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Whitepaper

Innovations for Sustainable Urban Living:
Insights into Smart City Solutions

Telecommunications Standards Development Society, India

(TSDSI)

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Foreword

The rapid growth, requirements, and demands of the cities provided a plethora of opportunities and challenges and led to the concept of 'Smart City' long ago. The same revolves around developing sustainable, citizen-friendly cities and enhancing the quality of life of its residents.

To realise smart cities, intelligent enabling technologies have regularly evolved and being deployed to improve the infrastructure and manage the cities' scarce resources efficiently. A careful selection of appropriate, contextual, and standards aligned solutions based on specific requirements are integral part of this evolution.

There is a continuous need to have appropriate intelligent analytic control tools for exchange of secure data between verticals, harmonizing with interoperability-based standards for making the platforms capable of adding further evolving features and requirements which are citizen friendly, enhanced ease of use by both the service providers and users as well besides taking care of data security & privacy, inclusion of Indian datasets, scalability, with well-defined plans of tool based easy upgradation and maintenance.

The IoT/M2M TRIP forum – Smart City subgroup was established to explore the standards landscape, leads, and to release the findings as a white-paper. The TRIP Forum works under the overall guidance from time to time from the roadmap committee which is a standing committee of the TSDSI governing council. Hence, the white paper is a collective effort of experts from IoT/M2M and 'Smart City' field and the roadmap committee

The team met periodically and brainstormed various aspects in the context of IoT/M2M and 'Smart City' to conceive this document.

The white paper examines various smart city specific solutions, standards, existing sandbox environments, and living labs. It covers a wide spectrum of IoT/M2M aspects, advancements, and recommendations. The white paper was championed by a seasoned smart city expert backed by a team of eminent members from industry, academia, and reputed organisations.

We are grateful to all the contributors who took time amidst their busy schedules to contribute, devise, review, and refine the white paper and to the roadmap committee for the guidance and support received from them.

There is a lot more work still to be done, with evolving technologies and advancements. Standards-driven innovations in the IoT/M2M domain that are appropriate for the Indian context and the collaborative efforts of experts to bring value additions for Indian Standards, will make our cities truly smart.

This is a game changer, made possible by TSDSI forum and related processes that serve as open and neutral platforms for exchanging technological knowledge and experiences for socio-economic advancement.

The white paper is just a beginning with a vision of pre-standardisation foundation in IoT/M2M and 'Smart City' space and is expected to lay the foundations for policy drafting, standards, proposals and recommendations for suitable roadmaps.

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1. Executive Summary

Purpose & Objective:

This document provides an overview of various components for implementing a smart city solution, making it reliable, usable and scalable based on some case studies.

Key Findings:

The key findings are the following:

The rudimentary platforms and the necessary IoT networks exist for the implementation of Smart Cities, and these include Service layer platforms (ex: oneM2M, OM2M, Mobius, ACME, etc.), Data exchange platforms, IoT devices and networks / systems (Wi-Fi, NB-IoT, GSM) etc. The opportunity domains cover the management of: Water Quantity/ Quality, Air Quality, Energy (conventional/Renewable), Weather, Smart Spaces, Street Lights, Mobility, Safety & Surveillance, Waste Management, Health, Education, Agriculture, Finance. These domains are critical for the objectives of “Digital India”.

There are still serious gaps that need to be addressed when a smart city “system” is put together and these include Data Security & Privacy, Availability of Indian Datasets, interoperability issues across cloud platforms and service platforms and Policy definitions. In smart city implementation, standards are indispensable in ensuring that different systems, technologies, and stakeholders interact in a coordinated manner. Smart cities are intricate networks relying on various technologies, data, and infrastructure, and without standardized guidelines, the process can become convoluted, inefficient, and error ridden. As “Smart City” objectives handle critical services, it is recommended that standards groups under TSDSI address these gaps to enable smart city realization in India.

Audience & Stakeholders

TSDSI, Academia, State & Central Governments, Research, startups, tech companies, smart city players and policymakers.

