowship will be tenable at academic and research institutions across India.

Scheme		CHANAKYA-DF (CHANAKYA Doctoral Fellowships) [on the pattern of JRF/SRF of CSIR]
Objective		To provide support for Doctoral candidates to do an in-depth analysis in CPS by applying independent methodologies of scientific research and creating new scientific knowledge/ technology solutions in CPS.
Intended/ Targeted Beneficiary	Category	M.Tech. in CPS or allied areas
	Numbers	500 in 5 yrs
Support Amount (per project) Maximum		As per norms
Project Duration		36 months; Extendable by another 12 months
Funding (Nature/ Pattern)		Stipend/ Grant
Workplace		Industry/ Academic Institution/R&D Institution
Expected Outcomes		IP, Technology, Research oriented technical minds
Performance Metrics		IP Generation New knowledge/ technology solutions in CPS
Any other information		Rules of host institutes where the fellowship is tenable will be applicable; research grants/ overheads to be paid to host institute;

4. CHANAKYA Post-Doctoral Fellowships (CHANAKYA-PDF) (24 to 36 months)

The fellowships will be supporting motivated young researchers in the area of CPS and groom them as an independent researcher. The fellows will be required to work under a faculty/scientist in an academic/research institution in India.

Scheme		CHANAKYA-PDF (CHANAKYA Post-Doctoral Fellowships) [on the pattern of Research Associateship of CSIR]
Objective		To provide support for motivated young researchers in the area of CPS and groom them as an independent researcher
Intended/ Targeted Beneficiary	Category	Researchers with Doctoral degree
	Numbers	500 in 5 yrs
Support Amount (per project) Maximum		As per norms
Project Duration		24 to 36 months
Funding (Nature/ Pattern)		Stipend + Research Grant
Workplace		Academic/ R&D Institution
Expected Outcomes		IP, Technology
Performance Metrics		IP Generation New application areas of CPS
Any other information		Rules of host institutes where the fellowship is tenable will be applicable; research grants/ overheads to be paid to host institute;

5. CHANAKYA Faculty Fellowships (CHANAKYA-FF) (Tenure track of 3 years term)

Offered at Assistant Professor, Associate Professor, and Professor levels, the tenure-track faculty is expected to engage heavily in research and teaching in CPS or related areas and should preferably; complement the ongoing work in the host institution. The eligibility criteria for tenure-track faculty positions will be similar as in IITs.

Scheme		CHANAKYA-FF (CHANAKYA Faculty Fellowships)
Objective		To provide support for faculties heavily engaged in research and teaching in CPS or related areas and complementing the ongoing work in the Host Institution in areas of CPS Domain
Intended/ Targeted Beneficiary	Category	Assistant Professor/Associate Professor/ Professor
	Numbers	125 in 5 yrs
Support Amount (per project) Maximum		As per norms
Project Duration		3 year
Funding (Nature/ Pattern)		Grant
Workplace		Academic/ Research Institution
Expected Outcomes		IP/Technology
Performance Metrics		IP Generation Technology development under his guidance No. of students guided
Any other information		Rules of host institutes where the fellowship is tenable will be applicable; research grants/ overheads to be paid to host institute;

6. CHANAKYA Chair Professors (CHANAKYA-CP) (3 year term)

Chair Professors are basically faculty, who are offered positions as an acknowledgement of contribution to research and teaching. It is proposed to create positions of chair professors in academic institutions excelling in CPS and allied area. They are highly valued in academic circles due to the prestige attached to them on the one handand to the contribution, the faculty makes during the tenure, on the other. Rules of host institutes where the fellowship is tenable will be applicable; research grants/ overheads to be paid to host institute;

Scheme		CHANAKYA-CP (CHANAKYA Chair Professors) [on the lines of scheme by Bose fellowship programme of DST]
Objective		To honor & to provide support and gain the Knowledge and guidance in Research from their expertise in the domain of CPS
Intended/ Targeted Beneficiary	Category	Anyone with a track record of an outstanding teacher or researcher in the rank of Associate Professor or Professor or a person with R&D experience from industry, retired professors, faculty from other countries.
	Numbers	125 in 5 yrs
Support Amount		As per norms
Duration		3 years
Funding Pattern		honorarium+Research Grant
Workplace		Academic/ R&D Institution
Expected Outcomes		IP/Technology Generation
Performance Metrics		IP Generation Technology developed in CPS under his guidance
Any other information		Rules of host institutes where the fellowship is tenable will be applicable; research grants/ overheads to be paid to host institute;

7. CPS-Upgrading PG Programme: Under this scheme some existing courses in academic Institutions will be considered for upgradation with focus on CPS technologies in different areas like agriculture, healthcare, environment etc.

Scheme		CPS-Upgrading PG Programme
Objective		To acknowledge and upgrade PG programmes in CPS and allied areas
Intended/ Targeted Beneficiary	Category	Academic institutions having infrastructure, laboratories and faculty in the areas of CPS
	Numbers	20
Support Amount		Rs. 5 Crore per institute (to supplement the existing infrastructure, Guest/Visiting faculty, industry linkages/visits)

Duration	1 year
Funding Pattern	Grant to institution
Workplace	Academic Institution
Expected Outcomes	Trained professionals, Prototypes
Performance Metrics	Students passed out Industry projects done, prototypes developed

8. CPS- PSDW (Professional Skill Development Workshop): Under this scheme a 2 weeks skill development workshop Working Professionals in different application sectors of CPSwill be organized.

Scheme		CPS- PSDW (Professional Skill Development Workshop)
Objective		To train professionals for contribution in successful delivery of CPS products.
Intended/ Targeted Beneficiary	Category	Working Professionals in different application sectors of CPS
	Numbers	20
Support Amount (per project) Maximum		Rs. 5 lakh
Project Duration		2 Weeks
Funding (Nature/ Pattern)		Grant
Site/ Workplace		Academic Institutions and/or B-Schools
Expected Outcomes		Better contribution from professionals in developing sector specific products
Performance Metrics		Number of institutions funded Professionals trained, Trained workforce added to the pool

9. CPS-Advanced Skill Training School

Once a technology is commercialized and diffused in the society, it requires well trained technicians for installation, diagnostics, repairs, operations and maintenance. Under the Mission it is proposed to train such high skilled personnel at the level of B.VoC, Polytechnics (Diploma level) and ATI's who can take care of these requirements. Training for these requires a sound infrastructure, well trained trainers and trainers of trainers in the area of CPS. It is proposed to set up advanced skill training school in existing ITI & Polytechnics.

Scheme		CPS-Advanced Skill Training School
Objective		To train individuals for maintenance and diagnostics after successful delivery of CPS products.
Intended/ Targeted Beneficiary	Category	B.VoC/ Polytechnics/ATIs in different states to selected
	Numbers	100
Support Amount (per project) Maximum		Rs. 10 lakh
Project Duration		1 year
Funding (Nature/ Pattern)		Grant, to upgrade existing infrastructure related to CPS
Site/ Workplace		ITI/ Polytechnics
Expected Outcomes		Employable technicians, Self-employable technicians
Performance Metrics		Number of institutions funded Students trained, Technicians added to the pool

3.2.4 Innovation, Entrepreneurship &Start-up ecosystem:

In the knowledge society there is a growing inclination among people to add value in their work instead of growth, making entrepreneurship natural. Entrepreneurship is not just important for the business itself, for it plays an important role in the economy of a country also. It generates new job opportunities, besides causing economic growth. For advanced society it is demanded from entrepreneurs to bring new ideas and product to the market. Therefore, most governments around the world support individuals who want to start their own business.

Towards promoting Entrepreneurship- specially start-ups and creating an enabling eco-system for entrepreneurship, following schemes are proposed on the lines of NIDHI Programme (By DST):

1- CPS-GCC - Grand Challenges and Competitions for scouting innovations

CPS-Grand Challenges and Competition (CPS-GCC) will strengthen the entrepreneurial ecosystem as well as deliver immense value to other TBIs. CPS-GCC is a pre-incubation activity targeted mainly at scouting of innovations for building a pipeline for the TBIs. CPS-GCC targets large number of innovators.

Objectives of CPS-GCC

- To find & nurture new and innovative solutions for major challenges being faced by the society that are viable and sustainable.
- To pickup ideas from untapped sources and convert them into start-ups.

- To generate better awareness about entrepreneurship amongst India's masses and reach out to aspiring and existing entrepreneurs through active media outreach
- To expand the pipeline of potential incubatees for all TBIs
- To provide structured mentoring, guidance, prototyping grants, and seed-funding for ideas applying for such programmes
- To build a vibrant start-up ecosystem, by establishing a network between academia, financial institutions, industries and other institutions.

Scheme		**CPS-GCC - Grand Challenges and Competitions**
Objective		To motivate several aspiring entrepreneurs to take the plunge and convert their ideas into viable enterprises by scouting of innovations
Intended/ Targeted Beneficiary	Category	Individuals with innovative ideas
	Numbers	100
Support Amount (per project) Maximum		Rs.50.00 lakhs max.(seed fund support) Rs.5.00 lakh for prototype development
Project Duration		2 years(extendable by 6 months)
Funding (Nature/ Pattern)		Grant (to be released against targets)
Workplace		Academic Institutions and/or B-Schools
Expected Outcomes		Innovative solutions to challenges faced by societies Technologies developed Start-ups
Performance Metrics		Innovative solutions to challenges faced by societies Technologies developed Start-ups,

2. CPS-PRomotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS) - Support from Idea to Prototype.

There is a definite need to address the gap in the very early stage idea/ proof of concept funding. The CPS-PRAYAS programme focuses on addressing the idea to prototype funding gap. This programme would attract a large number of youngsters to come forward to try out their ideas without actually worrying about the failure. Eventually, such an approach would bring in a large number of potential ideas into the incubation programmes, thereby increasing the flow of quality incubate to the incubators. CPS-PRAYAS is positioned as a pre-incubation initiative.

Objectives of CPS-PRAYAS

- To enable translation of an innovative idea to a prototype.

- To provide a platform for faster experimentation and modify approaches in the idea to market journey.
- To generate innovative solutions relevant to the local and global problems.
- To attract a large number of youth who demonstrates problem solving zeal and abilities to work on their new technology/knowledge/innovation based start-ups.
- To enhance the pipeline in terms of quality and quantity of innovative start ups to the incubators.
- To build a vibrant innovation ecosystem, by establishing a network between innovators, academia, mentors and incubators.

A dedicated Fabrication lab (Fab Lab) is required to be set up in a PC to facilitate mechanical and digital fabrication (in case TBI/STEP does not have such facilities and infrastructure existing in the institute). Fab lab would enable innovators to go through a cycle of imagination, design, prototyping, reflection, and iteration as a part of process to find solutions to challenges or bring their ideas to reality. Few suggestive equipment in Fab Lab would generally include a laser cutter that makes 2D and 3D structures, a sign cutter that plots in copper to make antennas and flex circuits, a high-resolution numerically controlled milling machine, PCB fabrication equipment and a suite of electronic components, microcontrollers and programming tools for low-cost prototyping, a 3D Printer, essential design softwares, basic manufacturing tools and any other equipment which a PC would require for prototype building. The proper capacity utilization of various equipments in the Fab Lab should be ensured by each PC. The charges of using the equipment and consumables specific to an innovator would be decided by PC and be would be in built in the grant to be provided to the PC innovator. The condition and usability of the equipment in the Fab Lab would be reassessed at the end of five years for obsolescence and for possible replacement.

Scheme		**CPS-PRomotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS)**
Objective		To address the gap in the very early stage idea/ proof of concept funding
Intended/ Targeted Beneficiary	Category	Academic Institutions and/or B-Schools/ Existing STEP/TBI
	Numbers	10
Support Amount (per project) Maximum		Rs.3.7 crore
Project Duration		5 years
Funding (Nature/ Pattern)		Grant

Workplace	Academic Institutions and/or B-Schools
Expected Outcomes	Innovators facilitated and enabled (minimum 100 annually across the country) Ideas translated into prototype through funding support
Performance Metrics	Innovators facilitated and enabled Ideas translated into prototype

3. CPS-Entrepreneur In Residence (CPS-EIR) - Support system to reduce risk.

To inspire the best talents to be entrepreneurs, minimize the risk involved in pursuing start-ups, and to partially set off their opportunity costs of high paying jobs, CPS-Entrepreneurs-in-Residence (EIR) Programme is introduced. The CPS-EIR programme provides tremendous opportunities for innovative entrepreneurs to expand their networks and get critical feedback on their ventures in order to promote their entrepreneurial career goals and aspirations. The opportunities under CPS EIR Programme include:

- Guidance from experienced, innovative and highly successful entrepreneurs on the business concept, strategy or venture and insight into specific industries or markets.
- Best practices for starting a business and broaden the professional network.
- Co-working spaces for developing the idea into a marketable product.

Objectives of CPS-EIR

- To encourage graduating student to take to entrepreneurship by providing support as a fellowship
- To provide a prestigious forum for deserving and budding entrepreneurs to pursue their ventures without any additional risks involved in technology based businesses.
- To create, nurture and strengthen a pipeline of entrepreneurs for incubators
- To make pursuing entrepreneurship related to a technology business idea more attractive among options available career options.
- To enable creation of new start-ups by entrepreneurs and significant progress towards raising funding or investment.

The Programme thus encourages enterprising individuals to venture out and pursue daring entrepreneurial ideas as well as enhances the quantity and quality of start-ups.

Scheme		CPS-Entrepreneur In Residence (CPS-EIR)
Objective		To inspire the best talents to be entrepreneurs, minimise the risk involved in pursuing start-ups, and to partially set off their opportunity costs of high paying jobs
Intended/ Targeted Beneficiary	Category	enterprising individuals
	Numbers	500 (in 5 years)
Support Amount (per project) Maximum		30,000 per month as stipend
Project Duration		1 year
Funding (Nature/ Pattern)		Grant
Workplace		Academic Institutions and/or B-Schools
Expected Outcomes		Conversion of at least 30 % of the support recipient's ideas into start-up companies. At least 10% support recipient raising funds or investment for his or her company within 18 months of NIDHI-EIR support.
Performance Metrics		Technologies commercialized Start-ups Revenue generated

4. CPS-Start-up

Through Innovation and Entrepreneurship Development Centers (IEDCs) in academic institutions; encouraging Students to promote start-ups

Objective of CPS-Start-up

- To take forward student innovations in IEDC/NewGen IEDC programme to commercialization stage,
- To promote student start-ups,
- To accelerate the journey of idea to prototype by providing initial funding assistance

The programme CPS would help the start-ups with initial / ignition funding and hence would be called Start-up-CPS.

Scheme		CPS-Start-up
Objective		To promote student start-ups, accelerate the journey of idea to prototype by providing initial funding assistance and take forward student innovations to commercialization stage.
Intended/ Targeted Beneficiary	Category	Student Start-ups
	Numbers	260 (in 5 years)
Support Amount (per project) Maximum		10 lakhs
Project Duration		3 years
Funding (Nature/ Pattern)		Ignition Grant/ award
Workplace		Academic Institutions and/or B-Schools
Expected Outcomes		Prototypes developed Technology commercialized Start-ups
Performance Metrics		Technologies commercialized, Start-ups

5. CPS-Technology Business Incubator (TBI) - Converting Innovations to start-ups.

Business incubation has been globally recognized as an important tool for job creation and economic development. ICPS Division of the Department of Science and Technology, Government of India is supporting Technology Business Incubators primarily in and around academic, technical and management institutions to tap innovations and technologies for venture creation by utilizing expertise and infrastructure already available with the host institution. Recently non-academic institutions have shown interest in setting up CPS-TBIs. Technology based new enterprises are high risk and high growth ventures, and require an enabling environment like CPS-TBI to enhance the prospects of their success. There are different variants of incubators like - Technology Business Incubators (CPS-TBIs); Innovation Hubs; Centers for Innovation &Entrepreneurship; Virtual Incubators and Seed Accelerators.

Objectives of CPS-TBI

- To create jobs, wealth and businesses aligning with national priorities.
- To promote new technology/knowledge/innovation based startups.
- To provide a platform for speedy commercialization of technologies developed by the host institution or by any academic/technical/R&D institution or by an individual.
- To build a vibrant start-up ecosystem, by establishing a network between academia, financial

institutions, industries and other institutions.

- To provide cost effective, value added services to start-ups like mentoring, legal, financial, technical, intellectual property related services.

