Detailed Project Report (DPR)

# Technology Innovation Hub (TIH)
# on
# System Simulation, Modeling & Visualization

**Under**

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

IITI DRISHTI CPS Foundation
Indian Institute of Technology Indore
September 2021

# Endorsement from Head of the Institution

भारतीय प्रौद्योगिकी संस्थान इन्दौर
सिमरोल, इन्दौर 453 552, भारत

Indian Institute of Technology Indore
Simrol, Indore 453 552, India

Office : +91 731 2438711
+91 731 2438712

Fax : +91 731 2438710
E-mail : psdirector@iiti.ac.in

IIT Indore

## Endorsement from the Head of the Institution

1. Certified that the Institute welcomes participation of Dr. Bhupesh K. Lad as the Project Director for the Technology Innovation Hub (TIH) and that in the unforeseen event of discontinuance by the Project Director, the IIT Indore will identify and place a suitable faculty as Project Director for fruitful completion of the TIH activities.

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

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

**Date: September 17, 2021**
**Place: Indore**

INDIAN INSTITUTE OF TECHNOLOGY INDORE

17/09/2021

**Prof. Neelesh K. Jain**
**Director (Officiating)**

# Certificate from Project Director

भारतीय प्रौद्योगिकी संस्थान इन्दौर
यांत्रिक अभियांत्रिकी विभाग
खण्डवा रोड, सिमरोल इन्दौर - ४५३ ५५२ (म. प्र.), भारत

Indian Institute of Technology Indore
Department of Mechanical Engineering
Khandwa Road, Simrol, Indore - 453 552 (M.P.), India

IIT Indore

## CERTIFICATE

**Name of the TIH:** IITI DRISHTI CPS Foundation

**Technology Vertical:** System Simulation, Modelling & Visualization

1. This is to certify that the Detailed Project Report (DPR) on the Technology Vertical System Simulation, Modelling and Visualization is prepared and submitted to Mission Office, NM-ICPS, DST is as part of implementation of Technology Innovation Hub (TIH) at IIT Indore, Khandwa Road, Simrol, Indore, Madhya Pradesh, 453552 under National Mission on Interdisciplinary Cyber-Physical System (NM-ICPS).

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

3. The DPR will be implemented as per the Terms, Reference and Clauses stated in Tripartite Agreement signed on 31st Dec. 2020 between Mission Office, DST, IIT Indore and IITI DRISHTI CPS Foundation.

Date: 15th Sep 2021

Place: Indore

Dr. Bhupesh Ku. Lad,
Project Director

# Executive Summary

Cyber Physical Systems (CPS) herald unprecedented levels of capabilities and possibilities across a wide range of applications. It would not be wrong to say that CPS has the potential to positively impact the life of every individual on the Earth. In this respect, the Government of India has very timely launched the National Mission on Interdisciplinary Cyber-Physical Systems (NMICPS) with the intent to effectively capitalize and realize the potential of this rather virgin area. It is under the aegis of the NMICPS that the Technology Innovation Hub for System Simulation, Modelling, and Visualization of Cyber-Physical Systems was set up at IIT Indore. Aptly christened DRISHTI CPS that stands for **DR**iving **I**nnovation through **S**imulation **H**ub for **T**echnologies in **I**nterdisciplinary **C**yber **P**hysical **S**ystems, the hub is invested in developing into a single stop facility for CPS design and modelling and its applications thereof. The goals and objectives of DRISHTI CPS are clearly laid down in Chapter 2 of this DPR.

Understandably the spread of CPS has led to a *mushrooming* of developers and designers of such systems. It is not uncommon to find offerings of almost every application or product that the mind can imagine and perhaps beyond at surprisingly throwaway prices. Sadly, it is also not uncommon to see such products offer significantly below par facilities and functionalities. The standards of functional and non-functional capabilities expected of CPS deployments are very high given the critical applications that these often cater to. Failure in these deployments, be it in their physical, software, or communication systems, is not just undesirable but can also be catastrophic. This calls for a sound design of these systems based on appropriate modelling in spite of their heterogeneity that stems from continuous physical components, and discrete computation systems working together. Developing a homogeneous model for a heterogeneous system is what makes the task so challenging. The first motivation of DRISHTI CPS is therefore to devise means for appropriate design and modelling of CPS. Chapter 3 of this document has details on the available approaches adopted for designing and modelling CPS based systems. With design and modelling being the primary thrust area of DRISHTI CPS, it is imperative that the ideas explored be applied and validated in relevant domains. We chose the two extreme ends of the spectrum. The first application area of CPS that we consider are Industrial Systems, perhaps the most ordered and disciplined system; and the other is the least ordered and most chaotic system, the Social System. Each domain is explored in terms of the existing state of the art for modelling, simulation, and visualization and technology gaps are identified. The latter part of Chapter 3, in this document, has details on CPS based applications in industrial and social settings. Figure I portray the few challenging problem areas which are initially identified through our literature survey. These problems are discussed in Chapter 4. Further, inputs of end users and line ministries are continuously being captured based on initial problem areas identified in Figure I. This is has further helped us to identify some of the "Marquee Areas" for immediate focus of the Hub. These areas listed below.

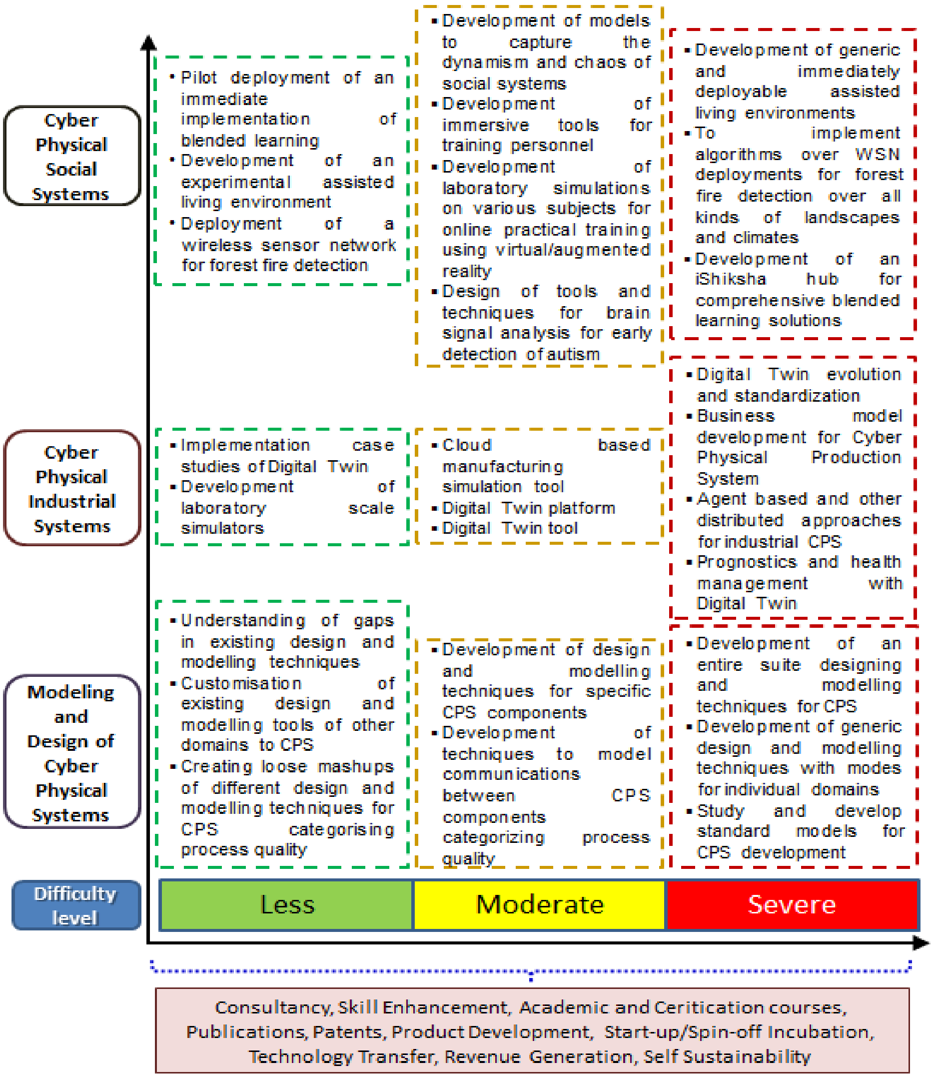


**Figure I:** Immediate technical focus of IITI DRISHTI CPS Foundation

## Digital Twin: Under following applications (not exhaustive)

- **Manufacturing and Machine tools**: digital twin for shop floor management, digital twin for manufacturing supply chain management, digital twin to improve product design, digital twin evaluation over the product lifecycle, digital twin based generative product design.
- **Healthcare:** digital twin for personalized treatment (patient-centric), pre and post-operative surgical procedure on digital replica to reduce the risk, advanced patient centric computation models for designing digital twins of human organs, digital twin in hospital management, digital twin to test drug efficiency and side effects, digital twin for healthcare supply chain management, digital twin in healthcare training.
- **Smart Farming:** digital twin of farms, livestock and machinery, digital twin-based farm management, heard management, farming supply chain management, digital twin for supporting agri-insurance, digital twin to support agriculture-based policy making.
- **Smart Cities and Smart Societies:** Digital twin for waste management, DT based future mobility solutions, disaster management using digital twin, use of DT to improve the quality of life (Assisted living for example), quality services, traffic management, performance management, and interactivity between different service providers of smart cities.

### Blended learning and Gamification

- Micro and nano learning modules development, digital assessment, Big data analytics for personalized leaning, gamification of course content, use of AR/VR/XR in gamification of course, virtual hands-on setups, cloud ERP or similar system for e-learning.

It is important to note that these areas mark the starting point of the work of the hub. The endeavours of the hub are expected to swell to many more problem areas with continuous inputs from end users, as we progress through the venture. This will eventually cast DRISHTI CPS as a technology accelerator in the direction of simulation and modelling for CPS.

Seated within the premises of IIT Indore, the hub has access to some of the best brains in the country across disciplines and areas of research. The aim is to harness these and closely engage with the industry to ensure that the endeavours result in tangible products and technologies. To bolster the working efforts of personnel involved, DRISHTI CPS plans to support *start-up* enterprises in the direction of CPS application development, adhering to the structured modelling, simulation, and visualization ideas developed. Details on the strategy and planned outcomes of the hub are included in Chapters 8 and 10 respectively. Figure II summarizes the overall framework adopted by DRISHTI CPS. A description of the management structure of DRISHTI to handle this framework is included in Chapter 6.

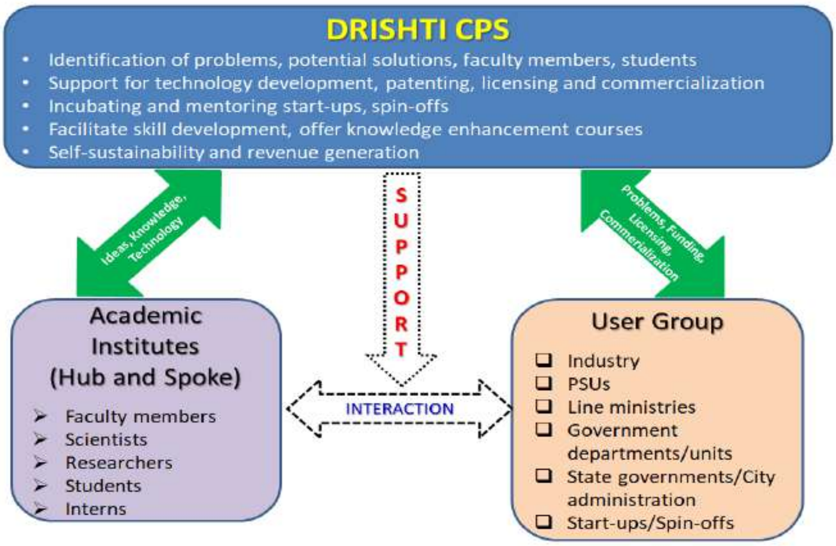


**Figure II:** Framework for interaction with various stakeholders at DRISHTI CPS.

Line ministries, Public Sector Units (PSUs), government agencies, defence establishments, state government departments are expected to be the major beneficiaries of the endeavours of DRISHTI CPS. The attempt would be to consistently obtain problem statements from these units and identify appropriate teams in the country to work on these and implement appropriate technology solutions. These ventures are expected to positively impact the lives of common people in the country and will ultimately contribute to initiatives of the Government of India such as *Digital India*, *AatmaNirbhar Bharat*, *Make in India*, *Smart Cities,* and the like. Details on the beneficiaries of DRISHTI CPS are available in Chapter 5 of this document. It is expected that the funds generated by the activities of the hub will make it self-sustainable over a period of four to five years.

# DPR Preparation Core Committee

At Indian Institute of Technology Indore (IIT Indore) an interdisciplinary committee of following faculty members worked for the completion of this Detailed Project Report (DPR).

1 Prof. Abhinav Kranti, Professor, Discipline of Electrical Engineering, IIT Indore

2 Dr. Abhishek Srivastava, Associate Professor, Discipline of Computer Science and Engineering, IIT Indore

3 Dr. Ankur Miglani, Assistant Professor, Discipline of Mechanical Engineering, IIT Indore

4 Dr. Bhargav Vaidya, Assistant Professor, Disciple of Astronomy, Astrophysics and Space Engineering, IIT Indore

5 Dr. Bhupesh Kumar Lad, Associate Professor, Discipline of Mechanical Engineering, IIT Indore

6 Dr. Kiran Bala, Discipline of Biosciences and Biomedical Engineering, IIT Indore

7 Dr. Pavan Kumar Kankar, Associate Professor, Discipline of Mechanical Engineering, IIT Indore

8 Prof. Sandeep Chaudhary, Professor, Discipline of Civil Engineering, IIT Indore

# Contents

# Chapter 1

# Background and Motivation

Most modern systems today have a digital presence in addition to being extensively interconnected via Internet of Things (IoT) deployments. Such systems, popularly known as Cyber Physical Systems (CPS), are capable of taking autonomous decisions using data analytics and artificial intelligence. There has been a rapid proliferation of CPS in the lives of human beings. The National Mission on Cyber Physical Systems clearly highlights the important part that CPS will play in the progress of the country. There is a definite positive impact that CPS is slated to have in our daily lives in the years to come. There are challenges, however, when it comes to effective modelling, simulation, and visualization of CPS deployments. For example, simulation environments for CPS normally include a distributed interactive framework with a loosely coupled architecture. In such a context, figuring out an appropriate level of abstraction in modelling CPS would be important in achieving desired results and responsiveness.

Unlike commercially available products (simulation software) that rely on centralized computing, the next generation of modelling and simulation tools/products will have a cloud based distributed architecture. In fact, several companies have already started migrating their existing products to such platforms. Despite this, the area of system simulation, modelling and visualization is challenging as it is a complex system consisting of both physical and computation components. Modeling requirements for both the components are pole apart. Therefore, development and application of such commercially viable products still need to be explored. The proposed Technology Innovation Hub (TIH) at IIT Indore is conceptualized to address this need.

The Technology Innovation Hub (TIH) at IIT Indore is named IITI DRISHTI CPS Foundation *i.e.*, IIT Indore (IITI) **DR**iving **I**nnovation through **S**imulation **H**ub for **T**echnologies in **I**nterdisciplinary **C**yber **P**hysical **S**ystem (**DRISHTI CPS**) Foundation. For brevity, IITI DRISHTI CPS Foundation will be referred to as DRISHTI CPS.

DRISHTI CPS plans to lead in skill enhancement, technology development, and product commercialization in the domain of system simulation, modeling and visualization of Cyber Physical Systems. The overarching objective of the proposed hub is to create an ecosystem that supports the development and commercialization of technologies facilitating modelling, simulation, and visualization of CPS. This objective will be achieved in the true sense when a self-sustaining system is created over a period of time that supports research and development projects, patenting, licensing, and commercialization, incubation of start-up companies and spin-offs, and initiation of joint projects with the industry. The hub would also contribute directly to the development of skilled human resources by organizing knowledge sharing and training activities that would include but not be limited to industry driven courses (executive development programs, continuing education programs), hands-on training, webinars, events, workshops, grand challenges, conferences, hackathons, online courses and tinkering activities.

Knowledge generation at the TIH would be channelised to cater to India's growing demand for professional competence in this field. Research, development, training and incubation under the TIH will support and be along the lines of flagship initiatives of the Government of India such as Skill India (SI), Make in India (MII), Prime Minister's Employment Generation Program (PMEGP), Start-up India and the recently coined Atmanirbhar Bharat. This will go a long way in ensuring that a large body of graduate and

undergraduate students is exposed and trained in this domain. All this will contribute towards achieving academic proficiency and lay a strong foundational framework in building national capacity in the areas of science and engineering besides contributing to the economic growth of the country.

The seamless integration between the physical and the cyber world has had a tremendous impact on society in general and the scientific community. It has completely transformed our perception of conventional physical systems in terms of design, use, maintenance, disposal/discard or reuse. This remarkable convergence of the physical and cyber world is aptly referred to as a cyber physical system. Understandably, there have been innumerable endeavors at comprehending and harnessing the nuances of cyber-physical systems. Among these, system modelling, simulation and visualization is integral especially in a world galloping towards interdisciplinarity. For instance, conventionally developed centralized models for manufacturing shop floor performance are now evolving into agent-based models for distributed decision making. An approach that has the world look at manufacturing from a totally different perspective. Perhaps the greatest impact cyber-physical systems have had is the advancement they have heralded in medical sciences wherein vital parameters of the human body can very explicitly be modeled and analyzed lending a much superior vantage point to practitioners. Furthermore, the social impact of cyber-physical systems is immense. The Aarogya Setu app of the Government of India to trace COVID-19 cases is an appropriate case in point aptly demonstrating the efficacy of such systems in the social context. However, using modelling and simulation to design and optional and efficient CPS for various applications is an open area of research. In fact, an ecosystem is required to bring such technologies to the users.

Realizing the importance of cyber physical systems and exploiting the vast expertise available at IIT Indore in system simulation, modelling and visualization, initially the TIH has identified two major thrust areas:

- Cyber Physical System Design
- Application specific development in CPS: Industrial and Social systems

The same is depicted in Figure 1.1.

CPSs are networked engineered systems that are coupled to the physical world through tightly coupled algorithms. System Simulation, Modeling and Visualization (SSMV) are integral to most Cyber Physical Systems' (CPS) solutions. Ideally, a model should be predictable and emulate the physical system. The challenge from a modeling perspective is to be able to model a networked system of systems from different engineering spheres.

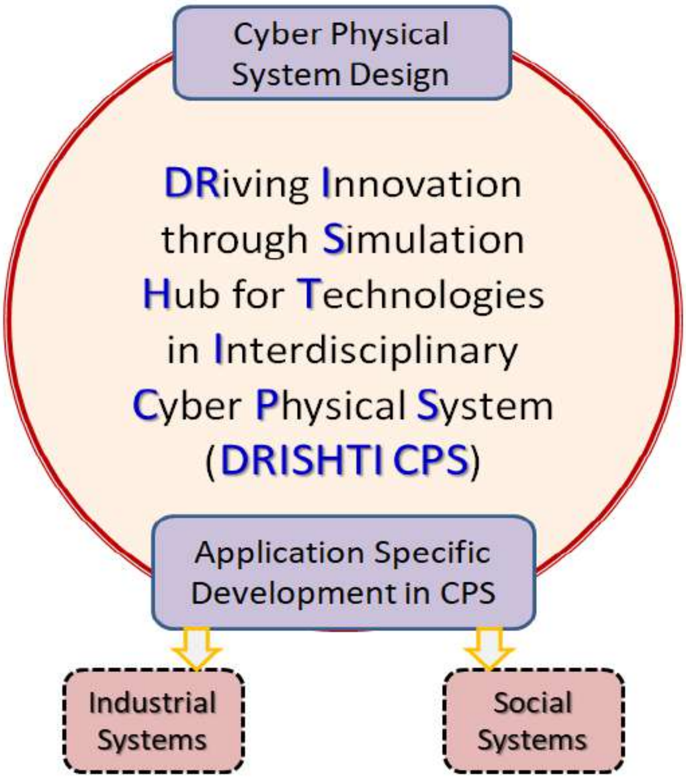


**Figure 1.1:** Thrust areas of DRISHTI CPS.

Designing of CPSs requires modeling abstract knowledge for development purposes. The abstraction in different segments of CPS can also be at different levels which prohibits a straightforward generalization. Given that a CPS is a heterogeneous combination of multi-domain physical and computational systems, and is thus a significantly complex system, it is imperative to employ both static and dynamic models to properly understand and study its characteristics and behavior. Probabilistic models, therefore, need to be appropriately harnessed to handle such uncertainty. With the above aspects in mind, the thrust of DRISHTI CPS has been divide into two primary areas (as shown in figure 1.1), first would be to develop an appropriate and generic process model for simulation, modelling and visualization of CPS, and the second area would highlight the design and development of CPS in specific application domains. In no two domains is this distinction starker than in the domains of industrial systems and social systems. Industrial systems are systematic, structured, predictive, and compact. Social systems, on the other hand, are chaotic, random, loose, and entirely unpredictable. CPS interestingly plays predominant part in both and simulation and modeling of such CPS systems is imperative.

Diverse customer demands are increasing the need for improved flexibility, adaptability, and transparency of production processes, and hence, traditional manufacturing systems must change. CPS technologies are being increasingly applied in industrial manufacturing to bring about the change. A reference architecture can be developed that would provide the structural framework and the design guidelines for realizing industrial demonstrators. These will facilitate modelling and simulation of CPS with scalable complexity, integration and modularity, while accounting for variation in size and incorporating the elements from both digital and physical spheres. In CPS, information from all related perspectives is closely monitored and synchronized between the physical factory floor and the cyber computational space. Such trends are fast transforming manufacturing industries and taking them to the next generation, namely Industry 4.0 or smart manufacturing.

Cyber Physical Social Systems (CPSS) utilizes the reach into the real world of CPS to melt the gap between the virtual and the physical worlds. Crowdsourcing and crowdsensing are other related and powerful offshoots of CPSS wherein the 'crowd' armed with smart devices provide information and content to draw useful and strategic conclusions. The unique nature of CPSS enables it to significantly contribute across domains such as Context Awareness, Smart Transportation, Smart Cities, Gamification for Blended Learning and Assisted Living Environments.

These thrust areas are considered initially and are likely to be appended with new areas based on expressions of interest by the industry, line ministries, start-ups, and the wider research community.

# Chapter 2

# Aims, Objectives and Activities

## A. Aims

a) Creating a knowledge hub in the area of cyber physical systems, in general and system simulation, modelling and visualization, in specific.

b) Supporting various initiatives of the Government of India such as Digital India, AatmaNirbhar Bharat, Make in India, Smart Cities, Sugamya Bharat Abhiyaan, and National Education Policy, and various other immediate and long term needs of the country.

c) Achieving self-sustainability of technology innovation hub IITI DRISHTI CPS Foundation (Section 8 company) within 4-5 years of time.

With above aims in mind, objectives of the company are decided and are listed below. To achieve these objectives, some of the key activities are decided and the same are listed at the end of this chapter.

## B. Objectives

a) To create a pool of experts in the relevant technology domain from India and abroad

b) To continuously identify the technology needs and challenges both from research and application point of view in the area of CPS in general, and system simulation, modelling and visualization in specific.

c) To ensure best utilization of the experts towards the development of required technology (products/tools/kits/algorithms/techniques)

d) To develop a mechanism for faster commercialization/licensing of the developed technologies to the industries, PSUs, line ministries, government agencies, state government departments, etc.

e) To ensure faster development and use of the developed technologies by the end users

f) To create a startup ecosystem in relevant technology areas

g) To create platform and programs for imparting required skill and knowledge to industry personnel and generating trained manpower (students, interns, teachers, trainers) in the area CPS in general and system simulation, modeling, and visualization in specific

h) To ensure the required spread of awareness the works carried out at IITI DRISHTI CPS Foundation.

Some of the key activities to achieve the above objectives are listed below.

## C. Activities

a) Identifying and involving various experts in this area

b) Continuous literature review

c) Continuous interactions with industries, line ministries, PSUs., government departments and units to capture their needs/problems

d) Floating call for proposals and support technology development in focused technology areas

e) Continuous monitoring and review of projects supported by the Hub

f) Identification and support of startups

g) Developing models for revenue generation for the company through shares of start-up/spin-off incubated, technology licensing/commercialization, skill enhancement courses, etc.

h) Development of skill centers

i) Creation of various CPS bases across the country

j) Wider publicity through social and other digital media

The details and the approach towards these activities with well-defined goals are reflected in chapter 8 i.e. Strategy.

# Chapter 3

# Existing Knowledge and Key Gaps

## 3.1 Introduction

System Simulation, Modeling & Visualization are integral to Cyber-Physical Systems' (CPS) development and applications. CPS is a rather complex system as it is mostly an intricate combination of physical and digital systems. Such systems are poles apart. Physical systems operate in continuous time and are governed by the laws of physics. Computational systems, on the other hand, operate in discrete time and are largely based on logic. Figure 3.1 shows working of any CPS. To add to this is the overarching fact that CPS specifications are mostly dynamic in nature.

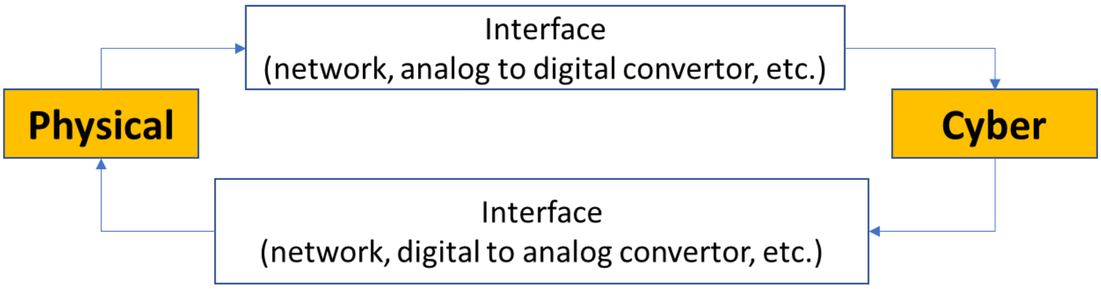


**Figure 3.1:** Overview of working of Cyber Physical System

Like all systems, to appropriately design a CPS it is prudent to comprehensively model the same. Modelling of CPS helps properly understand its structure and functionality. It provides a proper proof of concept of the system and significantly contributes to reducing development cost and time. Given that a CPS is a heterogeneous combination of multi-domain physical and computational systems, and is thus a significantly complex system, it is imperative to employ both static and dynamic models to properly understand and study its characteristics and behavior. Static modeling employs user-defined values of the parameters involved and an appropriate simulation environment; whereas dynamic modelling entails complex computations, and predictions on the behavior of the system.

In addition to modelling, simulation and visualization are also generously harnessed with CPS to understand its behavior and interactions with other systems like the data analytics' engine, the communication, etc. A very good example of this is from an industrial setting wherein detailed models of CPS systems are created in the form of 'digital twins' of the involved machines. To study the interactions between these models, an extensive simulation environment is developed that permits developers to play around with the parameters and identify the best conditions. The entire environment is appropriately visualized so as to provide an intuitive understanding of the system to all the stakeholders.

Modeling, Simulation, and Visualization of CPS systems as described above, across domains, is non-trivial. Each domain is unique and has significantly diverging characteristics. There are distinctive challenges, therefore, in each domain. The current approach to CPS development is more about 'putting the product together' and little or no effort is placed on a systematic and structured plan of doing this. Such approaches place significant premium on individual brilliance and lack an ecosystem of repeatable development. It is more about the functional characteristics being catered with no concern for the non-functional or quality aspects. This is acceptable during the initial phase of a technology but is far from sustainable in the long run.

With this in mind, we propose to divide the focus of the TIH into two primary areas: the thrust of the first area would be towards developing an appropriate and generic process model for simulation, modelling & visualization of Cyber-Physical Systems; and the second area would highlight the design and development of CPS in specific application domains. The application domains we choose are: Cyber Physical Industrial Systems and Cyber Physical Social Systems. Industrial systems are relatively systematic, structured, predictive, and compact. Social systems, on the other hand, are chaotic, random, loose, and entirely unpredictable. CPS interestingly plays a predominant part in both, and simulation and modeling of such CPS systems is imperative. The endeavor is to effectively manoeuvre both application ends of the spectrum without losing sight of the bigger picture of CPS design.

In this chapter, we comprehensively review literature on these two primary areas viz.,

*Section 3.2: Cyber Physical System Design*

*Section 3.3: Application specific development in CPS simulation, modeling & visualization*

At the end of each section, we identify gaps for further development.

## 3.2 Cyber-Physical System Design

CPSs are engineered systems, controlled, or monitored by computer-based algorithms tightly integrated with the physical world. CPSs are potentially networked. Like any other engineering system, design of CPSs requires modeling to abstract knowledge for development purposes. Models help in analyzing and simulating the system. They help in validating both functional and non-functional (e.g. reliability, security) characteristics. Ideally, a model is expected to be perfectly predictable and as close as possible to the real system. The challenge with modelling CPS is that this is a 'system of systems' from multiple engineering domains connected through networks. The knowledge disciplines and these are understandably difficult to integrate.

Each system that is part of the larger CPS system does modeling at a different level of abstraction. In addition to these are the integrating systems comprising computers, software, networks. Generalizing across such disparate landscapes is the issue that needs to be addressed while modeling CPS. The biggest stumbling block in this integration of models is the fact that physical systems within the CPS work on continuous time dynamics whereas computation systems work on discrete time dynamics. Getting these to work together whilst retaining the integrity of the model in terms of synchronized calculations, networking, timings is a major challenge [1].

The requirements of modelling these disparate and heterogeneous systems and their communications in a harmonious manner in a CPS is what makes the existing "modelling approaches, framework, and architecture inadequate" [2].

The current approach to designing CPS systems mainly includes the following stages [3]:

- Early design stage
- Detailed design stage
- Verification stage

The early design stage of CPS design involves viewing the system at an abstract level and segregating the disparate systems from each other. The utility of this stage is that it provides a very clear view of the entire landscape of the CPS system to be developed.

The detailed design stage is associated with handling each individual system of the CPS separately. The native design approach of the system is employed, and detailed design specifications are articulated. Tools like CAD, CAM are used for mechanical systems; ECAD is used for designing electronic systems; UML is used for software system design, and so on.

The verification stage deals with the integration of these systems into one large system and verifies the efficacy of the workings. It deals with the communication issues, deals with the heterogeneity in the formats of the data being shared, and does an overall verification of the working of the system.

This may appear right, but the fact of the matter remains that the various modelling approaches used for individual systems are not compatible with each other by a distance. This is exacerbated by the fact that the interactions between individual systems within the larger CPS systems increases exponentially with demand for greater functionality from such deployments. The approach for designing such demanding CPS, therefore, falls by the wayside and most developers adopt an arbitrary approach to integrate these heterogeneous systems. Their approach is simple: to debug until there are no bugs. This is unfortunately not an ideal approach and falls well short of providing quality products.

There are approaches and tools that make an endeavor to understand the complexity of CPS and provide adequate platforms for designing the same. These include the Programming Temporally Integrated Distributed Embedded Systems (PTIDES) - programming model for a distributed real-time embedded system [4]; Giotto – programming language for real time CPS [5]; and Ptolemy 2 – the modelling and simulation environment for heterogeneous systems [6]. Other model-based design and development approaches are Model-driven Architecture (MDA) [7] and Model-Integration Computing (MIC) [8]. These solutions are promising but have their own limitations and need further research to make them comprehensive solutions for the design of CPSs.

The following sections summarize the various aspects of CPS design from the system simulation, modelling and visualization point of view.

*3.2.1 Architecture and Modeling of CPSs*

*3.2.2 Simulation of CPSs: Tools and Frameworks*

*3.2.3 Verification and Validation of CPSs*

### 3.2.1 Architecture and Modeling of CPSs

In the last few years, heterogeneity in CPS is handled by researchers using various modeling methods and associated design methodologies and tools. As CPS involves both digital and physical components, modelling these distinct domains and integrating them together is challenging. As discussed earlier, digital components are normally discrete, whereas the physical components operate on a continuous time scale.

Classical software engineering models like Statecharts [9] that can model the dynamic nature of the system and support connectivity and automated verification. However, these are limited in terms of managing continuous phenomena and thus they are not useful for modeling a CPS. Similarly, models and tools, such as differential equations [10] and Simulink [11] can handle continuity well but they are constrained when the system has discrete constituents.

To cater to the heterogeneous nature of CPS, hybrid models are employed. Hybrid Automata [12] is an example of such an approach that harmonizes discrete and continuous system dynamics. In its simplest form, hybrid automata combine continuous evolution through differential equations with discrete state jumps. However, such models are quite complex due to a lack of modularity. Also, the scalability of such models is limited [13].

Some of the commonly used modeling methods are reviewed below.

#### A. Discrete Modelling Methods:

Certain discrete models describe complex states and their relationships as data schemes and object models. Alloy [14], TLA [15], Object-Z [16], VDM-SL [17] are examples of this category. Such models can handle complexity in large-scale software systems by employing modular design. These are also quite capable of handling scalability problems in software development. Other discrete modelling techniques focus on describing processes through system state transitions and changes [18]. These are based on algorithmic notations and different state machine forms [19].

*Examples of this category include*- Process algebra (such as CSP and FSP); Transition systems (statecharts and Promela/Spin); Petri networks; Dynamic logic (based on JML specification) and Reactive models.

## B. Continuous Modelling Methods:

Modelling of physical processes such as mechanics, thermodynamics, and electromagnetism is normally done by solving differential equations. These equations describe the system using state variables such as location and/or temperature, triggering conditions, and their development rules to assess the state of the system [19]. Such models are useful for simulations, theoretical analysis, and also for predicting future states of the system. Platforms used to create such models include Simulink (Matlab) [11] and SCADE [20].

## C. Hybrid Modelling Methods:

Hybrid Modelling techniques utilize mathematical equations to handle both continuous and discrete components of a system. They are often formalized as an extension of finite state machines like hybrid automata with a finite set of continuous variables whose values are described by a set of ordinary differential equations. [21]. The major challenges in defining a good hybrid system modelling language include [22]:

- Ensuring that models of deterministic systems are not based on arbitrary decisions made by a numerical differential equation solver.
- To appropriately represent simultaneous yet causally related events

[23] describes and compares various tools that support hybrid systems modeling and simulation. [24] and [25] elucidate the idea of using Models of Computation (MoC) that provide determinate semantics to hybrid systems. An open-source tool HyVisualis described in [26] that is quite useful for such hybrid modelling. In [27], abstract semantics are employed for representing hybrid systems as MoCs. This permits effective integration of heterogeneous hybrid systems and the interactions amongst components.

## D. Component and Connector (C&C) Modelling Methods:

An important requirement of CPS design is to enable various models running on different platforms to communicate and meet specific execution time requirements. Such disconnect between domain experts and software developers normally make CPS development rather challenging. Component and Connector (C&C) models are widely used to overcome such issues [19]. In C&C modelling, complex functions are subdivided hierarchically into sub-functions. These sub-functions are developed and managed by different domain experts. The idea in C&C modelling is to depict architectures as components that perform distinct functions and interact with other components through well-defined interfaces. The thrust is towards logical communication, and this permits individual developers to independently work and design their respective portions.

The following sections briefly discuss the various design methodologies for CPS that use some of the above discussed modelling techniques:

### I) **Model Based Development:**

As the name suggests, model-based design (MBD) utilizes mathematical modeling frameworks for different aspects of modelling such as designing, analysis of relevant parameters, evaluation and subsequent verification, and finally validation under various operating conditions. These often include evaluation of design extremes for a worst case evaluation. The MBD approach is well suited for both the discrete (cyber) and the physical components of CPS that need to be carefully designed and validated for various simulation scenarios. Such scenarios include *model-in-the-loop*, *software-in-the-loop* and *hardware-in-the-loop* [28]. The approach for modelling CPS can be structured in a manner to first focus on the physical part of the system, and after verification, the control part can be developed. The verification of the control part is essential and can be carried out through 'model-in-the-loop' simulations.

Owing to the sequential design process, reducing the design time for the physical components and control systems is a challenge. The sequential design process requires longer design time as it includes both the design time of the physical components and the control system [29]. In addition to time, the other challenge is appropriately testing and verifying the system. The latter can only be done after proper integration of the physical components and the control system [29]. This becomes difficult as it is a unified abstraction approach for cyber parts and the physical parts are rarely available in the CPS design literature. Literature in CPS design methods is limited to handling the cyber and physical parts separately. A software integrated multi-domain design methodology is therefore needed for CPS.

[30] uses an adaptive discrete event (ADE) model for CPS modelling. It incorporates discrete event calculus (DEC) to avoid inconsistencies in the specification of domain rules. The authors introduce an abnormal reasoning set to handle unanticipated events. The approach was clearly demonstrated using an object-motion tracking CPS system. A CPS architecture based on temporal and spatial properties of events is discussed in [31]. Events are represented as a function of attribute-based, spatial, and temporal event conditions. To capture the complex relationships between components of a CPS, the different types of event conditions are combined using logical operators. [32] discusses a ten steps iterative model-based design methodology. The approach is demonstrated using a Turning Ball Device example.

[33] proposes two variants of model-based design viz. "cyberizing the physical" and "physicalizing the cyber". These methods differ in terms of whether they are wrapped around software abstraction or abstractions of a physical subsystem. Using these approaches one can bridge the challenges in effectively modelling interactions of cyber and physical systems. [34] utilizes multi-modal dynamics to model CPS. In this approach, each mode is handled separately, and the emphasis is upon proper switching between modes wherein an appropriate switching logic is proposed.

### II) Meta-architecture and programming:

Incorporating real time constraints in CPS models is essential. In an important contribution [35] develop a structure for algorithmic evaluation of CPS models. The approach consists of specifying the desired properties through a meta-architectural approach. They develop an integer linear programming modulo theories solver and scheduling theory solver and utilize it to synthesize CPS architectural models with real-time constraints which has important potential applications in industrial design.

A software architecture description language (ADL) which is simple, and generic can also be utilized for architectural synthesis. [36] use Acme for design and subsequent evaluation of CPS. The use of behavioral annotations on components while incorporating plugins for analysis of CPS presents a unified approach for handling physical and cyber parts in the architecture.