2. Abbreviations & Acronyms

AI	Artificial Intelligence
AQI	Air Quality Index
ATCS	Adaptive Traffic Control System
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EBTC	European Business and Technology Centre
ESG	Environmental, Social, and Governance
eSIM	Embedded SIM
FWA	Fixed Wireless Access
ICT	Information and Communication Technologies
IoT	Internet of Things
LAAS-CNRS	Laboratory for Analysis and Architecture of Systems - National Centre for Scientific Research (CNRS)
LoRaWAN	Long Range Wide Area Network
PeSCo	Pedestrian Safety Enhancement Controller
PM	Particulate Matter
RFID	Radio Frequency Identification
TSS	Total Suspended Solids
VMS Display	Variable Message Sign Display
VOC	Volatile Organic Compounds

3. Introduction

A significant push for smart cities in India under the Smart Cities Mission was initiated by the Government of India to drive economic growth and improve the quality of life of people by enabling local development and harnessing technology to enable smart outcomes for citizens. The Smart Cities Mission was launched by the Indian government in 2015 to develop 100 cities across the country as "Smart Cities".

The focus of the smart city in India aims to invest in the development and infrastructure of Tier 1 and 2 cities, bringing them to the same level as global smart cities. As a result, many smart city solutions have been and are being developed in this process. To understand the solutions, challenges, and gaps and to plan enhancements, one needs to understand the various questions why, what, who and how related to smart cities.

The Necessity of Smart City Development

The need for setting up the smart cities can be attributed to the following:

- Cities will witness an inflow of 2.5 billion new urban dwellers by 2050, leading to a need for smart & sustainable development.
- To enhance the quality of living for its citizens through smart technology and awareness programs.

3.1. Objective of Smart Cities

The smart cities project aims to transform selected cities into vibrant and sustainable urban centres that offer residents a high quality of life while leveraging technology and data to address various urban challenges effectively. It is an ambitious initiative that seeks to create smarter, more connected, and efficient cities in India. This mission aims to develop inclusive and sustainable citizen-friendly cities by enhancing citizens' quality of life using technology-driven and data-driven solutions.

Figure 1: Key Objectives of the smart cities in India

The key objectives of smart cities in India include:

- **Improved Infrastructure:** Developing modern and sustainable infrastructure to provide better amenities such as 24x7 water and power supply, efficient public transportation, waste management, and a clean environment.
- **Technology Integration:** Utilizing information and communication technologies (ICT) to create a seamless network of connected devices and services that improve governance, service delivery, and

citizen engagement.

- **Sustainable Development:** Encouraging eco-friendly practices to reduce environmental impact and promote sustainable urban development.
- **Efficient Governance:** Utilizing data analytics and technology to enhance government processes and make them more transparent, participatory, and accountable.
- **Enhanced Quality of Life**: Focusing on citizen-centric initiatives that improve health, education, safety, and overall well-being.
- **Economic Growth:** Encouraging investment and economic opportunities to foster job creation and economic growth in the region.
- **Citizen Engagement:** Promoting active participation of citizens in the decision-making process and incorporating their feedback in urban planning and development. Also ensuring the security of citizens.

3.2. Stakeholders

The development and implementation of smart cities involve various key players from the public and private sectors, as well as academia and civil society. These players work together to plan, fund, and execute smart city projects.

Figure 2: Key Players in Smart Cities

Some of the key players in smart cities are:

Government Agencies: Government bodies at different levels, including national, state, and local governments, play a crucial role in initiating and overseeing smart city projects. They provide the necessary policies, regulations, and funding to support the implementation of smart city initiatives.

Urban Planners and Architects: Urban planners and architects design the blueprint for smart city development. They focus on creating sustainable and efficient urban infrastructure, public spaces, and land-use planning.

People:

- **Citizens and Community Groups:** Active participation and feedback from citizens are crucial for successful smart city projects. Engaged citizens can provide insights, identify local challenges, and contribute to decision-making processes.
- **Non-Governmental Organizations (NGOs):** NGOs and civil society organizations can work in collaboration with the government and other stakeholders to address social and environmental challenges within smart cities.

- **Academic and Research Institutions:** Universities and research organizations play a role in conducting research, providing expertise, and developing innovative solutions for smart cities.
- **Startups and Entrepreneurs:** Startups and entrepreneurial ventures often bring innovative ideas and technologies to the table, fostering a culture of innovation within smart city projects.