Scheme		CPS-Technology Business Incubator (TBI)
Objective		To enhance the prospects of success of technology based new enterprises
Intended/ Targeted Beneficiary	Category	Academic Institutions and/or B-Schools/ Existing STEP/TBI
	Numbers	10
Support Amount (per project) Maximum		Rs. 15 Crores
Project Duration		5 years
Funding (Nature/ Pattern)		Grant
Workplace		Academic Institutions and/or B-Schools
Expected Outcomes		Start-ups New products/technologies developed/ innovations commercialized
Performance Metrics		New ventures to be admitted for incubation Ventures to be graduated from the incubator New products/technologies developed/ innovations to be commercialized

6. CPS- Dedicated Innovation Accelerators (DIAL) - Fast tracking a start-up through focused intervention.

Over the last decade, "accelerators" have emerged as successful mechanism to enable fast tracking the seed and early stage start-ups through deep and intensive engagement model. These "accelerators" would be positioned as post incubation initiative linked with the existing incubators to supplement, complement the scaling up of the start -up value chain. Accelerator is atypically a 3-6 months' fast track structured programme helping ideas get accelerated to the next orbit. An accelerator aims at achieving one or more of the following objectives - introduction to entrepreneurial development to identify business opportunities (real problems that require real solutions), validate product ideas, engage with potential customers, build a scalable business model, build a product demonstration, manage team dynamics and pitch to investors. The Accelerators can be used to boost the Incubator's existing activities to build an attract high quality start-ups, and have a customer centric validation model which enhances investment readiness as well as worthiness. Entrepreneurs and start-ups undergoing an accelerator programme discover that their idea and product is just a small part of what makes up a successful, scalable start-up.

World class Accelerators are typically run for 2- 9 months by renowned faculty, entrepreneurs, mentors and leaders from the world of start-ups and design. By the end of the accelerator, start-up teams typically arrive at a "go" or "no go" decision and go on to create start-ups that can scale.

It is proposed to encourage the existing TBIs in its network to undertake Accelerator (both sectoral and sector-agnostic, regional and national), which will strengthen the entrepreneurial ecosystem as well as deliver immense value to other Incubation Programmes. This would help aspiring entrepreneurs in the country, including the ventures already being incubated in these TBIs, to be guided in a rigorous and more structured manner, through deep mentoring process and access to funding and market networks.

Objectives of CPS-DIAL

- To fast track the growth of potential start ups through rigorous mentoring and networking support in a short span through existing TBIs
- To attract subject matter experts, mentors, and angel investors get associated with TBIs through the structured accelerator programmes
- To build a vibrant start-up ecosystem, by establishing a network between academia, financial institutions, industries and other institutions.
- To act as a hub for several incubators in the region, so that high-potential start-ups can be fast-tracked for increased exposure and validation

Accelerators should employ a "fail fast" mentality: ideas or prototypes that are not getting traction should be abandoned (or modified) quickly, allowing founders to redeploy resources to other projects or even new companies at a rapid pace.

Scheme		CPS-DIAL (CPS- Dedicated Innovation Accelerators)
Objective		Push innovations into commercial domain
Intended/ Targeted Beneficiary	Category	Academic Institutions and/or B-Schools/ Existing STEP/TBI
	Numbers	25
Support Amount (per project) Maximum		Rs.2.00 crore
Project Duration		3 -9 months
Funding (Nature/ Pattern)		Grant (to be released against targets) Equity stake of DIAL in start-up
Workplace		Academic Institutions and/or B-Schools
Expected Outcomes		Technology commercialized Start-ups (10 per year)
Performance Metrics		Technologies commercialized, Start-ups, Revenue generated

7. CPS-Seed Support System (CPS-SSS)- Providing early stage investment

While the STEP/TBI are able to support the "Space, Services and Knowledge" requirements of start-ups but, wide gap exists in financial support required by a technology driven start up in its initial phase which are not being addressed properly. The basic idea of seed support is providing financial assistance to potential start-ups with promising ideas, innovations and technologies. This would enable some of these incubate start-ups with innovative ideas/technologies to graduate to a level where they will be able to raise investments from angel/Venture capitalist or they will reach a position to seek loans from commercial banks /financial institutions. Thus the proposed seed support disbursed by an incubator to an incubate is positioned to act as a bridge between development and commercialization of innovative technologies/products/services in a relatively hassle free manner.

The sole objective of the CPS-Seed Support System (CPS-SSS) is to ensure timely availability of the seed support to the deserving incubate start-ups within an incubator, thereby enabling them to take their venture to next level and facilitate towards their success in the market place. The scheme also enables the STEP/TBI to widen their pipeline of start-ups and also share the success of their start-ups which would also result in ensuring their long term operational sustainability.

Scheme		CPS-Seed Support System (CPS-SSS) for Start-ups in Incubators
Objective		To provide financial assistance to potential start-ups with promising ideas, innovations and technologies
Intended/ Targeted Beneficiary	Category	Academic Institutions and/or B-Schools/ Existing STEP/TBI
	Numbers	9
Support Amount (per project) Maximum		Rs.10.00 crore
Project Duration		3 years
Funding (Nature/ Pattern)		Grant
Workplace		Academic Institutions and/or B-Schools
Expected Outcomes		Innovative technologies/products/services commercialized Start-ups (10 per year)
Performance Metrics		Innovative technologies/products/services commercialized Start-ups, Revenue generate

8. CPS- Strategic Information Services for Entrepreneurship (SISE)

Patents are valuable know how for technology implementation. Relevant patents with respect to CPS that are already in public domain and are not protected in the country can be exploiting ethically to develop the said technology in CPS domain. CPS-SISE scheme is modelled to provide such analytical and strategic information on patent in CPS field for further research, development, and deployment of related technology identified from relevant patent analysis. Patent Strategic Information Services for Entrepreneurship are funding mechanism leveraged for product development and entrepreneurship.

Scheme		CPS- Strategic Information Services for Entrepreneurship (SISE)
Objective		To capitalize on patent information for research, product development and entrepreneurship
Intended/ Targeted Beneficiary	Category	Technology Information Institution
	Numbers	1
Support Amount (per project) Maximum		Rs 7 crore (60% Manpower + 30% Database + 10% Infrastructure)
Project Duration		5 years
Funding (Nature/ Pattern)		Grant
Site/ Workplace		Technology Information Institution
Expected Outcomes		Information on CPS related patents, development of product/ services based on identified patent. Increased Entrepreneurship, New areas for research
Performance Metrics		Number of patents identified, technologies commercialized based on the information

3.2.5 International Collaborations

India has a well established collaboration with more than 80 countries in the world. With existing mechanisms of DST (IC Divisions), International Collaborations dedicated to Cyber-Physical Systems will be built at the levels of researchers and thematic domain areas to leverage international best practices in India. HRD will be the one of the main focus in such activities. Projects will be governed by the norms and rules prescribed under the S&T Agreements.

Leverage international alliances which can value add to ICPS programmes and missions

- Gain global competitiveness and international visibility
- Connect Indian research with global efforts in frontier areas in addressing global challenges

- Participation and access to international projects and advanced facilities
- Enable human capacity building and individual excellence through fellowship and training
- Promote eco-system of innovation and techno-entrepreneurship

The countries with whom DST has cooperation and also planning to initiate partnerships in cyber physical research includes: France, Germany, Israel, Japan, Netherlands, Norway, Taiwan, UK and USA.

3.2.6 Synergy with ongoing initiatives of GoI

DST initiated R&D Programmes in the areas of Data Science, Technology, Research and Applications (dASTRA) Programme in 2014 to promote Data Science discipline.

(1) Sensor Networks & Web Enablement (SNWE) was initiated as a sub-Programme in 2008.

(2) Cyber Security Research Initiative (CSRI) was initiated in 2009 as a research Programme.

The above research areas are initiated keeping in view of the developments at International arena and also relevance in Indian context. Fundamentally, these are sensitisation programmes aiming at basic research, awareness building, capacity & Capability building, HRD and technology development. Only seed R&D grants are provided to very small group of advanced researchers.

ICPS, a paradigm shift in IT, emerged as a convergence system of systems which connects and combines various disciplines, technologies, subjects and areas of application. This is a new phenomenon.

Considering changed scenario, dASTRA, SNWE and CSRI Programmes are conceptually rationalised/ merged with the proposed ICPS Mission.

There is no tangible direct overlap with any of existing scheme/ Sub-scheme. However, being a Science based programme, there could be an element of common technologies that will be applicable in certain schemes like National Supercomputing Mission, Technology Development Programme, Nano technology etc. Duplications, if any, will be avoided and wastage of resources will be minimized through Inter-Ministerial/ Departmental Apex committees, Mission co-ordinators meetings and through stakeholders/ user level meetings. Being a knowledge driven, Science based cross cutting technology driven Programme, there will be a degree of overlaps which can't be totally avoidable but will be minimized to the possible extent.

ICPS is a new and emerging technology; as such there is no outcome overlap with any other schemes/ sub-schemes undertaken by Ministries/ Departments. However, ICPS is a converging and fusion technology; there could be significantly negligible amount of outcome overlap with the following Ministries/ Departments

(a) Ministry of Electronics & Information Technology (MeitY), GoI has schemes on Cyber Security, electronic manufacturing, e-Governance, SMART technologies etc.

(b) Department of Heavy Industries (DHI) has mandated to implement technologies related to Industry 4.0 (I4.0) which basically talk about Robotics, Artificial Intelligence (AI), SMART manufacturing etc.

(c) Ministry of Energy, Non-conventional energy sources are working on SMART Grids, energy optimisationetc

(d) Defence Research & Development Organization (DRDO) is working on autonomous systems, intelligent machines, AI based secured communications etc

(e) Ministry of Urban Development is working on SMART Cities

(f) Ministry of Surface transport is working on SMART transport systems

(g) Ministries/Departments of Agriculture, Health, Water resources, Education, Telecommunications are working on implementation of IoT/ AI based systems.

Convergence framework to consolidate outcomes and save public resource

ICPS is Inter-Ministerial National Mission, as part of Mission implementation, An Apex Committee with members from all stakeholders Ministries/ Departments/ Organizations will be formed to bring out the overlapping elements and to converge the outcomes.

DST will take up at least one CPS based technology development programme with each department of Ministries.

The above activities require strong R&D backbone to develop technologies and applications. ICPS programme DPR captured the stakeholder's aspirations and incorporated. NM-ICPS will work as back-end technology accelerator to feed required R&D for the above Ministries/ Departments.

At the Mission implementation level, an Inter-Ministerial sectoral groups will be formed to arrive at convergence frameworks and overlaps if will be avoided.

Chapter 4

Mission Finance

4.1 Finance

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

Cost Estimates

The cost estimates are arrived based on discussions/ deliberations with stakeholders, existing government

schemes and tacit knowledge available with the Department. The Mission cost estimates for the scheme duration: both year-wise, component-wise segregated into recurring and non-recurring expenses:

Table 4.1: Mission Cost Analysis (in Rs. Crore)

S No	Sub-Missions	Budget Head	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
1	Technology Development	Recurring	28.00	65.00	220.00	235.00	112.00	660.00
		Non-Recurring	14.50	35.00	130.00	140.00	70.50	390.00
		Capital	0.00	0.00	0.00	0.00	0.00	0.00
		Sub-Total	42.50	100.00	350.00	375.00	182.50	1050.00
2	Centers of Excellence	Recurring	90.00	150.00	390.00	180.00	60.00	870.00
		Non-Recurring	48.00	78.00	201.00	90.00	30.00	447.00
		Capital	12.00	22.00	59.00	30.00	10.00	133.00
		Sub-Total	150.00	250.00	650.00	300.00	100.00	1450.00
3	HRD & Skill Development	Recurring	43.03	88.64	173.92	90.11	69.92	465.62
		Non-Recurring	27.12	44.01	40.83	22.35	8.08	142.38
		Capital	0.00	0.00	0.00	0.00	0.00	0.00
		Sub-Total	70.15	132.65	214.75	112.45	78.00	608.00
4	Innovation, Entrepreneurship, and Start-ups Ecosystem	Recurring	52.65	70.60	90.05	63.80	52.60	329.70
		Non-Recurring	7.90	7.10	7.60	6.60	6.60	35.80
		Capital	14.65	18.90	17.15	16.90	16.90	84.50
		Sub-Total	75.20	96.60	114.80	87.30	76.10	450.00

S No	Sub-Missions	Budget Head	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
5	International collaborations	Recurring	0.00	4.00	8.00	8.00	12.00	32.00
		Non-Recurring	0.00	1.00	2.00	2.00	3.00	8.00
		Capital	0.00	0.00	0.00	0.00	0.00	0.00
		Sub-Total	0.00	5.00	10.00	10.00	15.00	40.00
6	Mission Management Unit (MMU)	Recurring	44.50	0.00	0.00	0.00	0.00	44.50
		Non-Recurring	17.50	0.00	0.00	0.00	0.00	17.50
		Capital	0.00	0.00	0.00	0.00	0.00	0.00
		Sub-Total	62.00	0.00	0.00	0.00	0.00	62.00
	Total	Recurring	258.18	378.24	881.97	576.91	306.52	2401.82
		Non-Recurring	115.02	165.11	381.43	260.95	118.18	1040.68
		Capital	26.65	40.90	76.15	46.90	26.90	217.50
	Grand Total in Rs Crore		399.85	584.25	1339.55	884.75	451.60	3660.00

Table 4.2: Sub-Mission wise and year-wise estimated costs

S No	Sub-Missions	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total	%
1	Technology Development	42.50	100.00	350.00	375.00	182.50	1050.00	28.69
2	Establishment of CoEs	150.00	250.00	650.00	300.00	100.00	1450.00	39.62
3	HRD & Skill Development	70.15	132.65	214.75	112.45	78.00	608.00	16.61
4	Innovation, Entrepreneurship and Start-up ecosystem	75.20	96.60	114.80	87.30	76.10	450.00	12.30
5	International collaborations	0.00	5.00	10.00	10.00	15.00	40.00	1.09
6	Mission Management Unit (MMU)	62.00	0.00	0.00	0.00	0.00	62.00	1.69
	Total Mission cost in Rs Crore	**399.85**	**584.25**	**1339.55**	**884.75**	**451.60**	**3660.00**	**100.00**

Table 4.3: Budget Head wise & year-wise estimated costs

S No	Budget Head	1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total	%
1	Recurring	258.18	378.24	881.97	576.91	306.52	2401.82	65.62
2	Non-Recurring	115.02	165.11	381.43	260.95	118.18	1040.68	28.43
3	Capital	26.65	40.90	76.15	46.90	26.90	217.50	5.94
	Grand Total in Rs Crore	**399.85**	**584.25**	**1339.55**	**884.75**	**451.60**	**3660.00**	**100.00**

Table 4.4: Year-wise Physical and Financial targets

S No	Sub-Missions	Year 1		Year 2		Year 3		Year 4		Year 5		Total	
		Physi-cal	Finan-cial	Physi-cal	Finan-cial	Physi-cal	Finan-cial	Physi-cal	Finan-cial	Physi-cal	Finan-cial	Physi-cal	Finan-cial
1	Technology Development	29	42.50	6	100.00	140	350.00	140	375.00	46	182.50	361	1050.00
2	Center of Excellences	2	150.00	4	250.00	11	650.00	6	300.00	2	100.00	25	1450.00
3	HRD & Skill Development	1123	70.15	1609	132.65	3838	214.75	3067	112.45	2398	78.00	12035	608.00
4	Entrepreneurship, Innovation and Start-ups	80	75.20	85	96.60	245	114.80	233	87.30	182	76.10	825	450.00
5	International collaborations	0	0.00	1	5.00	2	10.00	2	10.00	3	15.00	8	40.00
6	Mission management Unit	1	62.00	0	0.00	0	0.00	0	0.00	0	0.00	1	62.00
	Grand Total	**1235**	**399.85**	**1705**	**584.25**	**4236**	**1339.55**	**3448**	**884.75**	**2631**	**451.60**	**13255**	**3660.00**

Table 4.5: Estimated Expenditure (Rs crore) for Sub-Mission -Technology Development

S No	Major Components	Unit Cost	Targets						Budget					
			Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	Expert Driven New Knowledge Generation / Discovery	0.5	25	50	100	100	25	300	12.50	25.00	50.00	50.00	12.50	150.00
2	Development of products/ prototypes from existing Knowledge (By experts or teams)	10	2	5	20	25	13	65	20.00	50.00	200.00	250.00	130.00	650.00
3	Technology /product delivery in specific sectors	5	2	5	20	15	8	50	10.00	25.00	100.00	75.00	40.00	250.00
Total			**29**	**60**	**140**	**140**	**46**	**415**	**42.50**	**100.00**	**350.00**	**375.00**	**182.50**	**1050.00**

Table 4.6: Estimated Expenditure (Rs crore) for Sub-Mission Center of Excellences