Another approach described in [37] focuses on utilizing generic middleware for CPS domains through feature-oriented software development. The generic nature is accomplished by enhancing the abstraction level of the features of the middleware. An added benefit of the approach is reduced development, maintenance, and testing costs.

### III) Semantics:

Another approach for modelling of CPS described in [38] enables agents to have (i) continuous physical mobility, and (ii) evolve in an uncertain environment. This approach, coupled with human and automated control has the potential to mimic real-world possibilities.

An event-based semantics for CPS [39] could be a natural approach to specify components such as interfaces and observable behavior. Such an approach is shown to be beneficial for CPS in terms of covering the entire spectrum i.e. from design to implementation.

A Hibertean formal method in [40] can be used  denotational semantics of CPS. In their approach, physical causality and observability are depicted through a combination of algebraic models and denotational semantics.

### IV) Co-design:

As shown by [41], co-design could be yet another approach for CPS modelling wherein co-design of communication and control architectures is carried out to test the delay constraints for spatially distributed processing units.

The representation of the performance of real devices through real-time models in an interacting environment is essential for CPS. This is done in [42] using a co-design framework for CPS device development. The model integrates co-design of hardware and software to test models of different accuracy and speed through an embedded processor. This approach is shown to be useful for application specific platforms for testing CPS.

An investigation on task scheduling problems in CPS is done in [43]. This is essentially done on CPS regulated by feedback control. The co-designing of task scheduling algorithms and feedback control, predictable performance and power dissipation can be achieved in systems in which multiple inverted pendulums are controlled through a single processor.

### 3.2.2 Simulation of CPSs: Tools and Frameworks

A typical CPS consists of a multi-physics linked (electrical, mechanical, bio-chemical etc.) portion that is connected to the networking portion (control, sensors etc.). Simulating such a CPS is a surmountable task as not only there is interplay of physical processes but also their feedback on the control process. Additionally, the CPS is mostly affected by uncertain environments that may or may not include human factors. In addition to heterogeneity, the major challenge is how to integrate the technologies developed by different communities into a coherent system. The sheer complexity of many CPS use cases requires state-of-the-art simulation applications. These simulation application platforms typically include the traditional CAE testing applications like FEA, CFD, multi-physics, electro-magnetic, stress analysis, and other product design testing applications. Today, these platforms also include applications for modeling and simulating multi-discipline systems engineering.

The various physics-based components of the CPS also require one to model associated physical equations. Modelica (https://modelica.org) is one such equation-based language to conveniently model complex physical systems containing, e.g., mechanical, electrical, electronic, hydraulic, thermal, control, electric power or process-oriented subcomponents. This is used for simulating CPS focusing on multiple applications see [44] and [45]. However, such a framework is not catered to handle heterogeneous systems.

Recently, there have been few attempts world-wide to develop a framework that can cater to the challenge of simulating a CPS. In this regard, [46] have reported Cyber-Physical Systems Co-Simulator (CPS-Sim) which is realized by coordinating Matlab/Simulink as the physical system simulator and QualNet (or OMNeT++) as the communication network simulator. The important ingredient of CPS-Sim is its synchronization which is demonstrated using a case study in wireless sensor networks for clock synchronization.

Another example of an open-source framework aimed to model CPS is the COSSIM (https://cossim.org). COSSIM is built on top of several well-established simulators:

- GEM5, a state of the art full-system simulator, to simulate the digital components of each processing node in the simulated system.
- OMNeT++, which is an established network simulator, to simulate the networking infrastructure.

- McPAT to provide energy and power consumption estimations of the processing nodes and MiXiM (OMNeT++ addon) to estimate the energy consumption of the network.

COSSIM employs the HLA architecture through the open-source CERTI package for binding the framework together and is user-friendly having a provision of GUI.

Temporal variations and situation-specific control action [47, 48] complexities need to be adequately handled in simulation of CPS as the dynamics are quite fast. Situation calculus is used by [49] to address the above issue.

Using the approach of [50] analytical dynamics of a physical system can be transformed for executing a simulation code through the use of a domain-specific language (DSL). The approach showed the possibility for modelling complex features of the physical system.

[51] discuss system tools for translating high level CPS specification to actual execution and implementation on physical devices. High level CPS specifications should be translated through appropriate tools for actual execution on physical devices. An approach for the same was shown by [51] where CPS could be specified through motion description languages which reduce complexity and allows for sub-division of control tasks into smaller sets for easy implementation by the system.

[52] introduced Pessoa 2.0 which is a software toolbox developed at UCLA's CyPhyLab, for the synthesis of correct-by-design embedded control software. The inputs to the toolbox are a set of differential equations and automata and output of the toolbox is a controller for the system which can enforce the given specification with the necessary level of up to an abstraction.

Another approach could be to use a macro programming framework [53]. This approach, referred as MacroLab for programming CPS, allows for the decomposition of a code (to simulate CPS) into smaller micro-programmes for each node. This approach allows for easy use of data and reduces the implementation overhead.

### 3.2.3 Verification and Validation of CPSs

Another critical aspect in simulation and modeling of CPS is Debugging. However, the interconnected nature of the cyber and physical worlds makes it very difficult. There are several common conceptions and misconceptions related to CPS verification and validation, but very little existing research attempts to systematically clarify these mysteries. Typically, simulation-based testing is often used in mission-critical CPS applications; however, more often than not such testing methods are incomplete to capture the full complexity of CPS.

For example, in a 2007 DARPA Urban Challenge vehicle, a bug undetected by more than 300 miles of test- driving resulted in a near collision. An analysis of the incident found that, to protect the steering system, the interface to the physical hardware limited the steering rate to low speeds [54]. When the path planner produced a sharp turn at higher speeds, the vehicle physically could not follow. The analysis also concluded that, although simulation-centric tools are indispensable for rapid prototyping, design, and debugging, they are limited in providing correctness guarantees. However, there is no study to systematically analyze why simulation-based testing fails and show how CPS practitioners think about using simulation- based testings for CPS verification and validation. [55] have also listed several challenges in dealing with validation and verifications of CPS.

[56] propose a method for defining and evaluating consistency between architectural views derived from different heterogeneous models and the base architecture. They formulate the problem of consistency checking as a typed graph matching problem between the connectivity graphs of the different architectural views and the base architecture of the system. [57] present a method to extend formal methods of security specification and verification to describe confidentiality in CPSs. Due to the nature of cyber-physical systems, an observation about physical information flow may permit an observer to infer about possibly sensitive cyber actions. As an example, the operation of a wind turbine depends on its physical size, velocity of wind, etc., that are observable; and these properties may reveal the cyber features of the system. To address these issues, the authors present a methodology for information flow verification. [58] use the model-checking technique to verify the correctness of the cyber-physical composition. Using a decomposition approach, the system is logically divided into smaller modules, which can be efficiently checked.

### 3.2.4 Gaps and Challenges of CPS Design:

Based on the detailed literature review on modelling and simulation for CPS based systems, the following challenges and technology gaps are identified.

**Key Challenges:**

(a) *Intrinsic heterogeneity:* Physical systems work on a continuous time scale whereas computation systems work on a discrete time scale. Handling this heterogeneity during modelling is challenging. Modelling such systems with reasonable fidelity is challenging and requires inclusion of control engineering, software engineering, sensor networks, in addition to the physics involved for various physical systems. The design of such systems requires understanding the joint dynamics of computers, software, networks, and physical processes.

(b) *Concurrency:* Even within the physical systems, multi-domain dynamics is involved. Various physical components work together and jointly impact the system performance that needs to be addressed in CPS modelling. Software systems on the other hand work mainly in sequential steps. Achieving the required concurrency while dealing with inherently sequential semantics is challenging.

(c) *Performance requirements:* Quality, reliability, responsiveness are a few important requirements of real-world CPS applications. Supporting CPS in real-world situations that involve "non-ideal scenarios" through appropriate modelling techniques is quite challenging.

### Technology Gaps:

Despite considerable progress in languages, notations, and tools in modelling and simulation of CPS based systems, significant gaps do exist. Options like co-design, model-based design, hybrid modelling, component and connector modelling do provide some direction and have been used in embedded system design. However, there are certain typical characteristics of CPS that these techniques fall short of. These include real-world constraints, integration, adaptation and customization of available approaches, and the heterogeneity of subsystems. A few specific technology gaps are highlighted below.

(1) The benefits of platform-based design with respect to modelling of CPS are not adequately harnessed by model-based design approaches owing to lack of emphasis in the latter on the semantics of heterogeneous systems [22]

(2) Practical CPS models need to incorporate suitable abstractions that would allow intuitive modeling of real-world systems. Model-based development for CPS requires a collaborative environment that can facilitate integration of data, models, system simulation, available modelling tools and platforms. Such collaborative environments are not available currently.

(3) Results of the CPS modeling and simulation should ideally match the results in real-world systems. Over-simplification of the models sometimes shifts it away from the real world. Further, validation and verification frameworks are thus needed to minimize this semantic gap.

(4) Modelling of CPS normally ignores implementation related issues. For example, CPS involves communication networks that are commonly subject to communication delays. The models do not study, for example, how this delay could affect CPS performance. Therefore, it is important that the dynamics of software and network that would be involved in implementation are also modeled. Although some research on conjoining distinct and separately maintained models to solve such issues is available in literature, the same is not adequate for CPS based systems.

(5) As modeling of a CPS involves connecting several sub-models each of which represents individual components, any misconnection between these may result in an erroneous output. Some of these errors include: unit error, semantic error, and transposition error. [22] discusses some notions of these errors including scenarios where the errors are due to incorrect units of measurement, incorrect connection, or reversal of connection. Unfortunately, the complexity of CPS makes it difficult for current modelling literature to adequately handle such errors in the respective context.

(6) In existing modelling techniques, more emphasis is placed on computing elements and less on the link between computing and physical elements. Applying such modelling approaches to CPS is therefore not appropriate.

(7) Though progress has been made in CPS modelling, there exists a gap in terms of integration of the modeling tools to form a complete suite comprising the entire toolkit development cycle like verification, testing, and distributed compilation [59]. Such a modelling suite should have properties like interoperability, extensible, and open standards. To make the tool interoperable, an open standard textual language definition for CPS modelling is required. To handle the complexity and make the tool extensible, features like debugging and interactive simulation are required. Standards like, Functional Mock-up Interface (FMI), for model exchange and co-simulation are imperative and need to be worked on.

## 3.3 Application specific development in CPS simulation, modeling & visualization

Cyber Physical Systems are designed and used for variety of application ranging for health care to manufacturing, transportation to homes and buildings. In fact, many new applications of CPS are being regularly designed to make human life easy. Driverless car, smart grid, smart health care devices, smart machines, etc. are well known now. However, every domain offers unique challenges and opportunities. We intend to study various applications and design appropriate CPSs suiting applications. To start with we capture some of the aspects related to some of the applications. We divided the application based on its nature and inherent complexity, into two areas, viz. applications in the industrial systems and applications in social systems. Follow sections review the CPS in these application domains.

### 3.3.1. System Simulation, Modeling & Visualization in industrial CPS settings

Diverse customer demands are increasing the need for improved flexibility, adaptability, and transparency of production processes. Hence, traditional manufacturing systems must adapt and change. To meet these evolving requirements, cyber-physical system (CPS) technologies are being increasingly applied in industrial manufacturing. In Cyber-Physical System (CPS) information from all related perspectives is closely monitored and synchronized between the physical factory floor and the cyber computational space. Such trends are fast transforming manufacturing industries and taking them to the next generation, namely Industry 4.0 or smart manufacturing.

Industry 4.0 promises mass customization with an unprecedented level of lean operations and reduced cost. Germany was the first country to establish a national industrial strategy for Industry 4.0 followed by the UK. The Government of India’s target for manufacturing is to grow the existing contribution of the manufacturing sector from USD 390 billion to USD 1 trillion by 2025, which translates to a growth rate of 12-15% per year. This means doubling the current annual year on year growth rate [60]. Smart manufacturing has an important role to play in achieving this goal. Realizing this DHI and CII have also initiated various initiatives to help faster adoption of Smart Manufacturing in India. DHI initiated the Samarth Udyog

Programme in 2017 with the primary objective of building industry 4.0 capacities in the country. This was channeled through the creation of 4 Centres of Excellence–Kirloskar Centre for Learning in Industry 4.0, IITD-AIA Foundation for Smart Manufacturing, I4.0 India at IISc Factory R&D Platform and Smart Manufacturing Demo & Development Cell at CMTI. CII recently formed a smart manufacturing council and launched a smart manufacturing platform (http://ciismart.in) to bring together various stakeholders and provide inputs to CII national council for policy creation. While policy is being laid down, it is important for the country to focus on research and technology development and implementation.

Industry 4.0 or smart manufacturing mainly requires autonomous adaptation capabilities in industrial assets. This is achieved by incorporating physical objects and their virtual representations and enabling bidirectional information exchange between them. Virtual representations are created using digital twins. Therefore, digital twins are becoming imperative for industrial systems. They serve as foundations of connected products and services. Further, these digital twins should enable far more detailed understanding of what occurs within a system. Imagine your digital twin residing in a virtual world helps you in every decision, forestall any surprise, and helps you to optimize performance of your system. This often requires the use of simulation with the digital twins. In fact, simulation and digital twins are closely related. A simulation requires, as a starting point, basic data about a system, device, product, and process. Digital twin provides a structured approach to collect data and associated algorithms for further use in simulation in addition to basic analytics and visualization. Digital twins can also be seen as unified respiratory serving all relevant data associated with a device [61]. Digital twin requires not only data captured from various sources, but also models relating these data for better insight into the system. Most of the works related to system simulation, modelling and visualization for cyber physical systems in industrial settings are related to digital twin development. In addition, conventional diagnostics and prognostics modelling are evolving to utilize the capability of digital twins for more effective asset management.

On the manufacturing shop floor, the availability of digital twins and associated intelligent capability are being appreciated through agent-based modelling and simulations for responsive and adaptive operations planning. In this section, literature pertinent to system simulation and modelling for industrial systems are reviewed and gaps are identified. Though the majority of the focus is on manufacturing, main aspects viz. Digital twin development is also relevant in the context of any other industrial system. Hence many of the problems identified based on these gaps in next chapter will be relevant for various other applications also.

### (A) Digital twin development:

"Digital Twin (DT) is defined as an integrated multi-physics, multi-scale, probabilistic simulation of a complex product. It uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding physical twin [62]." Digital twin modelling and simulation when used appropriately has the potential to revolutionize the industrial world. [63] A digital twin is a model which can interact between autonomous system behaviours and the environment in the physical world. In a recent literature [62], the authors have classified the digital objects in three categories as: digital model, digital shadow, digital twin. As shown in figure 3.2, these digital objects vary in level of integration between physical and its digital counterpart.

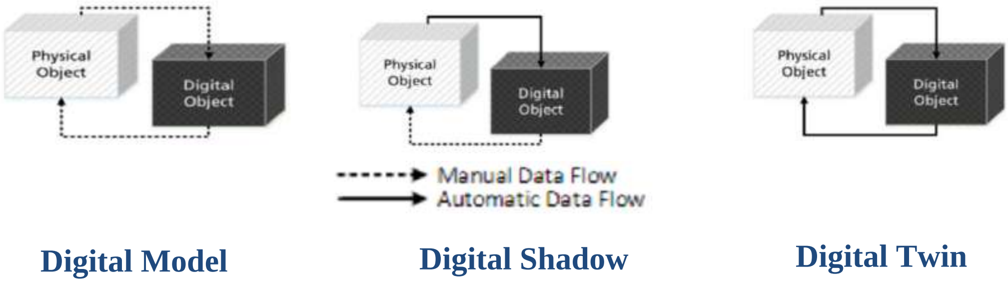


**Figure 3.2:** Types of digital objects [62].

Digital twining may be done at various level such as, part twining, product twining, process twining and system twining.

According to ISO 23247 [64], digital twin is a multi-dimensional model that empowers applications to create better products, more quickly and efficiently. Digital twin can even embed simulation algorithms.

One of the important aspects of DT development is its architecture. In [65, 66, 67] various DT reference architectures have been proposed. These DT architectures provide details on how to collect data for different applications. As product information is available at the design stage and is used throughout the life of the product, DT should be evolved throughout the life of the product. However, most of the available architectures do not provide details on how DT can be evolved throughout the life of the products. It can also be evident from contemporary literature that DT architectures are created mostly to serve the use phase of the product life cycle. In fact, many of the industrial projects on DT are initiated once the equipment is already running on their shop floor.

Most of the use cases of digital twins are in prognostics and health management and performance analysis. Such digital twins are used to predict the state of the asset and decide the corresponding maintenance plan for intelligent asset management [68, 69, 70, 71, 72]. For example, [70] proposed the use of digital twin for aircraft structure damage location, size, and orientation prediction. Maintenance DT is also used in connection with other CPS technologies. In [73], use of DT is integrated with Augmented Reality (AR) to simulate future failure of components and determine maintenance strategy. Use of the concept of DT for diagnostics and prognostics with overall CPS architecture is relatively a new area. Such literatures are reviewed in section "F" of this section (i.e. 3.3.1).

Apart from PHM, other uses of DT are in design, manufacturing, production planning, logistics, etc. In [74], digital twin driven product design, manufacturing and service concept was discussed. Similarly, more applications for product life cycle management based on digital twins are required. In [62], a digital twin-driven product design (DTPD) framework is proposed in this work. Such a framework is useful to guide manufacturers to create a digital twin and support the design process. Some of the issues identified by the authors are: Visualization of DT, Data storage and transfer in DT and Collaboration based on DT. Similarly, production control [75, 76], process optimization [77], shop floor management [78], are some of the other key areas within the manufacturing domain where DT concepts are applied. Though advancement of DT research is done in the last 4-5 years, huge diversity of industrial assets in terms of structure, operation and automation level, in addition to the shallow penetration of embedded-sensor technology into the existing systems, has become a bottleneck for the realization of Industry 4.0 in industries.

In [79] authors propose an event-based approach for creation of a transient system for the development of digital twins for legacy industrial assets. An event-based digital-twin (referred as cyber-twin) for a semi-automatic special-purpose facing and centering machine at a manufacturing facility is developed as shown in figure 3.3. Advantageous characteristics of an event-based cyber-twin include: i) developmental suitability irrespective of structure, operation or automation level; ii) induced connectability of the machine in the industrial network; iii) upgradability of hardware (though more sensors/embedded sensors) and performance (through Bayesian methods); iv) integrability into the physical-machine; v) analytics and operations planning Proposed DT did not use standards for capture product specific information, data type, format and communication. Thus, it does not provide a scalable architecture.

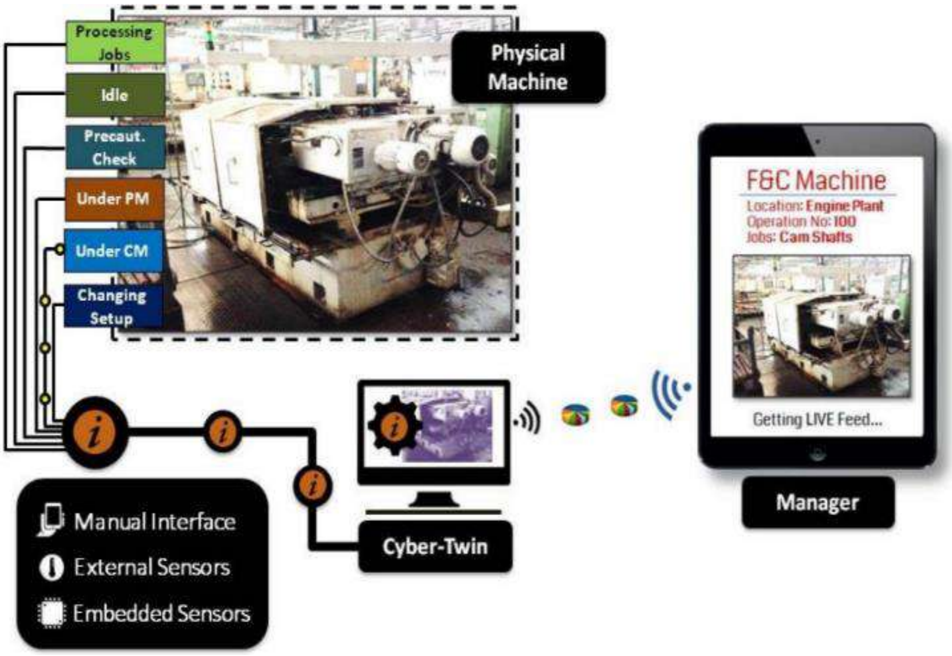


**Figure 3.3:** Digital twin for a legacy machine [79].

A fundamental basis used for the specification of digital twins is provided by STEP technology. STEP stands for "Standard for the Representation of Product Model Data" and is used as a working title for ISO 10303 [80]-"Product Data Representation and Exchange. "

ISO 10303 [80], known as Standard for the Exchange of Product Model Data (STEP), defines the computer-interpretable representation of product information and the exchange of product and process data. The objective of ISO 10303 series is to provide a neutral mechanism capable of describing products and their manufacturing processes throughout their life cycle. STEP series are used for data exchange among CAD/CAM systems and among CAD/CAM and manufacturing systems. The information models for ISO 10303 series are described using EXPRESS schemas.

The ISO 10303 series including 238, 239 and 242 can be used to define information models and 3D engineering for manufacturing elements. ISO 10303-238 specifies an application protocol (AP) for numerically controlled machining and associated processes. ISO 10303-238 includes the information requirements defined by the ISO 14649 series data model for numerical controllers, augmented with product geometry, geometric dimensioning and tolerance, and product data management information. ISO 10303-239 specifies the application protocol for product life cycle support. The scope of ISO 10303-239 includes information for defining and maintaining a complex product, and information required for life configuration change management of a product and its support solution. Also, it includes representation of product assemblies, product through life, specification and planning of activities for a product, the representations of the activity history of a product and product history. ISO 10303-242 specifies the application protocol for managed model-based 3D engineering. The scope of ISO 10303-242 includes products of automotive, aerospace and other mechanical manufacturers and of their suppliers, engineering and product data, product data management, process planning, mechanical design, kinematics, geometric definition and tolerancing and composite design.

ISE 23247 [64] descripts standards for digital twin framework for manufacturing. ISE 23247 describes Digital Twin Framework for Manufacturing. It describes a set of protocols for making and maintaining digital twins. It divides the digital twin systems into four layers defined by standards, as shown in figure 3.4.

First layer- It describes the observable manufacturing elements which need to be modeled, like products, machines, components, etc.

Second layer- It is the device communication entity which collects all the state changes of the observable manufacturing elements and sends control programs to those elements when adjustments become necessary.

Third layer- Is the core entity or the digital twin entity. This layer models the digital twins. It reads the data collated by the device communication entity and uses the information to update its models.

Fourth layer- IT is the user entity which are basically applications that use the digital twins to make your manufacturing more efficient. Such application could be legacy applications such as ERP and PLM or new applications that make processes work more quickly.

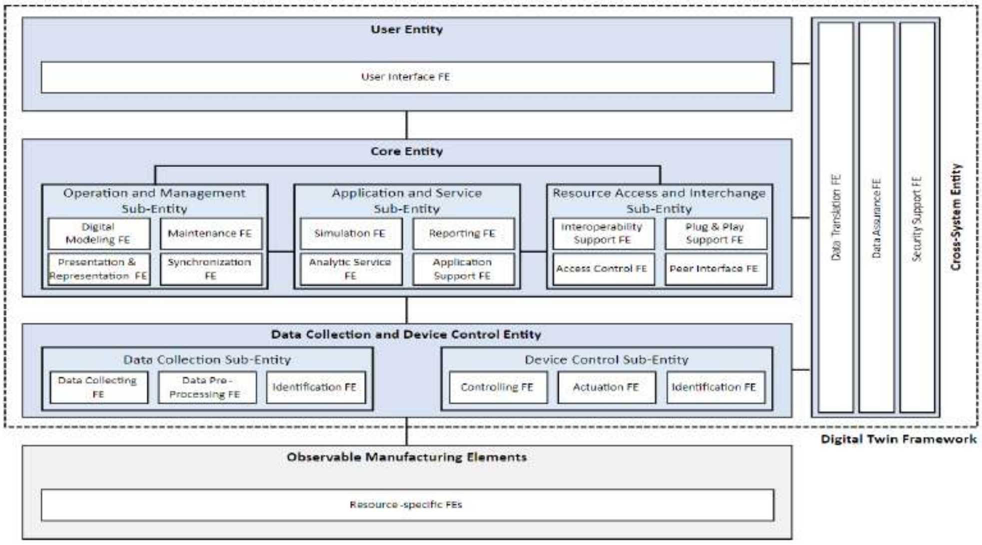


**Figure 3.4:** The digital twin framework for manufacturing [64].

Thus, three of the important areas of research for DT are: communication between observable units and DT, DT models, and application of DT. Simulation algorithms may be one such application.

There are other standards and specifications, IEC 62264 series [81], IEC 62714 series [82], ISO 13399 series [83], eCl@ss [84], IEC 62541 (OPC UA) [85], MTConnect [86], can be used to represent manufacturing elements in digital representation. IEC 62264 series [21] provide consistent terminology that is a foundation for supplier and manufacturer communications. IEC 62264 series also provide consistent information models and object models to integrate control systems with enterprise systems that improve communications among all elements involved in manufacturing value chain. IEC 62714 series [82], known as Automation Markup Language (AML), describe the data exchange format using XML schema. It can be used to represent data exchange format among manufacturing elements. ISO 13399 series [83] describe the computer-interpretable representation and exchange of industrial product data about cutting tools and tool holders. It can be used to represent and exchange data for cutting tools. The eCl@ss (classification and production description) defines various product classes and unique properties including procurement, storage, production and distribution activities [84]. IEC 62541 (OPC UA) represents the international standard of OPC UA, which is for vertical and horizontal communication in manufacturing and automation, providing semantic interoperability for the world of connected systems [85]. The MTConnect standard provides a semantic vocabulary for manufacturing equipment to provide structured, contextualized data with no proprietary format [86]. Though the standards provide guidelines of DT development, there are various issues which need to be addressed for DT development. Many of the applications do not use available standards. As a result, various applications face challenges such as communication with other DT and interoperability. Moreover, plug and play or plug and customize systems for DT development are not available. Another issue is how to use various standards to integrate DT information throughout the life of the product. Also, SMEs are often not aware about DT usages. Information required for DT is normally not collected in many of the SMEs. Creating awareness, developing low-cost solutions for data collection, developing low-cost DT solutions, and making a user friendly platform for DT development are important areas for further development.

## (B) Few sample DT test benches:

### B-1: Digital twin for robot manufacturing cell at University of Washington

For drill and fill operations a robot manufacturing cell was twinned in a lab at the University of Washington. Though it is easy to replace humans with robots for such operations, the challenge is to get flexibility that we get with humans and are many times required for such operations. For example, drilling and filling requirements may vary suddenly. In such cases asking the NC programmer to adjust the work will be time consuming. Digital twinning makes it easier because you have models of the manufacturing that can be compared with CAD models. With digital twins, intelligent software makes the adjustments, and visualization software shows the consequences for quick approval. At the observation level, the four robots were controlled using a command language known as Rapid. As the robots ran these commands, they reported their status using OPC/UA. These status reports were captured in an MTConnect data stream by the Device Communication Entity. The digital twin entity read the MTConnect and used the coordinate data to place each drill in the digital twin model. Moving the cutter in the digital twin resulted in a material being removed from the wing model. A digital twin of the process recorded all the starts and stop times and the speeds and feeds of the process. Four applications like, work analyzer, load balancing application, sequence scheduler, and monitor were developed to improve the system performance. It was estimated that the digital twin-based system can reduce production times by 25%.

### B-2: Digital twin for a bending beam test bench developed at the department of computer integrated design (DiK) research lab, Germany [87].

Authors defined digital twin as a comprehensive digital representation of any product or system which includes the properties, condition and behavior of the real-life object through models and data. The digital twin is a set of realistic models that can simulate its actual behavior in the deployed environment. Authors designed a digital twin test bench consisting of a physical system, a digital twin and a communication interface that connects the two. Physical system is a linear actuator on which the bending beam is clamped, and two load cells are attached to measure the resulting force. In their experiment, the digital twin only consists of an exact CAD representation of the beam. To replicate the physical system (only beam) virtually, multi body and finite element method simulations are used. In finite element analysis of the bending beam the force exerted on the beam is obtained through the physical twin. To connect the physical and the digital twin a publish-subscribe architecture based on Message Queuing Telemetry Transportation (MQTT) measuring protocol was chosen. The test bench provides digital twin use cases during the product development stage only. Figure 3.5 shoes the test bench and its various elements.

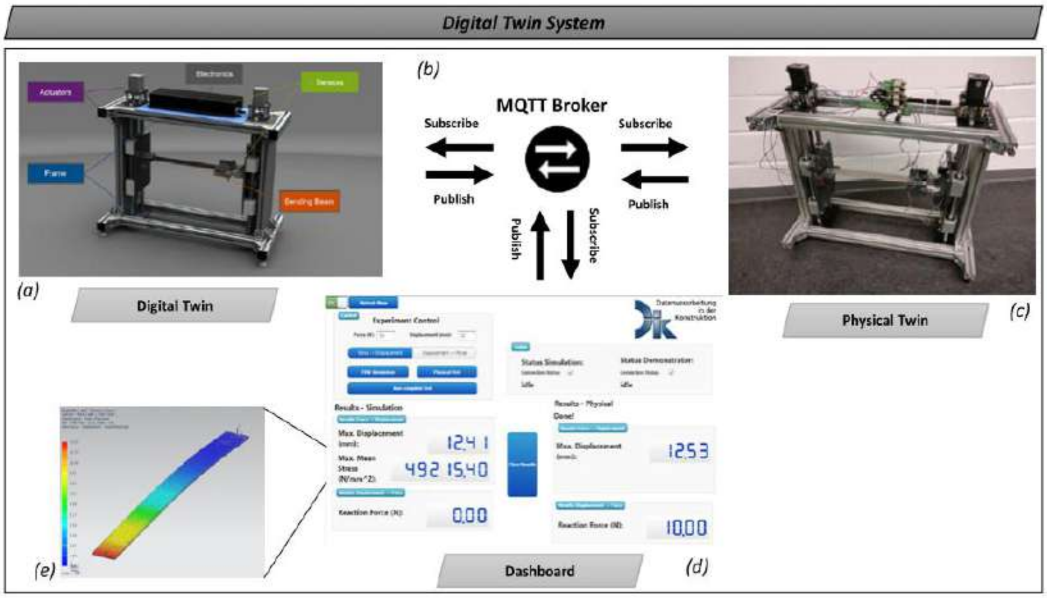


**Figure 3.5:** Digital Twin of a bending beam test bench [87].

### B-3: DT for a 3D printing test bench developed at the Industrial and System Engineering (ISE), IIT Indore, India.

IIT Indore has developed a digital twin test bench using 3D printers. A modular architecture was developed and tested (figure 3.6). Both static and dynamic information was captured by the digital twin. Architecture has an analytics module. It was made in such a way that various analytics algorithms or applications can be plugged with the existing architecture. Two of such applications used in the test bench are: prognostics module and AR/VR module. For prognostics both statistical approach and machine learning based models are embedded in the digital twin. Digital twin capability is extended to machine-to-machine communication. A networking interface was designed for the same. Various communication protocol was also used as shown in figure 3.7. Standardization of the information collected for digital twin is not adequately addressed in this digital twin. Thus, plug and play and interoperability are some of the issues to be targeted in future.

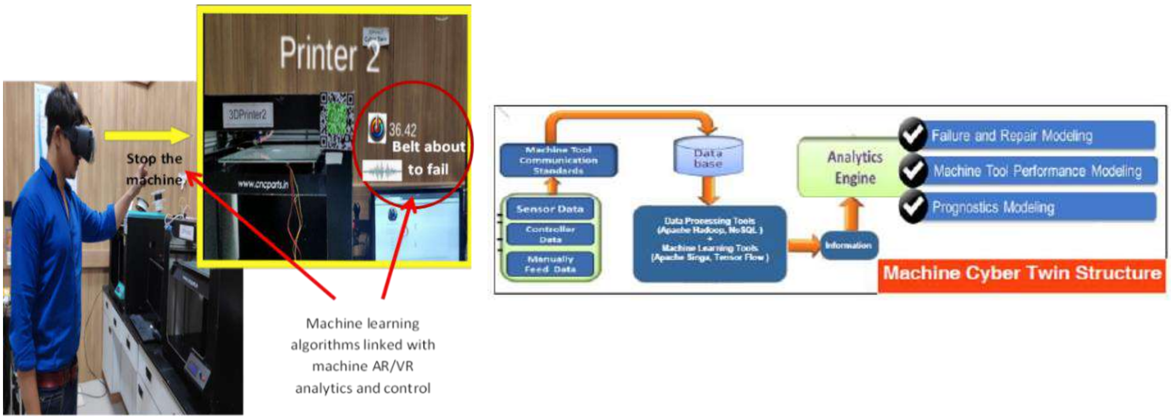


**Figure 3.6:** Digital twin for a 3D printing test bench, IIT Indore, India

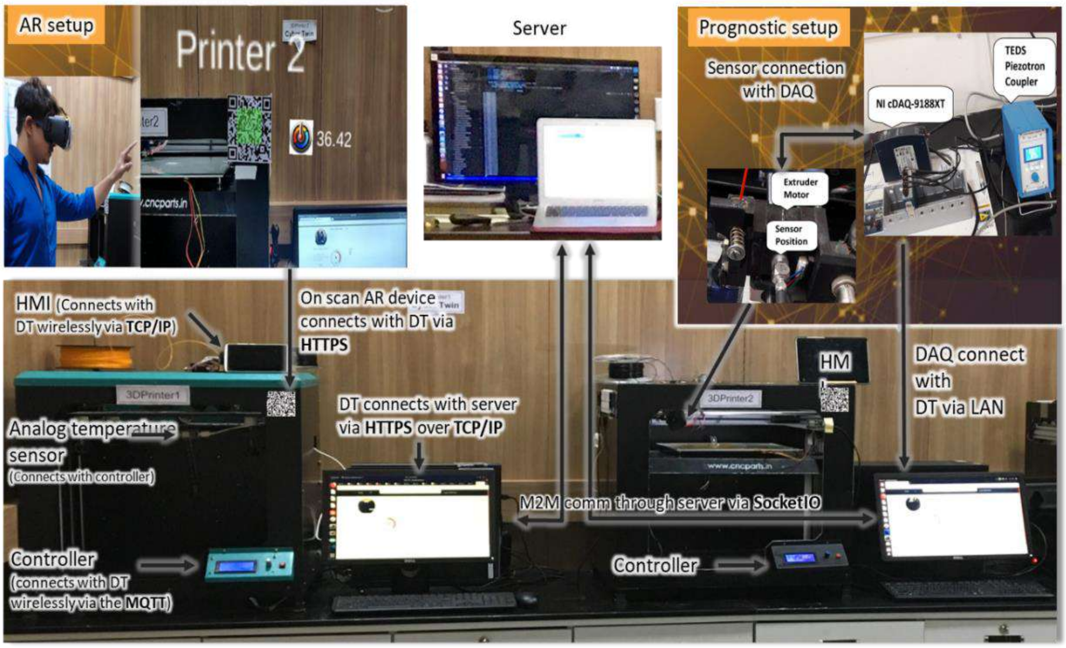


**Figure 3.7:** Digital twin-based prototype CPS, IIT Indore, India

### B-4: MTConnect based machine tool digital twin prototype, University of Auckland, New Zealand [88]

Department of Mechanical Engineering, University of Auckland, New Zealand, demonstrated the digital twin concept using a prototype [88]. MTConnect-based machine tool digital twin or Cyber Physical Machine Tool (CPMT) prototype is (figure 3.8) developed using a tabletop machine. Experimental results have proved great interoperability, connectivity and extensibility of the proposed CPMT. Generic system architecture is developed to provide guidelines for advancing existing Computer Numerical Control (CNC) machine tools to CPMT. The proposed architecture allows machine tool, machining processes, real-time machining data and intelligent algorithms to be deeply integrated through various types of networks. The development methodologies for the core of the CPMT, the Machine Tool Cyber Twin (MTCT), are studied and discussed in detail. MTCT enables different types of feedback loops among the physical world, the cyber space and humans to be realized.

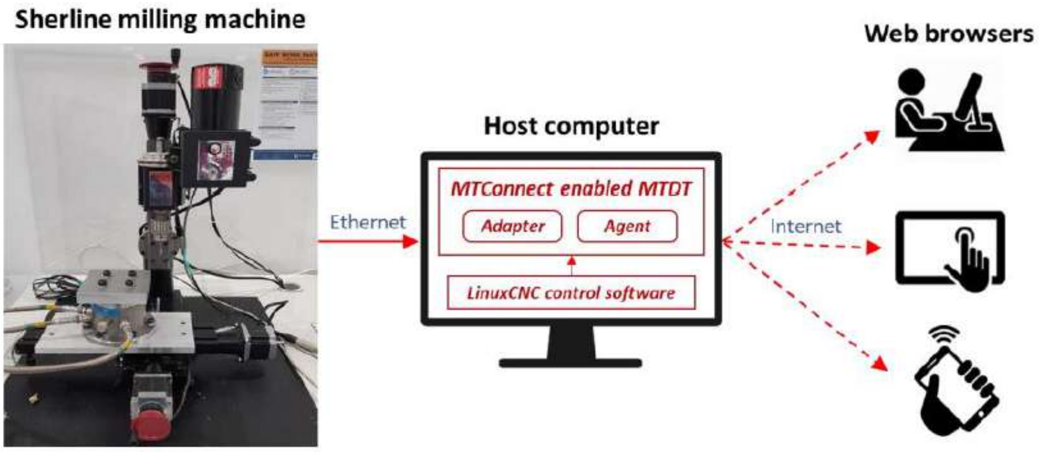


**Figure 3.8:** System architecture of the Web-based machine tool condition monitoring [88].

### C. RAMI Model and Asset Administration Shell:

RAMI 4.0-Reference Architectural Model Industrie 4.0 (Industry 4.0) was developed by the German Electrical and Electronic Manufacturers' Association (ZVEI) to support Industry 4.0 initiatives. RAMI 4.0 is a three-dimensional map of architecture, factory, and life cycle as shown in figure 3.9. It ensures that all participants involved share a common perspective and develop a common understanding [89]. It’s a service-oriented architecture [90].