Sensors/Technology and Communication Stakeholders

- **Technology Companies:** Technology firms and solution providers are essential players in smart cities. They offer a wide range of technologies such as Internet of Things (IoT) devices, sensors, data analytics platforms, and connectivity solutions that form the backbone of smart city infrastructure. AI/ML models for a wider deployment and other calibration
- **Utility Providers:** Companies providing essential utilities like electricity, water, and waste management services are integral to smart city development. They work on integrating smart grids, efficient water management systems, and waste-to-energy solutions.
- **Communication:** Communication infra like Wi-Fi, LoRaWAN, Wi-SUN, 4G,5G etc.
- **Data models/Info Models/Datasets:** These items make the data to be presentable, legible and structured. Hence a standards-based data will be made available for developing solutions/applications and Visualization.

The collaboration and cooperation among these key players are vital for the successful implementation and functioning of smart cities. Each player brings unique expertise and resources to address various aspects of urban development and make cities more sustainable, liveable, and technologically advanced.

3.3. Smart Implementation Attributes

Figure 3: Smart Acronym

The "SMART" acronym is a framework commonly used in goal setting and project management to ensure that objectives are clear, Specific, Measurable, Achievable, Realistic, And Timed. Each letter of the word "SMART" represents a specific characteristic that a goal or objective should possess to increase the likelihood of successful implementation.

It can be said that the word “SMART’ is both physically and functionally related to the smart city implementation also like any other project. Each element of the SMART acronym and its applicability to smart city solutions can be understood.

- **Specific:** The goal should be well-defined and clear, leaving no room for ambiguity. It should answer the questions of "what," "why," and "who." Specific goals provide focus and direction for the project. As mentioned in the earlier sections, for the implementation of smart city solutions, answers should be defined for the questions “what”, “why”,” who” and “how”.

- **Measurable:** The goal should be quantifiable, so progress and success can be objectively measured. This requires establishing concrete criteria for measuring the goal's attainment. It is obvious that measurability becomes one of the main requirements to meet the specified goals.
- **Achievable:** The goal should be realistic and attainable within the available resources, skills, and time frame. It is essential to set challenging goals, but they must still be achievable. Based on the existing city framework, the goals need to be planned first.
- **Relevant:** The goal should align with the overall objectives and strategy of the organization or project. It should be relevant to the current needs and priorities. Each city has their own specific environment, gaps and requirements. Accordingly, the relevant solutions need to be aimed at.
- **Time-bound:** The goal should have a specific deadline or time frame for completion. Setting a target date creates a sense of urgency and accountability. Some of the solutions related to the utilities being used by the cities need to be attended to in a timely fashion.

By using the SMART framework, smart cities, organizations, and individuals can create well-defined and achievable goals that are easier to track and evaluate. This approach helps ensure that projects stay on track, resources are used effectively, and progress can be measured against set targets.

4. Scope

The scope of smart cities is vast and encompasses various aspects of urban development and governance. The primary focus is on leveraging technology, data, and innovative solutions to enhance the quality of life for residents, improve city services, and address urban challenges more efficiently.

The scope of smart cities typically includes the following areas:

- **Public Services:** Enhancing the delivery of public services, such as healthcare, education, public safety, and waste management, through technology and automation.
- **Mobility and Transportation:** Developing smart mobility solutions to improve public transportation, reduce traffic congestion, promote sustainable transportation options, and enable seamless mobility for residents.
- **Environmental Sustainability:** Implementing eco-friendly practices and technologies to reduce environmental impact, promote green spaces, and encourage sustainable living.
- **Citizen Engagement:** Facilitating citizen participation and engagement in decision-making through digital platforms, open data initiatives, and participatory governance.
- **Safety and Security:** Integrating smart surveillance systems, emergency response mechanisms, and predictive analytics to enhance public safety and emergency services.
- **Economic Development:** Encouraging entrepreneurship, innovation, and investment to stimulate economic growth and job creation within the city.
- **Governance and Administration:** Implementing e-governance solutions to streamline government processes, enhance transparency, and improve service delivery.
- **Data Privacy and Security:** Addressing concerns related to data privacy and cybersecurity to safeguard sensitive information and protect citizens' data.

Additionally, smart city initiatives are often ongoing, with continuous innovation and adaptation to changing technologies and urban demands. The goal is to create sustainable, resilient, and liveable cities that cater to the needs of their residents while embracing the potential of technology for urban advancement.