	Major Components	Unit cost	Targets						Budget					
			Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	International Centers On New knowledge (ICON)	50.00	1	1	2	1	1	6	50.00	50.00	100.00	50.00	50.00	300.00
2	Center for Research On Sub-Systems (CROSS)	50.00	0	1	3	2	0	6	0.00	50.00	150.00	100.00	0.00	300.00
3	Center for Advanced Studies, Translational research & LEadership (CASTLE)	50.00	0	1	4	3	1	9	0.00	50.00	200.00	150.00	50.00	450.00
4	Center of Excellence in Technology Integration & Transfer (CETIT)	100.00	1	1	2	0	0	4	100.00	100.00	200.00	0.00	0.00	400.00
	Total		**2**	**4**	**11**	**6**	**2**	**25**	**150.00**	**250.00**	**650.00**	**300.00**	**100.00**	**1450.00**

Table 4.7: Estimated Expenditure (Rs crore) for Sub-Mission HRD & Skill Development

Major Components		Unit cost	Targets						Budget					
			Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	**CHANAKYA Schemes for UG courses**													
	(i) Graduate Internships	0.01	600	600	1800	1600	1400	6000	6.00	6.00	18.00	16.00	14.00	60.00
	(ii) Development Fund (For Projects done under Graduate Internships)	0.01	250	400	950	750	650	3000	2.50	4.00	9.50	7.50	6.50	30.00
	(iii) CPS Infrastructure development fund	1.00	6	10	10	2	2	30	6.00	10.00	10.00	2.00	2.00	30.00
2	**CHANAKYA Schemes for PG courses**													
	(i) Post-Graduation Fellowships	0.03	100	200	350	300	50	1000	3.00	6.00	10.50	9.00	1.50	30.00
	(ii) Development Fund (For Projects done under PG Fellowships)	0.02	40	70	170	200	120	600	0.80	1.40	3.40	4.00	2.40	12.00
	(iii) CPS Infrastructure development fund	1.00	2	5	6	1	1	15	2.00	5.00	6.00	1.00	1.00	15.00
3	CHANAKYA Doctoral Fellowships	0.17	40	160	200	60	40	500	6.80	27.20	34.00	10.20	6.80	85.00
4	CHANAKYA Post-Doctoral Fellowships	0.32	50	70	200	100	80	500	16.00	22.40	64.00	32.00	25.60	160.00
5	CHANAKYA-Faculty Fellowship	0.30	10	30	50	15	20	125	3.00	9.00	15.00	4.50	6.00	37.50
6	CHANAKYA-Chair Professor	0.30	10	30	50	15	20	125	3.00	9.00	15.00	4.50	6.00	37.50
7	CPS- SDW (Professional Skill Development Workshop)	0.05	1	3	7	5	4	20	0.05	0.15	0.35	0.25	0.20	1.00
8	CPS-Upgrading PG Programme	5.00	4	6	5	4	1	20	20.00	30.00	25.00	20.00	5.00	100.00
9	CPS-Advanced Skill Training School	0.10	10	25	40	15	10	100	1.00	2.50	4.00	1.50	1.00	10.00
Total			**1123**	**1609**	**3838**	**3067**	**2398**	**12035**	**70.15**	**132.65**	**214.75**	**112.45**	**78.00**	**608.00**

Table 4.8: Estimated Expenditure (Rs crore) for Sub-Mission Innovation, Entrepreneurship& Start-ups ecosystem

Major Components		Unit cost	Targets						Budget					
			Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
1	CPS-GCC - Grand Challenges and Competitions	7	1	2	3	2	2	10	7.00	14.00	21.00	14.00	14.00	70.00
2	CPS-PRomotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS	3.7	1	3	2	2	2	10	3.70	11.10	7.40	7.40	7.40	37.00
3	CPS-Entrepreneur In Residence (CPS-EIR)	0.04	60	60	135	135	110	500	2.40	2.40	5.40	5.40	4.40	20.00
4	CPS-Start-up	0.1	11	11	90	85	63	260	1.10	1.10	9.00	8.50	6.30	26.00
5	CPS-Technology Business Incubator (TBI)	15	2	2	2	2	2	10	30.00	30.00	30.00	30.00	30.00	150.00
6	CPS-Dedicated Innovation Accelerator (CPS-DIAL)	2	2	4	11	6	2	25	4.00	8.00	22.00	12.00	4.00	50.00
7	CPS-Seed Support System (CPS-SSS)	10	2	3	2	1	1	9	20.00	30.00	20.00	10.00	10.00	90.00
8	CPS-SISE (Strategic Information Services for Entrepreneurship)	7	1	0	0	0	0	1	7.00	0.00	0.00	0.00	0.00	7.00
	Total		**80**	**85**	**245**	**233**	**182**	**825**	**75.20**	**96.60**	**114.80**	**87.30**	**76.10**	**450.00**

Table 4.9: Estimated Expenditure (Rs crore) for Sub-Mission International Collaborations

Major Component	Unit cost	Targets						Budget in Rs Crore					
		Yr1	Yr2	Yr3	Yr4	Yr5	Total	Yr1	Yr2	Yr3	Yr4	Yr5	Total
1. International collaborations	5	0	1	2	2	3	8	0.00	5.00	10.00	10.00	15.00	40.00
Total		0	1	2	2	3	8	0.00	5.00	10.00	10.00	15.00	40.00

Table 4.10: Estimated Expenditure (Rs crore) for Mission Management Unit (MMU)

Major Components of Sub-Missions	Unit cost	Targets						Budget					
Mission Management Unit (MMU)	62	1	0	0	0	0	1	62.00	0.00	0.00	0.00	0.00	62.00
Total	62	1	0	0	0	0	1	62.00	0.00	0.00	0.00	0.00	62.00

1. UNIT COST ESTIMATIONS FOR MAJOR COMPONENTS UNDER SUB-MISSION – TECHNOLOGY DEVELOPMENT

Table 4.11: A. EXPERT DRIVEN RESEARCH

S No	Budget Head	ESTIMATED COST IN Rs LAKHS			
		Ist Yr	2nd Yr	3rd Yr	Total
A.	Recurring				
	1. Project Staff	9.00	8.00	8.00	25.00
	2. Domestic Travel	1.50	2.00	1.00	4.50
	3. Contingencies	0.5	0.50	0.50	1.50
	4. Consumables	1.00	0.50	1.00	2.50
	5. Miscellaneous	0.50	0.50	0.50	1.50
	6. Over Heads	1.50	1.50	2.00	5.00
	Sub-Total	14.00	13.00	13.00	40.00
B.	Non-Recurring				
	1. Equipment	3.00	3.00	4.00	10.00
	Sub-Total	3.00	3.00	4.00	10.00
C.	Capital	0	0	0	0
	Grand Total	17.00	16.00	17.00	50.00

Table 4.11: B. DEVELOPMENT OF PRODUCTS/ PROTOTYPES FROM EXISTING KNOWLEDGE

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		Ist Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	Recurring						
	1. Project Staff	100.00	100.00	150.00	100.00	50.00	500.00
	2. Domestic Travel	6.00	6.00	6.00	6.00	6.00	30.00
	3. Contingencies	4.00	6.00	4.00	4.00	2.00	20.00
	4. Consumables	6.00	6.00	6.00	6.00	6.00	30.00
	5. Miscellaneous	2.00	2.00	2.00	2.00	2.00	10.00
	6. Over Heads	2.00	2.00	2.00	2.00	2.00	10.00
	Sub-Total	120.00	122.00	170.00	120.00	68.00	600.00
B.	Non-Recurring						
	1. Equipment	80.00	120.00	80.00	80.00	40.00	400.00
	Sub-Total	80.00	120.00	80.00	80.00	40.00	400.00
C.	Capital						
	Grand Total	**200**	**242**	**250**	**200**	**108**	**1000.00**

Table 4.11: C. DEVELOPMENT OF TECHNOLOGY/ PRODUCT DELIVERY IN SPECIFIC SECTORS

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		Ist Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	Recurring						
	1. Project Staff	50.00	50.00	75.00	50.00	25.00	250.00
	2. Domestic Travel	3.00	3.00	3.00	3.00	3.00	15.00
	3. Contingencies	2.00	3.00	2.00	2.00	1.00	10.00
	4. Consumables	3.00	3.00	3.00	3.00	3.00	15.00
	5. Miscellaneous	1.00	1.00	1.00	1.00	1.00	5.00
	6. Over Heads	1.00	1.00	1.00	1.00	1.00	5.00
	Sub-Total	60.00	61.00	85.00	60.00	34.00	300.00
B.	Non-Recurring						
	1. Equipment	40.00	60.00	40.00	40.00	20.00	200.00
	Sub-Total	40.00	60.00	40.00	40.00	20.00	200.00
C.	Capital	0.00	0.00	0.00	0.00	0.00	0.00
	Grand Total	**100.00**	**121.00**	**125.00**	**100.00**	**54.00**	**500.00**

2. UNIT COST ESTIMATIONS OF MAJOR COMPONENTS UNDER SUB-MISSION – ESTABLISHMENT OF CENTER OF EXCELLENCES (CoE'S)

Table 4.12: A. CoEs ICON, CROSS and CASTLE

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		Ist Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	Recurring						
	1. Project Staff	500.00	500.00	750.00	500.00	250.00	2500.00
	2. Domestic Travel	30.00	30.00	30.00	30.00	30.00	150.00
	3. Contingencies	20.00	30.00	20.00	20.00	10.00	100.00
	4. Consumables	30.00	30.00	30.00	30.00	30.00	150.00
	5. Miscellaneous	10.00	10.00	10.00	10.00	10.00	50.00
	6. Over Heads	10.00	10.00	10.00	10.00	10.00	50.00
	Sub-Total	600.00	610.00	850.00	600.00	340.00	3000.00
B.	Non-Recurring						
	1. Lab R&D Infrastructure & Equipment	300.00	500.00	300.00	300.00	100.00	1500.00
	Sub-Total	300.00	500.00	300.00	300.00	100.00	1500.00
C.	Capital						
	1. Furnishing, Tables, Chairs, Cubicles, Electrical works and other Capex items	100.00	100.00	100.00	100.00	100.00	500.00
	Sub-Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**500.00**
	Grand Total	**1000.00**	**1210.00**	**1250.00**	**1000.00**	**540.00**	**5000.00**

Table 4.12: B. FOR CoE CETIT's

S No	Budget Head	ESTIMATED COST IN Rs crore					
		Ist Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	Recurring						
	1. Project Staff	10.00	10.00	15.00	10.00	5.00	50.00
	2. Domestic Travel	0.60	0.60	0.60	0.60	0.60	3.00
	3. Contingencies	0.40	0.60	0.40	0.40	0.20	2.00
	4. Consumables	0.60	0.60	0.60	0.60	0.60	3.00
	5. Miscellaneous	0.20	0.20	0.20	0.20	0.20	1.00
	6. Over Heads	0.20	0.20	0.20	0.20	0.20	1.00
	Sub-Total	12.00	12.20	17.00	12.00	6.80	60.00
B.	Non-Recurring						
	1. Equipment	6.00	10.00	7.00	7.00	3.00	33.00
	Sub-Total	6.00	10.00	7.00	7.00	3.00	33.00
C.	Capital						
	1. Furnishing, Tables, Chairs, Cubicles, Electrical works and other Capex items	2.00	2.00	1.00	1.00	1.00	7.00
	Sub-Total	2.00	2.00	1.00	1.00	1.00	7.00
	Grand Total	20.00	24.20	25.00	20.00	10.80	100.00

3. UNIT COST ESTIMATIONS OF MAJOR COMPONENTS UNDER SUB-MISSION – HRD AND SKILL DEVELOPMENT

A. CHANAKYA- GI Fellowships (for 10 months): UG fellowship for a period of 10 months i.e., during final year project duration. The fellowship will be Rs. 10,000/- per month for 10 months. The total estimated cost per unit is Rs 1,00,000-00 under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

B. Development fund for Projects done by UG Students undergoing the CHANAKYA- GI: When needed, a grant of Rs. 1,00,000 per two students can be given for Projects done by UG Students Undergoing the CHANAKYA-GI. The total estimated cost is Rs 1,00,000-00 per unit under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

C. Infrastructure Support linked to CHANAKYA-GI: One time Grant of Rs. 1,00,00,000 for infrastructure support for Under-graduate labs in CPS and Allied areas to institution where GI is offered. The total estimated cost per unit is Rs 1,00,00,000-00 under Non-Recurring and no Capital expenditure involved under this component.

D. CHANAKYA- PG Fellowships (for 2 years): PG fellowship for a period of 2 years i.e., during M. Tech./ M.S./ M.E. The fellowship will be Rs. 12,400/- per month for 2 years. The total estimated cost per unit is Rs 2,97,600-00 under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

E. Development fund for Projects done by PG Students undergoing the CHANAKYA-PG Fellowships: When needed, a grant of Rs. 2,00,000 can be given for Projects done by UG Students Undergoing the CHANAKYA-GI. The total estimated cost is Rs 2,00,000 per unit under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

F. Infrastructure Support linked to CHANAKYA- PGF: One time Grant of Rs. 1,00,00,000 for infrastructure support for Post-graduate labs in CPS and Allied areas to institution where GI is offered. The total estimated cost per unit is Rs 1,00,00,000-00under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

G. CHANAKYA- DF Doctoral Fellowships (duration 3 years to 4 years): Doctoral fellowship for a period of 3 to 4 years i.e., during PhD. The fellowship will be Rs.25,000/- + HRA per month for First 2 years, after that the fellowship will be Rs 28,000/- + HRA for remaining duration. The total estimated cost per unit is Rs 14,00,000 to Rs.17,00,000-00under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

H. CHANAKYA- PD Fellowships (for 2 to 3 years)(on the lines of INSPIRE Faculty award scheme): PD fellowship for a period of 2 to 3 years i.e., during Post Doctoral research. The fellowship will be Rs.80,000/- per month with all inclusive for 2 to 3 years. The total estimated cost per unit is Rs.24,00,000-00 to Rs.32,00,000-00 under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

I. CHANAKYA- Faculty Fellowships (for 3 years) (On the lines of INSPIRE faculty award Scheme): In line with INSPIRE Faculty fellowships, faculty/ young researchers with Ph.D will be awarded fellowship for a duration of 3 years and could be attached to CoEs or research/ academic institutes. The fellowship will be Rs.80,000-00 per month with all inclusive. The total estimated cost per unit is Rs.30,00,000-00 under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

J. CHANAKYA- Chair Professor Fellowships (for 3 years) (On the lines of National Geospatial Chair Professor Scheme): Chair Professor Fellowship for a period of 36 months i.e., during the duration of guidance of project in CoEs. The fellowship will be an honorarium of Max. Rs.80,000/- per month for 3 years, the annual contingencies/ Travel/ Miscellaneous costs of Rs.1.20 Lakh for travel to various institutions for attending conferences; review meetings etc. and to propagate the technologies in CPS and institutional overhead @ of 10% subject to maximum of Rs.1.00 lakh per annum . The total estimated cost per unit is Rs.30,00,000-00 under Recurring cost. No Non-Recurring and Capital expenditure involved under this component.