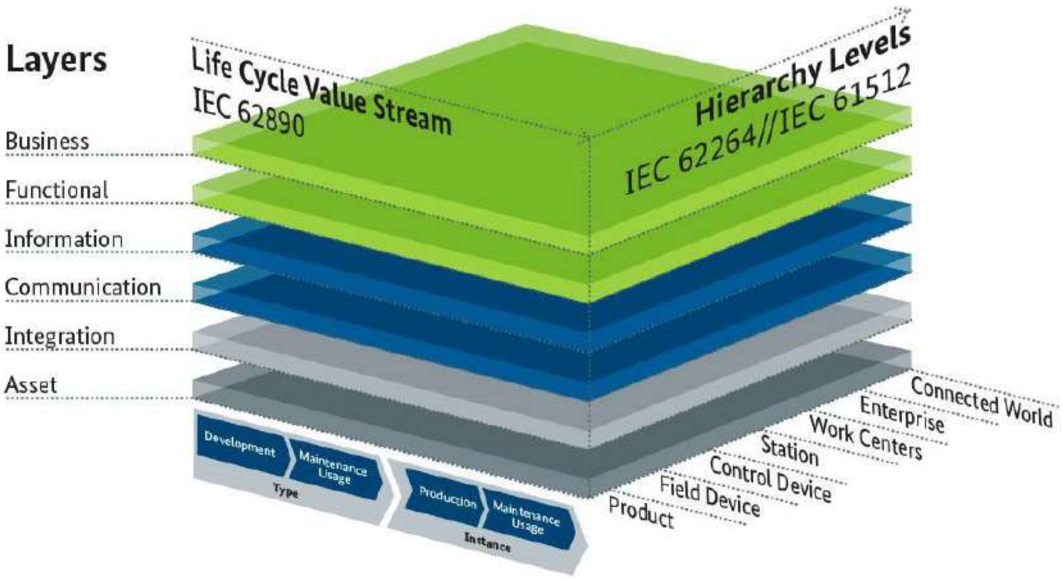


**Figure 3.9:** Reference Architectural Model Industrie 4.0 [https://www.plattform-i40.de/]

One of the important concepts in Industry 4.0 is an industry 4.0 component. In [91], Industry 4.0 component is defined as a model for representing the properties of CPS. It is comprised of two foundational elements: object and administrative shell. Every object or entity that is surrounded by an administrative shell is described as Industry4.0 component. Figure 3.10 shows an example of such a component.


**Figure 3.10:** Industry 4.0 component

An Industry 4.0 component can be a production system, an individual machine, or an assembly inside a machine connected with the virtual world. Asset Administration Shell provides a standard way to represent the digital version of any asset. It can be seen as a standard way to develop a digital twin. In can be considered as integration of assets into the world of information. Asset Administration Shell (AAS) describes all the information and functionalities of the assent in submodels. Conceptually, AAS is divided into two parts viz. the 'header' and the 'body' [92]. Identification of the administration shell is done through the header. It contains information about the and underlying asset. 'Manifest' stores the properties describing the sub-models. These are stored in as a readable directory. 'Sub-models' and the 'Component Manager' are included in the 'body'. The Component Manager represents a link between the Information and Communication Technology (ICT) and the industry 4.0 component [92]. [92] provided direction about ownership and authority to create and modify shell in their Open Asset Administration Shell for Industrial Systems (OAASIS) framework. Their work provided guidelines to make the AAS extensible, customizable, maintainable (using version control) and easy to interact using a graphical user interface. In [92], authors also provided an example of machine tool to describe how the industry will use these shell properties and OAASIS framework.

To increase the flexibility and adaptability of a machining system, AAS concept is used for programmable logic controller [93]. The concept is demonstrated for logistic component of an aluminum cold rolling mill. An event driven run-time access for components to the asset administration shell is provided which enables an automatic self-configuration infrastructure for component instances. The structural information of the logistic components has been described in terms of an AutomationML file, and it has been loaded into a BaseX Database. Despite the importance of AAS in creating interoperable digital twin, there are only a few research activities on AAS linking with DT. Especially in India there not many studies on AAS. We could find only work from the India in [92] focusing on AAS. As a result, most of the digital twin developed in industries is not interoperable. This defeats the value chain integration purpose of Industry 4.0. A standard platform to develop digital twin using AAS and other standards are required. [94] highlighted some potential challenges in AAS development such as semantic gap, coherent mechanism for exchanging information, universal communication interface, insufficiently product properties, and description. The major roles of AAS are to enable asset information sharing mechanism and providing interoperability so that asset information and functionality between the value chain partners throughout the lifecycle. However, literature mainly focuses on defining the role of AAS in the usage phase only. AAS is developed mostly for the usage phase only [95]. How to manage the evolution of AAS during various phase of product life cycle is not discussed in literature. Managing the evolution of AAS along the product life cycle will help not only in seamlessly sharing of asset information but also making the digital twin modelling more robust and autonomous. [96], [97] Both studies outlined a semantic knowledge description of I4.0 Components. Both works focused on the semantic aspect. No description of the structure of the AAS was provided in either study. [98] [99] In [98], a data model was developed of I4.0 Components. In [99], AASs were applied to service-oriented business. Both studies used a robot arm as a demonstration. Both studies focused on information modeling of an AAS and ignored its communication capabilities. To design an AAS template and to reveal relationships among component elements, a common information model is required to standardize how the AAS structure is described. Unified modeling language (UML) can be used [100]. The UML uses a form of object-oriented modelling [101].

### D. Digital Twin Evolution and Digital Threads:

Many large companies are responding to competitive pressures by “digitizing” their supply chain, manufacturing processes, parts, and in-service data. Data is captured throughout the product lifecycle and analyzed for opportunities to decrease tooling costs and lead times, while improving efficiency and innovation. The phrase, “Digital Thread,” is commonly used to describe this process [102]. According to one of the studies published by American Institute of Aeronautics and Astronautics [103] one of the important applications of digital twins and digital threads are in the filed Defense system. It is expected that digital twins and digital threads will help in entire life cycle of defense equipment starting from acquisition to design, manufacturing, deployment, Operations & Support (O&S), and Disposal. Similarly, another study highlighted the need to have a unified paradigm for sharing of digital data associated with the process: from design, to simulation, to build plan, to process monitoring and control, to verification and these data should be part of a single “digital thread” [104, 105]. [104] proposed digital thread concept for part design, process planning, execution, and verification phases. Paper clearly highlights the issue of disconnect between standards used at various stage of manufacturing processes. Though PLM products are now a days available in the market to manage product data and control processes, but vision of digital thread to develop solutions for smart products and services, according to an integrated approach. Digital thread enables model-based definition (MBD) or digital product definition (DPD) which uses 3D models to provide specifications for individual components and product assemblies. US Defense logistics Agency (DLA) estimates that moving to MBD data packages will reduce procurement cost by 27% scrap and rework cost by 19%. MBD can be immensely benefited with the digital thread concept. However, evolution of digital twin along the life cycle of physical product is an open research area. In specific, how such evolution can be managed throughout the life cycle is still unanswered. Moreover, digital twins can immensely benefit from sharing data and information with other similar twins and recent studies have shown the potential for transfer learning. However, how such mechanisms can be planned and incorporated at the design stage itself is still a topic of research.

### E. Modelling and Simulation for next generation factory

In the present-day industry, the style of implementing various algorithms to optimize shop floor decisions is highly centralized, i.e. all the required information is assembled and processed within a single computational unit by the responsible industry personnel/team. However, the onset of Industry 4.0 is rapidly changing the manufacturing paradigms from ‘centralized’ to ‘de-centralized’ production with the development of technologies such as Cyber-Physical Systems and Industrial IoT. The interactions of the real and virtual worlds represent a crucial new aspect of manufacturing – viz. decentralized intelligence. Such technological advances in CPS and Industrial IoT are reversing the conventional production process logic by transforming the shop floor into an intelligent network of industrial assets. This means a job will be communicating with the machine to "tell" exactly "what" process has to be performed on it. Similarly, machines will also be able to communicate with other machines and with departments within the industry to plan the required operations, maintenance actions, logistics, etc. Such new production paradigms mandate the requirement of a new generation of systematic methodologies to perform operations planning in a distributed environment. [106] validates the viability and superiority of capitalizing on the distributed architecture with CPS and demonstrates it with the example of preventive maintenance (PM) planning. In this work, authors developed individual machine models separately. Each machine model provide capability to machine to make its own decision. With machine-to-machine communication a global solution is obtained. Results are promising in terms of faster decisions making. Figure 3.11 shows the comparatively performance of such distributed approach.

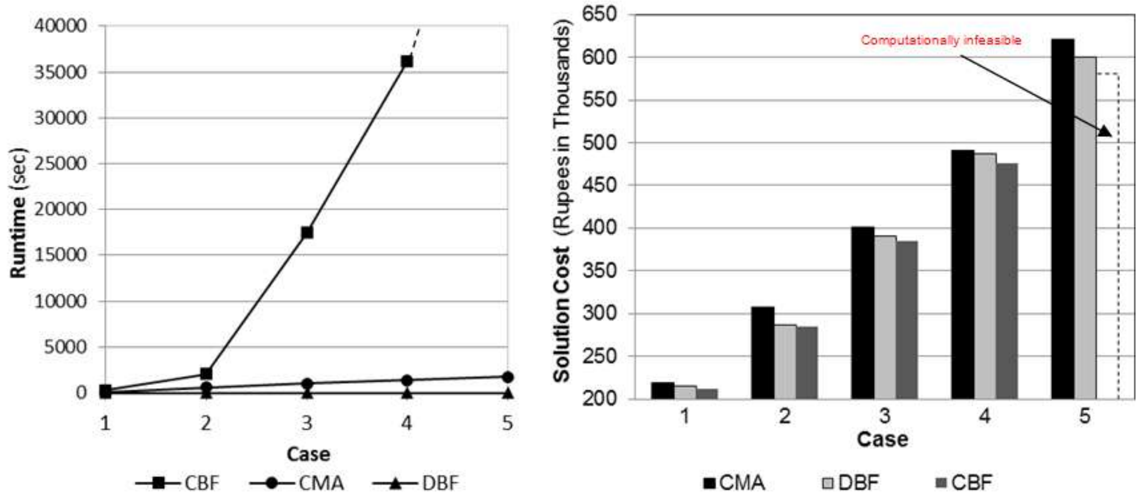


**Figure 3.11:** Comparison between Centralized Brut Force, (CBF), Centralized Memetic Algorithm (CMA), and Distributed Brut Force (DBF) [106]

Traditionally, the manufacturing control systems have been all centralized or hierarchical. Such systems are useful for mass production or for larger batch sizes. However, they fail to address the challenges of Cyber Physical Production System (CPPS) which demands for high quality customized products, in addition to flexibility, expansibility, agility and re-configurability for the manufacturing systems [107, 108]. [107] points out that the distributed and intelligent control systems satisfying these needs are different from the ones conventionally used. Characterized by autonomous and local decision-makers, the distributed heterarchical systems have strong tolerance to the disturbances and ease of expansion, although at the cost of reduced global optimization [107]. Of the distributed systems, Multi-Agent Systems (MAS) and Holonic Manufacturing Systems (HMS) have received major interest in academia, and in industry. MAS aim at dividing a system level task (or goal) into numerous sub-tasks being allotted to the entities which comprise the system. These entities, which interact with one another to achieve their goals, are called agents. HMS are a manufacturing-centric approach analogous to Koestler's idea of biological holons, where they interact with other holons at the same level but are also a part of other higher level holons [109].

Multi-Agent Systems (MAS) deal with behavior management in collections of several independent entities, or agents. MAS comprise of one or more agents, which interact with one another to achieve their goals and in turn the system approaches the overall global objective [110]. [107] defines an agent as "an autonomous component that represents physical or logical objects in the system, capable to act in order to achieve its goals, and being able to interact with other agents, when it does not possess knowledge and skills to reach alone its objectives". In a manufacturing facility, the decision-making ability of agents is realized by the use of CPS architecture, where the assets are each embedded with a computer. These agents can correspond to each machine, the functional divisions, the raw materials, the labor available, the products, etc. The distributed manufacturing systems offer advantages like parallel computing and tolerance to disturbances which reduce the computation time and make it possible for the system to accommodate the unforeseen disturbances such as a machine failure. The literature offers several examples of applying these for manufacturing operations planning. The current research trends show increasing use of heterarchical control systems for dealing with the manufacturing operations planning. The reduced complexity, flexibility and increased fault-tolerance and modularity offered by heterarchical architecture for manufacturing operations planning was first demonstrated by [111]. Since then, we see several instances of agent-based modelling and control. [112] made use of two-layer decentralized MAS to tackle the problem of production planning and scheduling. Here, the tasks and robots who perform those tasks are represented by agents which compete with one another for their preferences. In [113] authors have showed that the parallel implementation of the simple algorithms such as the Shifting Bottleneck Heuristics is faster than the sequential versions. They use a two-layered hierarchical approach to decompose the scheduling problem into numerous sub-problems which are assigned to different machines. In [114] authors have used a proactive-reactive approach to tackle the job scheduling problem where a proactive schedule is prepared which can be modified while the system operates. This algorithm uses a blackboard-approach where the machines and the scheduler can communicate with one another. Several more examples are found in the recent literature which glorifies the use of MAS for the manufacturing operations planning [115, 116, 117]. The approaches discussed above all show the benefits of either the reduced algorithm run-time or the increased flexibility. In [118] authors proposed an innovative Multi-Agent System based distributed operations planning approach for scheduling of jobs in a parallel machine shop-floor.

The approach harnesses the capabilities of Cyber-Physical Systems formed by bringing together physical machines, and various functional divisions, with their cyber space, or agents. These agents interact with one another to form a network of social machines. Using distributed decision-making and communications within the network of social assets, we tackle the complex, NP-hard problem of job scheduling, and compare the results with that of conventional centralized operations planning approach. The advantages of the proposed approach are clear in terms of reduction in computation time and lateness, and the flexibility offered by the distributed approach. Most of these approaches are demonstrated on simplistic problem environment. Also, identifying and optimizing hyper parameters relate to such approach is not discussed in the literature. Use of machine learning with such multi-agent-based system can be considered challenging problem to make the approach dynamics and autonomous.

Another important area where multi-agent systems can be utilized in manufacturing planning is the integration of decision making by various value chain functions and actors. Such integrated planning is very complex as far as problem size is concerned. Hence, designing a multi agent system for integrated operations planning in manufacturing can result in quick response to dynamic conditions created by machine failures, change in demand uncertainty in supply etc. This can result into next generation manufacturing planning systems. One such study is presented in [119]. The approach is built around the opportunities offered by modern digital factory viz., intelligence at the shop-floor and ubiquity of wireless communications. While intelligence at shop-floor allows distributing the decision-making tasks to various functional agents, the communication among the agents makes it feasible to incite integrated view through the coordination agent. Authors, through extensive investigation showed that the proposed operations planning system has capability to apprehend the benefits from next generation CPS based intelligent factory. The proposed multi-agent modelling and decision-making system is shown in figure 3.12.

A comparative performance is of such approach with conventional centralized system is shown in figure 3.13. The results are promising and needs further investigation with CPS design for such manufacturing systems.

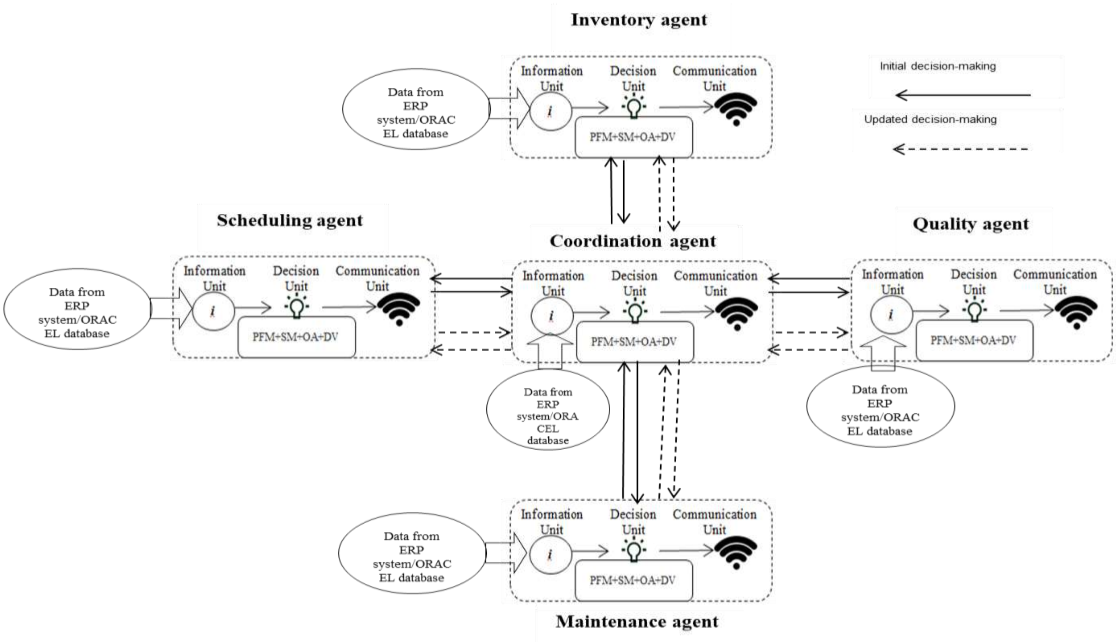


**Figure 3.12:** A multi agent modelling and decision-making system for manufacturing planning [119].

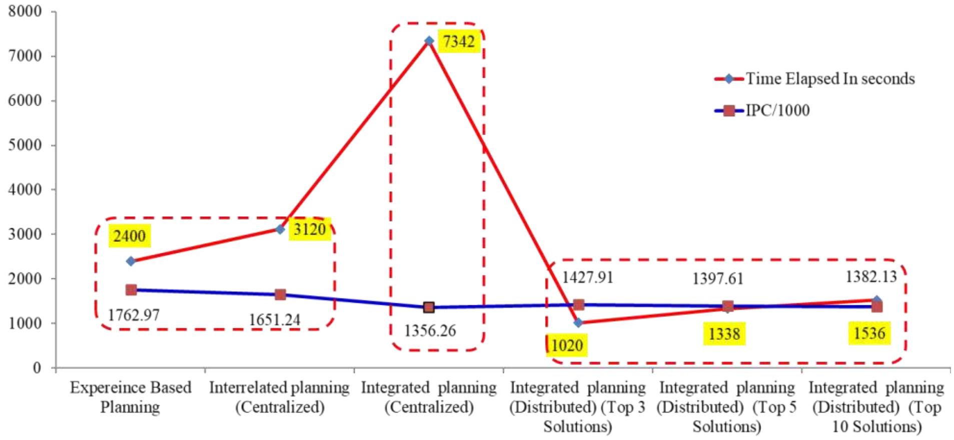


**Figure 3.13:** Comparative performance of distributed approach with centralized approach [119].

## F. Diagnostic and Prognostics modelling for intelligent asset management

Diagnostics and prognostics modelling for industrial systems and products are not new areas. However, challenges and opportunities offered by CPS needs to be considered and new approaches and tools are required. Asset health and performance management aims to maximize the whole-life value of an asset [120]. Diagnostics and prognostics modelling are important aspects of assent management. Assessment of the health state of any asset is known as diagnostics and prediction of future state is called prognostics

[121]. Prognostics models are normally of two types, viz. physics-based models, and data-driven models. Physics-based models use initial condition of the asses (assumed to be known with certainty) and future state is determined by governing differential equations. Physics-based models are computationally demanding, and such models are not always possible for many of the failure behaviours [122, 123]. This reduces their applicability to a subset of well-understood processes and limits their scalability in large fleets of assets [124]. Data-driven methods use statistical or machine learning algorithms to train computer generated models. We do not intend to review the traditional approaches used for diagnostics and prognostics modelling. Only approaches what are promising to be used with cyber-physical systems are reviewed here.

One of the challenges with data-driven prognostics is having enough run-to-failure examples to build accurate-enough prognostic models. In such cases, use of transfer learning can be helpful in more accurate and reliable prognostics. This also fits well into the CPS framework where data/learning can be shared between various units in a fleet. However, not much work is done to explore and exploit the use of transfer learning in prognostics. [125] applied a transfer learning is applied approach for prognostics for turbofan engines. It was concluded that transfer learning can improve the prediction performance of system.

Another issue is the black-box nature of the machine learning approaches used for diagnostics and prognostics [126]. [126] proposed a novel distributed yet integrated approach for diagnostics and prognostics. Through an experimentally study, it was demonstrated that the distributed prognostics give better performance in leaser computational time. In addition, the use of proposed approach was projected as an attempt towards human centric approach for diagnostics and prognostics. Though, authors concluded that more research is required to strengthen the claim. [127] also highlighted the black-box nature of the machine learning approaches for prognostics and proposed an interactive machine learning to include humans in the loop. Similarly, [128] in their prognostics approach based on the machine learning integrated domain knowledge and human reasoning to make it more explainable. In general, such human-centric machine learning approaches for prognostics requires further investigation. Especially, in case of CPS how various models can be integrated to make the approach more human centric is an important area of investigation.

Multi-Agent Systems for prognostics is another area which can be used for prognostics under CPS settings. Multi-Agent Systems are software systems, where many independent agents take decisions. It can be considered as distributed collaborative prognostics system. The concept is inspired by collaborative software agents where various pieces of software communicate with each other to learn an algorithm. In Distributed Collaborative Prognostics, an agent is assigned to each asset and learns a predictive model aimed at predicting its failure [124]. Different agents, corresponding to different assets, share information with each other and use this shared information to refine their predictive models in real time [124]. Application of multi-agent systems have applications in various field like prognostics, production planning, traffic management, etc. Application of multi-agent systems in production planning was reviewed in point “E” above. Some of the earlier work used multi-agent system to increase computational speed and accuracy of prognostics. For example, [129] a prognostics agent is designed for each subsystem of the device to reduce computational complexity. Similarly [130] used multi-agent-based prognostics from algorithmic point of view to reduce computational complexity. More recently, it is identified that multi-agent systems can handle dynamic and heterogeneous fleets. This makes it a suitable candidate for prognostics in CPS. [124] developed a multi-agent-based system with inter-agent communication capabilities, separated data spaces, decision making faculties. In his work multi-agent system was able to dynamically adapt to varying conditions in the asset fleet. It was demonstrated that such system through appropriate collaboration can significantly improve prognostics accuracy. Distributed real-time prognostics approaches though are hypothesized for a variety of scenarios, there are hardly any actual implementations. There is no tool for distributed prognostics. All the approaches are for specific industrial problems. The available solutions/approaches are therefore not scalable for various industrial scenarios. Apart from this lack of transferability, a frequent shortcoming of existing solutions is that some don’t provide true real-time capabilities, and use distribution just as means of improving computational speed or accuracy [124].

### G. Service oriented business models for next generation manufacturing system

Cyber Physical Production Systems having characteristics of enhanced system visibility, flexibility, networkability and real-time decision making, offer many benefits such as improved productivity, improved asset optimization, reduced operating cost and improved quality of products [131]. However, to capitalize such benefits novel business models are required. Such models are required to be integrated with CPS design. Some of the novel business models are given below [131].

- Servitization,
- Co-creation,
- Dynamic pricing,
- Manufacturing as a service

Traditionally, manufacturing industries were focused on selling the products. Lately, companies realized that customers do not always need the ownership of the product. Many times, they are only interested in functions provided by the products. Realizing this, manufacturing companies started focusing on satisfying the customers’ needs by selling the function of the product rather than the product itself, or by increasing the service component of a product offer. As mentioned in [131] servitization is defined in [132] as the processes to shift from selling products to selling integrated products and services that deliver value in use”. It is also called Product Service System (PSS). Some of the examples of servitization are given in table 3.1.

**Table 3.1:** Examples of Servitization [131]

| Company name | Product | PSS offerings |
|---|---|---|
| Xerox [78] | Office equipment | Pay-per-use model (1996)<br>Annuity based business models (2002)<br>Xerox splits into two companies: one hardware centric and one service centric (2016) |
| Rolls-Royce [79] | Aircraft engine | Power-by-the-hour service package, whereby maintenance, repair and overhaul are charged at a fixed price per hour of flight to the customers (i.e. airline companies) |
| Philips lighting [79] | Lighting systems | Selling a promised level of luminance in a building, according to a Pay per Lux concept |

Co-creation as mentioned in [131] is the process of involving customers, suppliers, and various other stake holders at different stages of the value creation process. Though, the co-creation concept is not new for industries, its application was not very common in practice. Table 3.2 presents some closely matching models used by some of the companies.

**Table 3.2:** Co-creation Examples [131]

| Company | Concept used |
|---|---|
| LEGO (Manufacturers of toys) | Created an online platform called "LEGO Ideas" where customers can submit their own designs. Some of the top voted designs are selected for production and worldwide sale [133]. |
| Made.com<br>(E-retail furniture company) | Made Talent Lab of Made.com company hosts an annual online contest called "Made Emerging Talent Award" in which budding new designers can submit their work for other designers and customers to vote on. Design which gets highest votes is produced and sold [134]. |
| BMW (Automobile manufacturer) | In 2010 BMW co-creation Lab gave consumers the opportunity to get closely involved in the design process from start to finish [135]. |

Dynamic pricing is a strategy in which product price gets updated depending on the market demand [131]. This is widely used in e-commerce sectors. There are few evidence of implementation of dynamic prices in manufacturing sectors. For example, Dell Computers offers dynamic pricing based on parameters such as demand variation, inventory levels, or production schedule, etc. [136].

Manufacturing as a Service (MaaS) is a concept where manufacturers share their manufacturing equipment via internet to produce goods [131]. It is similar to the concept of cloud based services for example Google's gmail service, where a company uses such services but doesn't buy or maintain its own servers. Thus, the server cost is shared across all the customers of the cloud services. Similarly, manufacturing companies that provides manufacturing as service will make their facility available for other manufacturers (customers). Thus, customers do not retain full ownership of all the assets they need to manufacture their products. The cost of ownership of such assets viz., cost of machines, maintenance, software, networking and more, is distributed across all customers. A property design MaaS model will help in reducing manufacturing cost.

As these business models are becoming popular, detailed theoretical investigation based on available models assessment is needed. Such assessment will involve various models to simulate and analyze suitability of such models for a particular factory. Thus, business oriented view of modelling and simulation must also be kept in mind.

#### 3.3.1.1 Gaps and Challenges in Industrial CPS settings:

Based on above reviews and other similar work in Cyber Physical Systems Application in Industrial Settings, following gaps and challenges are identified from system simulation, modelling & Visualization point of view.

#### Key Challenges:

(a) Diversity of application: Digital twin technology plays important role in horizontal and vertical life cycle integration requirement for cyber physical production system. Moreover, the digital twin technology is not limited to manufacturing context but also in many other Internet of Things (IoT) applications spanning over different application domains such as Energy, Healthcare, Building and Transportation. Within each application also, specific purpose of the digital twins may vary from simple process or product monitoring to predictive and prescriptive analysis. The diversity of application has made it difficult to standardize the DT creation. For different purpose different models and data are required. There are many standards for such data. Harmonizing between various standards are challenging.

(b) Interoperability of DT: Digital twin concepts are becoming very popular among industries. Various DT development projects are initiated for various purposes. Many of these projects are not developed following available standards. Lack of awareness about such standards and availability of standardized procedure for DT development contributes to this. Thus, available DTs are normally not interoperable. Thus, purpose of seamless connectivity required in a cyber–Physical System is defeated.

(c) Lack of awareness: Though digital twin concept is there for quite sometimes, industries do not have clear awareness about its use, standards, potential, development, etc. These poses a big challenge in development and adoption of this technology.

(d) Business oriented view of CPS: Various technologies are available that can lead to CPS development under industrial settings. However, many times industries need novel business models to utilize the full potential of such technologies. Due to this many of the technologies fail to deliver the maximum possible benefits. This hinders the development and adoption of such technologies

## Technology Gaps:

(1) As product information starts generating right at the concept stage and are used throughout the life of the product, DT should be evolved throughout the life of the product. However, most of the available architectures do not provide details on how DT evolution can be managed throughout the life of the products.

(2) A systematic procedure to develop digital twin is missing. Further, not many tools are available that helps in creating digital twin. Available tools require high level of domain expertise, are not easy to use, do not ensure use of available standards in development. It does not support plug-and-populate digital twins development.

(3) Technology to ensure interoperability of DT are scare in literature. Available technologies like Asset Administration Shell need further investigation. Ontology-Defined Middleware may be developed to extract domain knowledge and integrate it with AAS. More research is required on AAS to make it extensible, customizable, maintainable (using version control) and easy to interact using a graphical user interface.

(4) Complex relationship between individual Industry 4.0 Components will be required to be modeled into appropriate AAS submodels to create new and higher functionalities. The plug-and-produce capability realized by AASs needs to be further investigated, with the aim of enabling external I4.0 Components to be seamlessly integrated into existing I4.0 systems with no manual intervention. It is also envisioned that operation in a real-world factory will aid further assessment. Standardization of the implementation of the AAS is not addressed in the literature. Thus, most of the current AAS studies either are theoretical or are not scalable for wider application. For example, CIM (Common Information Model) described by IEC61970/61968 standards is recognized as the Smart Grid ontology, the Common Dictionary Model defined by IEC61360/ISO13584 standards, acronymed as “PLIB", has been widely used as the common basis for representing product ontologies in many ISO-IEC communities. These need to be integrated with AAS.

(5) DT creation and modelling requires various data such as 3D models, CAD files, real time data, metadata, etc. Technology for exchanging 3D geometry with metadata keeping semantic relations as they are defined in native CAD systems needs further research. Howe to integrate various platforms used to process such data are not explored.

(6) Lack of open/standard based data exchange mechanism for mainstream and downstream applications, production processes and long term archiving. Modelling a digital twin with properties such as, interoperability, global unique identification, standardization compliance, etc., is not explored in literature.

(7) Cloud based platform for digital twin development, uses, maintenance which ensures standard compliances is not available.

(8) Literature does not define clear characteristics for a digital twin. Many even classify a simple software application or data visualization tool as a digital twin. Many of the DTs are developed for visualization and basic analytics purposes. Use of DT in predictive analytics and prescriptive analytics is needed. While an existing virtual model for example, one modeled in much of the simulation software, may be an accurate representation of the product's design, it has no actual link to a specific manufactured part, serving merely as a blueprint for it. Only recently, the real-time connection between physical and virtual products made it possible to be more useful as digital twins and formed an important technology for CPS. Digital twin typically requires answering questions about system events like "what happened?" (descriptive), "why did it happen?" (diagnostic), "what is likely going to happen?" (predictive), and "what needs to be done?" (prescriptive). These analyses, however, will be based on different sets of models that could again be defined as a digital twin of the system.

(9) PLM tools need to evolve to adopt digital twin and digital thread concepts to facilitate creation of smart products, processes and systems.

(10) Research on making the digital twin light-weight needs further attention

(11) The literature review shows that the development of the DT is still at its infancy as literature mainly consists of concept papers without concrete case-studies. Only few case studies, especially in the context of India, and India Indian MSMEs are reported. More of such case studies are required to systematize development in this area.

(12) More detailed laboratory scale demonstration is required which demonstrates various concepts like, DT, AAS, Digital thread, evolution of DT, lightweight DT, Cloud based secure DT platform, etc. for various domains and various application areas.

(13) Most of the use cases of digital twins are in product or equipment prognostics and health management and performance analysis. Use of DT in other areas like product design, process optimization, maintenance, etc. requires appropriate modelling and simulation to be integrated with the DT.

(14) Systematize agent-based modelling for DT development and use for various purposes in the CPS is missing. Use of machine learning approaches with available agent based approaches for manufacturing planning needs further investigation.

(15) Concept of transfer learning is used for prognostics. However, how to make such approaches an integral part of DT and overall CPS is an open area of research.

(16) Various new business models are evolving to utilize CPS based production system capabilities. Such models need detailed investigation before they are widely applied in industrial scenarios. Moreover, how to integrate such models with CPS design and Digital twin concept needs to be investigated.

### 3.3.2 System Simulation, Modeling & Visualization in Social CPS settings

The Webster dictionary defines a social system as a "patterned series of interrelationships existing between individuals, groups, and institutions and forming a coherent whole". Social systems refer to a very broad domain of entities randomly related or unrelated to one another. An entity may be part of several social systems simultaneously and may participate to different degrees in each. In addition to this, social systems are dynamic in nature and are in a constant state of change. Although patterns can be formed on the behavior of such systems, they are largely temporary and fragile.

Perhaps this is what makes the study of social systems challenging and exciting at the same time. Modelling the behavior of social systems is non-trivial and stochastic at best. The current global environment dominated by political and medical uncertainty has pushed social systems into further chaos making the task of social scientists even more unenviable.

Scientific and technological interventions in social systems endeavor to herald some semblance of order in the anarchy. Transportation, industrialization, automation have over the years contributed towards providing some structure to social systems. This, interestingly, comes at the cost of bringing in greater monotonicity to such systems. The most recent intervention in social systems that has had far reaching impact on regulating its nature are Cyber-Physical Systems (CPS). In layman terms, CPS, is the intertwining of computational systems with physical systems. Computational systems have historically been virtual in their existence, functioning behind the screens of our computers. CPS permits these systems to go beyond the closed confines of computers and extend their influence to real world objects and equipment. The results have been expectedly miraculous.

#### 3.3.2.1 Cyber-Physical Social Systems (CPSS)

Cyber-Physical Social Systems are an intelligent and useful combination of cyber-space, physical-space, and social space. Cyber-Physical Systems (CPS), as is now well known, are an integration of computing capabilities with the real world physical objects with the intent of making them more useful and efficient. Cyber Social Systems (CSS) are also a very common phenomenon nowadays wherein social systems particularly individuals have a social presence in the cyber world. This is augmented by the phenomenal reach and penetration of the Internet and makes virtual connections between individuals not just possible but also commonplace. Platforms like Facebook, Twitter, LinkedIn are seeing participation in billions and are no longer the resort of a chosen few.

The combination of these two phenomena makes for a powerful potion with incredible potential. Cyber-Physical Social Systems (CPSS) utilises the reach into the real world of CPS to melt the gap between the virtual and the physical worlds. A new and very interesting term that is currently being discussed is Internet of Minds (IoM) [4-find a good reference] that is strengthened and facilitated by CPSS. IoM is about the productive composition of the thinking process of common people who voluntarily put forth ideas and solutions and to get useful work done.

Crowdsourcing and crowdsensing are other related and powerful offshoots of CPSS wherein the 'crowd' armed with smart devices provides information and content to draw useful and strategic conclusions. Platforms like Amazon Mechanical Turk (AMT) utilised these ideas to the hilt and have devised sustainable working models. The unique nature of CPSS enables it to significantly contribute across domains. We discuss a few important and representative examples of CPSS in the following section.

### 3.3.2.2 Examples of Cyber-Physical Social Systems (CPSS)

In this section, we discuss in more detail a few application areas of Cyber-Physical Social Systems that we are planning for immediate intervention.

#### A. Gamification for Blended Learning

The National Education Policy [137] has recommended several key initiatives to cater to the emergence of digital technologies and leveraging them for teaching-learning at all levels of school education. Some of these initiatives are integral as India ushers into a new "Digital Age". For example, creating digital infrastructure along with compatible content with development of a digital repository and virtual labs is a key for easy and universal access of course material.

This is crucial as "Education" is undergoing a phase transformation particularly with the advent of *"Blended Learning".* In recent times, blended learning at all levels of school education has been immensely enhanced by augmenting the technology of *"gamification".*

There are several ways presented in the literature to define "Blended Learning". In general, blended learning is active, engaged learning online combined with active, engaged learning offline to give students more control over the time, place, pace, and path of their learning. It primarily incorporates both a traditional classroom setting and an e-learning environment with a larger focus on technology usage. [138] defines blended learning as follows: "Blended learning combines face-to-face with distance delivery systems... but it's more than showing a page from a website on the classroom screen...those who use blended learning environments are trying to maximize the benefits of both face-to-face and online methods." According to [139], blended learning refers to four different concepts:

1. To combine or mix modes of web-based technology to accomplish an educational goal
2. To combine various pedagogical approaches to produce an optimal learning outcome with or without instructional technology
3. To combine any form of instructional technology with face-to-face instructor-led training
4. To mix or combine instructional technology with actual job tasks in order to create a harmonious effect of learning and working.

In 2000, [140] carried out one of the first studies that used the term "blended learning". This study was aimed to combine elements of play and work in a pre-kindergarten school in order to acquire blended activities. [141] discussed the potential of blended learning in higher education by considering problems faced in higher education. In particular, they explored benefits of blended learning in higher education with respect to administration and development characteristics viz., policy, planning, resources, scheduling and support. From their study it was indicated that blended learning can lead the process for redefining higher education institutions as being learner centered and facilitating higher learning experience. Typically, research has found that blended learning results in improvement in student success and satisfaction, [142, 143, 144] as well as an improvement in students' sense of community [145] when compared with face-to-face courses. The 2017 New Media Consortium Horizon Report also found that blended learning designs were one of the drivers for technology adoption in higher education in the next few years [146]

### Advantages of blended learning:

1. Blended learning goes beyond the traditional "lecture" setting by introducing a novel and interactive way of disseminating knowledge accounting for individual learning needs and interests. This is essential for an effective transfer for skills [147]. Blended learning approaches can increase the level of active learning, peer-to-peer learning and learner-centered strategies [148]. This may be particularly useful in the field of agriculture and natural resources management, where problem-solving, collaboration and team effort are often essential.
2. Blended learning facilitates establishing a sense of community amongst learners [141] and for learners to develop connections with course co-ordinators and subject matter specialists.
3. The component of face-to-face interaction as part of Blended learning is extremely crucial particularly in areas with poor bandwidth and poor access to technology [149]. In the arena of blended learning, usage of video conferencing platforms have helped to address the concern of isolation and alienation in

distance learning courses as well. [150, 151]. In general, students who are used to only face-to-face instruction are provided a room for the development of autonomy, self-efficacy, and individual organizational skills via the adoption of a blended learning approach. Further, this approach of learning is not only limited to schools. Given its versatile nature, using a blended learning approach has allowed industries and professional courses like medicine and dental for training their personnels as well.