5. Architecture

The standard 6-layer architecture recommended for implementing smart city solutions are:

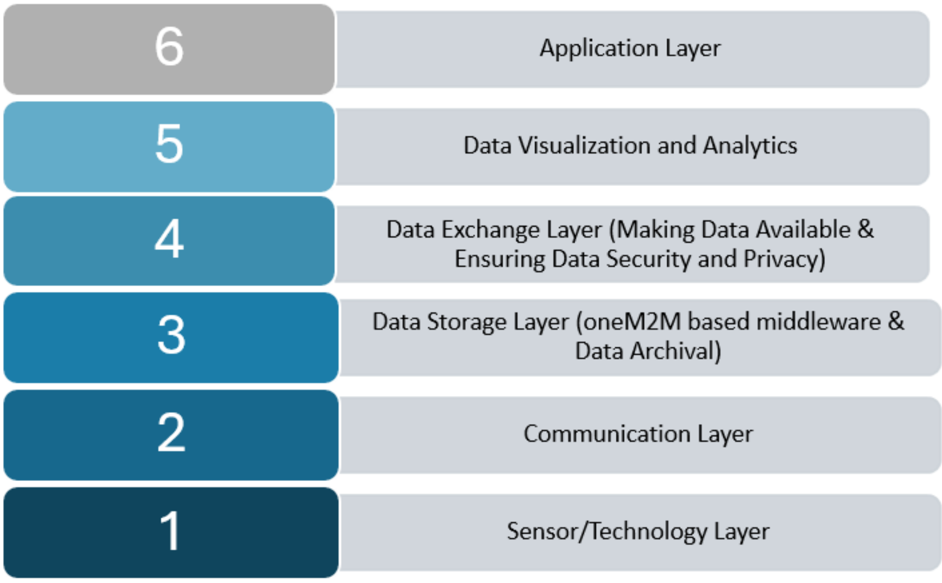


Figure 4: Standard Six-Layer Architecture for Implementing Smart City Solutions

This section provides a high-level summary of the technology stack used in smart city implementations. A detailed description of each layer is explained in the following sections.

The stack consists of six key layers, each with a specific role in ensuring seamless functionality and integration of smart city components:

1. **Sensor and Technology Layer** – Responsible for collecting real-time data from various urban infrastructures, such as pollution levels, water quality, energy usage, and mobility trends.
2. **Communication Layer** – Facilitates secure and reliable data transmission between sensors, devices, and central systems using technologies like Wi-Fi, 4G, 5G, LoRaWAN, and Wi-SUN.
3. **Data Storage Layer** – Ensures efficient organization, processing, and retrieval of large-scale IoT data through middleware solutions like oneM2M and data warehousing platforms.
4. **Data Exchange Layer** – Establishes standard models and interoperability frameworks to allow seamless data sharing between various entities, promoting collaboration and innovation.
5. **Data Analytics & Visualization Layer** – Transforms raw data into actionable insights using dashboards, geospatial visualization, and predictive analytics to aid decision-making
6. **Application Layer** – This Layer, in the context of a smart city refers to the topmost level of the smart city architecture, where services and solutions are designed to directly interact with end-users—such as citizens, businesses, and government entities. This layer plays a critical role in ensuring that the benefits of smart city technologies are accessible and effective in improving daily life, promoting sustainability, and enhancing urban governance.

6. Six Layer Architecture – Detailed Description

Functional details of each layer described in Section 5 are given below:

6.1. Sensor/ Technology Layer

A network of connected devices and sensors that gather real-time information to enable data-driven decision-making and improvement of city operations and services form the Sensor/Technology Layer. They are required for developing and upgrading urban infrastructure to make it more efficient, sustainable, and interconnected. This includes systems like smart transportation systems, modernized utilities (electricity, water, waste management), smart grids, and renewable energy integration.

The scope of smart cities is not limited to these areas alone and can vary depending on the specific needs and priorities of each city. Different cities may choose to focus on aspects based on their unique challenges and opportunities. This can be achieved through Retrofitting, Redevelopment, and innovative development in various domains.