K. CPS-Upgrading PG Programme: One time Grant of Rs. 5,00,00,000 for Upgrading PG programmes in CPS and Allied areas. The Grant will be a one time grant of Rs.5,00,00,000/-. The total estimated cost per unit is Rs.5,00,00,000-00 as detailed below

S No	Budget Head	Amount in Rs Lakhs
A.	Recurring	
	Contingencies	20.00
	Miscellaneous	10.00
	Sub-Total	30.00
B.	Non-Recurring	
	Equipment	450.00
	Teaching Material	10.00
	Books, Journals etc	10.00
	Sub-Total	470.00
C.	Capital	0.00
	Grand Total	500.00

L. CPS-PSDW (Professional Skill Development Workshop):

S No	Budget Head	Amount in Rs Lakhs
A.	Recurring	
	1. Contingencies	0.40
	2. Travel, honorarium to experts etc	2.50
	3. Miscellaneous	0.20
	Sub-Total	3.10
B.	Non-Recurring	
	1. Teaching Material	0.90
	2. Used case studies, Books, Journals etc	1.00
	Sub-Total	1.90
C.	Capital	0.00
	Grand Total	5.00

M. CHANAKYA- CPS-Advanced Skill Training Institute: A grant of total Rs 10.00 lakhs in 2 years. The total estimated cost per unit is Rs 10.00 lakhs as detailed below

S No	Budget Head	Amount in Rs Lakhs		
		Year-1	Year-2	Total
A.	Recurring			
	Contingencies	0.50	0.50	1.00
	Travel, honorarium to experts etc	2.00	2.00	4.00
	Miscellaneous	1.00	1.00	2.00
	Sub-Total	3.50	3.50	7.00
B.	Non-Recurring			
	Equipment	2.00	0.00	2.00
	Teaching Material	0.30	0.30	0.60
	Used case studies, Books, Journals etc	0.20	0.20	0.40
	Sub-Total	2.50	0.50	3.00
C.	Capital	0.00	0.00	
	Grand Total	6.00	4.00	10.00

4. UNIT COST ESTIMATIONS OF MAJOR COMPONENTS UNDER SUB-MISSION –INNOVATION, ENTERPRENEURSHIP AND START-UP ECOSYSTEM

Table 4.13: A. CPS-GCC - Grand Challenges and Competitions:

S No	Budget Head	Amount in Rs Lakhs
A.	Recurring	
	I. All India Competitions (Operating Costs for 20 challenges under 1 GCC)	
	1. Human Resources	100.00
	2. Travel, honorarium to experts etc	200.00
	3. Miscellaneous	40.00
	4. Marketing, promotion and publicity	60.00
	5. Networking and training programmes	50.00
	6. Other administrative expenses including consumables, printing, publications, books, journals etc	100.00
	II. Awards	
	1. Reward @ Rs 5.00 lakhs per winner for 5 ideas	25.00
	Sub-Total	575.00
B.	Non-Recurring	
	I. Prototyping Grant/ Seed Fund @Rs 20.00 Lakhs each for 5 winners	100.00
	Sub-Total	100.00
C.	Capital	
	1. Competitions location specific arrangements like furniture, tables, chairs, dash boards, product development and demonstration arrangements etc	25.00
	Sub-Total	25.00
	Grand Total	700.00

Table 4.13:B. CPS-PRomotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS)

S No	Budget Head	Amount in Rs Lakhs
A.	Recurring	
	1. Prototyping Grant/ Seed Fund @Rs 10.00 Lakhs each for 10 ideas	100.00
	2. Travel, honorarium to experts etc	10.00
	3. Miscellaneous	5.00
	4. Other administrative expenses including consumables, printing, publications, books, journals etc	5
	Sub-Total	120.00
B.	Non-Recurring	
	1. Raw material, Spare parts, consumables etc	25.00
	2. Fabrication/ Synthesis charges of working model development or process that includes design engineering/ Consultancy/ Testing/ Experts costs etc	25.00
	Sub-Total	50.00
C.	Capital	
	1. Establishment of PRAYAS Center, Fabrication LAB, location specific arrangements like furniture, tables, chairs, dash boards, product development and demonstration arrangements etc	100.00
	2. Operation and maintenance of Fab lab @ Rs 20.00 lakhs per year for 5 years	100.00
	Sub-Total	200.00
	Grand Total	**370.00**

C. CPS-Entrepreneur In Residence (CPS-EIR): A grant of maximum Rs.30,000-00 per month for a period of 12 months. The total estimated cost per unit is Rs 3.60 Lakhs under recurring

D. CPS-Start-up: A onetime grant of Rs 10.00 Lakhs to each selected student start-up. The total estimated cost per unit is Rs 10.00 Lakhs under recurring.

Table 4.13: E. CPS-TBI

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A	Recurring						
	1. Human Resources**(Core Management Team /Mentors and Tech Support Persons /Business Development Professionals)	55.00	55.00	55.00	55.00	53.00	273.00
	2. Travel (@ Rs. 40,000 pm)	3.60	3.60	3.60	3.60	3.60	18.00
	3. Utility and maintenance	19.00	19.00	19.00	19.00	19.00	95.00
	4. Marketing, networking & publicity	18.00	18.00	18.00	18.00	18.00	90.00
	5. Training Programmes, Events, and Start-up-Resonators	27.00	27.00	27.00	27.00	27.00	135.00
	6. Other Administrative Expenses including consumables, printing, publications, books, journals, etc.	12.00	12.00	12.00	12.00	12.00	60.00
	7. Miscellaneous and Contingencies	5.80	5.80	5.80	5.80	5.80	29.00
	Sub-Total	140.40	140.40	140.40	140.40	138.40	700.00
B	Non-Recurring						
	1. D&D Rooms (Dies & Designs, FAB lab)	20.00	20.00	20.00	20.00	20.00	100.00
	2. Office Equipment including state-of-the art communication network, Video Conferencing Facilities	10.00	10.00	10.00	10.00	10.00	50.00
	3. Contingencies for non-recurring expenditure and other items	6.00	6.00	6.00	6.00	6.00	30.00
	Sub-Total	36.00	36.00	36.00	36.00	36.00	180.00
C	Capital						
	1. Renovation/furnishing of space for CPS-TBI ; (20,000 sf ; @ 600 psf);(Furniture / Test Benches / Installations; Incubation Cubicles and Spaces /Interaction Centers) excluding the cost of land & building	36.00	24.00	24.00	24.00	12.00	120.00

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		1st Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
	2. Thrust Area Equipment (Equipment /Machineries; Clean Rooms / Test Rigs / IT Systems; Instruments/Tools & Dies/ Measuring Devices, etc)	150.00	100.00	100.00	100.00	50.00	500.00
	Sub-Total	186.00	124.00	124.00	124.00	62.00	620.00
	Grand Total	**362.40**	**300.40**	**300.40**	**300.40**	**236.40**	**1500.00**

F. CPS- Dedicated Innovation AcceLerators (DIAL) The budget includes Human resource, logistics, travel, mentoring, infrastructure, training etc. The overall budget for running accelerators shall be Rs 1.5 crore per year with participation of 10-15 start-ups. Rs 1.00 crore as soft loan and Rs.2.00 lakh per technology as project handling charges, as grant to DIAL. The total estimated cost per unit is maximum Rs 2.00 crore under recurring.

G. CPS-Seed Support System (CPS-SSS): Given to eligible TBI's under recurring Head with a maximum cap of Rs 10.00 crore. However, the support should be utilised in 2-3 years. It is given as investment or debt to incubate with a maximum support of Rs 1.00 crore. The total estimated cost per unit is Rs 10.00 crore under recurring.

Table 4.13: H. CPS- Strategic Information Services for Entrepreneurship (SISE)

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS					
		Ist Yr	2nd Yr	3rd Yr	4th Yr	5th Yr	Total
A.	Recurring						
	Project Staff	70.00	70.00	105.00	70.00	35.00	350.00
	Domestic Travel	4.20	4.20	4.20	4.20	4.20	21.00
	Contingencies	2.80	4.20	2.80	2.80	1.40	14.00
	Consumables	4.20	4.20	4.20	4.20	4.20	21.00
	Miscellaneous	1.40	1.40	1.40	1.40	1.40	7.00
	Over Heads	1.40	1.40	1.40	1.40	1.40	7.00
	Sub-Total						
B.	Non-Recurring						
	Equipment	56.00	84.00	56.00	56.00	28.00	280.00
	Sub-Total	56.00	84.00	56.00	56.00	28.00	280.00
C.	Capital						
	Grand Total	**140.00**	**169.40**	**175.00**	**140.00**	**75.60**	**700.00**

5. UNIT COST ESTIMATIONS OF MAJOR COMPONENTS UNDER SUB-MISSION – INTERNATIONAL COLLABORATIONS

A. INTERNATIONAL COLLABORATIVE RESEARCH PROGRAMME: International collaborations will be based on existing International co-operation modalities. Each collaboration will have around 10 projects and will be on 50:50 cost sharing basis between India and participating country/ Int. Institutions. Thus, the unit cost for India is as per cost details given below

Table 4.14: INTERNATIONAL COLLABORATIVE RESEARCH PROGRAMME

S No	Budget Head	ESTIMATED COST IN Rs. LAKHS			
		Ist Yr	2nd Yr	3rd Yr	Total
A.	Recurring				
	1. Project Staff	50.00	50.00	50.00	150.00
	2. Contingencies	10.00	10.00	10.00	30.00
	3. Consumables	10.00	20.00	5.00	35.00
	4. Miscellaneous	10.00	10.00	10.00	30.00
	5. International travel/ exchange programmes	40.00	50.00	0.00	90.00
	6. International workshops/conferences/ meetings		50.00		50.00
	7. Over Heads	5.00	5.00	5.00	15.00
	Sub-Total	125.00	195.00	80.00	400.00
B.	Non-Recurring				
	1. Equipment	50.00	50.00	0.00	100.00
	Sub-Total	50.00	50.00	0.00	100.00
C.	Capital	0.00	0.00	0.00	0.00
	Grand Total	175.00	145.00	80.00	500.00

6. UNIT COST ESTIMATIONS OF MAJOR COMPONENTS UNDER SUB-MISSION – MISSION MANAGEMENT

Table 4.15: NM – ICPS Mission Management Unit (MMU)

S No	Budget Head	ESTIMATED COST IN Rs Crore					
		Ist Yr	2nd Yr	3rd Yr	4th yr	5th yr	Total
A.	Recurring						
	1. Project staff salaries & wages	5.00	5.00	5.00	5.00	5.00	25.00
	2. expenses towards conducting of Apex committee, executive committee and Sub-missions co-ordination meetings	2.00	2.00	2.00	2.00	2.00	10.00
	3. Travel	1.70	1.70	1.70	1.70	1.70	8.50
	4. Miscellaneous	0.10	0.10	0.10	0.10	0.10	0.50
	5. Contingencies	0.10	0.10	0.10	0.10	0.10	0.50
	Sub-Total	8.90	8.90	8.90	8.90	8.90	44.50
B.	Non-Recurring						
	Mission Office expenses	0.10	0.10	0.10	0.10	0.10	0.50
	Cloud Technology Platform for Mission, Portal development, Services, databases etc	2.00	4.00	5.00	4.00	2.00	17.00
	Sub-Total	2.10	4.10	5.10	4.10	2.10	17.50
C.	Capital	0.00	0.00	0.00	0.00	0.00	0.00
	Grand Total	**11.00**	**13.00**	**14.00**	**13.00**	**11.00**	**62.00**

4.2 Time Frame

Implementation of the project will involve, apart from the many administrative actions, the following major activities:

1. Establishment of MMU
2. Preparing Guidelines
3. Calling for proposals
4. Selection of agencies
5. Assigning/sanctioning projects
6. Review of Schemes
7. Yearly review of progress
8. Mid Term Review
9. Preparation and Publication of progress reports

As evident some of the activities are one time, however the remaining activities need to be carried out on periodic or as the need be basis. The Project Head will undertake the activities in time so that the aims of the project are achieved. Considering the major activities, an action plan for the implementation of the project is as given below in table 4.16.

TABLE 4.16: TENTATIVE IMPLEMENTATION ACTION PLAN

	YEAR 1 & MONTHS												YEAR 2				YEAR 3				YEAR 4				YEAR 5			
MAJOR ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Establishment of MMU	■	■	■																									
Preparing Guidelines	■	■												■				■										
Calling for proposals			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Selection of agencies			■	■	■						■	■			■	■			■	■								
Assigning/sanctioning projects				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Review of Schemes							■				■					■				■								
Yearly review of progress													■				■				■				■			
Mid Term Review																			■									
Preparation and Publication of progress reports			■			■			■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

4.3 Cost Benefit Analysis

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

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

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

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

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

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

4.4 Risk Analysis

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

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

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

Chapter 5

Mission Management

5.1 Management

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

Based on the experience from successful missions and lessons from the ones where delivery was not upto the mark, it is proposed to create a Mission Apex Council (MAC) to guide the entire mission, It is proposed to create a Mission Management Unit (MMU) which will be a Special Purpose Vehicle (SPV) which will oversee the implementation of the Mission. The 4 categories of Centers of Excellence will be the crucibles of major actions, strongly linked with academic institutions, research establishments, industries, think-tanks, policy makers etc participating in the Mission. The entire mission will be executed through over 13,000 projects of variable sizes, ranging from CoEs to internships bunched into 5 broad Programmes viz. Technology Development; HRD & Skill Development; Centers of Excellence; Innovation, Entrepreneurship & Start-up; and International Collaboration, The mission management have two broad entities MAC & MMU, who will oversee the implementation of the Mission through 5 programmes. Figure 5.1 gives an overview.

5.1.1 Mission Apex Committee (MAC)

MAC will be the topmost executive body for NM-ICPS, It would be empowered body to take key decision for the success of the Mission and be responsible for its periodic review and guidance. It would be Chaired by Secretary, DST and have two co-chairs. It will have representatives of principal departments/ ministries of the government as members. Eminent domain experts from research and academic institutions, from national as well as international agencies will be members of MAC. Experts from industry and industry associations in the committee will be there to keep the mission focussed on deliverables. The broad powers, functions and duties of the MAC would be as follows:

a) Assign roles and responsibilities to participating Ministries/ Departments/ Agencies

b) To control overlaps, overlaps in outputs and suggest measures to minimize them.

c) Review, periodically (at least once in a year), the technical and financial activities of the Mission and suggest suitable measures, as deemed fit, to meet the aims and objectives of the Mission.

d) Considering the latest trends and relevance, propose from time to time alterations and modifications to the deliverable to meet the aims and objectives of the Mission.

The committee will have Mission Director (the chief executive of the Mission Management Unit which will oversee implementation of the Mission) as the ex-officio Member-Secretary of MAC.

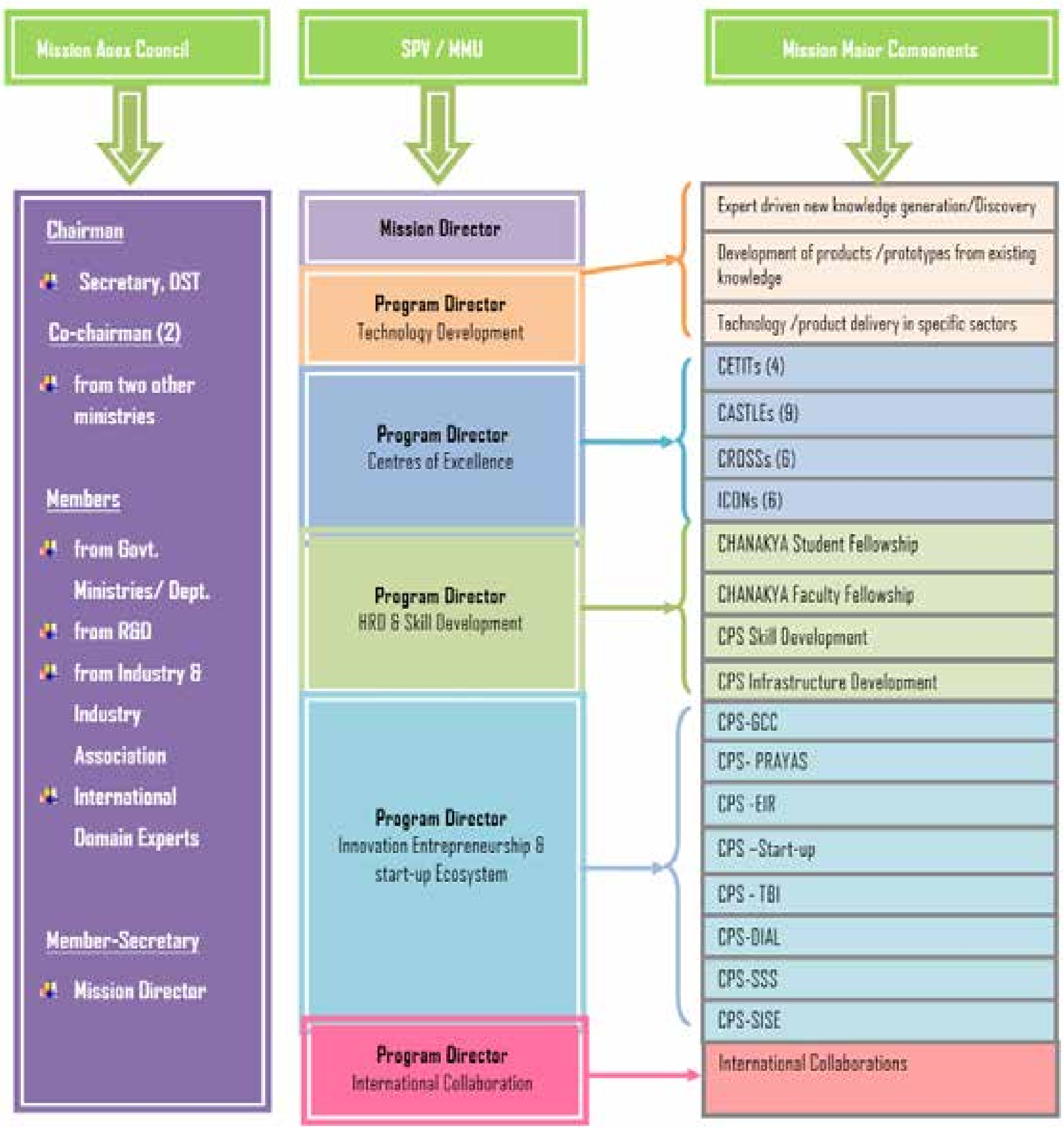


Fig. 5.1: Mission Management Model for NM-ICPS

5.1.2 Mission Management Unit (MMU)

The implementation of the Mission will be done by a Mission Management Unit (MMU) created for the purpose. It will plan, appraise, approve, release funds, implement, manage, operate, monitor and evaluate the components or projects that will be clubbed into 5 broad Programmes. Technology Development; HRD & Skill Development; Centers of Excellence; Innovation, Entrepreneurship & Start-up; and International Collaboration, The MMU will be headed by a full time Mission Director and will have Programme Directors as its part. DST/ Govt agencies shall ensure that a dedicated and befitting revenue stream is made available to the MMU so as to run the Mission, ensure participation of stakeholding ministries/ department, attract financial stakes of industry at appropriate maturity level of technology and create infrastructure/ mechanisms that have public benefit outcomes. The MMU headed by a Mission Director will have administrative, financial independence for functional autonomy so as to realise the mission goals and objectives. The major functions of the MMU would be:

(i) To work as the nodal agency of the Government of India for ICPS Mission and to coordinate with all the stakeholders.