### Limitations of blended learning:

1. An efficient adoption of a blended learning approach to tap into its full potential requires significant training of subject experts/course co-coordinators [152].
2. Blended learning can reduce the time needed for the face-to-face part and thus positively impact on the cost of a learning event. However, there can also be additional costs (for hardware, internet cost etc.) that need to be taken into account and thus a detailed cost/benefit analysis is needed.

The real challenge in blended learning lies in developing and innovating new means of engagement particularly during the virtual setting. “Gamification” is one such technology adopted that immensely enhances the reach and applicability of a blended learning approach. The term “gamification” was first used in 2008 [153] and was defined simply as using game design elements in non-game contexts. It is essentially the process of using game thinking and game mechanics to solve problems. The Gartner Group extends the definition as the trend of employing game mechanics to non-game environments such as innovation, marketing, training, employee performance, health, and social change.

Benefits of Gamification are known to be physiological [154] as it makes us more receptive to learning [155]. The brain is unable to distinguish between actual and simulated events. This allows us to "learn" by simulating conditions and demonstrating the skill resulting in forming the neural connection in our brain. Our learned response will come into play when the simulated situation occurs in the real world. Gaming and problem solving skills such as the powers of deduction, spatial thinking (in addition to linear thinking), and evidence based decision making go hand-in-hand [156]. Further, gaming allows one to exercise his/her imagination.

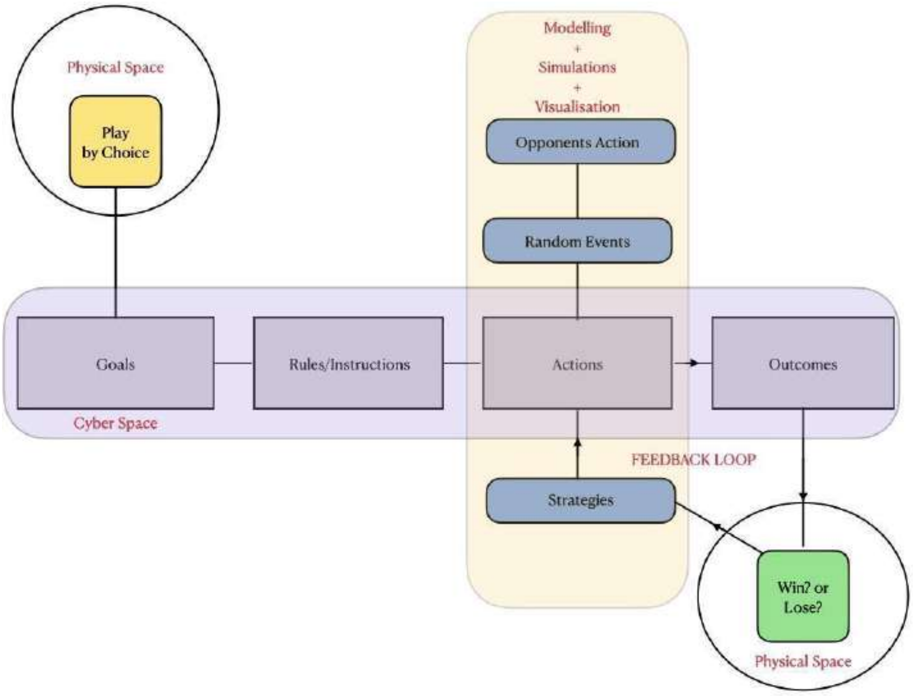


**Figure 3.14:** The standard Gamification Model where the CPS entities are highlighted.

In the current age of blended learning, it is important that students are allowed to "experience" knowledge rather than the traditional book-lecture approach. Developing the connection between the student (physical entity) with technology supporting learning (cyber entity) through simulated/modelled gaming environments is believed to be a winning strategy. This is where the future of innovation in education lies. Additionally, extending this connection to enhance learning capabilities via iterative feedback loop based on the game outcome defines a complete Cyber Physical System. For example, A detective game involving science concepts will allow a student to safely fail, affiliate with other students, and affirms hard work and performance in a more visceral manner than test scores. Students will need to practice and hopefully improve their powers of deduction, establish a credible hypothesis, conceptualize complex and abstract ideas, and improve their ability to process visual and spatial information. The figure 3.14 identifies the different entities with the standard gamification model proposed by [157].

While blended learning is a tool to impart knowledge in an innovative manner, it still has a major challenge of integrating children that require special needs. Schools, colleges and the education industry in general should focus on how to identify children with Learning disabilities right from the early stage and take corrective measures respecting the dignity of children and supporting parents. It is therefore imperative to develop a rather more inclusive learning environment catering to the needs of children with Learning disability. However, detecting the same is a major task that requires aid from simulation and modelling.

## Applications of Gamification/Simulations in Blended Learning environments

### Primary and Higher Education

This is the biggest application sector where gamification can be adopted to augment the blended learning approach and enhance the learning experience. At University of Colorado Boulder, a very nice initiative called the *PhET Interactive Simulations project* has been started (https://phet.colorado.edu). A central component of PhET is the goal of supporting effective and widespread implementation directly through the design of the simulations [158, 159]. This is essentially a suite of web-based interactive simulations (sims) that support learning of science and mathematics content through exploration and discovery. Over the last decade, PhET has advanced incorporating additional features / content and also have focussed on Interoperability which is crucial for extending the reach and providing an universal access. Several EdTech start-ups in India that have emerged since the last year are also using simulations from PhET for teaching concepts.

In recent times, EdTech service providers have translated such simulated environments into a Virtual reality (VR) setting. This provides learners a much richer and immersive environment where they can feel and control the process. For example, Kachhua Education Services LLP using the brand name FotonVR (https://fotonvr.com) has tried to develop a platform to encourage virtual reality in science education particularly at high school level from 5th to 10th standard following the CBSE pattern. Some state governments are also pro-actively aiding VR start-ups. The Shrimati M.G. Patel Sainik School for Girls situated in Kherva has set up India's first interactive VR based education classroom in 2019. In addition to focusing on basic science education, there are several attempts to develop "virtual labs" primarily developed to teach practical courses (experiments) using a blended learning approach. For example, Denmark and Indonesia-based Labster (https://www.labster.com) has developed interactive advanced lab simulations using the methods of gamification. Its content is delivered in either VR or through a digital interface. Labster has already developed more than 200+ simulations across different scientific disciplines, including topics such as protein synthesis, medical genetics, or embryology. It has partnered with prominent global universities such as Harvard Medical School, MIT, Stanford, Berkeley, or ETH Zurich and has received more than USD $10M from scientific institutions to aid with R&D. The Virtual Lab initiative (https://www.vlab.co.in) from the Ministry of Education is also a step in the right direction to provide web-based remote-access to experimental labs in different areas of Science and Engineering.

In addition to the above listed initiatives, there are several that either cater to certain sections of school education or relate to providing remote access to laboratory environments. The basic fabric that connects such CPS tools is simulation and modelling. Further, there is a need to enhance the capabilities of both Ministry of Education (MoE) initiatives of Virtual Lab and also provide a Virtual platform to teach

NCERT syllabus through gamification. This can be done by creating digital content using a novel simulator ensuring universal access.

### Training/Visualisation in all spheres of Industry:

In addition to school and college education, the potential of blended learning and application of gamification is recently being explored in transmitting vocational training to employees in industries and other professional sectors including medicine and paramedics. Such an exercise is crucial as this is cost effective and also efficient in terms of usage of employee time as these blended learning assisted training modules are typically self-paced.

Even imparting soft-skill training including teaching leadership qualities is also being explored through the blended learning approach. For example, Virtual Speech (https://virtualspeech.com/simulations) has adopted simulations to provide training on soft skill courses like presentation preparation, delivering speech, business organization etc. for employees in several industries in the US. Even in India, several multinational corporations. MNCs have realised the importance of an immersive learning environment for training and have invested in developing an in-house AR/VR excellence centers for training their employees worldwide (e.g., Mahindra & Mahindra, Siemens).

### Possible Ways to Address the Challenges in Blended Learning:

#### *iShiksha* Simulator and Hubs

To develop a holistic and interactive environment for education at school and college level, we need to adopt a blended learning approach. Developing a library of simulated and gamified content is the need of the hour to cater to both primary and secondary education. This is akin to creating “textbooks" in the traditional teaching approach followed in the pre-COVID era. The proposed *“iShiksha*” simulator will provide a flexible interface that can be integrated with ease in conventional school and college environments for the ease of blended learning. The simulator will essentially aim to develop gamified content which is concept based using a standard and open source framework based on Python, C, C++ and Java. The USP of such a simulator would be its interoperability feature that will ensure universal access independent of the hardware compatibility. The gamified environment would involve physically motivated simulations and real data-driven models that will closely resemble the real system. Further, the simulator would be developed under two modes: Web-based Interface (based on HTML5) and also VR based interface. Such a versatile framework will ensure that it can reach the masses irrespective of the constraint in hardware procurement.

The simulator will be designed to develop gamified digital content for primary education, secondary education including practical courses and technical education.

Some examples and their benefits are listed below:

1. A data-driven planetarium can be developed to nurture the curiosity of young minds in the field of astronomy. Such a virtual and immersive planetarium focusing on contribution from Indian scientists would be a great value addition both in terms of knowledge enhancement and ready and easy access to the sky. Also, the immersive environment will allow users to enjoy the wonders of space sitting in their homes. This also will be greatly beneficial in terms of saving the cost of building a planetarium dome particularly for schools and colleges that desire to give immersive astronomy and space education.
2. Designing a virtual hi-tech laboratory for technical education will aid engineering colleges that cannot afford expensive machines to get a virtual feeling of carrying out lab experiments involving such instruments.
3. Virtual laboratories that require the highest safety standards can be developed using the proposed simulator with an additional module to train students in terms of laboratory safety. This will ensure less hazardous accidents.

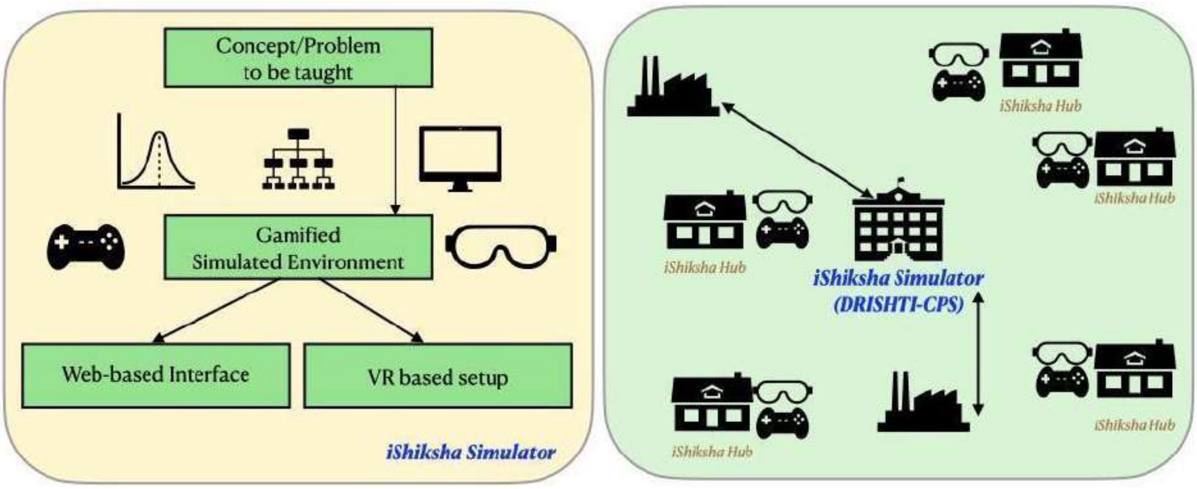


**Figure 3.15:** The proposed *iShikha* environment including the Simulator and Hub distribution

The above lists are some of the representative applications that can be potentially developed under the umbrella of *"iShiskha" Simulator.* However, as mentioned the biggest challenge is to mitigate the digital divide. In this regard, the strategy would be to create ***iShiskha hubs*** as demonstrated in Figure 3.15. These hubs would be established in schools at villages where infrastructure for immersive and blended learning would be installed and teachers would be trained in that direction. Further the simulator developed would be installed and upgraded periodically with more and relevant digital content.

These hubs would be designed to have a dual purpose. Along with imparting education to schools in villages, they can be used for training farmers and familiarising them to new technologies. Even SMEs manufacturing farming tools can demonstrate their product and its usage to farmers using this simulator. In this manner, SMEs can increase their reach in the market and not be localized without much cost to the company.

The *"iShiskha" simulator* would also cater to the needs of small scale industries and medium enterprises through its *Training Modules Hosting Platform.*

With an aim to provide ready and easy access to SMEs and incubated start-ups, the training module hosting platform will be developed within the enterprise version of this simulator based on requirements. Physically, this would be a "training" center with state-of-the-art infrastructure that would aid in immersive and blended learning.

The main tasks of such a platform would be two-fold:

1. Develop/Integrate virtual models of machines following the requirements of the concerned SMEs that wish to train their employees.
2. Provide a remote hosting environment with established AR/VR and cyber infrastructure so the personnels from SMEs can access to give training to their employees.

The training modules hosting platform infrastructure would also be useful for several other sectors. For example, the platform can be utilized by tourism sectors to attract tourists from around the world by simulating various tourist places both locally and within the country and further propagate the *"Incredible India"* poster. Further, "virtual" religious places could be developed using the platform to cater to those senior citizens who are unable to travel, for instance, a simulated "*char-dham yatra*" can be developed within the framework of the proposed simulator with the platform to host training modules.

### Visualisation Snippets Library for redefining reading experience

With the consistent governmental and public efforts, by now the books have made its reach up to every layer of education in our country. In the era of internet, where everyone is connected through outcomes of the smart technologies, the experience of reading and learning from a hard copy of the book can be made more effective, such that the every aspects which an author of the book wants his or her readers to read, learn, or experience, can actually be embedded in the book itself with the help of technologies. 'Book 360' is a novel concept to provide a holistic dimension to technical learning. It is a hard copy book with embedded Augmented Reality (AR) and Virtual Reality (VR) applications for enhanced learning experience. With book 360 readers can have an enhanced and comprehensive reading and learning experience by understanding everything beyond the text and between the lines.

'Book 360' attempts to transform the technical writing and learning field by developing books for higher education (for Ex. engineering or medical) students and practitioners by making use of augmented and virtual reality technologies.

In the absence of expert teachers, students take help of internet based content to get a clearer understanding. However, as the internet is flooded with the content, finding the authentic and correct content is difficult. The authors of the book are always considered as the reliable source. In Book 360, the authors of the book can readily embed their e-content with the book write up. Wherever needed, the authors can embed video lectures of themselves or other experts explaining the concept written in the book. An illustration of the diagram or flowchart can be given in appropriate 3D - video formats augmented with the diagram printed on the textbook with the help of augmented reality. Therefore, the reader can directly learn from the author by seeing the video lecture, diagrams or flowcharts in 3D perspective augmented in the book itself with the help of any available gadget like their smartphones which are omnipresent these days.

To facilitate the readers with the help in numerical example solving and programming concepts, authors can embed their support in the form of augmented reality. Numerical problems as well as programming for the complex cases can be learnt from the author's material augmented in the book itself. This approach provides the author an option to provide the readers with newer learning resources directly in the book without going for printing a newer version every time.

And all of this with the easily available smartphones and one VR Headset. With the continuous governmental efforts with their schemes like Digital India, and persistent decline in the prices of these gadgets due to technological advancement, every educational institute will be able to have at least a few of such gadgets which will benefit all of their students. Having multiple different sophisticated experimental facilities for all the experiments in the curriculum is not easy for all the institutes though expected. But such gadgets where in one VR Headset, experimental setups of hundreds of experiments can be managed are affordable. And the actual textbook is always there with which the students are very well acquainted.

With Book 360, for better understanding of technical concepts, the reader of the book can have access to authentic content augmented with the text on the textbook itself. Anywhere and anytime, the reader can have hands-on experience of the experimental facility with the virtual experimental setup provided with the VR headset. And as all this content is embedded with the textbook itself, it prevents the reader from getting interrupted from learning.

In essence, Book 360 provides following features:

1. Reader can go to the virtual laboratory and perform the experiment wherever required/explained in the book,
2. All visual explanations can be extended to augment the reality,
3. Teacher can add the appropriate audio/video lecture/explanation at appropriate chapter and location within the chapter,

4. Case studies can be added in the form of augmented or virtual reality tour,
5. Solution to some of the numerical problems/corresponding explanation and coding can be taught effectively,
6. All the content can be dynamically added/updated

### B. Non-invasive Methods for Brain Signal Analyses

The proposed tool aims to analyze brain signal data to detect Autism Spectrum Disorder (ASD) and Attention Deficiency Hyperactivity Disorder (ADHD) in children. The proposed technology solution plans to capture brain signal data using two non-invasive and user-friendly brain computer interfaces, namely Electroencephalogram (EEG) and Functional Near Infrared Spectroscopy (fNIRS). Investigations are planned to explore the applicability of EEG which provides a higher temporal resolution, whereas a fNIRS which gives a higher spatial resolution in data acquisition. The main objective is to develop AI-based simulation models to detect ASD and ADHD without any intervention of a medical expert. Another objective is to develop a self-adaptive learning tool which would periodically assess disease and recommend right content to a patient so as to overcome her disease and analyze the improvement in disease recovery. To validate the efficacy of the tools, field studies with children at primary level would be conducted.

The development of such an AI-based tool is very much relevant in the context of secularizing education particularly as day-to-day learning in schools and colleges is progressing towards a blended learning approach.

The primary scope of the proposed tool would be:

#### Advanced computing paradigm for solving complex real-life problems effectively

Brain signal data are high dimensional and high-volume data. Processing of such data needs high-end computing infrastructures as well as artificial intelligence approaches like machine learning (ML), deep learning (DL), soft computing, etc. The proliferation of VLSI technology makes it possible to have computing resources within a reach; at the same time, the recent advancement in computational intelligence techniques makes it feasible and opens an opportunity to analyze brain signal data and solve many real-life problems which includes neurological disorders related to learning difficulties.

#### Facilitating Huge Internet repositories to retrieve content for ASD/ADHD children

If neurological disorder detection using brain signal analysis is one facet of a coin, then another facet is leveraging the same to develop a learning model as per the special needs of the target students. In other words, contents to be delivered dynamically. This poses a question of how such a repository with exhaustive learning materials be maintained. The Internet repository is expanding rapidly and if we can devise an appropriate web-data retrieval methodology, this problem can be addressed easily.

The outcome of the project would be beneficial for the children with learning difficulties, in particular, in rural areas in India and to assess their diseases without any intervention of a medical expert. Further, it also helps teachers in primary schools to deal with the target children. Furthermore, parents of the children with ASD and ADHD will get an automatic system to cure the diseases. Thus, in general, the outcome of the project would be utilized to uplift the children with learning disabilities. The brain signal analysis procedures developed in the project would be applicable to many other applications, namely cognitive load estimation, detection of mind wandering and focus, vigilance or sustainable attention, human reliability estimation, etc.

### C. Assisted Living Environments

#### Background

Countries around the world are grappling with the issue of developing effective monitoring capability to facilitate independent living for the elderly. As the world continues to age rapidly, monitoring of daily activities of the elderly via the conventional route of caretakers is becoming increasingly challenging. There is an urgent need to develop efficient and effective automated systems for such monitoring. This broadly involves recognizing normal daily activities of the elderly such as walking, standing, sitting, cooking, resting. Any deviation from established normal behavior signals a possible emergency.

Literature seeks to address this issue in formal (hospitals, assisted living spaces) and informal (residences) settings. There are proposals for wearable sensor-based monitoring [160, 161, 162, 163] such as accelerometers, gyroscopes, pressure sensors, ECG sensors, GPS, magnetometers, and digital temperature sensors. Such sensors need to be in proximity or close contact with the body of an individual at all times. Combinations of sensors may be necessary for appropriate monitoring. Wearing a multitude of sensors is generally perceived as inconvenient and uncomfortable, discouraging seniors from wearing them. Additionally, individuals may forget to wear them. Thus, a framework depending solely on wearable sensors can be of limited utility. It is possible that sensors placed in the environment [162, 164, 165], e.g. on walls, furnishings, and objects, can complement the wearable sensors. Typically, such sensors work in a stand-alone manner or in combination with other sensors, both wearable and deployed in the environment. Examples of such sensors include electric current sensors on appliances that track their usage, pressure sensors on furniture and toilet commodes, magnetic contact switches on doors and windows, passive infrared sensors to monitor movement, ultrasonic sensors on the floor to track the position of the occupant in the house. Some work has also been done that utilizes water-flow monitoring sensors to track the usage of water, temperature and light sensors to assess the environment. Environment sensors allow us to, indirectly, draw conclusions about the activities of the resident. Although sensor-based systems for monitoring individuals, especially the elderly, have been largely successful in proof-of-concept settings, they entail certain disadvantages as well. They can be costly because of the large number and variety of sensors, and can be cumbersome to install. Another overhead is the need for efficient communication and processing units that can transfer and process data from the sensors with minimal data loss. Sensor-based systems are also sometimes causing false alarms arising out of small changes in readings in otherwise normal situations. False alarms may require human intervention which is at odds with the intention to reduce caretaker workload.

Recent advances in vision-based sensing techniques demonstrate promising performance in human activity monitoring using video data. Vision-based monitoring provides a simpler and unintrusive option for such monitoring as compared to sensor-based systems. Image processing techniques facilitate precise classification of relevant activities using data from a small number of vision-based sensors. In most approaches [163, 166], color camera-based monitoring is used to track human presence and actions. While vision-based systems are quite effective and accurate in monitoring the daily activities of the elderly, the main issue with them is that they potentially compromise the privacy of the individual. Videos are captured and stored at service stations which are a significant breach of confidentiality. This limits the acceptance of such systems in daily life. In addition to the privacy issues of vision-based systems, color cameras are sensitive to varying lighting conditions and do not work well in low light conditions like night-time when the lights are switched off. To overcome this, thermal infrared (IR) cameras are effective [167] operating on the principle of sensing the temperature of objects. Today, high resolution, good SNR IR cameras are expensive, and this limits their large scale deployment and adoption. Top quality IR/thermal cameras are also limited in terms of distribution due to their "dual use" potential, i.e., in military as well as in civilian settings. Another solution proposed in literature is by harnessing depth information captured with depth sensors [168, 169]. Depth sensors work on the principle of distance of the object from the sensor and capture images based on that. Depth images are, therefore, not sensitive to light and work well in low lighting conditions as well. Depth sensors are relatively inexpensive compared to thermal cameras and the images captured appear distorted to the human perception and therefore fare better in terms of preserving privacy.

Image Processing techniques can be applied on all visual domain sensing, such as blob features' ex- traction, motion energy image, optical flow analysis, space-time shapes, gradient information (using HOG, SIFT, HOF, STIP), skin color features, Fourier transform, depth features extraction with skeleton joints are effective in comprehending depth images [170]. Subsequently, the comprehended images are appropriately classified using Machine Learning (ML) techniques like Näıve Bayes, Support Vector Machine, Hidden Markov Model, distance-based measures, Maximum Likelihood Estimation. We can apply ML techniques on depth data at three distinct processing pipeline steps/modules: a Region Of Interest (ROI) selection module; a module for feature extraction; and a classification module. Each of the modules depends on the others to work effectively, thus the overall performance is expected to be limited by the poorest performing module. To overcome this vulnerability, the potential of Convolutional Neural Networks (CNN) can be utilized to map raw data to output (activity classes) with minimal human intervention and fine-tuning. The use of CNNs in capturing and classifying depth images avoids the need for hand engineered features and can provide a superior performance compared to the current state of the art [169,171].

### Possible Approach

Both wearable and environment sensors (including vision-based sensing techniques) are effective but come with their individual limitations. Our objective is that of monitoring the daily activities of the elderly living in independent settings whilst preserving their privacy. Given the context, our proposed research leverages the strengths of certain sensor categories to compensate for the shortcomings of other sensors. In particular, we start by using vision-based sensing to counteract the limitations of wearable sensors. For the same reasons, we also have to address the privacy and cost issues of vision-based approaches.

### Elderly Care Monitoring

The goal of the proposed system is to monitor the activities of the elderly in indoor environments. We propose to employ depth-based sensors for video recording of the scene. Very few depth sensors (1 in each room) are required for the task and this would significantly reduce the complexity and cost of the system. Depth data and the skeleton joint data, as shown in Figure 3.16, obtained from depth sensors would be utilized for monitoring. This is similar to the work carried out in [173] with some major improvements.

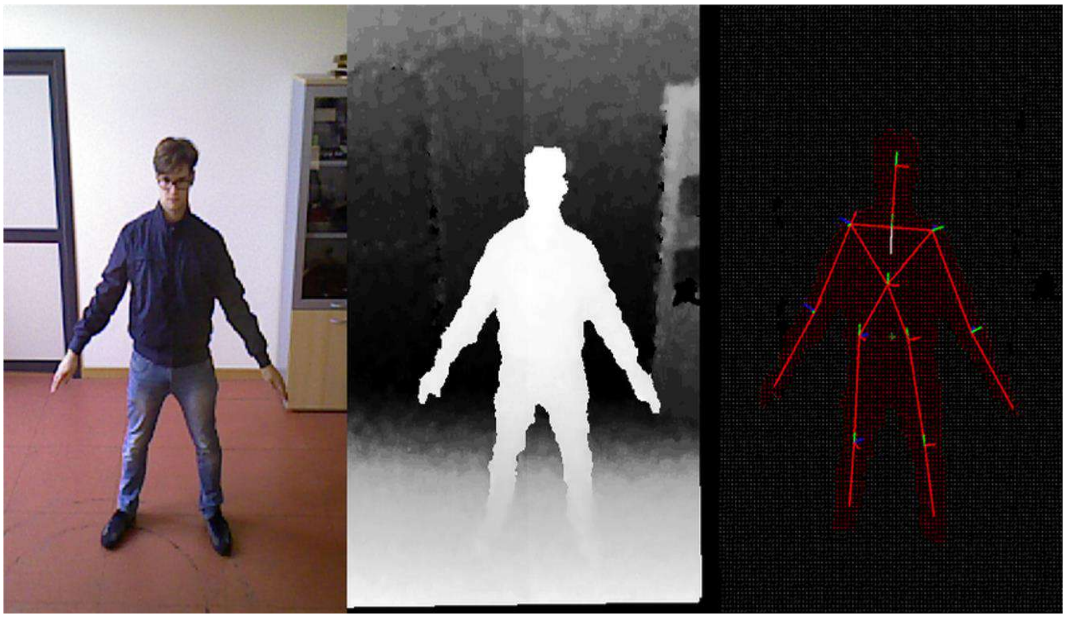

**Figure 3.16:** An example of depth data and skeleton data.

Depth cameras will continuously capture the scene and fixed size clips of depth video extracted from the continuous stream. The segment length of the clips depends on the kind of activities being monitored (some activities are longer than others) and this size will be decided empirically from the dataset. The extracted clips of depth video will further be used for extracting skeleton joints' information of the human body using specialized algorithms [176] embedded in most of the Kinect devices. A high-level depiction of the analysis of data is shown in Figure 3.17. The skeleton joint information of each clip will be mapped into a 3-channel color image. Subsequently, both 3D depth video clips and skeleton data will be sent to a 3D CNN and 2D CNN respectively. Finally, both 3D and 2D CNN would be trained and score level fusion would be done using appropriate techniques.

We will start from the definition of activities of daily living described in [161,177]. We will augment the activities and classify them into two main groups: those requiring prompt intervention such as a fall, skipped critical medication, sleep significantly beyond the usual hours, washroom usage significantly beyond the usual duration; and those that need to be assessed and responded to over the long term such as deviation in sleep patterns, deviation in eating and drinking patterns, deviations in duration of activities such as walking, sitting. Activities of the former category require immediate response by a caregiver whereas activities of the latter category would be logged into a database, analyzed for patterns and deviations, and periodically reported to the caregiver.

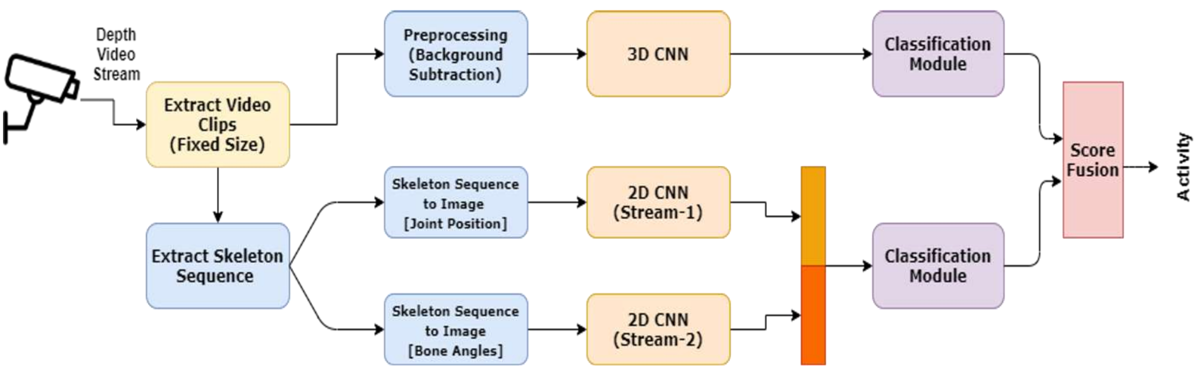


**Figure 3.17:** Analysis of collected data

Thus, two kinds of metrics for the same system will be assessed, the "real-time" identification of exceptions, which requires both accuracy and immediacy, and the long-term identification of exceptions, almost singularly concerned with accuracy. Since the real-time interventions usually involve the presence of a caregiver, they are considered high-cost interventions.

### Pilot Implementation of the proposed model

We propose to set up a 'smart space' for assessing capabilities that support independent living for the elderly. The space would facilitate deployment of various kinds of sensors for monitoring the activities of the elderly. We propose to deploy depth sensors as described in this proposal in this smart space to more effectively monitor the activities of the occupants. The collection of data from these depth sensors and the pre-processing tasks will be performed "in-network" to avoid communicating privacy-sensitive data outside of the local installation. Both depth and skeleton data then will be fed to the respective CNN for classification and alert conditions will be defined to trigger messaging the caregiver as and when required. Long term analysis and visualization will also be carried out from the data streams stored on a database server. The primary aim is to demonstrate decrease of complexity of the overall system installation by reducing the number of sensors, basing the inferences about the resident activity on a single, yet powerful, sensor (visual or depth sensor).

## D. Forest Fire Detection

### Background

Our forests and wildlife are natural assets that we should strive to conserve and protect. An important step towards doing this is to reduce human and machine intervention in such areas to a minimum. While this is important and with government and community support possible, certain monitoring and support tasks do require human presence. These include and are not limited to early detection of forest fires, replenishing artificially provided drinking water supplies for animals, early detection of storms, floods, to name a few. Forests are usually spread out over large areas and managing surveillance tasks without permanent deployment of human personnel is challenging.

We have partnered with the Melghat Tiger Reserve in the Vidarbha region of Maharashtra, India to test and subsequently set up an effective and automated surveillance system to primarily detect forest fires with minimal time lag. The Melghat Tiger Reserve is spread over an area of roughly 1500 sq. km and has for long been unfortunately susceptible to forest fires. Most of these are either set off due to natural causes such as lightning strikes or inadvertently by the human population living within and around the forest region. The fires are usually small to start with and by the time they are detected, which is currently through manual surveillance and several hours after the start, the fires take on large proportions causing destruction, displacement, and disturbance to the flora and fauna of the region. The figure 3.18 below is a satellite image depicting the locations of forest fires in the Melghat Tiger Reserve in the year 2017.

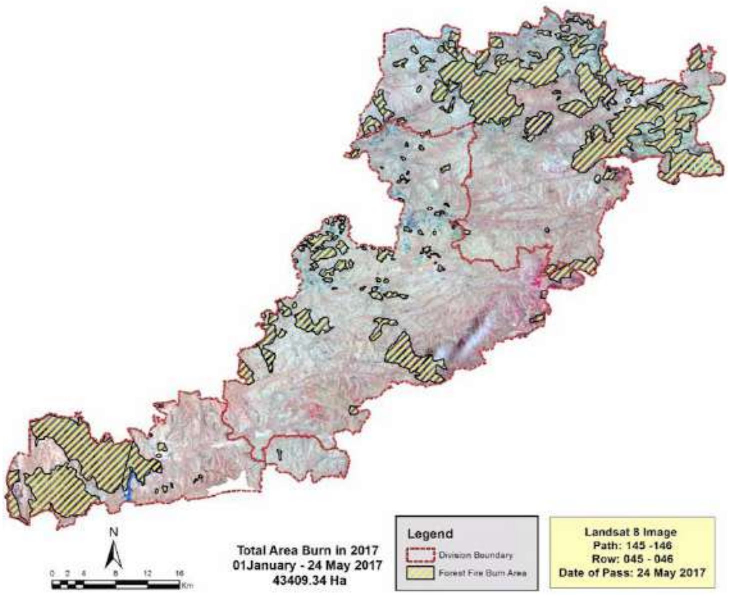


**Figure 3.18:** A satellite image of the Melghat Tiger reserve showing locations of forest fires

We propose an approach to facilitate early detection of fires in forests without constant human presence. The idea is to utilize Wireless Sensor Networks (WSN) [160] across the forests for such surveillance. WSN comprises scattering a large number of very small power sensor nodes across the forests. Scattering nodes is a one-time activity and may be done through the use of helicopters or drones in areas not accessible by humans. Wireless Sensor Networks require no infrastructure and the wireless nodes called ‘motes’ are able to communicate with each other autonomously without requiring additional communication infrastructure like the Internet.

The motes communicate with each at the standard 2.4 GHz ISM band [161] and require very little energy to do so. Each mote is laden with one or more sensors based on the specific requirement and the sensed signals can be passed on from one mote to another using low power Wireless Personal Area Network (WPAN) [162] protocols. The signals are passed from one mote to another until a ‘sink’ is reached which is usually the edge of the network and represents the destination for the communicated signals. The figure 3.19 below depicts the normal mode of communication in Wireless Sensor Networks.

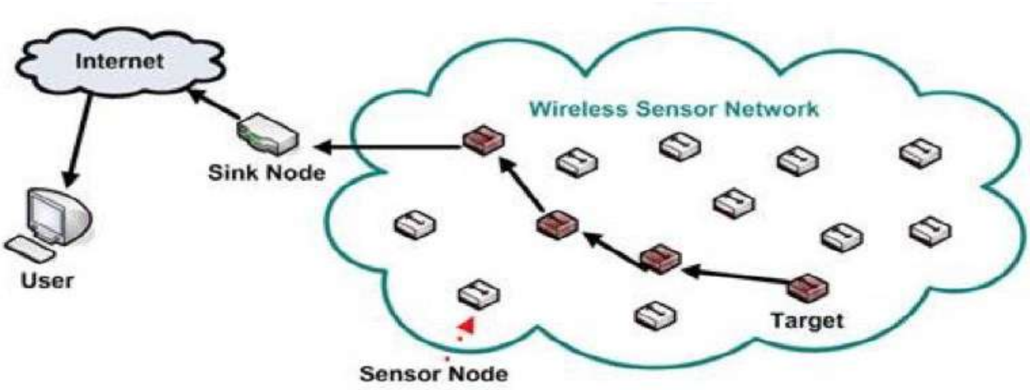


**Figure 3.19:** A typical Wireless Sensor Network

The idea of using WSN for forest fire detection is useful and conventional. There are, however, several constraints of doing this.

These include:

1) false alarms that are often triggered overheat sensors owing to the particularly high temperatures in central India;

2) even though WSNs are able to signal the start of a fire, the issue of determining the location of the fire is very real. This is exacerbated by the large size of most forest areas in India;

3) WSN nodes are quite expensive especially when hundreds of thousands are required for proper coverage of the forest area. An optimal approach for placement of WSN nodes is therefore the need of the hour.

### Possible Approach

A possible approach would be to utilize various Machine Learning algorithms to further refine the systems developed for fire detection and subsequent surveillance of animal movement. We develop new algorithms in some cases and in others massage and fine tune existing Machine Learning Algorithms to work within the constraints imposed by the hostile forest terrain. Our efforts will more specifically target the following domains:

### False positives in fire detection:

In WSN deployments of the kind developed by us for fire detection, false alarms are quite common. This is because the sensors in use for fire detection are heat sensors, humidity sensors, CO sensors, smoke sensors among others. It is quite possible for the heat sensor to be stimulated by the direct rays of the Sun on an unusually hot day. Similarly, it is quite plausible for the humidity sensor to be incorrectly stimulated by high levels of humidity in otherwise safe circumstances. Such incidents constitute false positives that have the potential to wrongly send out signals of fire and understandably cause anxiety and inconvenience.

To avoid such occurrences, we propose implementing Machine Learning algorithms on WSN nodes that would be trained to detect fires and eliminate false positives. While implementing such algorithms are simple on large machines, doing so on resource constrained WSN nodes is non-trivial. WSN nodes can have primary memories as small as 2KB and hence implementing algorithms to effectively work on such nodes demands a focused research. We plan to work with streaming data (where the need to store data is eliminated) and put together extremely lightweight implementations of Machine Learning algorithms to make this possible.

### Localization of fire:

The dense forest cover and the resource constrained nature of WSN nodes do not permit the use of Global Positioning Systems (GPS) in WSN deployments. Thus, even when a fire is successfully detected by the WSN, determining its position is rather difficult. In a landscape as uneven as the Melghat Tiger Reserve and one spread across 15,000 square kilometres, it is rather uncomfortable to be aware that a fire has started but have little or no idea of the location of the fire.

We propose to utilise probabilistic approaches to localisation [162] for determining the location of forest fires with a fair degree of precision. Such approaches have been successful in guiding robots to effectively find their way across hostile terrains. We intend to utilise the intensity and directions of signals received in the WSN deployment to make sense of the location of the fires.