The domains related to smart cities and the sensors/technologies used details are given below for a better understanding. This need not be considered as an exhaustive list, as still there are many other areas like disaster management etc where it is an equally prioritized element for smart cities. Hence the areas can be added as and when the requirement and applicability arise for making the cities a better place to live.

6.1.1. Pollution

Pollution is the introduction of harmful contaminants into the environment, causing adverse effects on living organisms and natural ecosystems. It can take various forms, such as air pollution (from emissions like smog and fine particles), water pollution (from chemicals and waste), soil pollution (due to contaminants like pesticides and heavy metals), and noise pollution (resulting from excessive sound levels). Pollution poses a serious global challenge, affecting human health, biodiversity, and climate change.

6.1.1.1. Air Pollution (Outdoor & Indoor)

Air Quality monitoring is used to measure different pollutants present in the atmosphere (outdoors) and indoors.

6.1.1.1.1. Description

Air pollution is one of the world's largest environmental causes of diseases and premature deaths. Out of different air pollutants, particulate matter (PM) has been identified as one of the most dangerous pollutants. Every year millions of people die and many more become seriously ill with cardiovascular and respiratory diseases because of long-term exposure to PM. With increasing urbanization, the situation is only going to get worse.

For localized monitoring and real-time analysis of outdoor PM (1,2.5,10), a dense IoT system is needed, which is scalable with low-cost portable ambient sensors. The temperature and humidity also need to be measured to understand its impact on the PM values.

Co2 is one more typical parameter which is equally harmful and is caused by carbon footprint and presence of crowds (both indoor and outdoor) VOC (Volatile Organic Compounds) is a parameter which is mostly found in indoors and is found to be harmful when it goes beyond certain levels.

6.1.1.2. Light Pollution

Light pollution is measured by quantifying the artificial brightness and skyglow from excessive or misdirected outdoor lighting.

6.1.1.2.1. Description

Light pollution is the excessive, misdirected, or intrusive artificial light that disrupts the natural darkness of the night sky and affects the environment. It can obscure celestial objects, hinder astronomical observations, and disrupt ecosystems. Additionally, light pollution has adverse effects on human health by disrupting sleep patterns and circadian rhythms. Mitigating light pollution through proper outdoor lighting practices is crucial to preserving our natural environment and improving our overall well-being.

6.1.1.3. Noise Pollution

Noise Pollution measures the intensity and frequency of sound waves to assess noise pollution.

6.1.1.3.1. Description

Noise pollution is the unwanted or harmful presence of noise in the environment, often caused by various human activities and industrial processes. It can have detrimental effects on both physical and mental health, disrupting sleep patterns, increasing stress levels, and impairing communication. Common sources include traffic, construction, industrial machinery, and loud recreational activities. Effective measures such as sound barriers, noise regulations, and public awareness campaigns are essential to mitigate this pervasive issue.

6.1.1.4. Pollution because of RF Radiation

RF (Radio Frequency) radiation refers to electromagnetic waves with frequencies within the radio spectrum. RF radiation is commonly used for wireless communication, including cell phones, Wi-Fi, and radio broadcasting. Exposure to excessive/high power RF radiation can potentially pose health risks, and hence regulatory limits are set to ensure safe levels of exposure. Understanding and managing RF radiation is crucial in modern technology to balance communication needs with health and safety concerns.

6.1.2. Water

Water is one of the most important and basic requirements of human beings. There is only about 0.3% usable water, and the rest is sea water frozen in glaciers. Non-revenue water, Water leakage and Water pollution are the primary areas that need to be addressed w.r.t water.

Some of the main sources of water pollution are the following:

- Discharge of untreated Raw Sewage from households and factories
- Chemicals dumped from Factories.
- Agricultural run-offs that make their way into the rivers and streams and groundwater sources Urbanization.
- The rising use of synthetic organic substances.
- Oil Spills
- Acid Rain caused by the burning of Fossil Fuels.
- Humans litter in rivers, oceans, lakes, and other water bodies. Harmful litter includes plastics, aluminium, glass, and Styrofoam.
- Chemicals used in water/Sewerage Treatment Plants.

Hence the parameters that need to be measured for water to the betterment of the communities are: For Water Quality (Drinking, Domestic)

- pH, Turbidity, and TDS (Total Dissolved Solids) are measured.