(ii) Selecting components and activities included in the Mission from time to time and preparing annual action plans.

(iii) Developing and fine tuning the final delivery contents, mechanisms and performance measurement criterion of each of the component/activity to be undertaken by the Mission.

(iv) Developing and finalizing the guidelines & terms and conditions of the grants and various other formats and documents needed for making requests to participate in the project activities, submitting periodic reports, funds utilization statements etc.

(v) Seeking proposals from individuals, institutions and other organizations for undertaking the various components and activities selected to be included in the Mission from time to time.

(vi) Assign the responsibility of the delivery to competent agencies within government (State & Central) and outside such as national institutes of higher learning, research organizations, service providers and others in the Mission ecosystem.

(vii) Monitoring all the aspects of the delivery of the Mission components and activities and ensuring the quality of delivery.

(viii) To ensure effective coordination with implementing agencies together with collection of information pertaining to implementation and progress.

(ix) Overseeing and Management of the Mission funds, preparation of budget statements, utilization and re-appropriation etc.

Funds provided by the Government of India in the Mission to the MMU will be (in the form of tied grant and) kept in a separate Fund. These funds will be utilized only for the purposes for which they have been given and subject to the conditions laid down by the MAC.

Under each of the 5 Programmes, there will be sub-missions or components. Implementation of these Programmes will be overseen by Programme Directors, who by being part of MMU will ensure synergy and cohesion among the components. The components will cover the complete spectrum of technology life cycle stages on one hand, to addressing the development of human resource, skills, entrepreneurship and international linkages on the other. The details of each Programme are given under the chapter on Strategy.

5.1.2.1 Project Advisory and Monitoring Committees (PAMC)/ Working Groups/ Sub-Committee/SAC/EAC etc.

For effective monitoring of the schemes DST shall constitute PAMC/ WG. The members of the PAMC/ Working Group would be drawn from stakeholders, such as Government, academia, research institutions, end-users organizations and industry. The PAMC/ Working Group would meet at least twice in a year. The broad powers, functions and duties of the Working Group would be as follows:

a) Working PAMC/ Working Groups shall be the recommending Body of projects/ schemes under the Mission, and be responsible for evaluation, monitoring the progress of those projects.

b) The PAMC/ Working Group shall have powers to recommend projects, purchases and expenses of all types within the technical and financial scope of the Mission.

DST will have committees as per its Standard Operating Procedures (SOP) of Grants-In-Aid for promoting ICPS and associated research in the country.

5.1.2.2 Human Resources at MMU

The overall Mission will be spearheaded by Mission Director NM-ICPS and will be coordinated by Head, ICPS, DST. The project has five major Programmes- (i) Technology Development (R&D), (ii) Center of Excellence (iii) HRD & Skill Development, (iv) Innovation, Entrepreneurship& Start-ups and (v) International Collaborations. These areas will be looked after by Programme Directors. Implementation of the project will involve considerable amount of coordination with external agencies both national and international, it is suggested, therefore, to provide a domain Coordinator to each of the Sector Coordinators. To take care of the very large number of stakeholders such as Students, Participants of the training programmes, Faculty Members etc. and to keep track of the information and documents received and sent out from the project, a pool of Technical Assistants. The Organization Structure is as given in TABLE 5.1

TABLE 5.1: ORGANIZATION STRUCTURE

S N	Project Position	Numbers
1.	Mission Director	1
2.	Sector Coordinators (Scientist-E/F)/ Financial Advisor	6
3.	Domain coordinators (Scientist-C/D)	6
4.	Portfolio Managers (Technical Assistants)	4

The cost estimates for Salary are based on 7th Pay Commission recommendations and GOI rules as on day. The number of posts and pay scales are elaborated in TABLE 5.2.

TABLE 5.2: SCIENTIFIC/TECHNICAL HUMAN RESOURCE

S No	DESIGNATION Grade	No of Posts	Level	Pay scale
1	Scientist-E/F/ Financial Advisor	6	Level-12	Rs.78800/-
2	Scientist-C/D	6	Level-11	Rs.67700/-
3	Technical Assistant	4	Level-6	Rs.35400/-
	Total	16		

No permanent or temporary post will be created by NM-ICPS; the projected HR will be taken on contractual/ deputation basis only. No outsourcing of services or hiring of consultants is involved.

5.1.2.3 Cloud based technology platform for the Mission: Towards effective implementation of the Mission, third-party Cloud based technology platform will be created. This will have both computational and storage facility, accessible to all projects. It will also have centralized Web Portal for Mission Management which will provide collective information of running status of all the activities under the mission. Such portal will be a dynamic repository of information on all activities/components, resources and outputs, associated with the Mission. This will be continuously updated for monitoring the progress of the mission by the Mission Management Unit (MMU). The information will be used for periodic review of the Mission for seeking guidance from Mission Apex Committee (MAC). Also, the information will be shared with all the stakeholders and participants in the mission to ensure synergy. The funding to set up Web portal and its maintenance will be drawn from the MMU.

5.2 Evaluation

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

TABLE 5.3 INDICATORS

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

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

(1) Accountability: demonstrating to funding agency, beneficiaries and implementing partners that expenditure, actions and results are as agreed or can reasonably be expected in the situation.

(2) Operational management/Implementation: provision of the information needed to co-ordinate the human, financial and physical resources committed to the project and to improve performance.

(3) Strategic management: provision of information to inform setting and adjustment of objectives and strategies.

(4) Capacity building: building the capacity, self-reliance and confidence of beneficiaries and implementing staff and partners to effectively initiate and implement development initiatives.

(5) Benefits at the project level:

   a) Provide regular feedback on project performance and show any need for 'mid-course' corrections

   b) Identify problems early and propose solutions

   c) Monitor access to project services and outcomes by the target population;

   d) Evaluate achievement of project objectives

   e) Incorporate stakeholder views and promote participation, ownership and accountability

(6) The key indicators: Indicators may be qualitative or quantitative variables that measure project performance and achievements. Indicators are developed for all levels of project logic i.e. indicators are needed to monitor progress with respect to inputs, activities, outputs, outcomes and impact, to feedback on areas of success and where improvement is required.

Inputs, Outputs and Outcomes for the Mission

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

TABLE 5.4: Technology Development

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

TABLE 5.5: CENTER OF EXCELLENCE

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

TABLE 5.6: HRD& Skill Development

HRD &Skill Development			
Project component	**Inputs**	**Outputs**	**Outcomes**
CHANAKYA Schemes for UG courses (i) Graduate Internships	Funds Review	Graduates exposed to problem-solving	Trained Professionals
(ii) Development Fund (For Projects done under Graduate Internships)	Funds Review	Solution/ new knowledge	Problem-solving oriented education
(iii) CPS Infrastructure development fund	Funds Review	Infrastructure to support internship	Development of UG Labs
CHANAKYA Schemes for PG courses (i) Post-Graduation Fellowships	Funds Review	Post-Graduates exposed to problem-solving	Trained Professionals
(ii) Development Fund (For Projects done under PG Fellowships)	Funds Review	Solution/ new knowledge	Problem-solving oriented education
(iii) CPS Infrastructure development fund	Funds Review	Infrastructure to support internship	Development of PG Labs
CHANAKYA Doctoral Fellowships	Funds Review	Young professionals trained in CPS	IP/ Technology generation Pool of trained professionals
CHANAKYA Post-Doctoral Fellowships	Funds Review	Young professionals with advanced knowledge of CPS	IP/ Technology generation Pool of trained professionals with advanced knowledge
CHANAKYA-Faculty Fellowship	Funds	Faculty with advanced exposure to CPS	IP/ Technology generation Mentors for UG, PG and Doctoral students
CHANAKYA-Chair Professor	Funds	Specialist in CPS	IP/ Technology generation Mentors for UG, PG and Doctoral students Improved ecosystem for teaching and research New educational material
CPS- PSDW (Professional Skill Development Workshop)	Funds Review	Skilled human resources	Trained Professionals
CPS-Upgrading PG Programme	Funds Review	Upgraded/ New courses in CPS	Institutions with better lab facilities Employable Professionals IP/ Technology generation
CPS-Advanced Skill Training School (ASTS)	Funds Review	Advanced skill training schools established Self-employable technicians	Employable technicians Improved employability Improved installation, operation and maintenance services

TABLE 5.7: Innovation, Entrepreneurship & Start-up ecosystem

Innovation, Entrepreneurship & Start-up ecosystem			
Project component	**Inputs**	**Outputs**	**Outcomes**
CPS-GCC - Grand Challenges and Competitions	Funds Evaluation	Ideas/ concepts/ challenges Prototypes	Start-ups New CPS application areas
CPS-PRomotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS	Funds Evaluation	Young Entrepreneur	Employment generation Increased business in CPS
CPS-Entrepreneur In Residence (CPS-EIR)	Funds Evaluation	Entrepreneurs New ventures	Increased no. of start-ups Commercialized technologies Employment generation Increased business in CPS
CPS-Start-up	Funds Evaluation	New ventures Entrepreneurs	Increased no. of student start-ups Commercialized technologies Employment generation Increased business in CPS Higher start-up success rate
CPS-Technology Business Incubator (TBI)	Funds Evaluation	Technology-basedenterprises	Commercialization of technologies New technology/ knowledge/ innovation-based start-ups Employment generation Increased business in CPS Higher start-up success rate
CPS-Dedicated Innovation Accelerator (CPS-DIAL)	Funds Evaluation	Fast track commercialized technologies	Speedy commercialization of technologies Increased prospects of commercialization of technologies New technology/ knowledge/ innovation-based start-ups Increased business in CPS
CPS-Seed Support System (CPS-SSS)	Funds Evaluation	New technologies/ solutions	Technology refinement and marketing support mechanisms New technology/ knowledge/ innovation-based start-ups Employment generation Increased business in CPS
CPS- Strategic Information Services for Entrepreneurship (SISE)	Funds Evaluation	Centralized Strategic Information services established	Information on CPS related patents Development of product/services based on identified patent Increased Entrepreneurship Identification of new areas for research

TABLE 5.8: INTERNATIONAL COLLABORATION

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

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

5.3 Legal Framework

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

5.3.1 National Intellectual Property Rights (IPR)

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

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

The Policy recognizes that India has a well-established Trade-Related Aspects of Intellectual Property Rights (TRIPS)-compliant legislative, administrative and judicial framework to safeguard

IPRs, which meets its international obligations while utilizing the flexibilities provided in the international regime to address its developmental concerns. It reiterates India's commitment to the Doha Development Agenda and the TRIPS agreement.

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

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

The Mission Statement of the policy reads as follows:

Stimulate a dynamic, vibrant and balanced intellectual property rights system in India to:

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

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

The Policy lays down the following seven objectives:

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

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

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

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

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

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

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

Patent Rules

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

5.3.2 STANDARDS FOR CPS

A standard is a published document that serves as the fundamental building block for product or process development and defines usability, predictability, and safety. A standard ensuring intra- and inter-operability of goods and services produced and manufacturing compliance is mandatory for the future of CPS. Many international organizations are developing relevant standards. If enterprises are creating specific standards to follow, then I 4.0 technologies and solutions are evaluated and utilized.

A. STANDARDIZATION BODIES

The standardization organizations such as IEEE, ETSI, IERC, IETF, ITU-T, OASIS, OGC, W3C, and GS1 are critical to the technology development of CPS. The international organization IEC and ISO have established many relevant standards for CPS. This section focuses on CPS standards, which considers industry technical specifications officially issued by the international standards holders such as IEC and ISO.

1) International Electrotechnical Commission (IEC)

The IEC, established in 1906, is the oldest international organization for Electrotechnical Standardization. The IEC is responsible for standardization in the field of electrical engineering and electronic engineering. IEC's Standardization Management Board (SMB) is the agency managing the IEC technical specifications and standardization. SMB is responsible for strategic planning, adjustment, execution, and supervision of the activities of the Technical Committee. IEC/SMB/SG8 is the strategic working group for smart manufacturing technologies and is responsible for developing I 4.0 technical standards. The results of IEC/TC65 (technical committee 65) are critical to I 4.0 since the results focus on industrial processes, measurement, control, and automation.

2) International Organization for Standardization (ISO)

The ISO, established in 1947, is an independent and non-government organization with 162 global members. The organization brings experts together to share knowledge and develop international standards. The ISO works closely with the IEC on the development of I 4.0 standards. For instance, ISO/TC 184 is important to the international standardization of I 4.0 and focuses on automation systems and integration.

3) Deutsches Institut für Normung (DIN)

DIN is a German national standardization organization founded in 1975, and is located in Berlin. DIN is avery important national standardization organization. Many of DIN's standards become ISO standards that are internationally recognized.

4) Standardization Administration of the People's Republic of China (SAC)

SAC is a subordinate group of the China State Administration of quality supervision and administration of public institutions with authority to create and promote the standards.

5) IEEE Standards Association (IEEE-SA)

IEEE-SA is an international organization for industry standards governed by the Board of Governors (BOG) elected by IEEE-SA members. The IEEE-SA standards development process is open to IEEE-SA members and non-members from more than 160 countries. IEEE's mission is advancing technology for the benefit of humanity by providing a globally open, inclusive and transparent environment for market relevant, voluntary consensus standardization.

6) The World Wide Web Consortium (W3C)

W3C is a non-profit international organization for the development of web standards such as CSS, SVG, WOFF, the Semantic Web stack, XML, HTML, and a variety of APIs. W3C is working with many other IoT industry alliances and standards development organizations to solve the lack of interoperability across platforms in the emerging IoT field.

B. FRAMEWORK OF CPS STANDARDS: CPS ISO/IEC standards

(1) The ISO/IEC 19762:2016 provides terms and definitions for AIDC. The ISO/IEC 15459 series specifies the unique identification of registration procedures, common rules, individual transport units, individual products and product packages, individual returnable transport items, and groupings.

(2) The ISO/IEC/IEEE 21450:2010 defines the basic functions required to control and manage smart sensors. The ISO/IEC/IEEE 21451 series defines the Network.

(3) The IEC 61131 series identify the principal functional characteristics of programmable controller systems.

(4) The IEC 61499 defines a generic model for distributed control systems based on the IEC

61131 standard.

(5) The IEC 61131 and IEC 61499 help establish a reliable, interchangeable control system.

(6) The IEC 61804-3, IEC 61804-4, IEC 61804-5, and IEC 61804-6 (Electronic device description language, EDDL) are used to describe the characteristics of devices.

(7) The IEC 61360 series provides a basis for the clear and unambiguous definition of characteristic properties (data element types) of all elements of electrotechnical systems from basic components to sub-assemblies and full systems.

(8) The IEC 62714 series provides a data exchange format called the Automation Mark-up Language (AML)

(9) The IEC/ISO 13236:1998 establishes a high-quality system for the Information Technology (IT) environment.

(10) The ISO 27000 standard provides the best practice recommendations for information and security risks management and control.

(11) The IEC 62443 series (ISA99) is used to ensure the security of industrial automation and control systems and provides comprehensive security protection.

(12) The ISO/IEC 8802 provides the set of international standards which describe local area networks. There are several standards for wired communications.

(13) The IEC 61158 series and IEC 61784 series are standards for fieldbus types and profiles including foundation field buses, common industrial protocols, PROFIBUS and PROFINET, P-Net, WorldFIP, INTERBUS, SwiftNet, CC-Link, HART, VNET/IP, TCnet,

(14) EtherCAT, Ethernet POWERLINK, Ethernet for Plant Automation (EPA), Modbus, SERCOS, Rapi Net, SafetyNet p andMECHATROLINK. These protocols enable real-time distributed control in CPS and wire-less communications.

(15) The IEC 62591:2016 (Wireless HART TM) and IEC 62601:2015 (WIA-PA) are suitable for industrial wireless communication of industrial measurement, monitoring, and control. The ISO/IEC 14476 series enhances the communications transport protocol to ensure that there is a good quality of service (QoS).

(16) ISO/IEC 20005:2013, ISO / IEC 29180, ISO/IEC 29182, ISO/IEC 30101:2014, and ISO/IEC 30128:2014 are used to build intelligent, reliability and secure sensor networks. There are several standards related to the cyber level.