### Placement of WSN nodes:

The Melghat Forest Reserve as mentioned earlier is spread across 15,000 square kilometres and comprises uneven terrain. Deploying WSN nodes across such a large area so as to effectively detect forest fires is by no means trivial. This is because WSN nodes have a communication range that is as small as 10 metres and this is further exacerbated by the uneven terrain of the forest reserve. Effective fire detection in such a large area would require a very dense deployment of WSN nodes. This would not only be impractical but also prohibitively expensive.

A possible approach would be to model the issue of WSN nodes as a Constraint Satisfaction Problem [163] with the WSN deployment being looked upon as a geometric graph. The areas in the forest most vulnerable to fires would be identified based on historical data, the species and nature of the plantations, the nature of the landscape, and other parameters. This would enable us to more optimally distribute nodes across the forest area while maximising effectiveness of detection.

### E. Machine vision system for high-fidelity quality evaluation of food grains

#### Background

Cereals are one of the most penny-wise sources of energy that provide a high amount of protein (approximately 20%) and calories (19%) in our diet. They play a pivotal role in satisfying the worlds food requirements of the growing population, especially in the developing nations. The Nutri-rich cereals are grown in various locations and in diverse environmental conditions. Wheat (Triticum aestivum L.) is a major staple food crop occupying approximately 220 million hectares with an annual production capacity of about 760 million tonnes. For the less developed and middle-income nations it is one of the key sources of protein (just next to rice) in terms of fulfilling the calorie and dietary requirement. It caters to nearly half of all the calorie requirement of the North African region, and the Central and West Asia. Wheat is cultivated both as a winter and a spring crop across the world. It serves as winter-crop for cold countries such as Europe, USA, Australia, Russia, while it serves as a spring-crop for majority of regions of the Asia sub-continent, and a few parts of South America [177]. Three kinds of wheat are grown in India, with the bread wheat (T.aestivum) being the most common. It is grown in several geographical regions including northern parts such as Bihar, Uttar Pradesh, Punjab, Haryana, eastern parts such as Rajasthan, and western parts including West Bengal, Assam, etc. The second most popular variety is the macaroni or pasta wheat (T.durum), which is cultivated in Maharashtra, Gujarat, Madhya Pradesh, Southern Rajasthan, and selective locations in Punjab. T.dicoccum (Emmer). The third kind is seldom grown in India and occupies a significantly small cultivation area compared to other varieties; except in a few regions of Tamil Nadu, Maharashtra, and Karnataka. Wheat is usually planted from September to December and harvested from February to May. Low temperatures are required for sowing, while high temperatures are required for proper ripening before harvesting. [178]. Wheat crop production and productivity were extremely poor when India gained independence in 1947. During 1950-51, wheat production was a mere 6.46 million tonnes, with a productivity of just 663 kg/ha, that was barely sufficient to feed the entire Indian population. To meet the food demands, large amounts of wheat was imported foreign nations, including the US. The Wheat situation in our country has fully changed because of concerted efforts by policymakers, agricultural scientists, extension staff, and receptive farmers. In the post-Independence era, India imported Wheat to meet the needs, but thanks to the “Green Revolution” in late 1960s that accelerated and amplified the Wheat production. Since then, India has become self-sufficient. Currently, the Wheat production in India exceeding its demand, and as a result, the storages (warehouses) are overflowing with it [178]. Agriculture and related industries employ more than half of India's population, making them the backbone of the country's economy. Agriculture and allied sectors account for 17.8% of the country's Gross Value Added (GVA) at current prices in 2019-20, according to the Provisional Estimates of National Income released by the CSO (Central Statistics Office) on May 29, 2020. Thanks to its diverse agro-ecological conditions, India is the currently the world's second-largest producer of wheat (just behind China). During recent years, India has enabled the food and nutrition security for most of its population by ensuring a continuous production and a robust supply chain network [177]. Wheat is India's most important staple crop; next only to rice [179]. It is consumed primarily in India’s northern and north-western regions. Around 31 million hectares [180] (14.1 per cent of the global area) of Wheat was planted, which recorded an all-time high production of 107.80 million tonnes [179] (14.18 per cent of global production), with a record average productivity of 3477 kg/ha. Out of a total of 339.50 million tonnes of food grains produced in India during 2020, 99.50 million tonnes [181] was consumed, which amounts to 29.3% of total food grains. While India has huge potential of becoming a major exporter of rice and wheat, its share of the current global market is significantly low. This is due several factors such as the post-harvest losses during handling and processing, a mismanaged supply chain system, lack of IoT based devices to monitor the quality of food grains for such massive tonnage, and a lack of knowledge of long-term preservation and quality assessment techniques. Furthermore, as the world's population is growing, so will the demand for high-quality, nutritious food products. In this light, it is imperative to devise quality evaluation methods that are fast, reliable, user-friendly, and at the same time cost-effective. However, before the export of food and agricultural products, one of the most critical and difficult tasks for the industries is to ensure product quality [182]. Pre-processed food grain quality is an important factor in ensuring market acceptability, stability during storage, the postprocessing quality, and the customer acceptability. Pricing is determined by grain quality, and quality indexes vary depending on end-use requirements. Physical characteristics of the grain such as its geometrical shape, hardness, moisture content, and surface features (such as discoloration, speckles, pin holes, pitting, craters etc.) are used as metrics to determine the grain quality by the grain handling units. An acceptable quality also indicates that the no adulterants or other potentially harmful components that are inedible are present in the grain stock [183]. Food and agricultural product quality control is complex and time-consuming. In India, these operations are mostly manual now. Quality has historically been measured by hand, by testing individual items or sampling large batches, which is often time-intensive, expensive, and inaccurate. This is due the inherent limitations of the human decision-making process in determining grain quality such as its physical appearance, taste, nutritional content, surface texture, etc. tends to be inconsistent, biased, and generally slow [182]. Another choice is to conduct a lab test, which is the most reliable but also has some drawbacks. It's expensive, time-consuming, and we must rely on the lab for reports, which we can't get at our leisure or whenever we want; one possibility is that there isn't such a lab nearby. Flatbed scanners are often used to evaluate the consistency of food grains, but we don't get high fidelity results here either, or the processing time is dependent on the dpi of the images used [184]. The state-of-the-art colour sorter machine is expensive, not portable, and only sorts good/bad grains without providing us with data on how much good/bad the grain is, so it is not justified from an inspection perspective.

Cyber physical systems can be used to provide a low-cost machine vision based system for high-fidelity quality evaluation of food grains. This is due to their ability to adapt and to learn. A CPS based system embedded with AI can help in analysing environment, recognize patterns, and based on that pattern recognition generate predictions. Some features of a CPS system are condition monitoring, predictive maintenance, image processing, diagnosis which makes them ideal for smart decision making in any setting. Machine Learning (ML) is at the heart of these features that can be exploited for intelligent automation and help achieve technological innovation. In the Indian scenario, agriculture is one key sector where CPS based on ML tools will have a direct bearing on productivity. Agricultural cyber physical systems ACPSs can collect fundamental information about the food grains, the soil and ambient moisture and temperature in a timely manner to enable more accurate systems of agricultural management to be realized. The image analysis and processing-based inspection using machine visions systems have numerous applications in the food industry. Its ability to inspect and classify fruits and vegetables, the surface quality of food grains, and quality assessment of other food items such as the bakery products, and fast-food including pizza, burger, and noodles, has been well explored. Machine vision systems allow quick and reliable information on the surface quality of food grains. The key components of a typical machine vision system are as follows: First, an image acquisition system consisting of a sample holder, which also serves as a background, a high-resolution camera for image acquisition, a frame grabber PC for image digitization, and a diffused light source coupled with a photodiode for uniform illumination. The acquired image is used to extract digital information about the object, and effective image processing algorithms are used to provide qualitative and quantitative results [183]. Images can be captured using cameras [185] or flatbed scanners. Based on the image size, its resolution, the noise-to-pixel ratio, and the processing time of the software the camera is chosen to be either coloured or monochrome with either a CCD [186] or a CMOS based sensor [187]. Illumination is crucial, and careful selection will help you avoid common issues like reflection, shadowing, and noises. Several factors determine the clarity, consistency, and accuracy of the machine vision device. These include the type of light source, its power rating, the direction of illumination, the geometry and size of the sample, the intensity profile of light beam, and its colour [188, 189]. The light source's intensity must be consistent and regulated. Some light sources that have been extensively used (based on the application) include, incandescent lamps, fluorescent lamps, monochromatic light sources, halogen lamps, metal halide lamps, LED’s, cathoderay tubes, IR lamps, to name a few. The imaging context is important for providing an adequate contrast between the object and its background, and eliminating the shadows, to reduce the complexity of the image processing algorithm. The background colour is governed by the application [183]. While the image processing seeks to improve the quality of the acquired photographs, the image analysis formulates the processes for extracting desired information from the image (features, gradients, hue etc.) for use in the subsequent decision-making stages. A computer is used as a platform for processing the digital image, which is like the human brain. Image pre-processing improves the accuracy of a digital image before it is analysed, using techniques such as resizing, contrast enhancement, brightness adjustment, background noise removal, object boundary detection, and applying different filters. To identify and differentiate the individual grains, an additional image segmentation operation is performed, which is based on one of the following attributes: thresholding, region, gradient, or classification [190]. The final steps in the machine vision-based processing are recognition and perception. Most image analysis algorithms were created with proprietary tools such as MATLAB or Image J or Visual C, as well as specialised image processing toolboxes. Morphology [191], colour [192], and texture [193] are all [194] important factors in determining the quality of food grains. In layman's terms, morphology describes an object's geometric structure, colour (its optical property), and texture. A machine learning algorithm is used to recognise patterns. ANN, CNN, statistical learning, deep learning methods, fuzzy logic, and other genetic algorithms are the most used learning techniques for quality assessment of food grains using the machine-vision systems. A learning technique aims to use automated methods to mimic the human vision-based decision-making. The learning strategies work with a training collection to build a knowledge base, which then serves as a basis for making decisions about unknown causes. The classification efficiency of the entire system is determined by the established algorithm [195, 196]. Previous research has included a small number of grain counts [197] for damaged or different types of wheat grains, and this has a direct impact on the results obtained after applying machine learning. This proposal aims to collect over 30000+ grains of each type. Most of the work has done for identifying various types of grains, such as wheat, oats, and corn, as well as different varieties and whole or broken grains. There hasn't been much work done to determine the types of damage based on a percentage of the wheat sample. In Indian context, its important to create a large image database (50,000 + Images) of the damages in different food grain refractions (damaged, sound, chalky etc.), which is not available in the open literature. Further, it will be highly useful to develop a machine learning based predictive tool that combines the trained machine learning based image processing algorithm with optical imaging techniques that can detect and classify the food grain refractions with high-fidelity and allows quick and accurate information about their surface quality aspects. At the end, it is required to develop a cost-effective, user-friendly, and portable food grain quality (surface damage) assessment product that enables high fidelity sorting of food grains in terms of type and degree of grain damage. The analyser will have a low turnaround time which is vital towards the automation of grain handling and grain evaluation equipment to be used by the wholesale dealers and end consumers.

#### 3.3.2.3 Gaps in Modelling and Simulation of Cyber-Physical Social Systems

We extensively discuss modelling and simulation of CPS as part of the first ‘Primary Area’ of this document. The current state of the art in CPS development is arbitrary and is largely dependent on inconsistent designs and individual brilliance. This makes for some excellent CPS deployments that work very well but the concept of repeatability is missing. Repeatability implies the ability of a development environment to repeatedly develop a product of high quality irrespective of the constitution of the individuals involved. This idea has been passed down through the times of research in manufacturing, to software development, and is now very much relevant in the design and development of CPS. Modelling and Simulation enables and ensures systematic and repeatable CPS deployments that closely conform to the expectations of all stakeholders.

Cyber-Physical Social Systems (CPSS) put on an additional layer of complexity and challenge to the modelling and simulation endeavors in CPS. This complexity arises owing to the nature of CPSS and the nature of the stakeholders it caters to. We discuss here a few gaps that make modelling and simulation of CPSS goes a few notches beyond CPS.

1. **Randomness and Chaos:** The behavior of human beings by their very nature is random and chaotic. Accurately predicting and modelling human beings is, for all practical purposes, impossible. The best studies on human behavior leave room for unexpected and random results. At the heart of most CPSS deployments are these very human beings. Modelling the behavior of the 'human in the loop' is expectedly difficult and this makes the model of the entire CPSS unpredictable. This is an important challenge that we are bracing to face as we prepare to move forward in our endeavors to model and simulate the behavior of CPSS.
2. **Scalability:** A CPSS deployment would be deemed a success if it is embraced by a large fraction of mankind. This sounds exciting but points to the involvement of at least millions if not billions of people. Preparing CPSS deployments through modelling and simulation for such scales is an important challenge that we perceive. We would be looking to very carefully explore and study the challenges of scalability as we prepare to propose successful modelling and simulation approaches for CPSS.
3. **Dynamism:** Yet another factor governing social systems, in addition to chaos and randomness, is dynamism. Unlike more structured and disciplined industrial settings, social systems change all the time. Often, decisions cannot be anticipated and are known while the systems are functioning in real time. Computations and decisions need to be made during these dynamic circumstances whilst ensuring a high degree of reliability.
4. **Inclusiveness:** Social systems are meant to serve the world. While this is the right thing to do, it is much easier said than done. Social systems need to be designed and developed in such a manner that they work well in different circumstances, environments, and settings with little or no customization. This presents a significant challenge while modelling and simulating such systems. We propose to come out with solutions that take such variables into account and ensure systems that are prepared to be inclusive.

### 3.3.2.4 Application Specific Gaps in CPSS

#### A. Gaps in Gamification for Blended Learning

1. **Digital Divide in terms of resource availability in schools:** Technology-based distance education emerged today due to advancements in information and communication technology. These high hopes in technology-based distance education however, turned into disillusionment because of the challenges relating to digital infrastructure. For example, the availability of seamless Internet Connectivity, access to high priced digital infrastructure is a significant barrier for many users.

2. **Creating an equal playing field for SMEs and start-ups:** Since the last 5 years or so, incorporating immersive tools for training employees has gained impetus, however, it has been limited to several big industries and significant scope remains to develop a more universal platform that can cater to needs of several industries particularly Small scale and Medium Enterprises (SMEs) and start-ups. In-fact access to such state-of-the-art and cost effective training tools will benefit the SMEs and start-ups in a significant manner and provide an equal playing field as far as employee and intern training is concerned.

3. **Scarcity of expert and trained teachers or availability of experimental facilities:** Huge lack of infrastructure and teachers are among the fundamental reasons behind this stumbling block. Such a scarcity of well-trained teachers and infrastructure gets amplified when it comes to technical higher education especially in the rural sector of our nation. Technical education is expected to be created by transforming the experience. However, with the scarcity of experimental facilities, imparting this knowledge in the form of experience is not possible. The quality of teachers in the premier technical institute and some of the institutes in the rural section of our country is not even comparable.

   In the present pandemic situation, where even the premier institutes of the nation are experiencing the lockdown, the students are forced to study in the online mode with the e-classes. After learning any theoretical concept from the e-class, the student takes help of internet video content for learning the experimental facet of the studied concept. Merely watching a video where the experiment is performed by the tutor, does not give the hands-on experience to the student. In this situation, where the student is not even able to go to the classroom, having the industrial or field visits to experience the actual application of theory learnt is impossible. This again hinders the comprehensive learning for the student of higher technical education.

4. **Provide an "Inclusive" learning environment:** An integral step in reforming education and learning experience is to be inclusive. Even today admitting that your child has a learning disability is considered a taboo. This puts an immense pressure on children suffering undetected (or ignored) learning disability due to neurological disorders like Autism Spectrum Disorder (ASD) and Attention

Deficiency Hyperactivity Disorder (ADHD). Detecting such disorders in children at an early stage still is a big challenge.

### B. Gaps in Non-Invasive Methods for Brain Signal Analyses

1. **Developing appropriate computing infrastructure:** Brain signal data are high dimensional and high-volume data. Processing of such data needs high-end computing infrastructures as well as artificial intelligence approaches like machine learning (ML), deep learning (DL), and soft-computing. Developing effective solutions for such computing is a major gap that needs to be bridged.
2. **Maintaining data repositories on the Internet:** To sustain an effective learning model for the proposed solution, large data repositories need to be maintained on the Internet. This poses important challenges that need to be overcome.

### C. Gaps in Assisted Living Environments

1. **To reduce dependence on wearable and ambient sensors:** Wearable and ambient sensors have disadvantages that need to be overcome. Wearable sensors are uncomfortable and inconvenient and elders avoid wearing these after a point of time. Ambient sensors, on the other hand, require a dense deployment to be effective. This leads to reduced reliability and communication issues.
2. **Preservation of privacy with visual sensors:** Visual sensors are effective for monitoring assisted living environments and do not have the limitations of sensors. The main impedance to mass adoption of visual sensors is that they compromise the privacy of resident individuals. This important gap needs to be bridged.
3. **Development of lightweight computing systems:** A complicated implementation of CNN is required for effectively monitoring assisted living environments with visual sensors that preserve the privacy of individuals. Such an implementation is not convenient for relatively constrained computing environments. Thus, another important gap to be bridged is to develop lightweight implementations of CNN.

### D. Gaps in Detection of Forest Fires

1. **Elimination of false positives:** Wireless Sensor Network (WSN) deployments for forest fire detection are plagued with the issue of false positives. This is especially true in India where the climate is so hot that it may trigger heat sensors meant for fire detection. An important gap to be bridged is to eliminate false positives in fire detection using WSN.

2. **Localisation of detected fire:** WSN may be effective in detecting and reporting a fire but the issue is information on the precise location of the fire. WSN are usually dense deployments and in this case within forest areas that are spread out over at least a few thousands of square kilometers. Localization of the fire is such large areas especially is the absence of GPS systems is non-trivial and an important gap.

3. **Optimal placement of WSN nodes:** Given the large size of forest areas, optimal deployment of WSN nodes is an important issue that needs to be addressed. In doing this, factors such as nature of the forest, climatic conditions, settlement patterns of the indigenous population among others need to be considered. This is an important gap in the use of the proposed idea and needs to be bridged.

### E. Gap in machine vision system for high-fidelity quality evaluation of food grains

1. Conventional methods of sorting that are time-intensive (manual: 5 hrs., flat-bed scanners: at least couple of hours)
2. Low-cost solution for food grain sorting compared to the current state-of-the-art sorting machines (Sortex©) that are extremely expensive (~ 1.5 Cr) is not available
3. To cater to sorting of massive volume of grains (India produces 275 million tons (MT) of food grains each year) which is portable and hence accessible to local stakeholders (farmers, food inspectors etc.); unlike Sortex© machines which are huge, have a large footprint and require dedicated installation infrastructure.

# Chapter 4
# Problem Areas

## 4.1 Introduction

This chapter depicts a few representative challenging Problem Areas (PA) based on the review and gaps in the current state of the art discussed in Chapter 3. Each problem area can be addressed by multiple technology solutions. Neither these problem areas nor the specific technologies proposed in these areas constitutes a comprehensive list of possible endeavours of the TIH. They are representative and reflect the focus and mode of operation of the TIH. As more researchers get associated with this initiative, we expect the opening up of new and contemporary problems areas. Interaction with ministries, state government departments, industries, PSUs will lead to further refinement of the problems. We envisage and look forward to a continuous and evolving process. This is a realistic approach to viewing complex and dynamic systems like CPS. The following paragraph provides information on the structure of this chapter and how to navigate through it.

From a development complexity point of view, we divide our representative problem areas into three zones viz. red, yellow, and green. Red indicates the ‘most challenging’ problems, yellow implies ‘moderately challenging’, and green represents ‘less challenging’. A crisp division between these zones does not necessarily exist and it is expected that certain problem areas will overlap between zones. In some ways these zones are related to Technology Readiness Levels (TRL). For example, red zone technologies are expected to have lower TRL whereas green zone technologies would have the highest TRLs. To reiterate, however, it is important to note that the basis of this classification is development complexity and not TRL. In an attempt to map this classification with the expected outcomes of the TIH, we have put the most probable outcomes just below each of the three levels in the classification diagrams. We repeat and emphasise that these relations are not rigid, and outcomes may vary across problem cases. It is also expected that as work progresses and technologies are developed, problems areas in the red zone will move into the yellow zone and subsequently into the green zone.

## 4.2 Key problem areas

Conforming to the pattern across this document, we divide the problem areas to be addressed into:

*1) Design and Modelling of Cyber-Physical Systems.*
*2) Cyber-Physical Industrial Systems.*
*3) Cyber-Physical Social Systems.*

### 4.2.1 Design and Modelling of Cyber-Physical Systems

PA1: Comprehension of gaps in existing design and modelling techniques
PA2: Customisation of existing design and modelling tools of other domains to CPS
PA3: Creating loose mashups of different design and modelling techniques for CPS
PA4: Development of design and modelling techniques for specific CPS components
PA5: Development of techniques to model communications between CPS components
PA6: Development of an entire suite for designing and modelling techniques for CPS
PA7: Development of generic design and modelling techniques with modes for individual domains
PA8: Study and develop standard models for CPS development
PA9: Development of models for categorising process quality

#### PA1: Comprehension of gaps in existing design and modelling techniques

This is the first and foremost area that we intend to deal with in our endeavours at developing useful design and modelling tools for CPS based systems. We intend to immediately study and fully comprehend the existing state of the art in designing CPS and identifying gaps. The approach being adopted today is rather arbitrary and inconsistent across domains and organisations. In fact, it is not uncommon for the same organisation to employ different design and modelling techniques for different batches of the same system. Understanding the existing approaches and identifying gaps is expected to provide a direction to channelise our efforts in our bid to develop a complete suite for modelling and design of such systems, to be designed and modelled differently, proposing customisations to the existing techniques for more effective design and modelling of CPS.

#### PA2: Customisation of existing design and modelling tools of other domains to CPS

There are quite a few design and modelling tools that are in use in domains other than CPS. Examples of these include OrCAD for hardware design and Unified Modelling Language (UML) software systems. These and several others are well established and mature offerings. An immediate aim of the hub is to harness such offerings with appropriate customisations for CPS design and modelling. This includes creating models at various levels of abstraction starting from a high-level block structure down to the absolute minute details. This task is non-trivial and the customisations are expected to be domain specific. Each CPS based system to be developed may require a separate set of customisations. The idea behind this approach is to immediately set the ball rolling in creating appropriate designs and models of CPS systems before their actual development.

### PA3: Creating loose mashups of different design and modelling techniques for CPS

A CPS deployment is a heterogeneous combination of components across disparate domains. A few such components are predominantly hardware based and a few software. Communication systems also play an important role in making CPS systems function properly. To immediately facilitate design and modelling of such complex systems before the actual development, we aim to create loosely coupled compositions of design and modelling tools from different domains. We intend the compositions to be over ReSTful APIs so as to keep it as light as possible. Each tool would be a mature tool dedicated to the specific domain of the component and these would be modified somewhat to work in a complimentary manner with other tools. We expect this to be done quickly and with relatively less investment. This could also serve as a precursor to the development of dedicated and specialised tools specifically for CPS.

### PA4: Development of design and modelling techniques for specific CPS components

This endeavour is expected to be slightly more challenging wherein the aim would be to develop specific design and modelling tools for individual components within CPS deployments. Each of the tools would be developed with the assumption of independence from other tools so as to reduce the complexity of the task somewhat. Even with this independence the tools would be provided with standard WSDL interfaces to facilitate interactions if the need were to arise. The components chosen would be ones that are the most common in CPS deployments and development of these would lay the blueprint for less common CPS components' design. The design and modelling techniques would leave enough room to facilitate interactions of the components with other components.

### PA5: Development of techniques to model communications between CPS components

Communication between CPS components is quite complicated and the manner in which it is currently handled is rather arbitrary with the approach of getting things done in a 'quickfix' manner. Wireless Personal Area network technologies like 6LoWPAN are mostly employed for facilitating communication currently. These are low power and effective but fall short on reliability aspects. To overcome this, proper planning and subsequent modelling of the communication infrastructure of CPS systems is imperative for developing high quality CPS deployments. Our endeavour within this problem area would be to develop tools for modelling and designing the communication infrastructure of CPS. The approach could be one of borrowing from existing approaches in other domains and customising these for CPS. It is also important to plan and model the system appropriately so that it is open to accommodate new CPS components in a dynamic manner on the fly.

### PA6: Development of an entire suite for designing and modelling techniques for CPS

This is perhaps the most ambitious but also the most important planned endeavour of the hub. CPS as mentioned several times earlier is a significantly heterogeneous deployment. It comprises components that are very different from each other and can stem from very different domains. These could be both hardware and software components. The idea is to develop an entire suite of modelling and design tools that would make it possible to handle any kind of requirement. The suite would cater to all levels of modelling including: functional modelling; system modelling; process modelling; enterprise modelling. The suite is expected to be technology agnostic and be able to deftly handle varied technologies. The suite would also be able to handle dynamism in the CPS system and be able to easily accommodate new and unexpected components.

### PA7: Development of generic design and modelling techniques with modes for individual domains

This problem area is expected to serve as steppingstone to PA6 and would comprise development of tools for CPS design and modelling with a 'mode' facility. The mode would permit the designer to provide information to the tool on the kind of CPS to be developed. The tool would then employ domain specific facilities to adequately model the concerned CPS. While this endeavour is expected to be one step behind the earlier one in terms of being challenging, it is expected to result in a much more efficient and effective tool. Also, using this tool is expected to be significantly easier than a completely generic tool.

### PA8: Study and develop standard models for CPS development

Unlike software development environments that have a wide spectrum of process models, CPS environments use significantly ad-hoc approaches to development. An ideal scenario would comprise a multitude of process models for development that could be employed based on the nature of the CPS system expected. This is another example of a very challenging task wherein extensive survey of existing models, their benefits, gaps, and applications would need to be understood and analysed and based on this a process model for CPS would be developed. The models, depending on the application area, would be amenable for modifications based on feedback, would be of a planned type like the Waterfall Model in software development or an agile technique of quickly putting the application together and incrementally refining it. The aim is to devise a complete end to end modelling solution much akin to the Rational Unified Process for software development.

### PA9: Development of models for categorising process quality

Capability maturity models (CMM) are the crux of developing high quality products in both hardware and software domains. CMMs are certifications that place development units in categories based on the maturity of their process quality. A software development organisation that closely adheres to all the tenets of software development is placed at a high CMM level. We seek to develop a similar maturity model for CPS development. The idea is to propose and validate a set of points that a development unit needs to fulfil to find a place at a particular CMM level. This task requires substantial investment in terms of closely studying existing literature and approaches for comprehending process quality and customising these for the unique characteristics of CPS systems.

A summary of above problems areas, associated difficulty level, and most expected outcomes are summarized in figure 4.1 as Technical Focus Graph (TFA) for thrust area 1.

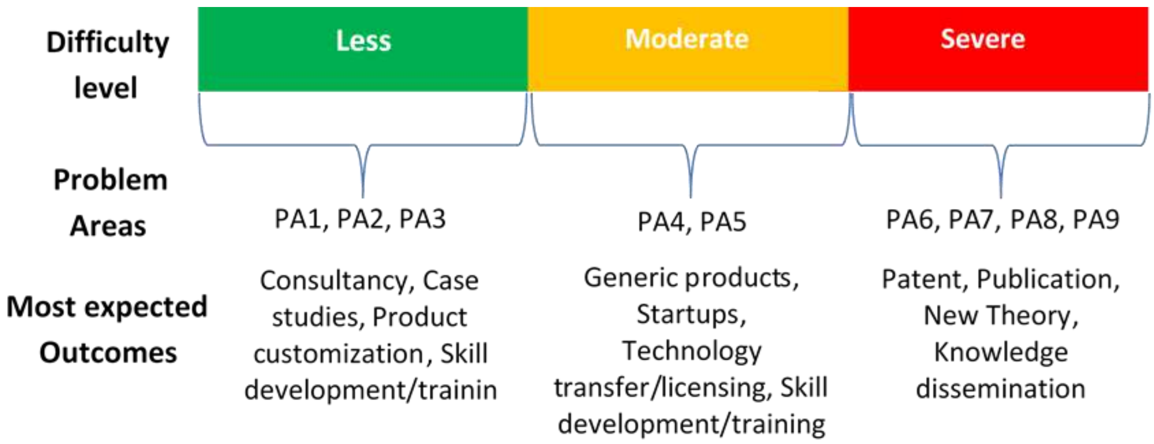


**Figure 4.1:** Technical focus graph for *Design and Modelling of CPS*

### 4.2.2. Cyber-Physical Industrial Systems

PA1: Cloud based manufacturing simulation tool
PA2: Development of laboratory scale simulators
PA3: Implementation case studies of Digital Twin (DT)
PA4: DT tool
PA5: DT platform
PA6: Standardization of DT development
PA7: Digital twin evolution
PA8: Business models development for Cyber Physical Production Systems (CPPS)
PA9: Agent based approaches for industrial CPS
PA10: Prognostics and health management with DT

### PA1: Cloud based manufacturing simulation tool

Several small and medium-scale manufacturing industries rely on experience-based decision-making to tackle uncertainties such as demand fluctuations, change in dispatch schedule, machine failures, power failures, unavailability of operators, etc., which is not always optimal.

The cost and skill associated with most commercial simulation tools make it an unattractive choice for SMEs. These industries are thus deprived of the benefits of simulation-based decision-making. Moreover, many of the simulation tools are not designed to cater to the need of cyber physical systems. Thus, under this problem area development of cloud-based simulation tools, integrating such tools with technologies like block chain, DT development, agent-based algorithms will be challenging. Developing a pay-per-use model will explore its commercial aspects and make it suitable to SMEs. Using open-source technologies is important and challenging. Further challenge will be to use available DTs and develop capability to autonomously generate simulation models without much involvement of shop floor managers.

### PA2: Development of laboratory scale simulators

Awareness about CPS design and applications from a modelling and simulation point of view would be targeted in this problem area. Developing laboratory scale simulators to demonstrate design challenges for various applications are required. Demonstrations as well as 'Do It Yourself' (DIY) approaches are intended to be used here. Integrating concepts of computer sciences, electronics, domain knowledge makes this challenging. Moreover, the demonstrator should also use industry grade hardware to replicate the industrial challenges.

### PA3: Implementation case studies of DT

In this problem area, we intend to conduct case studies for DT development and to understand real life challenges like integration with PLM software, ERP software, MES software, and the like. The challenge would be to identify the purpose of DT, identifying and extracting available data from existing systems, developing, and integrating required models in the DT and using the available standards to make DT interoperable.

### PA4: DT tool

DT tools would help in creating a basic architecture without the requirement of expertise in the software field. It will provide guidance on where to get data, which format of data to use, where to pass data within the DT, and so on. Creating an easy-to-use tool of this kind would be the challenge.

### PA5: DT platform

Under this problem category, the issue of hosting, running, and providing the required resources for DT would be addressed. Th. is further needs to be integrates with DT tool proposed in PA4

## PA6: Standardization of DT development

Digital twin is a widely talked about and much needed concept nowadays, especially in the industrial CPS field. The ability to design a 'plug and play' system for the creation of digital twins has the potential to revolutionize the entire CPS domain. However, it is quite challenging owing to the diversity of data, information, models required for diverse systems and their applications. The data and information available are often not along well-defined standards. Wherever standards are available, harmonizing between the standards becomes a challenge. A few problems that can immediately be identified and solved in this area are:

- Asset Administration Shell development
- Creating digital twin autonomously
- Interoperability of digital twin
- Enabling digital thread
- Model based enterprise concept development and implementation

## PA7: Digital Twin Evolution

This problem area is expected to comprise several challenging problems like, development of a suitable architecture to support Digital Twin (DT) evolution, integrating such evolution with Asset Administration Shell (AAS) concepts, optimizing data storage (edge, cloud, local) and making DT light-weight, data security, applications of evolution to various scenarios and integrating these with DT tools and platforms.

In every phase of the product life cycle starting from the concept phase to the end-of-life phase, information gets created, which is required by the DT to cater to several intended functions or subsequent lifecycle phases and to simultaneously evolve in terms of changes in the physical assets and knowledge acquired. The challenge would be to handle a variety of data like documents, CAD models, simulation models, reliability models, maintenance, and operation data, in a way that allows the DT to evolve along the lifecycle and effectively execute tasks or support decision-making in the subsequent phases. The challenges of solving such problems are mainly because of following reasons:

- The architecture needs to support capturing very diverse data and information.
- The complex relationships between data and information in various life cycle phases needs to be modelled.
- Digital twin evolution should optimally handle the abstraction vs detailing.
- Evolution requires communication among the various DTs and third-party applications in the value chain.
- Open-source technology are required to make the solution widely acceptable and for easy penetration into the industry.
- Standardized tools and platforms for DT creation are not available.

## PA8: Business models development for CPPS

Cyber Physical Industrial Systems are required to prove their benefit to the industry. For example, a manufacturing industry evaluates a Cyber Physical Production System (CPPS) based on how much it contributes to their key performance indices such as timely delivery, reduced cost, increase in profits, improved quality, and the like. To perform along these parameters, new business models need to be evaluated. Thus far, the focus has been only on developing technologies to enable various smart characteristics. Another domain where modelling and simulation is expected to play an important role is business model evaluation. Even commonly considered business models, such as sterilization, co-creation, manufacturing as services are not evaluated for their performance with respect to CPS characteristics.
For example,

- What characteristics of smart products will help in serviticizing?
- Will it make a profitable business model?
- What operations planning across the value chain need to be considered with these characteristics?
- How can various characteristics of a smart product be integrated with various value chain operations?
- What level of integration is required in the value chain?
- Similarly, can a ‘manufacturing as a service’ model help in reducing manufacturing costs for a particular business case? If yes, what features a CPPS should have to realize these benefits?

Addressing the above and many similar other questions, requires simulation models with parameters from connected systems. The problem is challenging as no clear formulation is available, capturing required parameters is not easy, integrating such formulation with CPS at the time of design is complex.

## PA9: Agent based and other distributed approaches for industrial CPS

Agent based approaches are decentralized approaches. Hence, these enjoy the inherent characteristics of distributed intelligence of cyber physical systems. However, developing such an approach is challenging for real life industrial problems. Solution quality gets compromised due to distribution/division of the larger problem into smaller problems at agent levels. However, we compensate for this through facilitating communication. A trade-off exists. How to make this trade-off and decide the level of distributed approach is a challenging area. It expected that new theory may emerge if we investigate such distributed approach over conventional centralized approaches. In addition, there are several parameters in such an agent-based approach that need to be optimized, which in itself is a challenge. Use of machine learning with an agent-based approach opens up new areas for research. Most importantly, several commercially available simulation modelling software for manufacturing planning do not support agent-based decision making. Available platforms for such modelling have limitations. One challenging problem could be to provide the required agent-based modelling and computation capability to digital twins themselves and create an autonomous agent based decision support systems out of the digital twins. Providing learning capability to a digital twin is important in such cases.

### PA10: Prognostics and health management with DT

Imagine you are driving in a car and your car learns in real time from other similar cars running on the road and predicts the health and remaining life of its various components. Furthermore, the care coordinates with the nearest service center, schedules maintenance services, and does a plethora of such tasks. Modelling this scenario is complex. Identifying closeness with other systems based on product characteristics, operating characteristics, and current health are required. Transfer learning approaches are useful in such scenarios. These are, however, developed for certain simplistic scenarios only. Identifying factors influencing the life of the components, identifying similarities, establishing required communication, creating a learning-based approach to predict the life of the components are challenging.

As prognostic information is very important and affects the safety and cost of a product, relying on a black-box approach like machine learning may not instil confidence among users. The need is to address this challenge and develop an interactive machine learning system that includes humans in the loop. The distributed intelligence, communication and autonomous decision making presents a possibility to develop such approaches.

Multi-agent based approaches need to be further developed to address the heterogeneous nature of CPS while solving prognostics problems. Testing such approaches in actual scenarios would be challenging. Moreover, the issue of handling scalability of such approaches will be handled under this category.

Exploring the problem in diverse areas of application like health monitoring of infrastructure, power plants, domestic appliances, automobiles, machine tools will pose varied challenges and would be solved under this problem category.

A summary of above problems areas, associated difficulty level, and most expected outcomes are summarized in figure 4.2 as Technical Focus Graph (TFA) for thrust area 2 with specific focus on industrial systems.

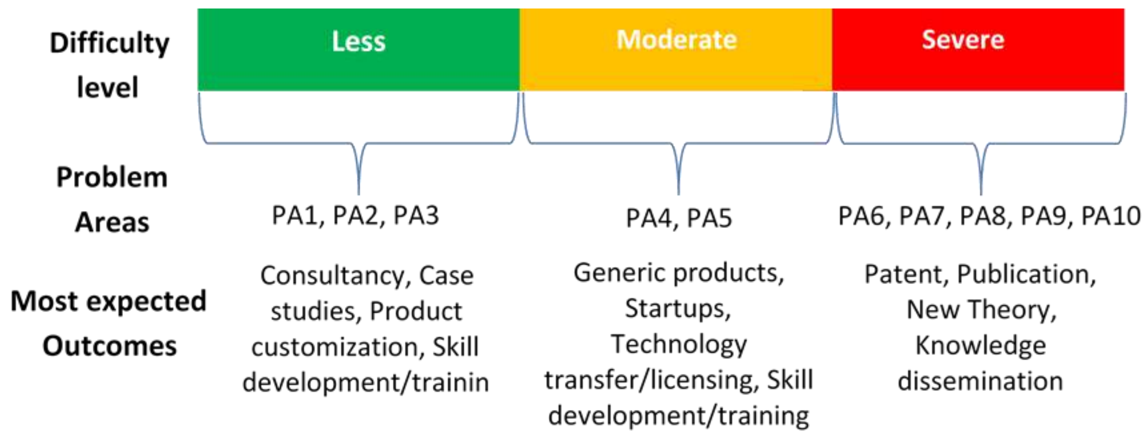


**Figure 4.2:** Technical focus graph for *CPIS*

### 4.2.3 Cyber-Physical Social Systems (CPSS)

PA1: Pilot deployment of an immediate implementation of blended learning
PA2: Development of an experimental assisted living environment
PA3: Deployment of a wireless sensor network for forest fire detection
PA4: Development of models to capture the dynamism and chaos of social systems
PA5: Development of immersive tools for training personnel in various domains
PA6: Development of laboratory simulations on various subjects for online practical training using virtual/augmented reality
PA7: Design of tools and techniques for brain signal analysis for early detection of autism
PA8: Development of generic and immediately deployable assisted living environments
PA9: To implement algorithms over WSN deployments for forest fire detection over all kinds of landscapes and climates
PA10: Development of an *iShiksha* hub for comprehensive blended learning solutions

#### PA1: Pilot deployment of an immediate implementation of blended learning

Blended learning through gamification is an area that has immense potential to contribute to the *sarv shiksha* initiative of the Government of India. It, therefore, holds a very important place in the plans of the hub. Development of a comprehensive platform for blended learning through gamification is a complex task and may take some time but the hub plans to immediately put into practise certain immediate implementations of blended learning. We are looking to utilise a few village schools around IIT Indore as the pilot sites for our endeavours and would be implementing immediate applications of blended learning. This could, for example, include simple depictions of internal body parts, tracing the path of blood in various organs in the body, simulating simple science experiments, and so on. These immediate implementations would be used to reach out to village children through the village schools and their general feedback would be registered and used for developing more sophisticated applications.

#### PA2: Development of an experimental assisted living environment

Assisted living environments are becoming very important in not just India but around the world as our elderly in large numbers are choosing to live independently and with dignity. In such circumstances, automatically monitoring their well being would be imperative and also very useful. We plan to put together a comprehensive and complete solution for assisted living environments. We plan to immediately put out efforts to practice by developing a pilot ‘smart space’ with features of assisted living available. This smart space will serve as a test bed to validate our ideas which would comprise the use of advanced analytical tools and techniques. We plan to equip this smart space with extensive deployments of sensors and cameras and back-end computing resources to support our analysis.

#### PA3: Deployment of a wireless sensor network for forest fire detection

Yet another important direction of work that the hub plans to undertake is forest fire detection. This area also has national recognition and is closely connected to the *Save the Tiger* initiative of the Government of India. The hub plans a complete end to end solution for automatically detecting forest fires whilst dealing with the unique climatic challenges that present themselves in the subcontinent. We plan to immediately set in motion our endeavours in this direction by putting together a pilot deployment of wireless sensor network (WSN) at the Melghat Tiger Reserve in Maharashtra. IIT Indore and the Melghat Tiger Reserve are working in partnership to develop smart means for forest fire detection and the endeavours of the hub would feed into this endeavour. With the WSN in place, an initial backbone structure for forest fire detection would be in place. With the passage of time, the WSN deployment would be augmented with machine learning implementations for more superior detection of forest fires.

**PA4: Development of models to capture the dynamism and chaos of social systems**

The one factor common across social systems of all kinds is the chaos that they are associated with. Social systems have the human factor playing a very important role in them and humans by their very nature are unpredictable. To accurately model such systems is non-trivial. A more medium-term challenge that the hub hopes to address is to model social systems as precisely as possible. This is a very difficult task and is expected to involve extensive study and research on human behaviour and the nature of their interactions with other components in a social system. An understanding of this and modelling the same would make it much easier to design and model CPS systems for social settings.

**PA5: Development of immersive tools for training personnel in various domains**

Much like blended learning systems, immersive tools like virtual/augmented reality systems, social networks are available and need to be harnessed appropriately. The hub plans to do just this and create customised training modules using these. Depending on the domain, customised training modules would be developed by the hub by using existing virtual/augmented reality systems. The hub would also be looking at developing such systems on its own and using them for appropriate applications. A slightly longer-term endeavour in this respect would be the development of generic immersive systems that could be modified on the go and used for disparate groups of personnel.

**PA6: Development of laboratory simulations on various subjects for online practical training using virtual/augmented reality**

This follows from the previous problem area and is a more specific application of virtual/augmented reality systems wherein laboratory courses across engineering and science disciplines would be simulated. The idea here would be to address concerns raised during the pandemic times wherein large sections of students have missed out on important practical training. Simulated systems would permit students to remotely run and 'get a feel' for tools and equipment through such immersive systems. In addition to supporting the country in this way in unfortunate times like the pandemic, such systems can also contribute to involving underprivileged students and remotely located students to the mainstream education initiatives and ultimately add substantial value to human resource development.

**PA7: Design of tools and techniques for brain signal analysis for early detection of autism**

We plan to develop CPS systems for monitoring brain signals for early and non-invasive detection of Autism Spectrum Disorder (ASD) and Attention Deficiency Hyperactivity Disorder (ADHD) in children. The tool that is proposed to be developed would be dynamic in nature and would be continuously learning and improving through an effective feedback mechanism. We plan to harness appropriate learning algorithms for optimal results and compare the same with conventional systems. This tool holds significance for the hub as it is expected to provide the blue-print for further forays in the healthcare domain and can meaningfully contribute in the context of our country.

**PA8: Development of generic and immediately deployable assisted living environments**

Building upon the smart assisted living environment developed as part of our immediate plans, the hub is looking to provide generic solutions in this domain. We intend to appropriately package the assisted living environment solution such that it becomes a 'plug and play' system and can be immediately deployed in any setting with minimal computational resources. The idea is to put together a system that is technology agnostic and can be orchestrated using a simple smart mobile device. The sensors, actuators, cameras, and other supporting equipment would be part of the package and be available in a form so as to be immediately deployable with detailed instructions on their working. This venture is especially important given the number of elderly people in the country and beyond that want to live independent lives with dignity.

**PA9: To implement algorithms over WSN deployments for forest fire detection over all kinds of landscapes and climates**

Subsequent to deploying a WSN system in a pilot forest setting to detect forest fires we intend to augment this network with appropriate learning algorithms. The intent would be to eliminate false positives, accurately determine the location of the fire, and devise means for optimal deployment of WSN motes. The challenge of implementing these algorithms is that they need to run over WSN motes that are extremely resource constrained environments with as little as 2 KB of primary memory, 32 KB of flash memory, and just 14 Hz of processing capability. The algorithm would need to work over such environments though deftly handling streaming data, extremely lightweight implementations, and little or no overhead in terms of energy consumption. Though challenging, the direction of this work is expected to be interesting and fulfilling.

**PA10: Development of an *iShiksha* hub for comprehensive blended learning solutions**

This initiative would also be based on some immediate work done on utilising gamification for blended learning. We plan to develop a complete solution for blended learning by creating a network of *iShiksha* simulator and hubs and initiate the learning process across industries, institutions, and schools. This simulator will include micro and nano learning modules development, digital assessment, big data analytics for personalized leaning, gamification of course content, use of AR/VR/XR in gamification of course, virtual hands-on setups, cloud ERP or similar system for e-learning.

A summary of above problems areas, associated difficulty level, and most expected outcomes are summarized in figure 4.3 as Technical Focus Graph (TFA) for thrust area 2 with specific focus on social systems.

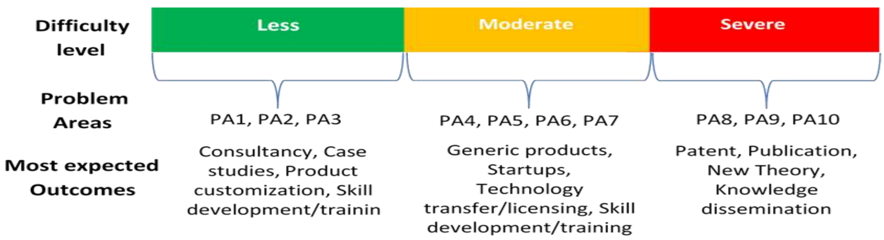


**Figure 4.3:** Technical focus graph for *CPSS*

Being application specific exploration in second thrust area, it is expected that many more application area experts and users will come together to define such problem areas in future.

### 4.2.4 Few Marquee Areas

Problem areas identified through literature review and as summarised in sub-section 4.2.3 were further discussed with some of the relevant end users. Further, it is observed that some of the offerings of industrial systems will also be applicable in social systems. For example, development of digital twin architecture in manufacturing can also be explored for farming or health care. Considering the same following "Marquee Areas" are identified for immediate focus of the Hub. It mainly summarizes various problem areas mentioned section 4.2.3 into few offerings expected from our hub.

#### Digital Twin: Under following applications (not exhaustive)

- **Manufacturing and Machine tools**: digital twin for shop floor management, digital twin for manufacturing supply chain management, digital twin to improve product design, digital twin evaluation over the product lifecycle, digital twin based generative product design.
- **Healthcare:** digital twin for personalized treatment (patient-centric), pre and post-operative surgical procedure on digital replica to reduce the risk, advanced patient centric computation models for designing digital twins of human organs, digital twin in hospital management, digital twin to test drug efficiency and side effects, digital twin for healthcare supply chain management, digital twin in healthcare training.
- **Smart Farming:** digital twin of farms, livestock and machinery, digital twin-based farm management, heard management, farming supply chain management, digital twin for supporting agri-insurance, digital twin to support agriculture-based policy making.
- **Smart Cities and Smart Societies:** Digital twin for waste management, DT based future mobility solutions, disaster management using digital twin, use of DT to improve the quality of life (Assisted living for example), quality services, traffic management, performance management, and interactivity between different service providers of smart cities.

#### Blended learning and Gamification

- Micro and nano learning modules development, digital assessment, Big data analytics for personalized leaning, gamification of course content, use of AR/VR/XR in gamification of course, virtual hands-on setups, cloud ERP or similar system for e-learning.

It is expected that with continuous interaction with End Users, development in many of these areas will result into technology products (TRL level 7 and above) for the hub.

# Chapter 5

# Target Beneficiaries

IITI DRISHTI CPS Foundation plans to be at the forefront of creating sustaining an ecosystem which would act as focal point for the convergence of the efforts of academia, industry and government agencies for technology development, translational research, product commercialization and skill enhancement in the area of system simulation, modelling and visualization (SSMV) of Cyber Physical Systems (CPS) under the below mentioned thrust areas.

***Thrust Area 1: Cyber Physical Systems Design***

***Thrust Area 2: Application Specific Development in CPS: Industrial and Social Systems***

## 5.1 Beneficiaries

Based on the activities proposed at IITI DRISHTI CPS Foundation in the above mentioned thrust areas on SSMV aspects of CPS, following are the beneficiaries:

### Direct Beneficiaries:

(a) Line ministries

(b) Public sector units

(c) Government agencies/departments

(d) Industries

### Indirect Beneficiaries:

(e) Academic institutes

(f) Faculty members

(g) Students

(h) General population

Following paragraphs provide rationale behind the above beneficiaries.

- Line ministries, Public Sector Units (PSUs), Government agencies, Defence establishment, State government departments would be the major beneficiaries. IITI DRISHTI CPS Foundation will continuously strive to obtain problem statements from these units and identify the appropriate team in the country to develop and implement the required technology. Joint funding with such government units may also be explored. Wherever feasible, technology developed under such projects will be continuously evaluated for commercialization. Industries working in related areas will be brought on board for implementation and commercialization. Technology transfer may be carried out for mass scale production. Wherever required, appropriate start-ups will also be identified, mentored and supported to develop such technology. It is expected that many of such solutions will directly and positively touch the life of people in the country.

- In cases where industries already have problem statements, real world scenarios will be understood and relevant experts/researchers/faculty members/students from the country will be brought on board for solving such problems. Some of the solutions/prototypes might directly come from faculty members/students/researchers. These solutions will be widely publicized to attract relevant industries/start-ups for technology transfer and commercialization. Various models for commercialization of findings and intellectual property rights sharing will be explored. Thus, faculty members, and in turn, their parent institutes will get the opportunity to work in real world problems through consultancy and associated IP sharing. Students will also be involved in such technology development projects and supported through fellowships. Some of the students may adopt an entrepreneurship career path and shall be initially supported by the hub. Thus, it will also help them in overcoming some initial risks and lead towards successful entrepreneurs in future. In addition, proposed skill center at IITI DRISHTI CPS Foundation and various skill development/enhancement programs will help the industries in enhancing skills of their existing manpower.
- IITI DRISHTI CPS Foundation will aim to act as a bridge between available experts/researchers in various academic institutes and industries, R&D Organizations, line ministries and state government departments for technology development and commercialization. This will ultimately contribute to various initiatives of the Government of India such as Digital India, AatmaNirbhar Bharat, Make in India, Smart Cities, Sugamya Bharat Abhiyaan, National Education Policy, Digital Healthcare Mission, etc., all of which will directly impact the general population.

# Chapter 6

# Management

## 6.1 Organization Structure

Efficiently managing the TIH at IIT Indore is very important for achieving the milestones mentioned in DPR and also for effectively contributing towards the aims and objectives of the National Mission on Interdisciplinary Cyber Physical Systems. The registration of a Section 8 company, IITI DRISHTI CPS Foundation, has already been carried out and tripartite agreement (between Mission, Host Institute and the Section 8 Company) has been already executed. The following organization structure (figure 6.1) for effective management of the TIH shall be adopted.

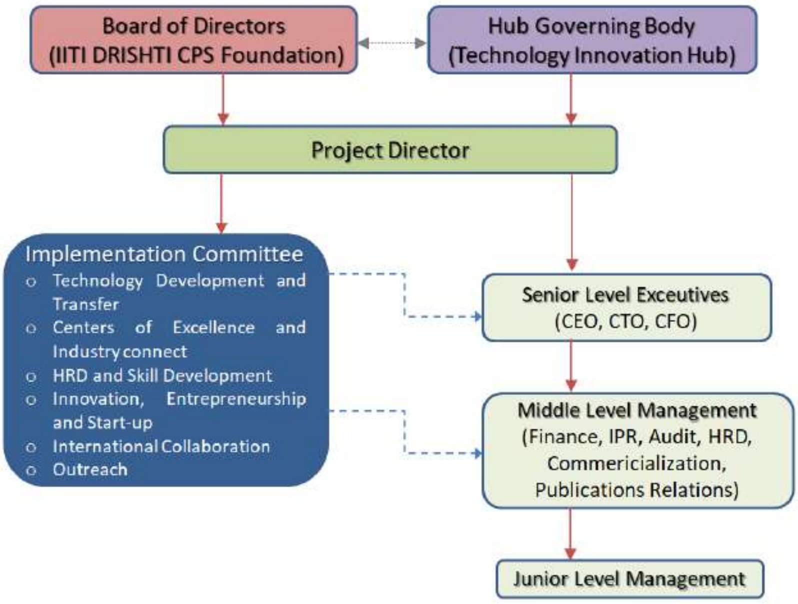


**Figure 6.1:** Management structure of Technology Innovation Hub (TIH) at IIT Indore

## 6.2 Board of Directors (BoDs)

Board of Directors (BoDs) will be the apex body to formulate and approve various policies, procedures, rules and norms relating to the Section 8 Company, named as IITI DRISHTI CPS Foundation. BoDs will work in accordance with the terms and references laid down by the Registrar of Companies (RoC). BoDs shall review and approve administrative activities of the hub. It will also facilitate approval of funds and procedures for the activities approved by the Hub Governing Body (HGB). IITI DRISHTI CPS Foundation is in the process of constituting the Board of Directors. A tentative composition of the same, as shown in figure 6.2, is given as below.

- Director and Chairman BoD: Director of the host institute (IIT Indore)
- 2-3 Directors: It may include Dean, Research and Development of the Host Institute

(HI), Project Director who is a faculty member from HI, joint or co-director (if appointed) from HI

- 1-2 senior faculty members from organizations other than HI who are working in the areas identified by hub
- 4 or more members from industry having sufficient experience of various activities of the hub
- 1 or more members from PSUs or Line ministries/department

In addition, if joint/co-directors are appointed then they shall also be included in the HGB. Meeting of BoDs shall be conducted as per the norms of RoC. During the initial stages, it is proposed to have frequent meetings for formulating norms and streamlining various procedures. Once these procedures and norms are finalized, board meetings may be conducted at least once in each quarter of the year or as per the norms under company act. Allocation of space identified by the HI and associated infrastructure development and manpower recruitment are the next steps for IITI DRISHTI CPS Foundation. The manpower recruitment would be at appropriate levels and on a requirement basis so as to facilitate all activities of the hub. The staff is likely to include Chief Executive Officer (CEO), intellectual property expert, finance expert and required staff. Based on the activities and outcomes, inclusion of other staff members may be considered.

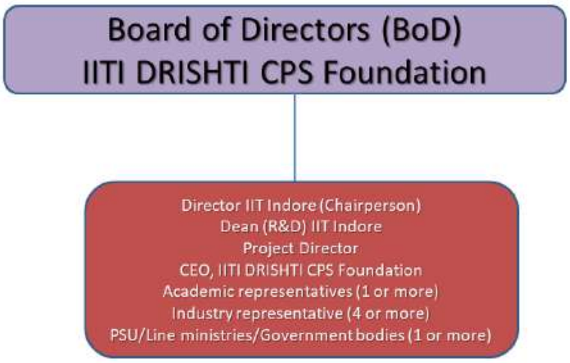


**Figure 6.2:** Composition of Board of Directors (BoD) of IITI DRISHTI CPS Foundation

**Figure 6.3:** Composition of Hub Governing Body (HGB) of TIH at IIT Indore

## 6.3 Hub Governing Body (HGB)

Hub Governing Body (HGB) is expected to review scientific vision and provide direction to the activities of the hub while providing the necessary approval for the same. As shown in figure 6.3, HGB is expected to have the following composition.

- Chairman HGB: Director of the host institute (IIT Indore)
- Ex-officio member: Dean, Research and Development of HI
- Project Director and Member Secretary: Faculty member from HI
- 3 or more faculty members from other than HI who are working in the areas identified by hub
- 1 or more member from industry
- 1 or more member from PSUs or Line ministries/department
- Representative of DST
- CEO of Hub, Convener of HGB

In addition, if joint/co-directors are appointed, then they shall also be included in the HGB. Two meetings of the HGB of TIH have been held. The CEO would report to the Project Director (PD) and shall be responsible for executing the decision HGB and BoD. The CEO is expected to coordinate with all spokes, hubs, funding agencies and line ministries for smooth execution of the project. In addition, the CEO would ensure that decisions of BoD are implemented in letter and spirit and be responsible for all necessary compliance in accordance with rules and regulations. Further, administrative actions leading to smooth implementation of the project shall be the responsibility of the CEO.

To encourage fresh ideas, members of HGB and BoD would be having the fixed tenure. PD shall be responsible for the overall execution of the project. PD will be the central person for coordinating various tasks between HGB, BoDs, spokes and committees. An implementation committee shall be constituted to manage different activities of the hub. As shown in figure 6.1, these activities would include technology development and transfer, industry connect, incubation and entrepreneurship, international collaboration and outreach. CEO will ensure required support of staff members to various implementation committee as shown in figure 6.1.

## 6.4 Coordination

IITI DRISHTI CPS Foundation was able to generate appreciable interest amongst spokes (partner institutes/universities) and industry. It is envisaged to build up on the same and come up with a fruitful hub and spoke framework for achieving the deliverables. The implementation committee, as shown in figure 6.1, consisting of faculty members of the institute would be constituted to better coordinate various tasks under NM-ICPS scheme. The committee would work towards resolving bottlenecks to better coordinate with various stakeholders during the execution of the project. The committee would share its viewpoints with the CEO and PD while harmonizing the execution with the spokes. The tripartite agreement shall be followed, and the host institute will extend the required space and infrastructure support as outlined in the agreement. A proposal for applying for a Technology Business Incubator (TBI) to the National Science and Technology Entrepreneurship Development, DST, shall also be initiated. A SWOT analysis would be carried out for every idea/start-up. Start-ups applying for incubation at TIH would be evaluated on a points-based system, and the performance of each start-up would be periodically reviewed. IITI DRISHTI CPS Foundation would extend possible help to connect start-ups with Venture Capitalists. A pre-incubation office supporting the transition of ideas into start-ups would also be established. Internal and external audit as per the norms of the Government of India would be conducted. As a hub and spoke model will be adopted, IITI DRISHTI CPS Foundation would have at least an annual meeting with all spokes for a more productive and fruitful engagement. Interactions with other technology innovation hubs in other academic institutes would also be held. Regular and timely communication with DST shall be ensured for proper execution of the project.

# Chapter 7

# Finance

## 7.1 Budget

The budget for the proposed TIH has been divided in terms of six hub activities as follows.

i. Technology Development,

ii. Centre of Excellence,

iii. HRD & Skill Development,

iv. Innovation, Entrepreneurship, and Start-up Ecosystem,

v. International collaborations, and

vi. TIH Management Unit

**Table 7.1:** Summary of budget (in Rs Crore)

| S. No. | Hub activity | Budget Head | 1st Yr | 2nd Yr | 3rd Yr | 4th Yr | 5th Yr | Total |
|---|---|---|---|---|---|---|---|---|
| 1 | **Technology Development** | Recurring | 2.40 | 2.40 | 3.00 | 3.00 | 2.80 | 13.60 |
| | | Non-Recurring | 0.00 | 2.40 | 3.00 | 3.00 | 2.80 | 11.20 |
| | | **Sub-Total** | **2.40** | **4.80** | **6.00** | **6.00** | **5.60** | **24.80** |
| 2 | **Centre of Excellence** | Recurring | 0.46 | 0.51 | 0.77 | 0.44 | 0.41 | 2.59 |
| | | Non-Recurring | 0.00 | 17.60 | 0.35 | 0.35 | 0.50 | 18.80 |
| | | **Sub-Total** | **0.46** | **18.11** | **1.12** | **0.79** | **0.91** | **21.39** |
| 3 | **HRD & Skill Development** | Recurring | 1.74 | 2.93 | 3.35 | 2.81 | 1.89 | 12.72 |
| | | Non-Recurring | 0.00 | 2.00 | 0.00 | 0.00 | 0.00 | 2.00 |
| | | **Sub-Total** | **1.74** | **4.93** | **3.35** | **2.81** | **1.89** | **14.72** |
| 4 | **Innovation, Entrepreneurship, and Start-up Ecosystem** | Recurring | 1.38 | 2.03 | 2.27 | 1.85 | 1.69 | 9.22 |
| | | Non-Recurring | 0.00 | 6.90 | 5.75 | 0.45 | 0.50 | 13.60 |
| | | **Sub-Total** | **1.38** | **8.93** | **8.02** | **2.30** | **2.19** | **22.82** |
| 5 | **International collaborations** | Recurring | 0.00 | 1.00 | 1.25 | 0.75 | 0.00 | 3.00 |
| | | Non-Recurring | 0.00 | 0.40 | 0.20 | 0.00 | 0.00 | 0.60 |
| | | **Sub-Total** | **0.00** | **1.40** | **1.45** | **0.75** | **0.00** | **3.60** |
| 6 | **TIH Management Unit** | Recurring | 1.27 | 1.63 | 2.11 | 1.90 | 1.96 | 8.87 |
| | | Non-Recurring | 0.00 | 3.20 | 0.20 | 0.20 | 0.20 | 3.80 |
| | | **Sub-Total** | **1.27** | **4.83** | **2.31** | **2.16** | **2.15** | **12.67** |
| | **Total** | Recurring | 7.25 | 10.50 | 12.75 | 10.75 | 8.75 | 50.00 |
| | | Non-Recurring | 0.00 | 32.50 | 9.50 | 4.00 | 4.00 | 50.00 |
| **Grand Total (in Rs Crore)** | | | **7.25** | **43.00** | **22.25** | **14.75** | **12.75** | **100.00** |

Total budget for the TIH is estimated at Rs. 100.00 crores. Budget distribution for the TIH has been provided in Table 7.1 to Table 7.3. Year wise break-up of budget in terms of budget heads, viz. recurring and non-recurring, for all six hub activities has been summarised in Table 7.1. In the given budget all capital expenses have been included under non-recurring budget head.

Although the proposed TIH shall utilize 50% of the budget for recurring expenses and remaining 50% of the budget for non-recurring expenses, fine tuning may be carried out depending on critical requirements to achieve time bound deliverables. Table 7.2 summarizes the year-wise distribution of the recurring and non-recurring (including capital expenses) budget heads.

**Table 7.2:** Estimated year-wise expenses under each Budget Head (in Rs Crore)

| S. No. | Budget Head | 1st Yr | 2nd Yr | 3rd Yr | 4th Yr | 5th Yr | Total | % |
|---|---|---|---|---|---|---|---|---|
| 1 | Recurring | 7.25 | 10.50 | 12.75 | 10.75 | 8.75 | 50.00 | **50.00** |
| 2 | Non-Recurring | 0.00 | 32.50 | 9.50 | 4.00 | 4.00 | 50.00 | **50.00** |
| | **Grand Total (in Rs Crore)** | 7.25 | 43.00 | 22.25 | 14.75 | 12.75 | 100.00 | **100.00** |

In terms of hub activities, Technology Development will utilize 24.80% of the budget; Centre of Excellence will utilize 21.39%; HRD & Skill Development will utilize 14.72%; Innovation, Entrepreneurship, and Start-up Ecosystem will utilize 22.82%; International Collaborations will utilize 3.60%; and TIH Management Unit will utilize 12.67% of the total budget. The year-wise distribution of the total budget for all six proposed sub-missions has been summarized in Table 7.3.

**Table 7.3:** Year-wise estimated expenses for hub activities (in Rs Crore)

| S. No. | Hub activity | 1st Yr | 2nd Yr | 3rd Yr | 4th Yr | 5th Yr | Total | % |
|---|---|---|---|---|---|---|---|---|
| 1 | Technology Development | 2.40 | 4.80 | 6.00 | 6.00 | 5.60 | 24.80 | 24.80 |
| 2 | Centre of Excellence | 0.46 | 18.11 | 1.12 | 0.79 | 0.91 | 21.39 | 21.39 |
| 3 | HRD & Skill Development | 1.74 | 4.93 | 3.35 | 2.81 | 1.89 | 14.72 | 14.72 |
| 4 | Innovation, Entrepreneurship and Start-up ecosystem | 1.38 | 8.93 | 8.02 | 2.30 | 2.19 | 22.82 | 22.82 |
| 5 | International collaborations | 0.00 | 1.40 | 1.45 | 0.75 | 0.00 | 3.60 | 3.60 |
| 6 | TIH Management Unit | 1.27 | 4.83 | 2.31 | 2.10 | 2.16 | 12.67 | 12.67 |
| | **Total Mission cost (in Rs Crore)** | **7.25** | **43.00** | **22.25** | **14.75** | **12.75** | **100.00** | **100.00** |

This section provides a summary of the complete budget. Individual budget breakup and justification for the same are included in subsequent sections.

### 7.2 Budget justification for Technology Development

One of the core hub activities is aimed towards technology development through various research projects. The budget for technology development includes support for R&D projects, prototype development, patenting, and commercialization.

In this hub activity, an average grant of Rs. 40 lakhs has been allocated. Some of these project outcomes will also result in the setting up of research bases at various locations in the country. A total of 62 CPS research bases are proposed. It is considered that the budget will comprise of both recurring expenses and non-recurring expenses; however, the actual break-up can vary, based on the sanctioned amount. Grant for individual sanctioned projects may vary but the total expenses for technology development will be limited to the value of Rs. 24.80 crores. Also, some part of the fund may be utilized for expenses like, patent filing, licensing process, etc., if not done by the PI within the sanctioned project cost. Yearly distribution of targets and estimated budget is given in the Table 7.4. Sanctioned amount also includes salary of project staff in individual projects, and will provide additional contribution towards HRD and skill development.

**Table 7.4:** Estimated budget for Technology Development

| Major Component | Unit cost | Targets | | | | | | Budget in Rs Crore | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Yr 1 | Yr 2 | Yr 3 | Yr 4 | Yr 5 | Total | Yr 1 | Yr 2 | Yr 3 | Yr 4 | Yr 5 | Total |
| CPS research grant | 0.4 | 6 | 12 | 15 | 15 | 14 | **62** | 2.4 | 4.8 | 6 | 6 | 5.6 | **24.8** |

The hub will select research projects in terms of their merits, to ensure that the project outcomes meet the targets specified in Table 7.5.

**Table 7.5:** Technology Development

| S. No. | Activity | Target | | | | | |
|---|---|---|---|---|---|---|---|
| | | Yr1 | Yr2 | Yr3 | Yr4 | Yr5 | Total |
| A. | No. of technologies (IP, licensing, patents, etc.) | 2 | 4 | 4 | 4 | 5 | **19** |
| B. | Technology Products | 1 | 2 | 3 | 3 | 3 | **12** |
| C. | Publication, IPR and other Intellectual activities | 5 | 7 | 8 | 8 | 8 | **36** |
| D. | Increase in CPS research base | 6 | 12 | 15 | 15 | 14 | **62** |

## 7.3 Budget justification for Centre of Excellence

A Centre of Excellence (CoE) for System Simulation, Modelling and Visualization will be developed as a part of TIH. The primary focus of the CoE will be translational research, i.e., converting the academic research into industry-oriented technology. The CoE will serve as a common unit for different activities and will facilitate interdisciplinary research in the field of CPS.

The CoE will be developed through an allocated budget of Rs. 21.39 crores, as shown in Table 7.6. An estimated budget of Rs. 17.00 crores will be used as a non-recurring expense for the development of CoE and will cover expenses required for the procurement and setting-up of cutting-edge software, machines, equipment and instruments, furniture etc.

**Table 7.6:** Estimated budget for the Centre of Excellence

| Budget component (in crore Rs.) | Targets | | | | | |
|---|---|---|---|---|---|---|
| | **Yr1** | **Yr2** | **Yr3** | **Yr4** | **Yr5** | **Total** |
| **A. Recurring** | | | | | | |
| 1. Staff | 0.11 | 0.16 | 0.17 | 0.19 | 0.21 | 0.84 |
| 2. Office supplies | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.50 |
| 3. Miscellaneous and Contingency | 0.25 | 0.25 | 0.50 | 0.15 | 0.10 | 1.25 |
| **Sub-total** | **0.46** | **0.51** | **0.77** | **0.44** | **0.41** | **2.59** |
| **B. Non-recurring** | | | | | | |
| 1. CoE development | 0.00 | 17.00 | 0.00 | 0.00 | 0.00 | 17.00 |
| 2. Office equipment and facilities | 0.00 | 0.30 | 0.05 | 0.05 | 0.20 | 0.60 |
| 3. Operational costs and other non-recurring miscellaneous expenses | 0.00 | 0.30 | 0.30 | 0.30 | 0.30 | 1.20 |
| **Sub-total** | **0.00** | **17.60** | **0.35** | **0.35** | **0.50** | **18.80** |
| **Grand total** | **0.46** | **18.11** | **1.12** | **0.79** | **0.91** | **21.39** |

Three staff will be hired for the operation CoE. The proposed year-wise salary breakup for the staff is as follows:

| Year | Monthly Emolument (In RS.) | Man months | Total Cost |
|---|---|---|---|
| Year 1 | 40,000 | 27 | 10,80,000 |
| Year 2 | 44,000 | 36 | 15,84,000 |
| Year 3 | 48,400 | 36 | 17,42,400 |
| Year 4 | 53,240 | 36 | 19,16,640 |
| Year 5 | 58,564 | 36 | 21,08,304 |

## 7.4 Budget justification for HRD and Skill Development

Hub activity, HRD & Skill Development, is aimed towards training and development of skilled professionals through fellowships and skill development workshops. Budget for HRD and Skill

Development includes fellowship for UG, PG, Doctoral students, Faculty members and Chair Professors, apart from development funds to support UG and PG internships and professional skill development workshops. Table 7.7 shows the distribution of HRD & skill development targets on a yearly basis and estimated budget for the same.

**Table 7.7:** Estimated Expenditure for HRD & Skill Development

| | Major Components | Unit cost | Targets | | | | | | Budget (in Rs crore) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Yr 1 | Yr 2 | Yr 3 | Yr 4 | Yr 5 | Total | Yr1 | Yr2 | Yr3 | Yr4 | Yr5 | Total |
| **1** | **UG internship** | | | | | | | | | | | | | |
| | (i) Graduate Internships | **0.005** | 25 | 35 | 50 | 50 | 50 | 210 | 0.13 | 0.18 | 0.25 | 0.25 | 0.25 | 1.05 |
| | (ii) Development Fund (For Projects done under Graduate Internships) | **0.01** | 25 | 25 | 50 | 45 | 25 | 170 | 0.25 | 0.25 | 0.50 | 0.45 | 0.25 | 1.70 |
| | (iii) CPS Infrastructure development fund | **1.00** | 0 | 1 | 0 | 0 | 0 | 1 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| **2** | **PG fellowships** | | | | | | | | | | | | | |
| | (i) Post-Graduation Fellowships | **0.03** | 4 | 7 | 8 | 10 | 10 | 39 | 0.12 | 0.21 | 0.24 | 0.30 | 0.30 | 1.17 |
| | (ii) Development Fund (For Projects done under PG Fellowships) | **0.02** | 4 | 5 | 8 | 7 | 7 | 31 | 0.08 | 0.10 | 0.16 | 0.14 | 0.14 | 0.62 |
| | (iii) CPS Infrastructure development fund | **1.00** | 0 | 1 | 0 | 0 | 0 | 1 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| **3** | **Doctoral Fellowships** | **0.15** | 3 | 5 | 5 | 5 | 5 | 23 | 0.45 | 0.75 | 0.75 | 0.75 | 0.75 | 3.45 |
| **4** | **Faculty Fellowship** | **0.54** | 1 | 1 | 1 | 0 | 0 | 3 | 0.54 | 0.54 | 0.54 | 0.00 | 0.00 | 1.62 |
| **5** | **Chair Professor** | **0.72** | 0 | 1 | 1 | 1 | 0 | 3 | 0.00 | 0.72 | 0.72 | 0.72 | 0.00 | 2.16 |
| **6** | **Skill Development** | **0.0025** | 70 | 75 | 75 | 80 | 80 | 380 | 0.18 | 0.19 | 0.19 | 0.20 | 0.20 | 0.95 |
| | | **Total** | 132 | 156 | 198 | 198 | 177 | 861 | 1.74 | 4.93 | 3.35 | 2.81 | 1.89 | 14.72 |

In addition, some of the technology development projects also include fellowship amount; hence the actual HRD and Skill development output and budget will be significantly higher than the values specified in Table 7.7. Different components of HRD and skill development activity along with their justification for specified costs are listed in Table 7.8.

**Table 7.8:** Components of HRD & skill development

| S No | Title | Unit cost (in Rs crore) | Justification |
|---|---|---|---|
| 1 | UG fellowships | | |
| | (i) Graduate Fellowships | 0.005 | UG fellowships/internships for a period of 10 months will be conducted during the final year project of the UG student along with their regular course work. This will engage UG students with the recent advances in CPS based technologies and their industrial applications. UG students will receive a stipend of Rs. 5,000 per month as a recurring expenditure during the internship, estimating a total of Rs. 0.50 lakh per student. |
| | (ii) Development Fund (For Projects done under Graduate Fellowships) | 0.01 | As per requirement a non-recurring grant of Rs. 1.00 lakh will be given for the projects done under UG fellowships. |
| | (iii) CPS Infrastructure development fund | 1.00 | Under-graduate labs, in CPS and allied areas of the institution, will receive a one-time grant, maximum of Rs. 1.00 crore. The fund will be utilized for developing infrastructure needed to support UG fellowships. This will be a non-recurring expenditure. |
| 2 | PG fellowships | | |
| | (i) Post-Graduation Fellowships | 0.03 | PG fellowship will be awarded for students to promote knowledge and innovation in the field of CPS during M. Tech./ M.S./ M.E. A monthly stipend of Rs. 12,400 will be provided for a period of 2 years, estimating a total of Rs 3.00 lakh per student under recurring costs. |
| | (ii) Development Fund (For Projects done under PG Fellowships) | 0.02 | As per requirement a non-recurring grant of Rs. 2.00 lakh will be given for the projects done under PG fellowship. |
| | (iii) CPS Infrastructure development fund | 1.00 | Post-graduate labs, in CPS and allied areas of the institution, will receive a one-time grant, maximum of Rs. 1.00 crore. The fund will be utilized for developing infrastructure needed to support PG internship. This will be a non-recurring expenditure. |
| 3 | Doctoral Fellowships | 0.15 | Doctoral fellowship will be awarded to encourage research and innovation and produce PhD graduates in the field of CPS. Doctoral fellowship includes a maximum monthly stipend of Rs |

| | | | |
|---|---|---|---|
| | | | 42,000, including TA, DA and HRA, for a period of 3 years; estimated a total recurring expenditure of Rs. 15.00 lakh per candidate. |
| 4 | Faculty Fellowship | 0.54 | Faculty fellowships will be awarded to faculty or PhD graduates working in the domain of CPS, to use their knowledge towards research, innovation and technology dissemination. Faculty fellowship will be awarded as a monthly stipend of Rs 1.50 lakhs, including TA, DA and HRA, for a period of 3 years. A total of Rs 54 lakhs will be needed for each candidate in recurring costs. |
| 5 | Chair Professor | 0.72 | Chair Professors will be selected for their expertise and will receive an honorarium of Rs 2.00 lakh per month, inclusive of everything, for a period of 3 years. Expertise of chair professors will provide support to all activities under TIH. A total budget of Rs 72 lakh will be allocated for each chair professor under recurring costs. |
| 6 | Skill Development | 0.0025 | Skill Development Workshops will be conducted during the course of 5 years to train skilled professionals. Workshops will span for a period of 5 days with an average expenditure of Rs 5,000 per candidate per day, estimating a total of Rs. 25,000 per candidate. Budget for individual workshops will be allocated as per the number of skilled professionals to be trained. |

## 7.5 Budget justification for Innovation, Entrepreneurship & Start-ups Ecosystem

The hub activity, Innovation, Entrepreneurship & Start-ups Ecosystem, will cover EIR, start-up incubation, pre-incubation and other entrepreneurship related activities like investors summit, incubation facilities. Budget for the hub activity accounts for the expenses required in the promotion, incubation, operation and development of start-ups and other entrepreneurial ventures in the domain of the CPS. Several components are identified under this activity. The budget allocated for each component has been summarized in Table 7.9.