(17) The ISO/IEC 17826:2012 specifies the interface to access cloud storage and to manage the

data stored within.

(18) The ISO/IEC 27033 series ensures network security. The IEC 62769 series (FDI) is used to integrate the devices with the use of communications technology.

(19) The ISO 13374 series provides the basic requirements for open software specifications, which allow machines to monitor data and information processing and communication.

(20) The IEC 62453 helps integrate all devices regardless of the suppliers.

(21) The IEC 61512 defines the models for batch control used in the process, the terms, and the data models.

(22) The IEC 62264 used for enterprise control system integration increases uniformity and consistency of interface construction. The standard reduces the risk, cost, and errors associated with implementing these interfaces.

(23) The IEC 61508 increases security and ensures life cycle safety for industrial process control.

5.3.3 CPS AND PUBLIC POLICY

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

(1) What do individuals think about the CPS and its activities (for example, through social media and the internet, sensors, radio-frequency identification chips, geospatial technologies, loyalty cards or transport cards)?

(2) What is the right trade-off between privacy, intellectual property rights and security and allowing society to benefit from CPS driven innovations and better ways of living?

(3) What sorts of curation mechanisms are most effective in ensuring data quality and interoperability across organizational boundaries, particularly in the case of open data sets?

(4) How can we assess the impact of CPS on existing communications, legal and regulatory systems?

(5) How can society benefit most from CPS?

CPS: MANAGING THE LEGAL AND REGULATORY RISKS

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

Controlling use of CPS

Data privacy law is one area of law that any business is going to have to take very seriously indeed in relation to the use of CPS. While these laws vary from country to country, in Europe there are certain commonalities. Among other things, such reuse would need to be 'not incompatible' with the original purpose for which the date was collected for reuse to be permissible. The Article 29 Working Party (consisting of the data privacy regulators across the EU) has set out a four-stage test to determine when this requirement is met. The four-stage test includes a requirement that safeguards are put in place to ensure fair processing and to prevent undue impact on the relevant individual. This could include 'functional separation' (that is, anonymizing / pseudonymising or aggregating the results). In many cases, the only way to overcome privacy concerns in relation to CPS will be by way of adequate consent notifications. To obtain effective consent in relation to CPS is not straightforward.

Privacy protection

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

What are the other potential liabilities?

Among the potential liabilities that need to be addressed is the question of sensors/ data reliability. Data sourced from publicly available sensors, from another business, or collated by the business itself, may contain errors.

What technical and organizational measures should be considered?

Interception, appropriation and corruption of data remain an issue for businesses possessing Big Data sets, just as with any other data. The data privacy laws in many countries require that the data controller implements appropriate technical and organizational measures to safeguard the security of personal data. Such laws typically require the data controller to flow down these requirements in contractual relations with their suppliers. These requirements will apply to Big Data sets held by businesses that contain personal data.

Businesses will also need to take into account the new Data Protection Regulation, which will require that technical and organizational measures ought to be provided for by design and default. Purely technical solutions, implemented in the absence of a more comprehensive approach to information governance, may not be adequate.

The need for expertise

A recent survey by Accenture (Big Success with Big Data Survey, April 2014) found that 41% of businesses reported a lack of appropriately skilled resources to implement a Big Data project. Such expertise will need to include a legal and regulatory compliance review. It is simply a case of taking steps to address these issues early on.

5.3.4 National Data Sharing and Accessibility Policy (NDSAP)

NDSAP aims to provide an enabling provision and platform for proactive and open access to the data generated by various Government of India entities. The objective of this policy is to facilitate access to Government of India owned shareable data (along with its usage information) in machine-readable form through a wide area network all over the country in a periodically updatable manner, within the framework of various related policies, acts and rules of Government of India, thereby permitting a wider accessibility and usage by public. National Data Sharing and Accessibility Policy (NDSAP) is designed so as to apply to all sharable non-sensitive data available either in digital or analog forms but generated using public funds by various Ministries/Departments / Subordinate offices/Organizations/ Agencies of Government of India as well as States. There is a need felt to elevate this Policy into an act so that the aim to provide an enabling provision and platform for proactive and open access to the data generated by various Government of India entities can be fully achieved.

5.3.5 Open Government Data (OGD) Platform India

OGD, (http://data.gov.in) has been set up to provide access to datasets published by different government entities in open format. It also provides a search, discovery & on-the-fly data conversion (to widely used open formats) mechanisms for instant access to desired datasets. OGD Platform has a backend data management system which is used by government departments to publish their datasets through a predefined workflow. They shall also have a dashboard to see the current status on their datasets, usage analytics as well as feedback and queries from citizens at one point. OGD Platform India is still at its nascent stage and is going through proportions of changes. One of the major challenges faced is that of the formation of an NDSAP Cell in every

Ministry/Department. As per policy guidelines, in order to implement NDSAP, each Department is required to establish an NDSAP Cell, which shall be headed by the Data Controller, who could be assisted by a number of Data Contributors and few domain specialists. These professionals would monitor and manage the open data initiative in their respective Ministry/Department and extend technical support to ensure quality as well as the correctness of the data.

5.3.6 CPS Regulatory Frame Work

Over a period short time the usage of CPS spreads in the country. That will eventually give rise to a number of issues related to usage of CPS and related legal aspects, especially concerning the Personal Information, privacy of personal data etc. Therefore, there is need to think about the ethical and regulatory framework around CPS, as it will increasingly impact on the lives of individuals and underpin customer service, innovation, quality and business operations.

Strengths of Legal Framework

(1) India has established legal systems which hasbasic framework to address IPR, Patents and Copyrights.

(2) Cyber Laws also are framed and/or operating at very broader level.

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

Weakness of Legal Framework

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

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

(3) Bureau of Indian Standards is the nodal agency for standards, there should be a core group within BIS to look into CPS standards.

5.4 Environmental Impact

ICPS is a soft computing in nature and thus, there will not be any environmental impact. The programme is structured to be operatedat academics, research organizations, IT industry and in existing immovable infrastructure. Center of Excellence's (CoEs) will be established at academic institutions where already built in building infrastructure is available. Thus, there are no new constructions, land acquisitions, dislocations and other environmental clearances are required.

a. Land acquisitions are not involved

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

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

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

TABLE 5.9 ENVIORNMENT IMPACT ASSISMENT

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

CONCLUSIONS

Scientific progress is a result of relentless academic research endeavour. The scientific community has been focused for a while now on the growing challenges of CPU and also its application in a number of socio-economic domains. This immense repository of past/current academic knowledge is increasing at an exponential rate. As the amount of knowledge grows, an assessment of state-of-the-art in any sub-fields becomes harder. One way of enabling the acceleration of the process of discovery, is to significantly enhance current search capabilities to support deep scientific queries, technology development and application. Keeping in view the fast growth of CPS across the various applications, it is imperative to chalk out a strategic Roadmap in this direction to reap the benefits towards the overall development of the country.

This DPR developed by involvingstakeholders and done on a consultative framework has established the need for a National Mission to (i) strengthen the CPS ecosystem of the country, and (ii) take steps to nurture the same, to leverage the unique advantageous position of the country's manpower in not only in the scientific research and development but in the business and industry also.

The strategy developed for the Mission and the programmes/ projects proposed under it have to be implemented in five years, and its cost has been estimated to be around Rs.3600 Crore. The sub-missions or, programmes under the Mission will include (i) Technology Development, (ii) Centers of Excellence, (iii) HRD & Skill Development, (iv) Innovation, Entrepreneurship & Start-up ecosystem and (v) International Collaboration.

Towards implementation of the Mission, the strategy involved besides the identified technologies, evaluation parameters, monitoring mechanism, and deliverables, have been delineated in this document. With timely investment and oversight Mission objectives could be realized within the stipulated period.

LIST OF ABBREVIATIONS

ACCM	:	Ant Colony Clustering Model
ACM	:	Association for Computing Machinery
AES	:	Advanced Encryption Standard
AI	:	Artificial Intelligence
ARP	:	Address Resolution Protocol
ASC	:	Apex Steering Committee
ASN	:	Application Service Node
AUV	:	Autonomous Underwater Vehicle
BDD	:	Behaviour Driven Development
BDMP	:	Boolean Logic Markov Processes
BNF	:	Backus New Form
BOG	:	Board of Governors
BPM	:	Business Process Modelling
CAD	:	Computer Aided Design
CASTLE	:	Center for Applied Studies, Translational Research and Leadership
CBA	:	Cost Benefit Analysis
CEP	:	Complex Event Processing
CHS	:	Cluster Heads
CMAC	:	Cipher-based Messages Authentication Code
CoE	:	Center of Excellence
CNC	:	Computer Numerical Control
CoT	:	Cloud of Things
CP	:	Chair Professors
CPES	:	Cyber Physical Energy System

CPS	:	Cyber Physical System
CPS-EDP	:	CPS Entrepreneurship Development Programme
CPCV	:	Cyber Physical Vehicle System
CPPS	:	Cyber Physical Production System
CS	:	Compressed Sensing
CSESM	:	Communication Subsystem Energy Consumption Model
CSIR	:	Cyber Security Research Institute
CUDA	:	Compute Unified Device Architecture
dASTRA	:	Data Science, Technology, Research and Applications
DCA	:	Distributed Control Algorithm
DCSC	:	Delft Center for Systems and Control
DDS	:	Data Distribution Service
DFM	:	Design for Manufacturability
DHI	:	Department of Heavy Industries
DIAL	:	Dedicated Innovation Accelerators
DIN	:	Deutsches Institute fur Normung
DL	:	Deep Learning
DNN	:	Dynamic Neutral Network
DietY	:	Department of Electronic and Information Technology
DIY	:	Do-it-yourself
DPR	:	Detailed Project Report
DRDO	:	Defence Research & Development Organization
DS	:	Data Science
DSML	:	Domain Specific Modelling Language
DST	:	Department of Science & Technology
DQBA	:	Different Qos-based Bandwidth Allocation
CASTLE	:	Center for Advanced Studies, Translational research & LEadership
CETIT	:	Center of Excellence in Technology Innovation & Transfer

CROSS	:	Center for Research On Sub-Systems
EDA	:	Event Driven Architecture
EDP	:	Entrepreneurship Development Programme
ESDM	:	Electronic System Design and Manufacturing
ETF	:	Effective Trade Fund
EVM	:	Embedded Vl Machine
EYE	:	Energy Efficient Sensor Networks
FESM	:	Fault Tolerant Energy Efficient and Secure Clustering Scheme for Mobile
FF	:	Faculty Fellowship
FINRA	:	Financial Industry Regulatory Authority
FPGA	:	Field Programmable Gate Array
FTC	:	Fault Tolerant Control
GAN	:	Generative Adversarial Networks
GHG	:	Green House Gases
Gol	:	Government of India
GPU	:	Graphic Processing Units
GV	:	Gradable Vehicles
HART	:	Highway Addressable Remote Transducer Protocol
HIO	:	Hybrid l/o Automation
HPC	:	High Performance Computing
HRD	:	Human Resource Development
ICON	:	International Centers of New Knowledge in CPS
ICPS	:	Interdisciplinary Cyber Physical Systems
ICS	:	Industrial Control Systems
ICT	:	Information and Communications Technology
IDE	:	Integrated Development Environment
IDS	:	Intrusion Detection System
IDSS	:	Institute for Data, System and Society
IEC	:	International Electrotechnical Commission

IEEE	:	Institute of Electric and Electronics Engineering
IEDC	:	Innovation and Entrepreneurship Development Center
IESA	:	Indian Electronics and Semiconductor Association
IIT	:	Indian Institute of Technology
ILSF	:	Indoor Location-based Smart Factory
IMS	:	Intelligent Manufacturing Systems
IN	:	Infrastructure Node
loBT	:	Internet of Battlefield Things
loT	:	Internet of Things
IP	:	Internet Protocol
IPR	:	Intellectual Property Rights
IPC	:	Internal Patent Classification
ISO	:	International Organization for Standardization
ISRO	:	Indian Space Research Organization
IT	:	Information Technology
ITI	:	Industrial Training Institute
ITRI	:	Industrial Technology Research Institute
IVA	:	Intelligent Video Analytics
IVS	:	Intelligent Video Systems
JRF	:	Junior Research Fellow
LBS	:	Location Based Services
LHPN	:	Labelled Hybrid Petri Net
LLNL	:	Lawrence Livermore National Laboratory
LWC	:	Lightweight Cryptography
MAC	:	Media Access Layer
MAC	:	Mission Apex Committee
MAS	:	Multi-Agent System
MCMC	:	Markov Chain Monte Carlo
MDA	:	Model Driven Architecture

MDD	:	Model Driven Design
MDI-QKD	:	Measurement Device-Independent Quantum-Key-Distribution
MeitY	:	Ministry of Electronics & Information Technology
MEMS	:	Micro Electro Mechanical Systems
MIC	:	Model Integrated Computing
MIMO	:	Multiple Input Multiple Output
MIS	:	Management Information System
M2M	:	Machine-to-Machine
ML	:	Machine Learning
MLP	:	Multi Layered Perception
MMA	:	Multi Mode Automata
MMU	:	Mission Management Unit
MN	:	Middle Node
MOOC	:	Massive Open-Online Course
MPC	:	Model Predictive Control
MRI	:	Magnetic Resonance Imaging
MSME	:	Medium, Small & Micro Enterprises
NASSCOM	:	National Association of Software and Services Companies
NCI	:	National Critical Infrastructure
NCIIPC	:	National Critical Information Infrastructure Protection Center
NDSAP	:	National Data Sharing and Accessibility Policy
NEMS	:	Nano Electro Mechanical Systems
NewGen IEDC	:	NewGeneration Innovation and Entrepreneurship Development Center
NIST	:	National Institute of Standards and Technology
NM-ICPS	:	National Mission on Interdisciplinary Cyber Physical Systems
NMR	:	Nuclear Magnetic Resonance
NNM	:	Neutral Network-Based Modelling
NP	:	Neutral Programming
NRI	:	Non-Resident Indians

NSF	National Science Foundation
NSTEDB	National Science & Technology Entrepreneurship Development Board
NWSG	National Weather Sensor Grid
OCTAVE	Operationally Critical Threat, Asset, and Vulnerability Evaluation
ODE	Ordinary Differential Equation
OGD	Open Government Data
OPC-UA	OPC Unified Architecture
PC	PRAYAS Center
PDF	Post Doctoral Fellowship
PI	Principal Investigator
PG	Post Graduate
PGF	Post Graduate Fellowship
PKL	Public Key Infrastructure
PPP	Public-Private-Partnership
PTMS	Parallel Transportation Management Systems
QoS	Quality of Service
R&D	Research & Development
REMP	Resilient End-to-End Massage Protection
RES	Renewable Energy Sources
RFI	Radio Frequency Identification
SA	Simulated Annealing
SAC	Standardization Administration of the People's Republic of China
SCADA	Supervisory Control and Data Acquisition
SDG	Sustainable Development Goals
SIDBI	Small Industrial Development Bank of India
SISE	Strategic Information Services for Entrepreneurship
SMS	Smart Manufacturing Systems
SNWE	Sensor Networks & Web Enablement

SoA	:	Service-Oriented Architecture
SOM	:	Self- Organizing Maps
SOP	:	Standard Operating Procedures
SRF	:	Senior Research Fellow
STAR	:	Smart Tissue Autonomous Robot
STQC	:	Standardization, Testing and Quality Certification
SVM	:	Support Vector Machine
SVR	:	Support Vector Regression
SWOT	:	Strengths, Weaknesses, Opportunities and Threats
TBD	:	Tunnelling Ball Device
TCP	:	Transmission Communication Protocol
TIFAC	:	Technology Information, Forecasting & Assessment Council
TRL	:	Technology Readiness Level
TSensors	:	Trillion Sensors
UAV	:	Unmanned Arial Vehicles
UDDI	:	Universal Description, Discovery and Integration
UDP	:	User Datagram Protocol
UG	:	Under Graduate
U.K.	:	United Kingdom
UML	:	Unified Modelling Language
UN	:	United Nations
VLSI	:	Very Large Scale Integration
WAN	:	Wide Area Network
W3C	:	World Wide Web Consortium
WMSN	:	Wireless Multimedia Sensor Network
WSN	:	Wireless Sensor Networks
WSAN	:	Wireless Sensor/Actuator Networks

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ANNEXURE A

FIRST APEX COMMITTEE MEETING HELD FOR ICPS-DPR
ON 08 June 2017 IN DST, Technology Bhawan