**Table 7.9:** Estimated Expenditure for Innovation, Entrepreneurship & Start-ups ecosystem

| Major Components | | Unit cost | Targets | | | | | | Budget (in Rs crore) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Yr1 | Yr 2 | Yr 3 | Yr 4 | Yr5 | Total | Yr1 | Yr2 | Yr3 | Yr4 | Yr 5 | Total |
| **1** | **CPS-Technology Business Incubator (TBI)** | 6.67 | 1 | 0 | 0 | 0 | 0 | 1 | 0.76 | 2.51 | 1.26 | 1.05 | 1.09 | 6.67 |
| **2** | **CPS Start-ups** | 0.10 | 3 | 9 | 9 | 6 | 5 | 32 | 0.30 | 0.90 | 0.90 | 0.60 | 0.50 | 3.20 |
| **3** | **Grand Challenges** | 3.00 | 0 | 1 | 0 | 0 | 0 | 1 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 3.00 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **and Competitions (CPS-GCC)** | | | | | | | | | | | | | |
| **4** | **Promotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS)** | 2.00 | 0 | 1 | 0 | 0 | 0 | 1 | 0.00 | 2.00 | 0.00 | 0.00 | 0.00 | 2.00 |
| **5** | **CPS-Entrepreneur In Residence (CPS-EIR)** | 0.04 | 2 | 3 | 4 | 5 | 5 | 19 | 0.08 | 0.12 | 0.16 | 0.20 | 0.20 | 0.76 |
| **6** | **CPS-Dedicated Innovation Accelerator (CPS-DIAL)** | 1.25 | 0 | 0 | 1 | 0 | 0 | 1 | 0.00 | 0.00 | 1.25 | 0.00 | 0.00 | 1.25 |
| **7** | **CPS-Seed Support System (CPS-SSS** | 4.00 | 0 | 0 | 1 | 0 | 0 | 1 | 0.00 | 0.00 | 4.00 | 0.00 | 0.00 | 4.00 |
| **8** | **Job Creation** | 0.00025 | 950 | 1600 | 1800 | 1800 | 1600 | 7750 | 0.24 | 0.40 | 0.45 | 0.45 | 0.40 | 1.94 |
| **Total (in Rs crore)** | | | **956** | **1614** | **1815** | **1811** | **1610** | **7806** | **1.38** | **8.93** | **8.02** | **2.30** | **2.19** | **22.82** |

Justification for the individual components is as follows:

1. *CPS-Technology Business Incubator (TBI).* CPS-TBI is intended to facilitate the development of an ecosystem of innovation and entrepreneurship. TBI will support the technology driven start-ups in various capacities for product development, licensing, commercialization, etc. The budget for the proposed TBI is Rs. 6.67 crore, and its distribution is summarized in Table 7.10. TBI will be established in the first year of the TIH, and its activities will span for the entire duration of 5 years.
2. *CPS Start-up*. In this component of the budget a one-time grant of will be provided to each selected start-up/spin-off company. Exact support will be decided based on the idea and business plan. A total of 32 start-ups/spin-off will be selected over the period of 5-years. One-time grant is intended to provide initial funding assistance, and accelerate the growth of start-ups.
3. *Grand Challenges and Competitions (CPS-GCC)*. CPS-GCC is designed to promote a culture of innovation and entrepreneurship in the domain of CPS. The activity, through national level competition, is aimed to identify several innovative ideas and ambitious entrepreneurs and nurture them into self-sustaining start-ups. GCC is envisioned to attract

over 100 participants with diverse CPS based niche and advanced solutions. GCC will be conducted in the second year, will require a one-time budget of Rs. 3.00 crores. The distribution of the budget for GCC has been summarized in Table 7.11.

**Table 7.10:** Technology Business Incubator (TBI)

| S No | Budget Head | Estimated cost (in Rs. crore) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1st Yr | 2nd Yr | 3rd Yr | 4th Yr | 5th Yr | Total |
| **A** | **Recurring** | | | | | | |
| | 1. Manpower (including mentors needed to support the startups) | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 1.25 |
| | 2. Travel (@ Rs 50,000 per month) | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.30 |
| | 3. Outreach activities (This will include different components like for marketing, networking, training programmes and short courses) | 0.20 | 0.15 | 0.20 | 0.15 | 0.15 | 0.85 |
| | 4. Office supplies and facilities | 0.10 | 0.05 | 0.10 | 0.05 | 0.05 | 0.35 |
| | 5. Utilities (and other operational expenses) | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.25 |
| | 6. Miscellaneous and Contingencies | 0.10 | 0.05 | 0.10 | 0.04 | 0.03 | 0.32 |
| | **Sub-Total** | **0.76** | **0.61** | **0.76** | **0.60** | **0.59** | **3.32** |
| **B** | **Non-Recurring** | | | | | | |
| | 1. Product development and licensing | 0.00 | 0.60 | 0.05 | 0.05 | 0.05 | 0.75 |
| | 2. Office Equipment and facilities | 0.00 | 0.10 | 0.05 | 0.05 | 0.05 | 0.25 |
| | 3. Contingent expenditures towards non-recurring component | 0.00 | 0.05 | 0.05 | 0.05 | 0.05 | 0.20 |
| | 4. Furnishing of the space and basic infrastructure for regular operations of the start-ups | 0.00 | 0.25 | 0.10 | 0.10 | 0.10 | 0.55 |
| | 5. Basic tools and equipment for supporting regular technological operations of the start-ups | 0.00 | 0.90 | 0.25 | 0.20 | 0.25 | 1.60 |
| | **Sub-Total** | **0.00** | **1.90** | **0.50** | **0.45** | **0.50** | **3.35** |
| | **Grand Total** | **0.76** | **2.51** | **1.26** | **1.05** | **1.09** | **6.67** |

**Table 7.11:** Grand Challenges and Competitions (GCC)

| S No | Budget Head | Amount (in Rs crores) |
|---|---|---|
| **A.** | **Non-Recurring** | |
| | **Operational Costs** | |
| | 1. Manpower | 0.70 |
| | 2. Travel, honorarium to experts | 0.50 |
| | 3. Marketing, promotion and publicity | 0.10 |
| | 4. Outreach activities (As a part of GCC, and will include events, training programmes, etc.) | 0.15 |
| | 5. Office supplies and facilities | 0.15 |
| | 6. Miscellaneous and contingencies | 0.10 |
| | 7. Awards (@ Rs 1.0 lakh each for 5 winners, and total of Rs 5.0 lakh for runner ups and other encouragement awards and certificates) | 0.10 |
| | 8. Start-up Seed Fund (@ Rs 20.00 Lakhs each for 5 Winners) | 1.00 |
| | 9. Furnishing and arrangement requirements (like tables, chairs, dashboards, demonstration arrangements, etc. for various events) | 0.20 |
| | **Total** | **3.00** |

**Table 7.12:** Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)

| S No | Budget Head | Amount (in Rs crores) |
|---|---|---|
| **A.** | **Non-Recurring** | |
| | 1. Prototyping Grant (@Rs 10.00 Lakhs each for 10 ideas) | 1.00 |
| | 2. TA/DA to experts and invited professionals | 0.10 |
| | 3. Office supplies and facilities | 0.03 |
| | 4. Miscellaneous and contingencies | 0.02 |
| | 5. Testing/Consultancy Charges | 0.20 |
| | 6. IPR, licensing, etc. | 0.10 |
| | 7. Establishment of a dedicated center for PRAYAS (Furnishing of the space and basic infrastructure for regular operations) | 0.30 |
| | 8. Basic tools and equipment for supporting regular operations of PRAYAS | 0.25 |
| | **Grand Total** | **2.00** |

4. *Promotion and Acceleration of Young and Aspiring technology entrepreneurs (CPS-PRAYAS).* PRAYAS is aimed towards rapid translation of an innovative idea to its prototype stage. The budget component is designed to provide financial aid for overcoming the monetary barrier from idea to prototype. PRAYAS is envisioned to encourage innovative solutions without financial risks, and encourage innovators towards entrepreneurship. The total budget for this activity is Rs. 2.0 crore and it will be conducted in the second year of the project. The distribution of the budget for PRAYAS has been summarized in Table 7.12.
5. *CPS-Entrepreneur In Residence (CPS-EIR).* CPS-EIR is aimed to recognize the time and efforts required in pursuing start-ups. A grant of maximum Rs. 33,333.33 per month will be provided to support the entrepreneurs, for a period of 12 months, with a total estimated cost of Rs 4.00 lakhs per grant. CPS-EIR encourages more entrepreneurs by providing financial stability, during the initial phase of start-up.
6. *CPS-Dedicated Innovation Accelerators (CPS-DIAL).* CPS-DIAL is aimed to help accelerate innovations that are ready to commercialize immediately or in the near future. CPS-DIAL will be initiated in the third year with a provision of Rs. 1.25 crore as non-recurring expense in the budget. The budget will be utilized on a need basis for accelerating the growth of start-up. CPS-DIAL will include two categories of grants viz., soft loan and dedicated accelerator. Soft loan will provide a loan based direct cash support to start-ups with financial constraints in commercialization. Dedicated accelerators will include consultancy, man power, logistics, mentoring, infrastructure, training, etc. needed to accelerate specific aspects of the start-up. A maximum grant of Rs. 10.0 lacs will be provided in soft loan. CPS-DIAL, through targeted support, is envisioned to accelerate 10-20 start-ups and ensure overall success of the TIH.
7. *CPS-Seed Support System (CPS-SSS).* CPS-SSS is aimed to nurture CPS start-ups through seed funding, in their initial phase within TBI. Incubator (TBI) will provide seed fund, i.e., financial support as investment or debt to eligible start-ups. Seed fund is expected to be utilized in 2-3 years with positive returns in 5 years. First round of seed-funding will be provided in the third year of TIH. Return from the first round of seed investment will be used to fund subsequent rounds of seed investments. A start-up will be eligible for a maximum seed fund of Rs 20.00 lacs. A provision of Rs 4.00 crore has been made for the CPS-SSS, in the form of non-recurring expense.
8. *Job Creation* is one of the core targets for the TIH. To facilitate job creation, and consecutively hiring of skilled workforce, a provision of Rs. 2500 per job has been kept separately in the budget. The provision will account for expenses incurred during activities like advertising, recruitment, administrative work, and the like.

## 7.6 Budget justification for International Collaboration

International collaboration serves as a two-way bridge for exchange of information at international platform. Collaborations will introduce state of the art international practices in the field of CPS in technology development in India and provide a platform for show casing the developed technology. In this activity bilateral technology development will be encouraged.

Budget for this activity will be mainly used for contacting/visiting foreign funding agencies who supports entrepreneurship and R&D projects in India, for join project support, inviting international experts, visiting foreign universities for initiating new international collaboration. International collaboration is planned from the second year of the proposed TIH project. Details of the budget for international collaborations are listed in Table 7.13.

**Table 7.13:** Estimated Expenditure (in Rs crore) for International Collaborations

| Major Component | Budget in Rs Crore | | | | | |
|---|---|---|---|---|---|---|
| | Yr1 | Yr2 | Yr3 | Yr4 | Yr5 | Total |
| Recurring | 0.00 | 1.00 | 1.25 | 0.75 | 0.00 | 3.00 |
| Non-recurring | 0.00 | 0.40 | 0.20 | 0.00 | 0.00 | 0.60 |
| **Total (in Rs crores)** | **0.00** | **1.40** | **1.45** | **0.75** | **0.00** | **3.60** |

International collaboration will require a total budget of Rs. 3.00 crores under the recurring head to provide joint project support, inviting international experts, visiting foreign universities and support bilateral research in technology development. This activity also includes a provision of Rs. 0.60 crore under the non-recurring head to account for expenses incurred during initiation and development of collaborations. The total budget requirement for the international collaboration will be Rs. 3.60 crores.

## 7.7 Budget justification for TIH Management Unit

A TIH management unit will be established to ensure effective operation and timely completion of target for different hub activities. The budget for the TIH Management Unit is Rs. 12.67 crores, and accounts for the payments to staff, and other expenses incurred during the setting up and operation of TIH Management Unit. Budget requirements for TIH management unit are listed in Table 7.14.

**Table 7.14:** TIH Management Unit (TIH-MU)

| S No | Budget Head | Estimated cost (in Rs. crore) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1st Yr | 2nd Yr | 3rd Yr | 4th Yr | 5th Yr | Total |
| **A.** | **Recurring** | | | | | | |
| | Domestic Travel | 0.30 | 0.30 | 0.60 | 0.30 | 0.21 | 1.71 |
| | Office supplies and facilities | 0.10 | 0.05 | 0.10 | 0.05 | 0.05 | 0.35 |
| | Manpower | 0.87 | 1.28 | 1.41 | 1.55 | 1.70 | 6.81 |
| | **Sub total** | **1.27** | **1.63** | **2.11** | **1.90** | **1.96** | **8.87** |
| **B.** | **Non-recurring** | | | | | | |
| | Office Furniture, equipment and facilities | 0.00 | 1.20 | 0.10 | 0.10 | 0.10 | 1.50 |
| | Virtual Class Room | 0.00 | 2.00 | 0.10 | 0.10 | 0.10 | 2.30 |
| | **Sub total** | **0.00** | **3.20** | **0.20** | **0.20** | **0.20** | **3.80** |
| | **Grand Total** | **1.27** | **4.83** | **2.31** | **2.10** | **2.16** | **12.67** |

Infrastructure support will be covered by IIT Indore. Budget will be needed for office furniture, conference rooms, and virtual classrooms, which will be covered in Non-recurring head. Furthermore, to facilitate TIH management operations a provision for domestic travel has been kept in budget under recurring expenses. It will include, attending all review meetings of the DST, outreach activities, integration activities with spokes, and other hubs, building connections with industries, attracting CSR fund, strengthening collaboration. It includes the cost of travel, accommodation, DA, etc. Table 7.15 covers the budget for the manpower needed to operate TIH.

**Table 7.15** TIH Management Unit Manpower

| | Major Components | Targets | | | | | | Budget (in Rs. lakhs) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1st Yr | 2nd Yr | 3rd Yr | 4th Yr | 5th Yr | Total | 1st Yr | 2nd Yr | 3rd Yr | 4th Yr | 5th Yr | Total |
| **1** | **CEO** | 1 | 1 | 1 | 1 | 1 | 5 | 15.30 | 22.44 | 24.68 | 27.15 | 29.87 | 119.44 |
| **2** | **Manager** | 5 | 5 | 5 | 5 | 5 | 25 | 29.25 | 42.90 | 47.19 | 51.91 | 57.10 | 228.35 |
| **3** | **Staff (Operations)** | 10 | 10 | 10 | 10 | 10 | 50 | 36.00 | 52.80 | 58.08 | 63.89 | 70.28 | 281.04 |
| **4** | **Staff (Supporting)** | 3 | 3 | 3 | 3 | 3 | 15 | 6.75 | 9.90 | 10.89 | 11.98 | 13.18 | 52.70 |
| | **Total (in Rs lakhs)** | **19** | **19** | **19** | **19** | **19** | **19** | **87.30** | **128.04** | **140.84** | **154.93** | **170.42** | **681.53** |
| | **Total (in Rs. crore)** | | | | | | | **0.87** | **1.28** | **1.49** | **1.55** | **1.70** | **6.82** |

Summary of required manpower:

1. *Chief Executive Officer (CEO)*. One CEO will be recruited for managing the administrative activities of the TIH towards achieving its outcomes. The CEO will report to the Board through the Project Director of TIH.

| Year | Monthly Emolument (In INR) | Man months | Total Cost |
|---|---|---|---|
| Year 1 | 1,70,000 | 09 | 15,30,000 |
| Year 2 | 1,87,000 | 12 | 22,44,000 |
| Year 3 | 2,05,700 | 12 | 24,68,400 |
| Year 4 | 2,26,270 | 12 | 27,15,240 |
| Year 5 | 2,48,897 | 12 | 29,86,764 |

Note: It is expected that the first 3 months will be spent in administrative procedure, company registration, and similar activities. Hence, for the first year all the charges are considered for 9 months only.

2. *Manager*. 5 Managers will be recruited to manage individual operations with the respective staff members in a particular operation and also to coordinate with the managers of other operations. These managers will report to the CEO. Operations for the 5 managers are divided as follows:

   a. *HR and Administration*: For managing all administrative and manpower hiring matters including floating the advertisements, managing interviews, ensuring the compliance of all government norms, coordinating and drafting MoUs and other arguments, coordinating with other funding agencies for eligible grants, internal operations management, like, cleaning, security, purchase, and the like.

b. *Finance*: All finance matters like salary, budget preparation and monitoring, audit, taxation, UC/SE preparation, financial matters related to (a) start-up companies, (b) centre of excellence, (c) industrial research center established in TIH.

c. *Information Technology (IT)*: Manage all activities related to IT like developing and maintaining websites, online portal, relevant online forms and applications, employee online attendance record capturing, online meeting arrangement, email server, digital data management, IT infrastructure management and maintenance, online workflow, and others.

d. *Intellectual Property Rights*: Patenting, patent search, identifying a patent attorney, coordination with the attorney for filing, resolving IPR queries of faculty members, students, start-up companies. Legal aspects in coordination with the manager admin for any MoU and other agreements, licensing, licensing agreement, and the like.

e. *Outreach and External Relations*: Connecting various industries, start-ups, other HUBs, and IITs, publicizing the TIH capabilities and achievements, attracting new industries/start-ups for collaboration/incubation, representing at various industrial and higher educational expos, media communication, creative designs like pamphlets, brochures, posters, and others.

| Year | Monthly Emolument (In INR) | Man months | Total Cost |
|---|---|---|---|
| Year 1 | 65,000 | 45 | 2,925,000 |
| Year 2 | 71,500 | 60 | 4,290,000 |
| Year 3 | 78,650 | 60 | 4,719,000 |
| Year 4 | 86,515 | 60 | 5,190,900 |
| Year 5 | 95,167 | 60 | 5,710,020 |

3. *Staff (Operations)*. 10 staff members will be recruited to provide support to managers. Though we have identified staff for each task, individual staff members will be expected to multitask and may be shuffled as per requirement. Certain staff members may be required only during the latter phase of the project (second years onwards). We have normalized these requirements and given uniform requirements for funding purposes. Thus, the overall budget is expected to be within this limit. These staff members will report to the respective managers.

   a. HR and Administration: 02

   b. Finance: 03

   c. Information Technology: 02

d. Intellectual Property Right: 02

e. Outreach and Media: 01

| Year | Monthly Emolument (In INR) | Man months | Total Cost |
|---|---|---|---|
| Year 1 | 40,000 | 90 | 3,600,000 |
| Year 2 | 44,000 | 120 | 5,282,000 |
| Year 3 | 48,400 | 120 | 5,808,000 |
| Year 4 | 53,240 | 120 | 6,388,800 |
| Year 5 | 58,564 | 120 | 7,027,680 |

4. *Staff (Supporting)*. Additionally, 3 staff members will be recruited to support the operations of the TIH management unit.

    a. Personal assistant to CEO: 01

    b. Personal assistant to Program Director: 01

    c. Staff for office maintenance, up keeping, front desk handling: 01

| Year | Monthly Emolument (In INR) | Man months | Total Cost |
|---|---|---|---|
| Year 1 | 25,000 | 27 | 6,75,000 |
| Year 2 | 27,500 | 36 | 9,90,000 |
| Year 3 | 30,250 | 36 | 10,89,000 |
| Year 4 | 33,275 | 36 | 11,97,900 |
| Year 5 | 36,603 | 36 | 13,17,690 |

The numbers given in this chapter are approximate and are aimed to showcase the vision and approach to achieve deliverables of the NM-ICPS scheme. Exact/actual amounts may vary and shall be decided by the Board of Directors (BoDs) of IITI DRISHTI CPS Foundation. BoDs may also re-appropriate and approve the funds under various heads based on the requirements of projects aimed to contribute towards the overall objectives of the NM-ICPS scheme. Also, it is anticipated that IITI DRISHTI CPS Foundation will start generating revenue through various activities and initiatives. Thus, additional funds may also be utilized along with the grant received from DST to better execute and manage the activities of the company.

# Chapter 8

# Strategy

The Technology Innovation Hub (TIH) on System Simulation, Modelling and Visualization (SSMV), named IITI DRISHTI CPS Foundation, has started functioning from the premises of the Indian Institute of Technology Indore. The endorsement for allocation of the required contiguous space, as mandated by DST, has been submitted by the institute. IITI DRISHTI CPS Foundation shall be governed by a Hub Governing Body (HGB) and Board of Directors (BoDs).

## 8.1 Interaction with Industries/PSUs

The involvement of industry is central to the success of IITI DRISHTI CPS Foundation. A structured approach to capture industry requirements and explore possibilities of partnerships leading to technology development and commercialization has been initiated. As a first step, an invitation was sent to a few industries to comprehend their interests and willingness to participate in the activities of the proposed eco-system of the TIH. In addition to this, a Google form based survey was conducted with the intention of understanding the requirements and challenges in working with SSMV aspects of CPS. In a span of around three to four weeks, DRISHTI-CPS was able to initiate partnership procedures with around 20 industrial establishments that included key players in the field of SSMV of CPS. Substantial interest was also generated in the manufacturing, biomedical, agriculture, construction sectors, all of which are important application areas of CPS. The list of industries that have shown interest to be associated with IITI DRISHTI CPS Foundation is given in Table 8.1. The classification of industry based on their involvement with CPS is shown in figure 8.1. This is an initiation and engagement with industry partners will continue through the duration of the project.

During the interactions with the industry, IITI DRISHTI CPS Foundation has identified key challenges faced while working with CPS as well as challenges that could be overcome by appropriate CPS based interventions. In addition to this, the endeavor has also been towards identifying focused areas for collaboration. Based on the initial response received from the industry, the factor that stood out was the lack of trained manpower for development and implementation of CPS technologies. The initial survey was followed up with specific interaction sessions with a few industry houses to provide an overview of IITI DRISHTI CPS Foundation, and identify possible modes of engagement. It is also envisaged that the technology or product that is being developed should be affordable and can be customized to the requirements of SMEs. In the Indian context, customization of the technology would be an added advantage in its implementation by industry. We propose to establish a formal mechanism to continuously interact with industries and PSUs to identify challenges and immediate needs. This engagement would be further enhanced by inviting them to share their problem statements with IITI DRISHTI CPS Foundation. These problems will be tackled by our TIH through technology development and commercialization. IIT Indore has successfully established a consortium of smart manufacturing in which several leading industries are members. The consortium intends to develop pathways for digital engagement with SMEs that can transform themselves into efficient digitally-enabled manufacturing businesses. Existing initiatives of this kind seamlessly amalgamate with the proposed TIH. It is envisaged to develop such consortia for other themes taken by the TIH.

**Table 8.1:** List of industries that have responded to the questionnaire floated by DRISHTI-CPS

| S.No. | Name of Industry |
|---|---|
| 1. | Indore Biotech Inputs and Research Pvt. Ltd. |
| 2. | Mahindra Institute of Quality, Mahindra & Mahindra Ltd. |
| 3. | WABCO INDIA LIMITED |
| 4. | Deepak Fertilizers & Petrochemicals Corporation Ltd |
| 5. | Siemens Industry Software Limited |
| 6. | Ekspe Software Services LLP |
| 7. | Nvidia |
| 8. | JIVA Innovative Automations Pvt Ltd |
| 9. | Production Modeling India (PMI) Pvt. Ltd. |
| 10. | John Deere India Pvt Ltd |
| 11. | John Deere Dewas |
| 12. | Akshay Infrasys Industries pvt. Ltd |
| 13. | LMS Solutions (India) Pvt. Ltd. |
| 14. | Ansys Software Pvt. Ltd. |
| 15. | Pisarv Technologies LLP |
| 16. | Carl Zeiss India (Bangalore) Private Limited |
| 17. | Dassault systemes |
| 18. | SOLIZE India Technologies Pvt Ltd |
| 19. | Aeronautical Development Agency |
| 20. | The MathWorks, Inc. |

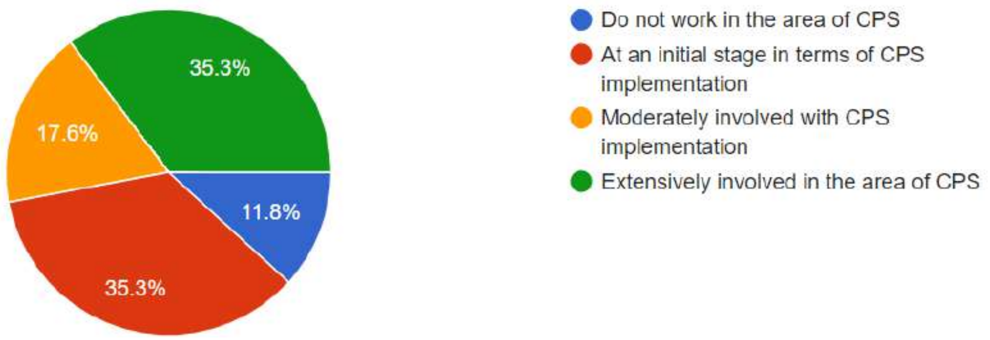


**Figure 8.1:** Classification of industries that responded to the initial survey by IITI DRISHTI CPS Foundation.

Indore is widely regarded as an automobile hub of Central India and recent developments are seeing it evolve into an IT hub as well. The city boasts two fully functional IT parks with most major IT companies. In this respect, the proposed TIH is very timely and shall augment the capacity building measures of the state government in the industrial sector. The strategy of IITI DRISHTI CPS Foundation would be to continuously engage with industries in a systematic manner. In particular, through sustained and structured interactions, MSMEs are expected to benefit significantly through skill development and quick access to new technologies.

### 8.2 Hub and Spoke Model

IITI DRISHTI CPS Foundation would work on the hub and spoke model. Hub is in the process of defining certain characteristics, roles and responsibilities of spokes so that the engagement is fruitful for the country. While every possible effort would be made to effectively engage with the spokes and expanding spokes, adequate care shall be taken to fast track the process so as to achieve the desired targets in a timely manner as outlined in the time frame. It is envisaged to interact at least once in a year with all spokes to have an open forum for suggestions, constructive feedback and comments. During the initial two years, this interaction may be held once every six months to identify and resolve bottlenecks. IITI DRISHTI CPS Foundation would encourage spokes to be a centre of excellence (CoEs) in SSMV of CPS while achieving the specified targets and also cater to the needs of the industry. CoEs are envisaged to be based on a public-private partnership model.

While functioning as the hub, IITI DRISHTI CPS Foundation would also serve as the focal point for connecting spokes with each other. This would be a focused initiative with respect to the given problem being addressed by the spoke. In addition, relevant policies and norms regarding the infrastructure created during the course of executing the NM-ICPS project would be formulated after considering the inputs from spokes. The functioning of IITI DRISHTI CPS Foundation would be structured to process paperwork and resolve all issues within a specified timeline (maximum 7 days). Interaction with other hubs would be encouraged as it will be a rich source of identifying the best practices adopted by them and avoiding pitfalls. Coordination with the funding agency (DST) is an essential aspect of executing the project. IITI DRISHTI CPS Foundation would strive to fulfill all statutory and regulatory requirements to the relevant agencies in the time bound manner. IITI DRISHTI CPS Foundation has been benefited by the advice from mission office at DST and the same would be requested for better execution of the project. The diverse background of spokes is expected to bring further value addition to the TIH in terms of networking, brainstorming, and exchange of ideas leading to innovation, all of which can be a resource for the industry. The focus would be to address local level problems through the involvement of all stakeholders.

### 8.3 Interaction with Line Ministries/State Government Units, City Administration

The technology development (including algorithms and tools) on SSMV aspects of CPS would be based on the solution of real world problems shared by line ministries, state governments, city administration, industry, defense establishments and project proposals received in the two-thrust areas identified by IITI DRISHTI CPS Foundation. Apart from working on the above approach, IITI DRISHTI CPS Foundation would actively interact with line ministries, state governments, city administration, industry and defense establishments to showcase the ongoing work and through brainstorming sessions to identify specific areas for joint work. This would serve dual purposes: enhance the outreach and identify problem areas with potential solutions. The NM-ICPS project is also expected to further boost several initiatives of the Government of India and coordination with city administration would be arranged for visible impact in the city. The spokes would also be encouraged for the same.

### 8.4 Strategy for Startup Ecosystem

A big challenge for the success of the NM-ICPS scheme would be to incubate start-ups and spin-offs working on SSMV aspects of CPS in specific and other related areas of CPS in general. IITI DRISHTI CPS Foundation would encourage the researchers/students and faculty members solving real world problems to take the route of an entrepreneur and initiate the process of a start-up. Apart from providing all necessary facilities for the same, IITI DRISHTI CPS Foundation would facilitate interactions between established entrepreneurs with students/researchers so that they can better understand the system and be prepared for the journey ahead. Such interactions would provide a greater clarity about the process to be followed, associated paperwork and government guidelines/norms. For a successful start-up incubation ecosystem, the student/researcher needs to be nurtured to the extent of elaborating the finer aspects of the journey. While the challenges may be different for various start-ups, such a programme would be immensely beneficial. A Technology Business Incubator (TBI) would also be registered within the first year of the project. Efforts shall also be made to connect to the existing start-ups with the aim of incubating them in the TBI with adequate pre-incubation and post-incubation support. A point based system will be evolved to monitor the performance of the incubated startups. Appropriate models for support Vs share of company and exit policy will be designed. This will generate revenue for the IITI DRISHTI CPS Foundation. This will help it in becoming self-sustainable in the long run.

### 8.5 Patenting and Licensing

DRISHTI CPS will motivate and support the researchers supported under this scheme to file patents for any new technology developed. If the student/researcher or faculty member does not want to take the start-up route then appropriate industry would be contacted for a possible deployment of the technology. In addition, IITI DRISHTI CPS Foundation would strive to have a licensing agreement for most of the technologies developed. This would involve contacting the correct industry, demonstrating the technology and showcasing its value addition to the industry. This would be managed by a dedicated team of professionals and would be a critical point for the success of IITI DRISHTI CPS Foundation. Licensing will also help in generating revenue to the company and inturn will lead to a self-sustainable unit.

### 8.6 Outreach and Publicity

To further augment the efforts of IITI DRISHTI CPS Foundation, an annual meet is being planned comprising outreach activities to attract industries, government units, venture capitalists and for showcasing products/technologies developed. An annual conclave is planned to showcase the projects supported and technologies developed through the TIH. During such conclave, a bridging-the-gap type session would be arranged which would further connect relevant industries with IITI DRISHTI CPS. Outreach will also involve schools and tier II/II colleges. To attract talent and create required awareness, IITI DRISHTI CPS Foundation plans to aggressively pursue marketing and publicity campaigns through a media partner. This would be carried out on different social media handles. IITI DRISHTI CPS Foundation newsletter will be published regularly and circulated widely to create required awareness.

### 8.7 Skill Enhancement

Training of manpower from industry, teachers and faculty members and students would be accomplished through a Skills Centre which shall include testing and prototyping facilities such as different types of sensors, data acquisition systems, open-source Programmable Logic Controller, human machine interface, table top machines, microprocessor based programmable boards, couplers for connecting multiple sensors, 3d printers, cloud platform and local systems, edge devices, electronic components and relevant computational facilities. The proposed Skills Centre at IITI DRISHTI CPS foundation would be available 24·7 for interested individuals, organizations, universities, industry and government bodies. Although the Skills Centre would conform to a ‘supervised DIY’ type of set up with largely open source platforms, the issue of industry standardization would also be taken up in SSMV with relevant protocols to bridge-the-gap between industrial and academic set-ups. This is expected to further formalize the process and give way to a detailed engagement model with each of the partnering industries over the short, medium, and long-term. The intention is to not let go of the initial momentum developed towards structured industry interaction which is key to the ultimate aim of achieving self-sustainability. Setting up of such skill centers will be an important criteria in the evaluation and support of spokes. We will motivate spokes to establish such centers and impart training. The skills base created would not be limited to the hub but would also extend to the spokes and tier-II and tier-III institutions across the country through the hub and spoke model. IIT Indore has been partnering with tier-II and tier-III institutes in Indore under different schemes and this connection would be an added advantage in terms of manpower training in SSMV of CPS. Existing schemes such as Teachers Association for Research Excellence (TARE) and Technical Education Quality Improvement Programme (TEQIP) would also serve as channels for extending the benefits of hub to tier-II and tier-III organizations. Introduction of certification and academic courses along with degree programs in SSMV of CPS alongside the development of CPS laboratories in synchronization with industry and R&D organization for nurturing the CPS talent pool would be a priority. IITI DRISHTI CPS Foundation shall also support students enrolled in such academic programmes. It is expected that competent manpower with an expertise in SSMV aspects of CPS would be helpful for other hubs, academic institutes, industry, R&D organizations and Defence establishment.

### 8.8 National and International Collaboration

We drive to identify experts in the domain of CPS with a specific focus on System Simulation, Modeling and Visualization (SSMV) from across the globe. Such experts would be contacted. Call for proposals, participation in bi-lateral schemes, joint workshops/training programs, etc. will help in connecting such experts with the activities of the hub. The international collaborations set up during the course of this grant would be a rich source of expertise in terms of R&D and technology development. The collaboration would also be a good reference for any possible CPS based solutions that might already exist. The challenge and main contribution would be to develop products which are competitive while aiding the Indian industry and line ministries through a greater degree of customization at lower cost.

It is expected that the above aspects of strategy will help IITI DRISHTI CPS Foundation in achieving the goals and objectives mentioned in Chapter 2 of this DPR. A cost, benefit and risk analysis for the above strategy is presented in chapter 12 of this DPR.

# Chapter 9

# Legal Framework and Environmental/Biological Impact

## 9.1 Legal framework

DRISHTI CPS shall coordinate with the research and development section of IIT Indore to ensure that the activities of the Hub are within the legal framework of the Institute and the Government of India. The Hub will have an active cell for safeguarding the Intellectual Property (IP) generated through the work being carried out at hub and spokes. Further, the policy for Intellectual Property Rights (IPR) shall be within the scope of National Intellectual Property Rights Policy of the Government of India. Adequate care shall be taken to avoid any pitfalls related to IP protection in India and abroad. In case of joint/collaborative work, IPR agreements between the parties/institutes/organizations shall be formulated. The same will also be adopted for any joint work with the industry. DRISHTI CPS shall encourage filing patent applications for various technologies developed through the projects supported support by the Hub. It shall also provide technical, legal and financial support for the same, and if required, shall coordinate with funding agency and other hubs for the resolution of any issue in a time bound manner. DRISHTI CPS shall strive to follow all Indian and International standards for product development. Also, as mandated, TIH will have a finance section to ensure necessary financial compliances like audits, timely filing/updating of GST, PFMS activities, etc. of Government India.

## 9.2 Environmental/Bio-medical impact

The Environmental Impact Assessment evaluates the possible environmental impacts of a proposed activity considering beneficial or adverse inter-related socio-economic, cultural and human-health impacts. The environmental clearance process covers aspects like screening, scoping and evaluation of the upcoming project/development activity. This is mainly related to assessing the impact of the planned activity on the environment and people to target abatement/minimization of the same.

Under DRISHTI CPS, an appropriate committee shall be set up to ensure environmental compliance and minimization of environmental impacts generated through different research and technology development activities of the hub. Environmental clearance would be necessary for projects having direct/indirect environmental impacts. Similarly, clearances from all relevant committees for bio-medical research and development such as human-ethics committee and biosafety committee shall be obtained in cases where there is a visible human-machine or human-human interaction related to data collection or field trials in an essentially

CPS based modeling and simulation research work. Under such cases, all relevant protocols can be strictly followed.

# Chapter 10

# Outcomes

IITI DRISHTI CPS Foundation aims at becoming a leading center in the country on System Simulation, Modelling, and Visualization aspects of Cyber Physical Systems. Bolstered by its location within IIT Indore with access to invaluable human resources and convenient connect with commercial firms, the hub is looking to provide a platform to facilitate active engagement between academia, industry and government agencies. The proposed endeavors of the hub to realize this are elaborated upon in this section. The attempt is to articulate the anticipated outcomes of the hub, both tangible and intangible.

## 10.1 Research output

DRISHTI-CPS is invested in furthering the state-of-the-art in research on CPS across domains particularly aligning with the theme of SSMV. In conformance to this, the hub has seen participation from researchers across the country through prospective projects with tangible outcomes. The hub is laying emphasis on supporting research proposals that address immediate issues of the industry and the society at large. The outcomes in this respect are, therefore, expected to be solutions generously harnessing the capabilities provisioned by cyber-physical systems. Sustained research endeavors should lead to the outcome of the hub getting recognized as a leading center in India and the world in simulation, modelling, and visualization with a special focus on cyber-physical systems.

## 10.2 Technology development

The thrust towards technology/tool development is at the heart of IITI DRISHTI CPS Foundation. Research projects that the hub is looking to support need to explicitly express the potential for technology development through product driven translation research. Technology development is expected to be both generic and customized. Generic solutions are ones that have broad applications and a large spectrum of adoption, whereas customized solutions cater to specific articulated requirements. The hub is actively interacting with industrial entities, PSUs, Government units and departments to better comprehend such requirements. In addition to this, the hub expects its participants to aggressively pursue ventures for developing products that benefit society.

### 10.3 Incubation of Start-ups/Spin-offs

In line with the vision of the Government of India, IITI DRISHTI CPS Foundation is looking to firmly put its weight behind 'budding' entrepreneurs and innovators by supporting 'start-up' endeavors. With some of the best talent in its own backyard, the hub intends to encourage students and faculty of IIT Indore and its spoke institutes to take the plunge and give shape to their ideas and imagination. Effectively utilizing simulation, modelling, and visualization techniques to realize cyber physical system offerings would be the thrust of such start-ups. This aligns perfectly with the entrepreneurship environment prevalent in the country today.

### 10.4 Human Resource Development

IITI DRISHTI CPS Foundation plans to invest generously towards human resource development. The hub is driven by the overwhelming belief that the greatest service rendered to society is to train its people. The hub has extensive plans to impart elementary and specialized training to personnel in the broad area of system simulation, modelling, and visualization in keeping with its theme. In addition to this, the hub is also looking to provide more hands-on training in development of effective cyber-physical systems' offerings. The provisioned training would be tailored for audiences across the spectrum: from school going children who would be introduced to the concepts and enabled enough to appreciate the consequences; to industry personnel who would be able to apply the concepts learned in a real world industrial setting. In addition to development of human resources through focused training sessions, the outcomes of the hub would also include the more holistically trained Bachelors', Masters', Doctorate, and Post-doctorate personnel.