LIST OF THE PARTICIPANTS

S. No.	Name	Designation & Organization
1.	Dr. V.K. Saraswat,	Chairman, Member (S&T) NITI, Aayog
2.	Prof. Ashutosh Sharma,	Member, Secretary, Department of Science & Technology
3.	Sh. Girish Shankar,	Member, Secretary, Department of Heavy Industries
4.	Prof. Santanu Chaudhury,	Member, Director CEERI- Pilani
5.	Prof. M. Chandrasekhar,	Member, Director, IIM- Vishakhapatnam
6.	Sh. Vishwanathan,	Member, Vice-President, NASSCOM
7.	Dr. B.K. Murthy	Member (Representative), Scientist 'G', MeITY
8.	Sh. Rakesh Maheshwari	Member (Representative), Sc 'G', MeITY
9.	Dr. K.R. Murali Mohan	Member-Secretary, Head, ICPS Division, DST
10.	Prof. Prabhat Ranjan	Invitee, TIFAC
11.	Sh. Sathis Kumar	Invitee, OSD, NITI Aayog
12.	Dr. C. Murali Krishna Kumar	Invitee, NITI Aayog
13.	Dr. R.K. Gupta,	Invitee, NITI Aayog
14.	Sh. Atul Kumar,	Invitee, Consultant, DSCI
15.	Dr. Rajeev Sharma,	Invitee, DST
16.	Dr. Neeraj Saxena	Invitee, TIFAC
17.	Ms. Neera Saxena	Invitee, TIFAC
18.	Ms. Ragni Ranjan,	Invitee, TIFAC

FIRST CONSULTATIVE MEETING HELD FOR ICPS-DPR
ON 22-23 June 2017 IN Robert-Bosch Center for Cyber Physical Systems , Bangalore

LIST OF THE PARTICIPANTS

S No	Name	Designation & Organization
1	Prof. L M Patnaik	NIAS, Bengaluru
2	Prof. Vijay Chandru	Strand Life Science
3	Mr. Phaneendra K. Yalavarthy	Associate Professor, Dept. of Computational and Data Science,IISc Bengaluru
4	Dr. V. Shankar	IIM, Bengaluru
5	Prof. Chiranjib Bhattacharyya	Robert Bosch Center for Cyber-Physical Systems, IISc, Bengaluru
6	Prof. Shalabh Bhatnagar	Robert Bosch Center for Cyber-Physical Systems, IISc, Bengaluru
7	Prof. Rajesh Sundaresan	Robert Bosch Center for Cyber-Physical Systems, IISc Bengaluru
8	Dr. Atryee Kundu	Robert Bosch Center for Cyber-Physical Systems, IISc Bengaluru
9	Dr. Arun Babu	Robert Bosch Center for Cyber-Physical Systems, IISc Bengaluru
10	Dr. Abhay Sharma	Robert Bosch Center for Cyber-Physical Systems, IISc Bengaluru
11	Dr. Shrihar S	Robert Bosch Center for Cyber-Physical Systems, IISc Bengaluru
12	Dr.K.K Venkataraman	Dept of Electronics and Communication Engineering, PSGIAS
13	Prof. Govind R Kadambi	Pro-Vice Chancellor(Research), M S Ramaiah University
14	Dr. Raghavendra V Kulkarni	Professor, & Head of Department , Dept of Computer Science Engineering, M S Ramaiah University
15	Dr. Narendra Babu	Dept of Computer Science Engineering, M S Ramaiah University, Bangalore
16	Prof. N D Gangadhar	Associate Professor,Dept of Computer Science Engineering,M S Ramaiah University
17	Mr. Srivatchsan Utham	IBM
18	Mr. Sudarshan Rao	IBM
19	Mr. Y V Prakash	Founder, Wooqer, Bangalore
20	Mr. Archan Mudwal	National Instruments
21	Mr. Piyush Sharma	Technology Professional &Enterpreneur, Bengaluru
22	Mr. Rajarama Nayak	Head, Embedded Technology Solutions,TCS
23	Mr. Sandeep Agarwal	Senior Vice President, Happiest Minds
24	Mr.Sudeepth Puthumana	Continental Automotive Components(India) Pvt. Ltd.
25	Mr. Santhosh Kumar Mandathil	Chief Technical Officer, L & T Technology Services, Bangalore
26	Mr. Manoj Kumar	All State
27	Mr. Niranjan Mandyam	Director, NASSCOM

S No	Name	Designation & Organization
28	Dr. Koshy George	Director & Professor PES Institute of Technology , Bengaluru
29	Prof. Panduranga Vittalal K.	Professor NITK , Surathkal
30	Mr. Murthy Indrakanti	CEO, Lave Solutions Pvt. Ltd., Bangalore
31	Dr. Amitabh Wahi	Professor Bannari Amman Institute of Technology, Bengaluru
32	Dr. R. Lokesh kumar	Assistant Professor Bannari Amman Institute of Technology, Bengaluru
33	Mr. Vignesh Kumar	Assistant Professor Bannari Amman Institute of Technology, Bengaluru
34	Mr. Prashant Adiver	Assistant Professor Bannari Amman Institute of Technology, Bengaluru
35	Dr. Sathish	CMTI , Bangaluru
36	Mr. Mushabbar Hussain	Solution Architect, KPIT Cummins Infosystems Ltd.
37	Dr. Cauvery N. K.	Professor, R.V. College of Engineering, Bengaluru
38	Mr.Narendra Kumar	Principal Scientist, KPIT Technologies Ltd.
39	Dr. K.V. Subramaniam	Professor, Dept. of Computer Science & Engg. PES University
40	Dr.N.R Sunitha	HOD, Dept. Of CSE,SIT, Tumkur
41	Dr. R. Aparna	HOD, Dept. Of ISE, SIT, Tumkur
42	Dr. Rajiv Sharma	Scientist, DST, GOI, Delhi
43	Dr. Neeraj Saxena	Scientist, TIFAC, DST, GOI
44	Ms. Ragni Ranjan	Project Associate on ICPS, TIFAC
45	Mrs. Neera Saxena	Project Associate on ICPS, TIFAC
46	Dr. U.T Vijay	Principal Scientific Officer, KSCST, Bengaluru
47	Dr. S G S Swamy	Secretary, KSCST, Bengaluru
48	Mr. Ramdas C. V.	Advisor Technology, C-DAC Bangalore
49	Dr. Suresh B.	Deam (R&D)
50	Dr. Ashish Joglekar	MTS, Robert Bosch Center for Cyber-Physical Systems, IISc, Bengaluru
51	Sanjay S. Shanbhag	SIEMENS
52	Dr. N. Jayasuryan	Director, Microtest Innovations Pvt. Ltd.
53	Dr. Dinkar Sitaram	PES University
54	Mr. Raja Shekhara G.	KSCST, IISc, Bangalore
55	Mr. Ajai Kumar G. C.	KSCST, IISc, Bangalore
56	Dr. M. K. Banga	Professor, Dept. of Computer Science Engg. Dayananda Sagar University, Bangalore

STAKEHOLDERS MEETING HELD FOR ICPS-DPR
ON 28 June 2017 IN Indian Institute of Technology, Delhi

LIST OF THE PARTICIPANTS

S. No.	Name	Designation & Organization
1	Prof. Santanu Chaudhury	Director, CEERI- Pilani
2	Dr. K.R. Murali Mohan	Head, ICPS Division, DST
3	Dr. Prabhat Ranjan	Executive Director, TIFAC
4	Dr. Shyamanta M. Hazarika	Professor, Department of Mechanical Engineering, IIT Guwahati
5	Dr. T Asokan	Professor, Department of Engineering Design, IIT Madras
6	Dr. Prabir K Pal (Retired)	Sr. Professor, BARC Mumbai
7	Dr. S Saravana Perumaal	Assistant Professor, Thiagarajar College of Engineering, Madurai, Tamil Nadu
8	Dr. Sumeet Agarwal	Assistant Professor, Department of Electrical Engineering, IIT Delhi
9	Dr. B. K. Panigrahi	Professor, Department of Electrical Engineering, IIT Delhi
10	Dr. Ashish Dutta	Professor, Department of Mechanical Engineering, IIT Kanpur
11	Dr. Indra Narayan Kar	Professor, Department of Electrical Engineering, IIT Delhi
12	Dr. Jitendra Prasad Khatait	Assistant Professor, Department of Mechanical Engineering, IIT Delhi
13	Dr. Abhishek Sarkar	Senior Research Scientist, IIIT Hyderabad
14	Dr. Shubhendu Bhasin	Associate Professor, Department of Electrical Engineering, IIT Delhi
15	Dr. Subir Kumar Saha	Professor, Department of Mechanical Engineering, IIT Delhi
16	Dr. Sudipto Mukherjee	Professor, Department of Mechanical Engineering, IIT Delhi
17	Dr. Sunil Jha	Associate Professor, Department of Mechanical Engineering, IIT Delhi
18	Dr. Mohd. Suhaib	Professor, Department of Mechanical Engineering, Jamia Millia Islamia, Delhi
19	Dr. Anjali Vishwas Kulkarni	Principal Research Engineer, Center for Mechatronics, IIT Kanpur

S. No.	Name	Designation & Organization
20	Mr. Ashiv Shah	Associate Professor, AKG College of Engineering, Ghaziabad, Uttar Pradesh
21	Dr. Subrat Kar	Professor, Department of Electrical Engineering, IIT Delhi
22	Dr. S. Ali Akbar	Senior Principal Scientist, CEERI-Pilani
23	Dr. S. C. Bose	Principal Scientist, CEERI-Pilani
24	Dr. B. P. Ajith Kumar	Scientist H, IUAC, Delhi
25	Mr. Anup Wadhwa	Director, Automation Industry Association, India
26	Dr. C. S. Kumar	Professor, Department of Mechanical Engineering, IIT Kharagpur
27	Dr. Juhi Ranjan	Assistant Professor, Indraprastha Institute Of Information Technology, Delhi
28.	Mr. Deepak Rai	Assistant Professor, AKG College of Engineering, Ghaziabad, Uttar Pradesh
29.	Dr. Neeraj Saxena	Scientist E, TIFAC, DST
30.	Mrs. Neera Saxena	Project Associate, TIFAC
31.	Ms. Ragni Ranjan	Project Associate, TIFAC

SECOND CONSULTATIVE MEETING HELD FOR ICPS-DPR ON 06 July 2017 IN Auditorium, Administrative Staff College of India, HYDERABAD

LIST OF THE PARTICIPANTS

S. No.	Name	Designation & Organization
1.	Dr. Uday B. Desai	Director, IIT Hyderabad
2.	Dr. P.J. Narayanan	Director, IIIT Hyderabad
3.	Dr. K.R. Murali Mohan	Head, ICPS Division, DST
4.	Maj. Gen. Dr. R. Siva Kumar (Retd.)	President- Geospatial Solutions, IIC Technologies Limited, Hyderabad
5.	Mr. Mukundhan Srinivasan	Deep Learning Solution Architect, Nvidia India, Hyderabad
6.	Dr. Narayana A. C.	Professor, Center for Earth & Space Sciences, University of Hyderabad
7.	Mr. Pramod Kumar Jha	Scientist F, Center for Advanced Systems (DRDO), Hyderabad
8.	Mr. Akash saxena	Software Engineer, Microsoft India Pvt. Ltd., Hyderabad
9.	Dr. Mohammad Zafar Ali Khan	Professor & Head, Department of Electrical Engineering, IIT Hyderabad
10.	Dr. Kamal Karlapalem	Professor, IIIT Hyderabad
11.	Dr. Vishal Garg	Associate Professor, IIIT Hyderabad
12.	Dr. Suresh Purini	Assistant Professor, IIIT Hyderabad
13.	Dr. Sachin Chaudhari	Assistant Professor, IIIT Hyderabad
14.	Mr. N. abid Ali Khan	Assistant Professor, Department of ECE, Vasavi College of Engineering, Hyderabad
15.	Dr. L. V. Narasimha Prasad	Principal, IARE, Hyderabad
16.	Dr. A. Mohan	Director, Chadalawada Ramanamma Engineering College, Tirupati, Andhra Pradesh
17.	Dr. M. Madhubala	Professor, Department of CSE, IARE, Hyderabad
18.	Dr. K. Rajendra Prasad	Professor, Department of CSE, IARE, Hyderabad
19.	Dr. J. Sirisha Devi	Professor, Department of CSE, IARE, Hyderabad
20.	Dr. P. Rajalakshmi	Associate Professor, Department of electrical Engineering, IIT Hyderabad
21.	Dr. Ravi V	Professor, Institute for Development and Research in Banking Technology (IDRBT), Hyderabad

S. No.	Name	Designation & Organization
22.	Dr. K. Sri Rama Krishna	Professor & Head, ECE, Coordinator, TIFAC CORE, Siddhartha Engineering College, Vijayawada, Andhra Pradesh
23.	Dr. Sudhakar Gummadi	Director-Technology, Netcon Technologies India Pvt. Ltd., Hyderabad
24.	Dr. G. Ramesh Chandra	Head, Research and Consultancy Center, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad
25.	Dr. T. Sunil Kumar	Associate Professor, CSE, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad
26.	Dr. RVH Prasad	Assistant Professor, ECE, V. R. Siddhartha Engineering College, Vijayawada, Andhra Pradesh
27.	Dr. Y. Srinivas	Professor and Head, Department of IT, GITAM Institute of Technology, Visakhapatnam, Andhra Pradesh
28.	Mr. Murty Indrakanti	CEO, Lave Solutions Pvt. Ltd., Bengaluru
29.	Dr. Antony Franklin	Assistant Professor, Department of CSE, IIT Hyderabad
30.	Mr. K. Amarender	Director-Technical, SmartBridge Edu. Services Pvt. Ltd., Hyderabad
31.	Dr. A. S. Rao	Director, Center for Project Mobilization and Globalization, VNR Vignana Jyoti Institute of Engineering and Technology, Hyderabad
32.	Dr. Neeraj Saxena	Scientist E, TIFAC, DST
33.	Mrs. Neera Saxena	Project Associate, TIFAC
34.	Ms. Ragni Ranjan	Project Associate, TIFAC

STAKEHOLDERS MEETING HELD FOR ICPS-DPR
ON 19 Sept. 2017 IN DA-IICT, GANDHINAGAR

LIST OF THE PARTICIPANTS

S. No.	Name	Designation & Organization
1	Dr. K.S. Dasgupta	Director, DA-IICT, Gandhinagar
2	Dr. R. Nandkumar	Former Scientist, SAC-ISRO
3	Dr. Vishwajit K. Thakur	Faculty, AIIE, Ahmedabad
4	Dr. Srikrishnan Diwakaran	Associate Professor, SEAS, Ahmedabad University
5	Mr. Ritesh A. Mistry	Student, IIMC
6	Dr. Kirit J. Modi	Associate Professor, Deptt. of IT, UVPCE, Ganpat University, Gujarat
7	Dr. Sourish Dasgupta	Assistant Professor, DA-IICT, Gandhinagar
8	Dr. Kalyan Sasidhar	Assistant Professor, DA-IICT, Gandhinagar
9	Dr. Dhaval Patel	Assistant Professor, Ahmedabad University
10	Dr. Sudeep Tanwar	Associate Professor, Nirma University
11	Dr. Ratnik Gandhi	Assistant Professor, SEAS, Ahmedabad University
12	Dr. Sanjay Chaudhary	Professor & Associate Dean, SEAS, Ahmedabad University
13	Dr. Anish Mathuria	Professor, DA-IICT, Gandhinagar
14	Dr. Sanjeev Gupta	Professor & Dean (R&D), DA-IICT, Gandhinagar
15	Dr. Manjunath Joshi	Professor, DA-IICT, Gandhinagar
16	Mr. Vaibhav Amit Patel	Student, DA-IICT, Gandhinagar
17	Mr. Jignesh R. Patel	PhD Scholar, DA-IICT, Gandhinagar
18	Dr. Dipak M. Adhyaru	Professor & Head, IC Deptt. , Nirma University
19.	Dr. Manish K. Gupta	Professor, DA-IICT, Gandhinagar
20.	Dr. Rajendra Mitharwal	Faculty, DA-IICT, Gandhinagar
21.	Dr. V. Sunitha	Faculty, DA-IICT, Gandhinagar
22.	Mr.Pruthvish Rajput	JRF, PDPU, Gandhinagar
23.	Dr. Sanjay Patel	Assistant Professor, LDRP-ITR, Gandhinagar
24.	Prof. Hemant A. Patil	Professor, DA-IICT, Gandhinagar
25.	Dr. Anil K. Roy	Associate Professor, DA-IICT, Gandhinagar
26.	Ms. Jeni S. Shah	Student, DA-IICT, Gandhinagar

S. No.	Name	Designation & Organization
27.	Mr. Rishikant Rajdeepak	PhD Scholar, DA-IICT, Gandhinagar
28.	Dr. Sanjay Srivastava	Faculty, DA-IICT, Gandhinagar
29.	Mr. Lavneet Singh	Faculty, DA-IICT, Gandhinagar
30.	Dr. Biswajit Mishra	Faculty, DA-IICT, Gandhinagar
31.	Dr. Jyoti Pareek	Professor, Computer Science, Gujarat University
32.	Dr. Manik Lal Das	Professor, DA-IICT, Gandhinagar
33.	Dr. Minal Bhise	Associate Professor, DA-IICT, Gandhinagar
34.	Dr. Asim Banerjee	Faculty,DA-IICT, Gandhinagar
35.	Dr. Manish Narwaria	Assistant Professor, DA-IICT, Gandhinagar
36.	Dr. Rutu Parekh	Assistant Professor, DA-IICT, Gandhinagar
37.	Dr. Prasenjit Majumdar	Associate Professor, DA-IICT, Gandhinagar
38.	Ms. Dixita Limbachiya	PhD Scholar, DA-IICT, Gandhinagar
39.	Mr. Krishna Gopal	PhD Scholar, DA-IICT, Gandhinagar
40.	Mr. Abdul Zummerwala	Visiting Faculty, BISAG-Gandhinagar
41.	Dr. Rajeev Sharma	Scientist-' D', DST
42.	Dr. Prabhat Ranjan	Executive Director, TIFAC, DST
43.	Ms. Ragni Ranjan	Project Associate, TIFAC

STAKEHOLDERS MEETING HELD FOR ICPS-DPR ON 24.09.2017
VENUE: BAMETI, PATNA

LIST OF THE PARTICIPANTS

Sl No.	Name	Designation & Organization
1	Dr. M.P. Singh	Assistant Professor, CSE, NIT Patna
2	Prof. Shridhar Kumar	Assistant Professor, CSE, BIT Patna
3	Mr. Madhup Kumar	Asst. Prof., CSE, BIT Patna
4	Mr. Ajit Kumar Singh	Technical Director,Bihar Vidyapith Patna
5	Mr. Rajendra Kumar	Manager, Agriculture,Pricewaterhousecoopers, Pvt. Ltd
6	Dr. Rajan K. Behera	Associate Professor, Electrical,IIT, Patna
7	Dr. S. Tripathy	Associate Professor, CSE, IIT, Patna
8	Dr. Jimson Mathew	Associate Professor, CSE, IIT, Patna
9	Dr. Murshid Iman	Assistant Professor, ME, IIT, Patna
10	Dr. Sumanta Gupta	Associate Professor, Electrical Engg, IIT, Patna
11	Dr. Karali Patra	Associate Professor, Mechical Engg., IIT, Patna
12	Dr. Subrata Hait	Assistant Professor, Civil & Env. Engg, IIT, Patna
13	Mr. Naveen Chandra Jha	IPS, SP(C), CID BIHAR, HOME Police
14	Dr. Rajeev Sharma	Scientist D, DST, New Delhi
15	Mrs. Neera Saxena	Project Associate, TIFAC, New Delhi
16	Mr. Ravi Kumar Keshri	CRM, PRC Patna
17	Mr. Rahul Kumar	Director, EcoVenture
18	Prof. Prabhat Ranjan	Executive Director, TIFAC, New Delhi
19	Mr. Neeraj Kumar	DDPP, BAMETI, Patna
20	Dr. P. K. Mishra	State Coordinate, BAMETI, Patna
21	Dr. Mridula Prakash	Executive PResendent, APCL, Patna
22	Dr. Manoj Verma	Curator, RSS Patna
23	Ms. Swati Rani	Librarian, MMN Library
24	Mr. Rakesh Raman	Assiatant, Bihar Vidyapeeth
25	Mr. Ranjan Mistry	Founder Campus, Varta
26	Mr. Vivakanand PRashad	Founder, TechPro Lab2

Sl No.	Name	Designation & Organization
27	Mr. Vishal	Founder, UnityCrypto
28	Dr. Sandip K	Assistant Professor , Chemical & Bio-chemical Engg.,IIT Patna
29	Mr. Sameer Kumar Sinha	Engineer, BVCIE, Patna
30	Mr. Abhay Pandey	Project Incharge, Skylark Group
31	Mr. Arvind Sharma	JDA, Agriculture Department, BAMETI, Patna
32	Mr. Rajiv Ranjan	Ad. SP, EOU Bihar Police
33	Mr. Rashid Zaman	SP, EOU Bihar Police
34	Mr. Ajeet Kumar Singh	NHSRC, Health, Bihar
35	Dr. Anup Kumar	Assistant Professor, IIT Patna
36	Mr. Santosh Kumar	Secretariat, Patna
37	Mr. Prashant Prakash	Assistant Professor, BIT Patna
38	Mr. R.K. Mishra	Assistant Professor, BIT Patna
39	Mr. Ravi Shankar Sharma	Programmer, Agriculture Department, BAMETI Patna
40	Dr. Mani Bhushan	Scientist(SS), ICAR-RCER Patna
41	Mr. Kumar Nikhil	Programmer, FCP Depratment Patna
42	Mr. Nitish Kumar	IT Manager, FCP Department , Patna
43	Mr. B. N. Mathur	Bihar vidyapith
44	Mr. Kumar Abhijit	Software Engineer, BCEBC, Patna

STAKEHOLDERS MEETING HELD FOR ICPS-DPR ON 27 Sept. 2017 IN C-DAC, PUNE

LIST OF THE PARTICIPANTS

Sl No.	Name	Designation & Organization
1	Dr. B. Krishna Murthy	Senior Director (Scientist-'G'), MeiTY
2	Dr. Hemant Darbari	ED, C-DAC, Pune
3	Col. A. K. Nath (Retd.)	ED (Corporate), C-DAC, Pune
4	Dr. Ajai Kumar	Associate Director & HOD, Applied AI Group, C-DAC, Pune
5	Prof. B. M. Hooli	Consultant, C-DAC, Pune
6	Mr. Rajeev Rudrakshi	PTO, HPC-I&E, C-DAC, Pune
7	Mr. Vinod G. Kulkarni	Founder, Web Innovation Labs, Pune
8	Dr. Avinash Joshi	Group Head, Tech Mahindra, Pune
9	Mr. Suresh V.	JD, C-DAC, Pune
10	Dr. Hake Abhay	Professor & Vice Principal, Electronics & Telecommunication Engineering, MES CoE, Pune
11	Mr. Shrikant Kunden	Director, Lastmile Digital Solutions Pvt. Limited, Pune
12	Mr. Santosh Kumar	PTO, Applied AI Group, C-DAC, Pune
13	Mr. Sachin Pukale	DGM-IoT, Product Management, Tata Communication, Pune
14	Mr. Rajendra Joshi	Associate Director & HOD-MBA, C-DAC, Pune
15	Mr. Ashish Kuvelkar	Associate Director, C-DAC, Pune
16	Dr. Seetha Rama Krishna Nookala	Director, APAC& Japan, HPC/AI/Cloud solutions and Strategic Engagements, Intel Inc.
17	Dr. Y. Ravinder	Head & Professor, E&TC Deptt., PICT, Pune
18	Mr. Shashi Pal	PTO, C-DAC, Pune
19	Mr. Mahesh Bhargava	PTO, C-DAC, Pune
20	Ms. Priyanka Jain	Joint Director, C-DAC, Pune
21	Ms. Swati Mehta	Joint Director, C-DAC, Pune
22	Mr. Krishnanjan B.	PTO, C-DAC, Pune
23	Mr. Vinay Patil	STO, C-DAC, Pune
24	Ms. Lakshmi Panat	Joint Director, C-DAC, Pune
25	Dr. Rajeev Sharma	Scientist-' D', DST
26	Dr. Neeraj Saxena	Scientist E, TIFAC, DST
27	Ms. Ragni Ranjan	Project Associate, TIFAC

INTERMINITERIAL MEETING HELD FOR NM-ICPS IN TECHNOLOGY BHAWAN, DST, NEW DELHI ON 06-10-2017

LIST OF THE PARTICIPANTS

S No	Name	Designation, Organization
1.	Dr. Sanjay Saxena	Head, Investor, BIRAC
2.	Dr. Harpreet Singh	Scientist E, ICMR
3.	Mr. S.P. Katuanria	Director, Ministry of Textiles
4.	Mr. N. K. Singh	Assistant Director, Textile Commission
5.	Mr. Rajiv R. Chetwani	Director, Information Systems, ISRO, Dept. of Space
6.	Maj. Gen. H. S. Shanbhag	TM (LS), Ministry of Defence
7.	Mr. S. Bhattacharya	Deputy Secretary, Ministry of Steel
8.	Mr. Vishal Srivastava	Consultant IT, Ministry of AYUSH
9.	Mr. Daniel Richards	Joint Secretary, Ministry of AYUSH
10.	Mr. Mohd. Mamur Ali	Assistant Professor, NCERT, under MHRD
11.	Mr. Manoj K. Jani	Director, Ministry of Electronics & IT
12.	Ms. Meenakshi Agrawal	Scientist 'C', Ministry of Electronics & IT
13.	Mr. Manikandan K.	Scientist 'C', Bureau of Indian Standards
14.	Mr. Rajeev Sharma	Scientist 'E' , Head (ETO), Bureau of Indian Standards
15.	Mr. T. S. Vijay	H Director, Ministry of Statistics & Programme Implementation
16.	Dr. Neeraj Saxena	Scientist 'E', TIFAC, DST
17.	Mr. Anupam Sharma	OSD, Department of Atomic Energy
18.	Dr. T. Madan Mohan	Advisor, Department of Atomic Energy
19.	Mr. Ashok K. Verma	S.O., Department of Food &PD
20.	Mr. Abhishek Chandra	Director, Ministry of Shipping
21.	Mr. D. K.	Director, DP & PD
22.	Mr. Pankaj Mishra	Pr. Consultant, DP &PG
23.	Mr. N. F. Husain	Director, SE&L, MHRD
24.	Mr. P. K. Banerjee	Dy. Secretary, DADF, Ministry of A&FW
25.	Mr. G. Janardhan	Tech. Director, NIC-DADF
26.	Dr. Parveen Kumar	Scientist 'F' Ministry of Earth Science

S No	Name	Designation, Organization
27.	Brig. Pradeep A.	Director, Standardisation Dept of DP, Ministry of Defence
28.	Mr. G. C. Aron	Director, Ministry of I & B
29.	Ms. Kamini K.	Technical Director, NIC-Culture
30.	Mr. Suyash Narain	Director, Ministry of Civil Aviation
31.	Mr. S. Sathiyamani	Scientist 'F', Department of Heavy Industry
32.	Mr. Shersha	Director, Ministry of Mines
33.	Dr. K. R. Murali Mohan	Advisor, DST
34.	Dr. Rajeev Sharma	Scientist 'D', DST
35.	Mr. B. Praveen	Director, Department of Commerce
36.	Mr. Sanjay Chavre	Sr. DO, D/O H.I.
37.	Ms. Sunita Chhibba	Senior Advisor, IAS, MSDE
38.	Dr. R. Pitchiah	Scientist- G, MeitY
39.	Mr. G. S. Malik	Sr. Consultant, MHRD
40.	Mr. AVM V Gaur	Tech. Manager, MoD
41.	Mr. Promode Kr. Singh	Under Secretary, DAC
42.	Mr. Arkaja Dar	Asst. Director General, Dept. of Posts
43.	Mr. V. K. Agrawal	Head-IT, CSIR HQ
44.	Mr. Vimal Kumar Varun	Scientist- F, DSIR
45.	Ms. Anamika Nigain	Section Officer, MHRD
46.	Mr. Paresh Kumar Goel	Director- IT, MoRTH
47.	Mr. Saji K. Abraham	Tech. Director, NIC, MNRE
48.	Ms. Alka Arora	Pr. Scientist, ICAR-IASRI
49.	Mr. Shuvadeep Ray	Consultant, MSDE
50.	Mr. Jitendra Kumar	Director, MoFPI
51.	Dr. Sanjay Kumar	Director, DFS
52.	Mr. Dharmesh Makwana	Director, Department of consumer affairs
53.	Mr. M. Rajendran	Under Secretary, M/O Information and Broadcasting
54.	Mr. Rakesh Kumar	Deputy Secretary, D/O Fertilizers
55.	Dr. Lily Mitra	Chief Consultant, M/O Agriculture

Technology Information, Forecasting & Assessment Council (TIFAC) is an autonomous body set up under the Department of Science & Technology in 1988. It is primarily mandated to undertake Technology assessment and forecasting studies in select areas of national importance, watch global technology trends, promote key technologies and provide information on technologies. Inputs based on TIFAC activities and pursuits have been useful in setting directions for future preferred technological development options in important socio-economic sectors.

Major contributions of TIFAC to the nation have been the Technology Vision 2020 released in 1996 and its sequel Technology Vision 2035which was released by Hon'ble Prime Minister during the Indian Science Congress in 2016. The vision document expresses the needs and aspirations of Indians in 2035 in terms of prerogatives and identifies technologies towards their fulfillment and is being followed up with 12 sectoral technology roadmaps for realization of the vision.

TIFAC has made significant contribution to national Science, Technology & Innovation system by carrying out a number of Technology Assessment, Technology Forecasting and Techno-Market Survey studies spread over sectors of economic importance to India besides supporting Technology Innovation and Technology demonstration projects. Besides a review of technology status in India vis-à-vis global trends based on market pulls and technology push, the reports provide an assessment of the practical aspects of end-user and profitability in business ventures using different new technologies.

The uniqueness of TIFAC also gets reflected in the diversity of areas it deals with and its networks through which it has executed projects involving knowledge intermediation. Major TIFAC programmes over the years include Sugar Technology Mission, Fly Ash Mission, Advanced Composites Mission, Home Grown Technology (HGT) Programme, Technology Vision 2020 mission-mode projects (Agriculture, Agro-Food Processing, Health Care, Herbal/ Natural Products, Higher S&T Education- Mission REACH, Textile Machinery, Road Construction & Transportation Equipment, Bioprocess & Bio-products Programme, Synergizing Science & Technology with Judicial Processes, Collaborative Automotive R&D (CAR), SME Technological Upgradation Programme, TIFAC-SIDBI Technology Innovation Programme, Technopreneur Promotion Programme (TePP), Patent Facilitating Center (PFC) and the Technology Refinement & Marketing Programme (TREMAP).

TIFAC with its core mandate of Technology Foresight and experience of implementation of several mission-mode technology intermediation programmes, preparing DPR for National Innovation Project (NIP), participating in the National Mission on Strategic Knowledge for Climate Change (NMSKCC) etc, has taken up the assignment of preparing a Detailed Project Report (DPR) for implementation of National Mission on Interdisciplinary Cyber-Physical Systems (ICPS)

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The team working on this endeavor has studied, consulted and referred a very large number of research papers, reports, books, other public domain documents and presentations; in addition it has participated in number of CPS related conferences/seminars held recently in the country. A list of the materials referred has been included in the Bibliography given in the report. Many ideas from the above materials and personal interactions have directly or indirectly become the part of this DPR. The team would like to acknowledge with thanks the valuable contributions made by the various authors of these interactions, documents and presentations. It is requested that this may be taken as the personal acknowledgement for each and every one whose ideas have found place in this report.

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Potential Application Areas

The deployment, control, performance evaluation and security of CPS systems require both theoretical advances and system-level demonstrations. CPS could find important applications in India in future.

Electric power systems include the traditional electric power networks but also new constructs such as micro-grids, fleets of plug-in hybrid vehicles interacting with the grid, and electricity demand response by cooperation among devices within a building or home. India, being an energy-starved nation, developing smart, efficient and reliable power networks needs to be of utmost priority.

Transportation systems is an established area of research, but sensor networks, crowd-sourcing, smart parking, smart traffic lights, and vehicular communication networks are promising significant improvements. This will also be applicable to other mass transit systems like rail and air transport.

Sensor networks, often wireless, that have all characteristics of communication networks but with the addition of sensors which interact with the physical world. Examples of control-related problems concern estimation, consensus, averaging, and decision making over networks.

Communication systems and networks include both wireline and wireless networks and have to be modeled, controlled, optimized, priced, simulated, and secured. Particular control-related problems in this domain include: flow control, routing, admission control, dynamics of the spread of viruses and malware, and interactions among competing entities (network economics).

Systems of autonomous agents include networks of robots and UAVs giving rise to problems such as swarming, consensus, cooperative control, motion planning, formation control, deployment, robustness, and bio-inspired control. These can be used for numerous defence and civilian applications.

Health Care will see introduction of new automation tools to ensure effective delivery of services. The use of smart and mobile computing, wide availability of affordable and reliable MEMS and imaging sensors, growth of data analytics and augmented reality can be used to design and develop new medical engineering devices/systems.

Industrial Automation may witness integration of emerging technologies such as wireless sensor networks, increased computational power into industrial and process automation. Thus, the security of any automation system becomes increasingly critical as several networks are connected resulting in a system of systems, in a collaborative manufacturing environment.

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