### 10.5 Industry-Academia Connect

Perhaps the most important outcome of IITI DRISHTI CPS Foundation is the role it would play in forging alliances between the industry and academia. Strategically located within the IIT Indore campus and driven by students, faculty of the institute and personnel from the industry, the hub is expected to provide very fertile ground for academics to connect with the industry. IIT Indore is blessed with expertise in simulation, modelling, and visualisation across domains and has some of the most brilliant students working on developing innovative CPS solutions. The hub's close engagement with industries interested in these areas is expected to significantly augment efforts at effective industry-academia connect leading to establishment of centres of excellence through public-private partnership model. The hope is to bridge the gap between ideas and real applications that mostly disappear in the chasm of research papers that never see the light of the day.

A quantitative tabulation of the outcomes of IITI DRISHTI CPS Foundation is included in the Timeframe section of the proposal (i.e. Chapter 11).

# Chapter 11

# Time Frame

The Activity Plan for IITI DRISHTI CPS Foundation has been split up into two parts. The first part deals with milestones for 1 to 36 months while the second part outlines the deliverables for 37 to 60 months. In the first 6 months, the registration process for a Section 8 Company and other required clearances like CSR clearances, etc. would be completed, and thereafter, the process for initiation of TBI would be implemented.

Tasks related milestones/deliverables are divided into 4 broad categories: Technology development (T), Entrepreneurship (E), Human Resource Development (H) and International Collaborations (I). The numbers mentioned in the parentheses indicate the corresponding targets, the total number of which shall be consistent targets specified by DST. The specific details and numbers are outlined below. Figures 11.1 and 11.2 show the activity plan with timelines. The targets are summarized in Table 11.1.

## 11.1 Activity Plan Year 1

T1: Number of technologies (2), Technology products (1), Publications/IPR/Other (5), CPS research base (6)

E1: CPS-TBI (1), CPS-Start-ups/Spin-offs (3), CPS-EIR (2), Job creation (950)

H1: Fellowships-Graduate (25), Postgraduate (4), Doctoral (3), Faculty (1), Skill Development (70)

## 11.2 Activity Plan Year 2

T2: Number of technologies (4), Technology products (2), Publications/IPR/Other (7), CPS research base (12)

E2: CPS-Start-ups/Spin-offs (9), CPS-GCC (1), CPS-PRAYAS (1), CPS-EIR (3), Job creation (1600)

H2: Fellowships-Graduate (35), Postgraduate (7), Doctoral (5), Faculty (1), Chair Professors (1), Skill Development (75)

I1: International collaboration (1)

### 11.3 Activity Plan Year 3

T3: Number of technologies (4), Technology products (3), Publications/IPR/Other (8), CPS research base (15)

E3: CPS-Start-ups/Spin-offs (9), CPS-EIR (4), CPS-DIAL (1), CPS-SSS (1), Job creation (1800)

H3: Fellowships-Graduate (50), Postgraduate (8), Doctoral (5), Faculty (1), Chair Professors (1), Skill Development (75)

**Table 11.1:** List of targets over 5 years

| S No | Target Area | Targets | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1stYr | 2ndYr | 3rdYr | 4thYr | 5thYr | Total |
| **1** | **Technology Development** | | | | | | |
| **(a)** | No of Technologies (IP, Licensing, Patents etc) | 2 | 4 | 4 | 4 | 5 | 19 |
| **(b)** | Technology Products | 1 | 2 | 3 | 3 | 3 | 12 |
| **(c)** | Publications, IPR and other Intellectual activities | 5 | 7 | 8 | 8 | 8 | 36 |
| **(d)** | Increase in CPS Research Base | 6 | 12 | 15 | 15 | 14 | 62 |
| **2.** | **Entrepreneurship Development** | | | | | | |
| **(a)** | Technology Business Incubator (TBI) | 1 | 0 | 0 | 0 | 0 | 01 |
| **(b)** | Start-ups & Spin-off companies | 3 | 9 | 9 | 6 | 5 | 32 |
| **(c)** | GCC - Grand Challenges & Competitions | 0 | 1 | 0 | 0 | 0 | 01 |
| **(d)** | Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS) | 0 | 1 | 0 | 0 | 0 | 01 |
| **(e)** | CPS-Entrepreneur In Residence (EIR) | 2 | 3 | 4 | 5 | 5 | 19 |
| **(f)** | Dedicated Innovation Accelerator (DIAL) | 0 | 0 | 1 | 0 | 0 | 01 |
| **(g)** | CPS-Seed Support System (CPS- SSS) | 0 | 0 | 1 | 0 | 0 | 01 |
| **(h)** | Job Creation | 950 | 1600 | 1800 | 1800 | 1600 | 7750 |
| **3.** | **Human Resource Development** | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **(a)** | Graduate Fellowships | 25 | 35 | 50 | 50 | 50 | 210 |
| **(b)** | Post Graduate Fellowships | 4 | 7 | 8 | 10 | 10 | 39 |
| **(c)** | Doctoral Fellowships | 3 | 5 | 5 | 5 | 5 | 23 |
| **(d)** | Faculty Fellowships | 1 | 1 | 1 | 0 | 0 | 03 |
| **(e)** | Chair Professors | 0 | 1 | 1 | 1 | 0 | 03 |
| **(f)** | Skill Development | 70 | 75 | 75 | 80 | 80 | 380 |
| **4.** | **International Collaboration** | 0 | 1 | 0 | 0 | 0 | 01 |

## 11.4 Activity Plan Year 4

T4: Number of technologies (4), Technology products (3), Publications/IPR/Other (8), CPS research base (15)

E4: CPS-Start-ups/Spin-offs (6), CPS-EIR (5), Job creation (1800)

H4: Fellowships-Graduate (50), Postgraduate (10), Doctoral (5), Chair Professors (1), Skill Development (80)

## 11.5 Activity Plan Year 5

T5: Number of technologies (5), Technology products (3), Publications/IPR/Other (8), CPS research base (14)

E5: CPS-Start-ups/Spin-offs (5), CPS-EIR (5), Job creation (1600)

H5: Fellowships-Graduate (50), Postgraduate (10), Doctoral (5), Skill Development (80)

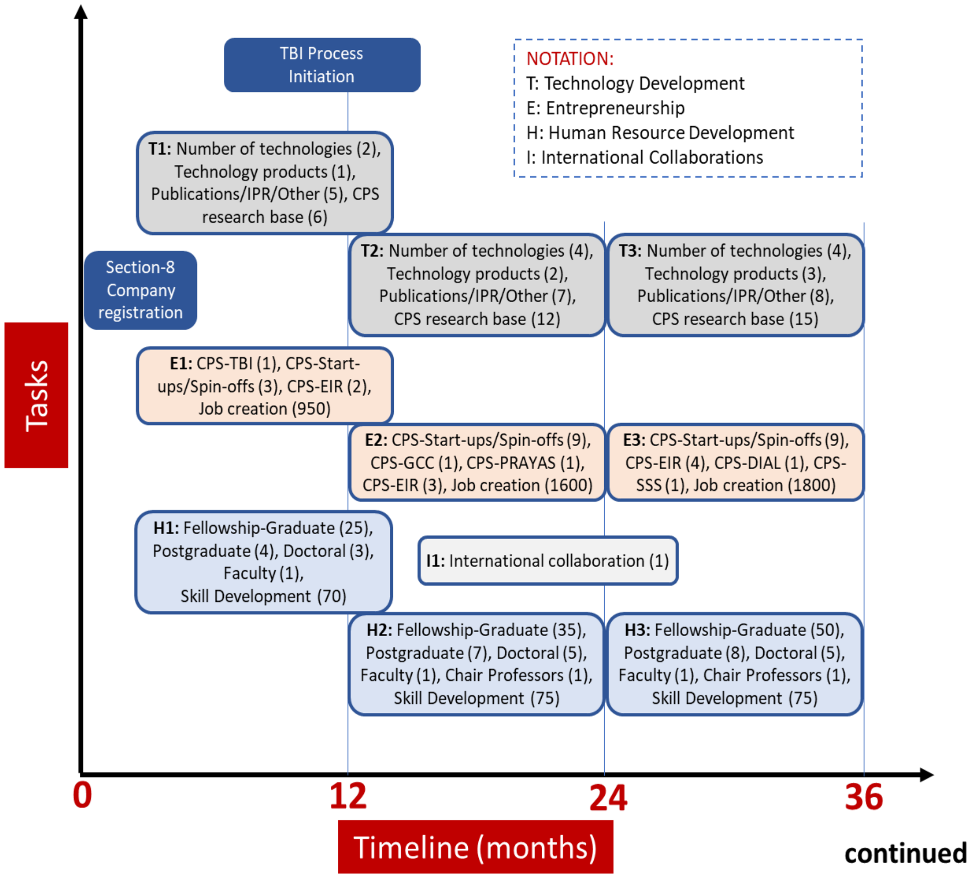


**Figure 11.1:** Activity plan with timelines (1 months to 36 months).

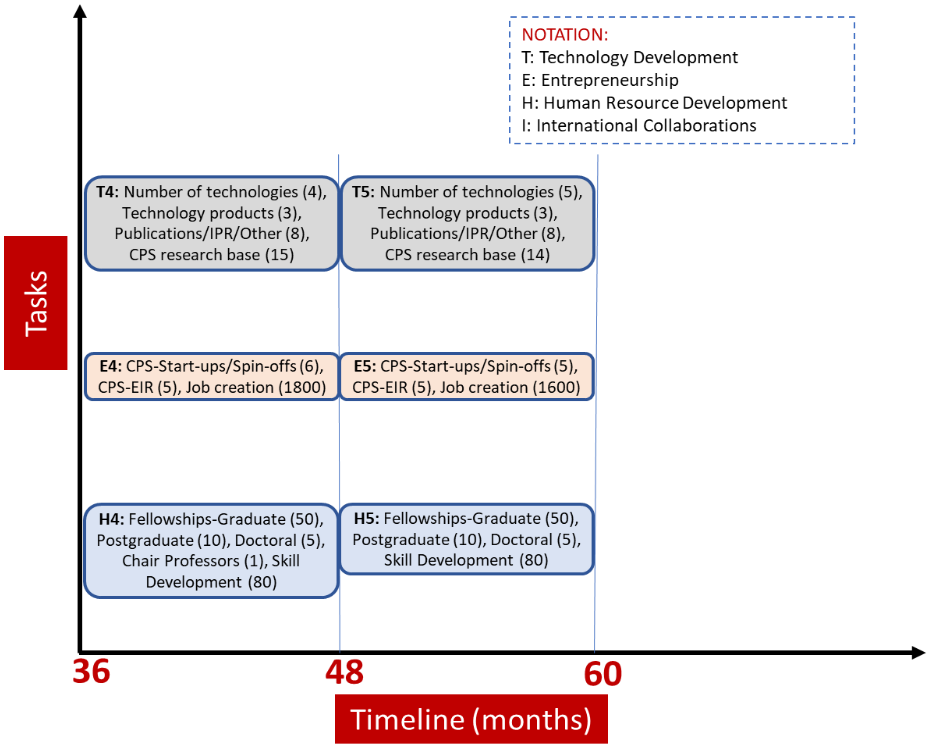


**Figure 11.2:** Activity plan with timelines (36 months to 60 months).

# Chapter 12

# Evaluation and Cost Benefit and Risk Analysis

## 12.1 Cost Benefit Analysis

The TIH, IITI DRISHTI CPS Foundation, comprises several components that require regular evaluation to effectively track their progress over the course of 5 years. The main components are:

a) Incubating start-ups and spin-offs
b) Individual Projects (funded by TIH)
c) Industry R&D units
d) Training of industry personnel in SSMV aspects of CPS

The HGB shall set up required committees comprising both internal (faculty members of IIT Indore) and external (if required) to evaluate whether the activities of the hub are in accordance with the goals and yearly targets set by IITI DRISHTI CPS Foundation. The tentative committee for evaluation of individual projects, start-ups and industrial R&D units can comprise of 5 members:

a) One member from Hub Governing Body / Board of Directors
b) Project Director or its representative
c) Two experts appointed by Chairman BoD (based on the recommendation of Project Director)
d) CEO of IITI DRISHTI CPS Foundation

For each component the evaluation will happen on a **3 to 6 month basis following a dedicated point-based system**.

A thorough feedback on resource allocation and its efficiency will be sought from the committee formed for evaluation. The committee will formulate and adopt a **point based system** that will provide a robust quantitative framework for evaluating the main components of the TIH. Such a point based system is demonstrably successful in evaluation of industries and start-ups setup at the IIT Madras Research Park.

The point based system will evaluate parameters related to the input, process, output, outcome and impact, based on the projects taken up by the TIH. The committee through this evaluation process will aim to ensure accountability, operational management, strategic management, and capacity building.

The exact evaluation criteria for each of the components will be formulated by the members of the Hub Governing Body. The cost-benefit analysis is summarized in table 12.1

**Table 12.1:** Cost-benefit analysis

| S.No. | Cost Head | Benefits |
|---|---|---|
| 1. | Support for technology development projects | IITI DRISHTI CPS Foundation has strategically designed its plan to support technology development projects in three categories viz. short term, medium term, and long term. As discussed in the evaluation section, these projects will be rigorously evaluated and only projects with a strong potential for technology development and commercialization shall be supported. A detailed cost-benefit analysis of individual projects will be carried out for taking necessary decisions. Ensuring that proposals go through a rigorous evaluation process to ascertain the benefits in terms of novel technology development, knowledge creation, skill enhancement, prototype development, IPRs and publications will be the priority. The same, along with the problem statement given by line ministries, shall potentially prove helpful in addressing industrial and societal issues. The licensing of patents and technology transfers will contribute towards revenue generation for the TIH and provide a thrust towards its ultimate aim of attaining self-sustainability. The Hub and Spoke model adopted by the TIH is expected to result in the creation of multiple CPS specialization centers in the country. This will go a long way in pushing forward the “Digital India” initiative of the Government of India and help in improving the technology readiness of the country in the area of CPS focused at System Modelling, Simulation, and Visualization. |
| 2. | Support for start-up and spin-offs and pre-incubation efforts | IITI DRISHTI CPS Foundation will identify and support start-ups and incubation ideas that promise high commercial potential and have a clear business plan. This is expected to result in the commercialization of several technologies in the CPS area. This in turn will help in broadly realizing initiatives of the Government of India such as ‘Make in India’ and ‘Aatmanirbhar Bharat’. It will also help in generating jobs in the county in the area of CPS. Successful start-ups will significantly add to the revenue of the TIH in terms of bolstering its share value and help in achieving its ultimate aim of self-sustainability. A detailed cost-benefit analysis will be done for each start-up idea before funding. |
| 3. | Expenditure in establishing Centres of Excellence (COEs) | Centres of Excellence (COEs) in a few focus areas will act as a catalyst for the development of CPS technologies in the country. They will effectively showcase the research prowess of individuals which in turn will attract industries and start-ups. They will eventually help in getting more financial support for supporting the technology development and commercialization initiatives of the TIH. This will ultimately lead the TIH towards self-sustainability. In addition to this, COEs will serve as nodal |

| | | |
|---|---|---|
| | | centers for technology development and hands-on training of manpower. |
| 4. | Support for Fellowships | The fellowships provided by DRISHTI CPS are expected to create trained and highly skilled manpower to further the research and development in the field of CPS. These will further help in accelerating implementation of CPS technologies and realize the Digital India vision of the government. |

In essence, the costs involved in the various activities are directed to achieve short term and long-term benefits in terms of technology development, patents, publication, commercialization, start-ups and spin-offs, manpower training and job creation. These activities are planned in such a way that the initial support will lead towards self-sustainability of all the initiatives of TIH in the long run. In terms of the country's vision, the initial financial support to the TIH activities will help in realizing India's missions like Digital India, Aatmnirbhar Bharat and Make in India. The cost benefit analysis of the TIH is summarized in Figure 12.1.

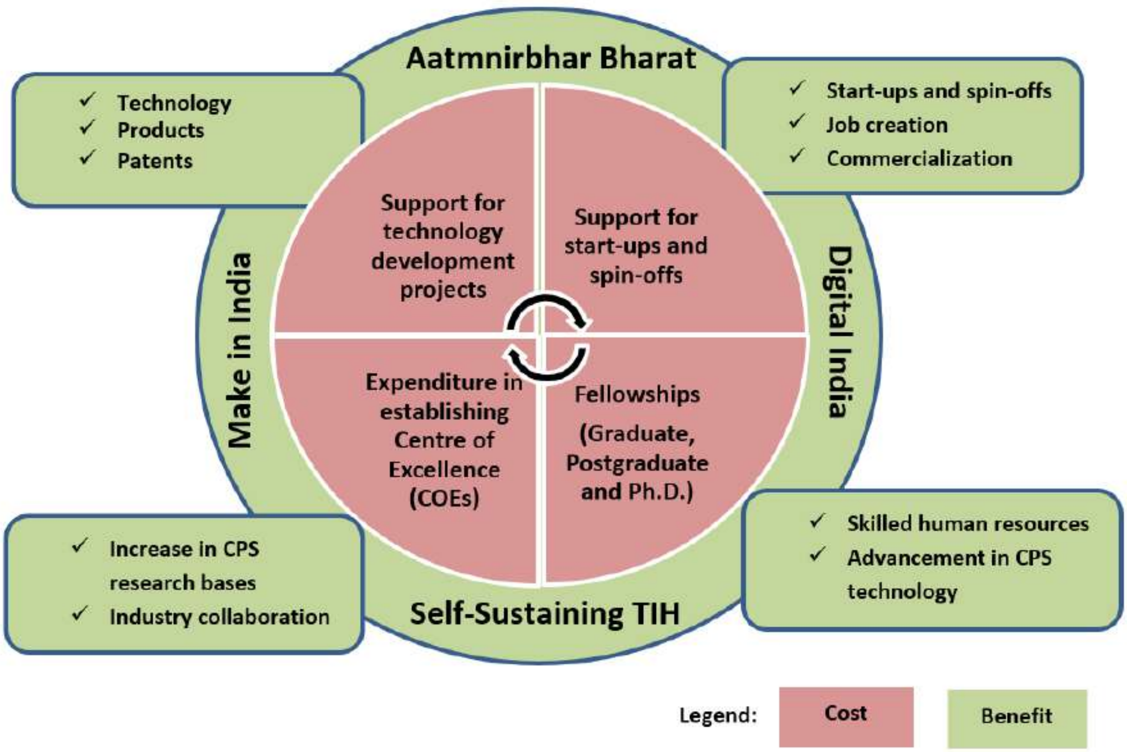


**Figure 12.1:** Cost-benefit Analysis

## 12.2 Risk Analysis

Following are a few anticipated risks in successfully running the TIH.

**Table 12.2:** Risk analysis

| S.No. | Risk related to | Foreseen risks | Mitigation plans |
|---|---|---|---|
| 1. | Technology Development Projects | Lack of commercialization focus in project received from institutes/organizations across the country | • Emphasis on a clear problem statement in 'Call for Proposals'<br>• Adoption of a strict screening and evaluation process<br>• Regular point-based monitoring of all approved projects<br>• Involvement of industries in defining problem statements, evaluation, and monitoring<br>• Encouraging researchers to submit short term and mid-term projects proposals also |
| 2. | Start-ups | Lack of an orientation towards 'start-ups' among faculty members | • Provision of pre-incubation support<br>• Organizing orientation webinars<br>• Provision of appropriate administrative support<br>• Involving academic experts with start-up experience as chair professors, advisors |
| | | Potential failure of start-ups supported by TIH | • Conducting rigorous evaluation of all start-up ideas for their commercial potential<br>• Regular point-based monitoring of all approved projects<br>• Ensuring performance-based release of funds<br>• Involvement of angel investors, venture capitalist - Facilitating connect with potential customers of proposed products |
| 3. | Corporate Orientation | Lack of a corporate orientation in academic circles in India | • Reminding all to not treat this as yet another funding scheme<br>• Laying greater emphasis on the commercialization from the inception phase |

| | | | |
|---|---|---|---|
| | | | • Ensuring the involvement of industry experts as advisors<br>• Inviting industries to become active members of the TIH eco-system. Luring them with appropriate incentives.<br>• Learning from examples of best practices like those of the IITM research park model |
| 4. | Funding related | Inordinate delay in attaining the goal of self-sustainability | • Focusing on generation of revenue from the early days of the Hub, through activities such as seeking CSR funds from industries, conducting training programs, facilitating joint R&D programs with the industry s<br>• Evaluation of activities targeted towards self-sustainability of the Hub<br>• Laying emphasis on outreach activities<br>• Ensuring aggressive marketing of products developed by the Hub |
| 5. | Management | Erosion of professionalism in the management of the Hub | • Involvement of professional individuals from academia and industry in the management team<br>• Conducting regular audits on the working of the Hub<br>• Following successful and established management protocols in running the Hub |

# List of Tables

# List of Figures

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# Appendix

# Expression of Interest from Industries

NVIDIA

NM-ICPS (TIH)

CONSENT LETTER FROM INDUSTRY PARTNER

This is to state that NVIDIA hereby consent to partner with Indraprastha Institute of Technology, Indore, in the proposed NM-ICPS Technology Innovation Hub (TIH) on Cyber Physical Systesm (CPS) with sepcial focus on System Simulation, Modelling and Visualization.

The scope of the collaboration could include joint research activities, technical and technology support, skill building workshops, professional continued education program, expert talks, seminars/conferences/competitions, tools and development kits, special rebates on Nvidia technology platforms and products etc. Details of the collaboration will be worked out on development of a detailed SOW.

Nvidia Corporation has keen interest and expertise in technologies related to HPC/AI/ML/Deep learning technologies and computing platforms. We would be happy to provide technical inputs, technical expertise, and research assistance for the proposed collaborative research activities.

For NVIDIA,

**Ganesh Mahabala**
Business Director – Strategic Projects, South Asia
gmahbala@nvidia.com

Date: September 17, 2020
Place: Bangalore

Nvidia Graphics Pvt Ltd., C1, Jacaranda, A Wing, Manyata Embassy Business Park, Bangalore 560045 Tel: +91 80 66948400 / 10

SIEMENS

Industry

*NM-ICPS (TIH)*

**CONSENT LETTER FROM INDUSTRY PARTNER**

This is to state that Siemens Industry Software (India) Private Limited ("SISW) hereby consent to partner with Indian Institute of Technology, Indore in the proposed NM-ICPS Technology Innovation Hub (TIH)/Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualization" (domain area) and agree to the activities to be mutually decided by parties.

We hereby consent to support the TIH in terms of:

1. Contribution in kind:
    - Grant in kind of SISW software

SISW will reasonably support IIT Indore through its partner in

- Training on SISW software
- Industry academia partnerships

Summary profile of the Industry is given below:

| | | |
|---|---|---|
| Name of Industry/Organization | : | Siemens Industry Software (India) Private Limited |
| Nature of Business | : | Software offerings across a broad spectrum of industry domains. |
| Number of Employees | : | 2168 |
| Annual Turnover | : | 13.49 Billion (in INR) |

We hereby affirm to be committed to participate in the proposed TIH/SAH as indicated above.

Date: 25th September 2020

Place : Gurgaon

Authorized Signatory

Seal

Siemens Industry Software (India) Pvt. Ltd.

Unrestricted

Siemens Industry Software (India) Pvt. Ltd.
Corporate Identity Number: U12500DL1998PTC094315

Regd. Office: E-20, 1st & 2nd Floor, Hauz Khas, New Delhi - 110 016

2nd Floor, SKCL- Central Square I
C-28 to C-35, CIPET Road,
Thiru-Vi-Ka Industrial Estate,
Guindy, Chennai 600032,
Tamil Nadu, India.

Phone : +91 44 4002 1500
Fax : +91 44 4002 1501
www.siemens.co.in/plm

**INDORE BIOTECH**
INPUTS & RESEARCH (P) LTD.
A DSIR Recognised Research Facility
CIN: U24124MP1994PTC008843
*Nurturing Nature*

NM-ICPS
AN ISO 9001:2015 CERTIFIED COMPANY
Regd. Office: 'ARUNDHATI' 49-C, Indrapuri Colony,
Near Bhanwarkua Square, A.B. Road, Indore-452001 (MP)
Telefax: 0731-4099394, 4966394,
E-mail: ibirpl@gmail.com, Website: www.indorebiotech.com

## CONSENT LETTER FROM INDUSTRY PARTNER

This is to state that **Indore Biotech Inputs and Research (P) Ltd.** hereby consent to partner with Indian Institute of Technology Indore (Host Institute name) in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in"System Simulation, Modelling & Visualization". I am aware and agree to the activities mentioned in the proposal under Industry Partnership.

I hereby consent to support the TIH / SAH in terms of:

1. Contribution in Cash: Nil
2. Contribution in Kind: **ProvideTechnical expertise, Carry out Collaborative projects, Participation in training programs**

Summary profile of the Industry is given below:

| | |
|---|---|
| Name of Industry/Organisation | : Indore Botech Inputs and Research (P) Ltd. |
| Nature of Business | : Agricultural Inputs |
| Number of Employees | : 60 |
| Annual Turnover | : Rs. 16.5 Cr |

I hereby affirm that my Industry/Organisation is committed to participate in the proposed TIH/SAH as indicated in the proposal including the financial liabilities as provided above.

Date 28/09/2020

Place Indore

Head of Industry/Organisation

Seal

INDORE BIOTECH INPUTS & RESEARCH

**Works:** Gram Dehri, Khasra No. 204/3, Rau-Pithampur Road, Opp. IIM, Rangwasa, Dist. Indore-452198 (M.P.)

Mahindra

**Mahindra & Mahindra Ltd.**
Mahindra Towers,
Dr. G. M. Bhosale Marg, Worli,
Mumbai 400 018 India

Tel: +91 22 24901441
Fax: +91 22 24975081

## LETTER FROM INDUSTRY PARTNER

This is to state that Mahindra Institute of Quality, Mahindra and Mahindra Ltd., hereby gives in principle consent to work for a partnership with Indian Institute of Technology Indore in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualization" (domain area), in terms of :

1. Contribution in Cash: ......Nil.............. (Rs in Lakh)
2. Contribution in Kind : Skill enhancement, training and consultation to suppliers, implementing projects of mutual interest, Advise to start ups.

Summary profile of the Industry is given below:

Name of Industry/Org: Mahindra Institute of Quality, Mahindra and Mahindra Ltd
Nature of Business : Centre of Excellence for Mahindra , suppliers etc
Number of Employees : 12,000 people are employed at M &M Ltd
Annual Turnover : Rs 45,000 crores is the annual sales turnover of M&M Ltd.
I affirm our interest for in principle participation in TIH / SAH proposal in above areas, as per mutual agreement.

Date: 17 September '20

Place: Mumbai

Rajinder Singh

Vice President

Mahindra Institute of Quality

Mahindra & Mahindra Ltd

MAHINDRA & MAHINDRA LIMITED MUMBAI

Regd. Office: Gateway Building, Apollo Bunder, Mumbai 400 001, India
Tel: +91 22 22021031 | Fax: + 91 22 22875485
Email : group.communications@mahindra.com
mahindra.com
CIN No. L65990MH1945PLC004558

SOLIZE

SOLIZE India Technologies Private Limited
(Formerly CSM Software Private Limited)
2nd Floor, Unit Nos. 201-B & 202, Brigade Opus,
No. 70/401, Kodigehalli Gate, Hebbal, Bangalore- 560092, India
t: +91-80-41782000 / f: +91-80-41782001
e: info.sid@solize.com / w: www.solize.com/india/
CIN: U72200KA1992PTC013433

**Ref: SITPL/IITI/29092020**

**Date: 29th September, 2020**

**CONSENT LETTER FROM INDUSTRY PARTNER**

This is to state that *SOLIZE India Technologies Private Limited* (Name of Industry/Organisation) hereby consent to partner with Indian Institute of Technology Indore (Host Institute name) in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualization" (domain area). I am aware and agree to the activities mentioned in the proposal under Industry Partnership.

I hereby consent to support the TIH / SAH in terms of:

1. Contribution in Cash: ....NA .. (Rs in Lakh)
2. **Contribution in Kind**:
   a. Manpower training of your organization in area of CPS
   b. Setting up an R&D laboratory in the area of simulation and modelling for CPS at IIT Indore under DRISHTI-CPS
   c. 3D CAD Engineering Services
   d. 3D Printing Engineering Services
   e. Onsite Engineering Services
   f. Offshore Contracted Engineering Services
   g. CAD/CAE Simulation & Digital Manufacturing Software setup.

Summary profile of the Industry is given below:

| | |
|---|---|
| Name of Industry/Organisation | : SOLIZE India Technologies Private Limited |
| Nature of Business | : Software Distribution & Engineering Services |
| Number of Employees | : 250 in India (1600 worldwide) |
| Annual Turnover | : 70 Cr. from India |

I hereby affirm that my Industry/Organisation is committed to participate in the proposed TIH/SAH as indicated in the proposal including the financial liabilities as provided above.

Date: 29th September, 2020

Head of Industry/Organisation
**Paramahans Singh**

Place: Bangalore

Seal

SOLIZE INDIA TECHNOLOGIES PVT. LTD. BANGALORE

DASSAULT SYSTEMES

29 September 2020

To,
Dr. Pavan Kumar Kankar
Core Committee DRISHTI-CPS
Indian Institute of Technology
Indore

**Sub:** Dassault Systemes India Pvt. Ltd. agrees to be a Technology partner with Indian Institute of Technology (IIT) - Indore for Technology Innovation Hub (DRISHTI-CPS)

**Dear Dr. Pawan,**

This is good to know that IIT-Indore is establishing a Technology Hub in driving Innovation through Simulation Hub for Technologies in Interdisciplinary Cyber Physical System (DRISHTI-CPS), to achieve Government of India's National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) to secure India's future by creation of basic R&D infrastructure, manpower and skills.

We understand that the proposed TIH at IIT Indore is named as "DRISHTI CPS" and IIT Indore has secured a grant of approximately Rs 100 crore over 5 years for establishing a Technology Innovation Hub (on System Simulation, Modelling and Visualization aspects of Cyber physical Systems) under NM ICPS.

We are familiar with the work that **IIT-Indore** is doing. Dassault Systemes India Pvt. Ltd. ("DS India") will be happy to support **IIT-Indore** in this venture with Dassault Systemes proprietary software & technology in accordance with appropriate agreements to be executed between **IIT-Indore** and DS India. Along with this letter, we are submitting our proposed engagement model in attached concept note.

Yours truly

for **Dassault Systèmes India Pvt Limited**

**Kishor Sarvade**
Email: Kishor.sarvade@3ds.com
Contact: 9890476885

PRODUCTION MODELING INDIA PVT. LTD.

Plot No. 1 & 2, Khasra No.57/4, At Mouza Isasani P.S.K. 46, Hingna 441110
Dist. Nagpur, Road From West Gate of MIHAN Towards Hingna
Phone : +91 8446053180,8446056583
www.pmi-services.in www.pmcorp.com

## CONSENT LETTER FROM PRODCUTION MODELING INDIA (PMI)

Production Modeling India (PMI) Pvt. Ltd. do hereby consent to partner with Indian Institute of Technology (IIT) Indore in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualization".

PMI is interested to support and participate with DRISTHI-CPS Team on Research related projects in field of Industrial Engg. & Simulation Modelling such as develop and market new tools for scheduling, process planning, Simulation plug in library development, etc.

PMI would like to extend support to NM-ICPS TIH / SAH in terms of:

1. **Contribution in Cash:** Due to lack of a detailed plan at this stage, PMI reserves its cash commitments to case to case basis considering the objective of research and commercial viability of the projects we embark together. To ensure the newly formed organisation is self-sustainable, PMI would also jointly conduct paid software training programs and execute projects for customers identified by this organisation. The revenue generated would be shared with DRISHTI-CPS Team for such programs.
2. **Contribution in Kind:** Conduct free webinar sessions on related topics to spread awareness, support team in identifying simulation projects, design course material for simulation labs, conduct session on simulation tools for students, etc.

Summary profile of the Industry is given below:

| | |
|---|---|
| Name of Industry/Organisation | : Production Modeling India (PMI) Pvt. Ltd. |
| Nature of Business | : Engineering Consultancy |
| Number of Employees | : 50+ |
| Annual Turnover | : 3.9 Cr |

R.M. Welekar

Date 02-Oct-2020 — Head of Industry/Organisation

Place Nagpur — Seal

PRODUCTION MODELING INDIA PVT. LTD. NAGPUR

Your Partner in Productivity Improvement

**Chota Hospital (P) Ltd.**™
Empowering Doctors & Creating Healthier Tomorrows

**CONSENT LETTER**

This is to state that **Chota Hospital Private Limited** hereby consent to partner with Indian Institute of Technology Indore in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualisation" (domain area). I am aware and agree to the activities mentioned in the proposal under Industry Partnership.

I hereby consent to support the TIH / SAH in terms of:

1. Contribution in Cash: ₹ 35,000
2. Contribution in Kind: ₹ 3,00,000 in Business Development / Technology Consulting

Summary profile of the Industry is given below:

| | | |
|---|---|---|
| Name of Industry/Organisation | : | **Chota Hospital Private Limited** |
| Nature of Business | : | **Digital Health** |
| Number of Employees | : | 5 |
| Annual Turnover | : | **8 lakh** |

I hereby affirm that my Industry/Organisation is committed to participate in the proposed TIH/ SAH as indicated in the proposal including the financial liabilities as provided above.

Date : 4th June, 2020

Place : Bengaluru

**Anmol Arora**

Founder & CEO

# Plasma and Vacuum Solutions

**We have proven experience and credibility**

8/17 Vijay Nagar, Indore
Madhya Pradesh, India
Ph. +91 (0) 9685236433, +91 (0) 9993700867
Email: sales@plasmavacuumsolutions.com
Website: www.plasmavacuumsolutions.com

**Registration No.:** C/79164
Sales/VAT/CST No. 23479158785
**GSTIN:** 23DOUPS6085C1ZG

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## CONSENT LETTER FROM INDUSTRY PARTNER

This is to state that **Plasma and Vacuum Solutions** (Name of Industry/Organisation) hereby consent to partner with Indian Institute of Technology Indore (Host Institute name) in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualization" (domain area). I am aware and agree to the activities mentioned in the proposal under Industry Partnership.

I hereby consent to support the TIH / SAH in terms of:

1. Contribution in Cash: **XXX** (Rs in Lakh)
2. Contribution in Kind: **Company will support plasma modelling and simulation spinouts, licensing, and commercialization. Incubate R&D activities and production/testing of new products in the TIH** (List activities)

Summary profile of the Industry is given below:

| | |
|---|---|
| Name of Industry/Organisation | : **Plasma and Vacuum Solutions** |
| Nature of Business | : **Distributors/Consulting/Manufacturing** |
| Number of Employees | : **Below 10** |
| Annual Turnover | : **<1 Crore** |

I hereby affirm that my Industry/Organisation is committed to participate in the proposed TIH/SAH as indicated in the proposal including the financial liabilities as provided above.

Yours faithfully,

Bulakh
Plasma and Vacuum Solutions
Indore

Varsha Bulakh
CAO
Plasma and Vacuum Solutions
Indore

Date: **14-02-2020**

Place: **Indore, India**

Swaaha
swachh aur hara

**Date: 21st May, 2020**

**TO WHOMSOEVER IT MAY CONCERN**

**CONSENT LETTER FROM INDUSTRY PARTNER**

This is to state that **M/s. Swaaha Resource Management Private Limited** hereby consent to partner with Indian Institute of Technology Indore in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualization" (domain area). I am aware and agree to the activities mentioned in the proposal under Industry Partnership.

I hereby consent to support the TIH / SAH in terms of:

1. Contribution in Kind: Through sharing of domain expertise, data, industry inputs for development of problem statements, partnership in deployment of pilot projects and collaboration in any kind of future prospects in Startup incubation opportunities

Summary profile of the Industry is given below:

| | |
|---|---|
| Name of Organisation | : M/s. Swaaha Resource Management Private Limited |
| Nature of Business | : Technology, Solutions and Service Provider in the domain of Solid Waste Management |
| Number of Employees | : 13 |
| Annual Turnover | : INR 1.00 crore |

I hereby affirm that my Industry/Organisation is committed to participate in the proposed TIH/SAH as indicated in the proposal including the financial liabilities as provided above.

Dated this 21st Day of May Month of 2020

For and on behalf of:

Swaaha Resource Management Private Limited
201, Bansi Plaza, 581, M.G.Road, Palasia, Indore – 452001, M.P.

SWAAHA RESOURCE MANAGEMENT PVT. LTD. SWAAHA swachh aur hara

Jwalant Shah
Co-Founder & Director
(+91)-8871749707
jwalant@swaaha.in

**SWAAHA RESOURCE MANAGEMENT PRIVATE LIMITED**
**Reg. office:** 201, Bansi Plaza, 581, M.G.Road, Palasia, Indore - 452001, M.P.
**Web:** www.swaaha.in |**Email:** namaste@swaaha.in |**Call:** (+91)-731-4989206
**CIN:** U90000MP2016PTC041065 |**DPIIT COR No.:** DIPP2749

**Incubated at:** IIT Indore **Recognised By:** #startupindia

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Techwarium
Converging Technology and Life

## CONSENT LETTER FROM INDUSTRY PARTNER

This is to state that Techwarium India Private Limited, Indore hereby consent to partner with Indian Institute of Technology Indore (Host Institute name) in the proposed NM-ICPS Technology Innovation Hub (TIH) / Sectoral Application Hub (SAH) in "System Simulation, Modelling & Visualization" (domain area). I am aware and agree to the activities mentioned in the proposal under Industry Partnership.

I hereby consent to support the TIH / SAH in terms of:

1. Contribution in Cash: NA
2. Contribution in Kind: ..................... (List activities)
    - Exploring possibility of licensing the developed technologies
    - Submitting incubation proposal under the proposed scheme (tentative areas of proposal: VR/AR interface with simulation and modelling)
    - Skill development

Summary profile of the Industry is given below:

| | |
|---|---|
| Name of Industry/Organisation | : Techwarium India Private Limited |
| Nature of Business | : Software development, customized automation solution development |
| Number of Employees | : < 10 |
| Annual Turnover | : < 10 lakh |

**Techwarium India Private Limited**
Registered Office - 16 Radhakrishna Vihar, Near Pipaliyahana East Ring Road,
Indore, Madhya Pradesh. Pin– 452016. INDIA.
Contact number: +91- 9644441707