For Water Quality (Water Treatment Plant/ Sewerage Treatment Plant -WTP/STP output)

- BOD (Biochemical Oxygen Demand), pH, Flow, TSS (Total Suspended Solids), COD (Chemical Oxygen Demand) etc. are measured.

For Water Quantity (Flow and Pressure)

- The water level and water flow of the water supply are measured.

6.1.3. Energy (Conventional, Renewable)

Energy Measurement is a necessity nowadays. As energy consumption increases, more fuel is used in energy production. This results in the increase of greenhouse gases, and this results in an increase in the average temperature of the planet and turn results in the melting of the glaciers, increase in sea level and change in climate conditions.

Hence it is essential to avoid energy wastage and use energy wisely. In this context, various measurements are done at various levels for energy saving.

Measurement

Energy (Conventional, Renewable)
Energy monitoring measures the power consumption, peak demand, and other important aspects of the energy consumption in each area which helps in understanding the demand patterns and helps in the predictive maintenance. It is applicable to both Conventional Energy and Renewable Energy.

Conventional Energy
Power consumption is monitored at regular intervals to regulate the usage of electronic appliances. and help in reducing power consumption. It also gives us details of the energy consumption patterns.

Renewable Energy
Energy from fossil fuels like coal produces a huge amount of carbon footprint. That is adversely affecting the global climate. Moreover, energy from fossil fuels available in limited amount. A renewable source of energy produces less carbon footprint. Thus, solar energy is being used as an alternative to fossil fuels. This does not have much carbon footprint. However, there are problems associated with solar energy. Solar panels, the main source of harnessing solar energy, are not very efficient if they are not regularly monitored.

Automation for Better Use

Smart Spaces
People often forget to switch off lights, fans, air conditioners, etc. That results in a wastage of electricity; a smart space can do that all by itself. Data is collected from various sensors connected to energy-consuming units to enable controls on power consumption and improving power energy efficiency and hence a healthy environment. With a smart space, the room will identify the crowd in the room and adjust the air conditioning, lighting, and ventilation as per the requirement.

Home automation systems monitor and/or control home attributes such as lighting, entertainment systems, and appliances. It may also include home security such as access control and alarm systems.

6.1.4. Weather Monitoring

Weather variables such as wind speed and direction, air temperature, solar radiation, humidity and rainfall are key factors in determining the course of a wide range of events. For example, agriculture has always been heavily dependent on the weather and weather forecasts, both for its control of the quality and quantity of a harvest and its effect on the farmer’s ability to work the land or to graze his stock. Hence weather monitoring is also important not just in defining present climate, but also for detecting climate change and providing the data to input into models which enable us to predict future changes in our environment.

6.1.5. Smart Street Lights

Streetlights are one of the important utilities in the society and has significant contribution in terms of energy usage. Due to lack of proper monitoring and segmented/individual control, a lot of energy is just wasted as the brightness requirements of light varies depending on traffic and person movement and the existing sunlight.

Typical Scenario for Lighting Expenses

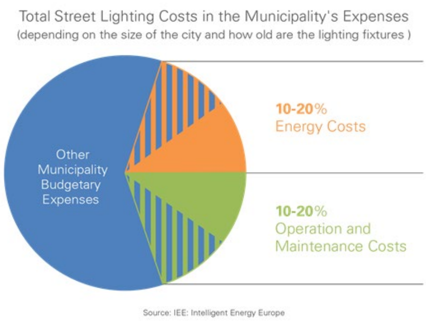


Figure 5: Source IEEE: Intelligent Energy Europe

Electricity Consumption and Comparison

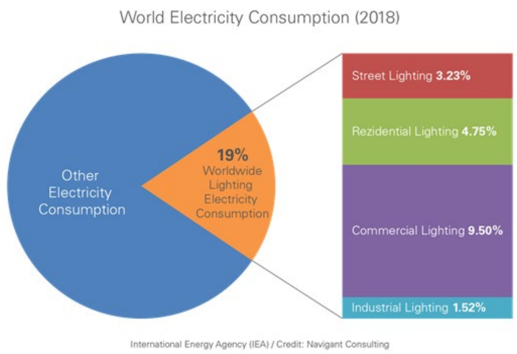


Figure 6: Energy Consumption

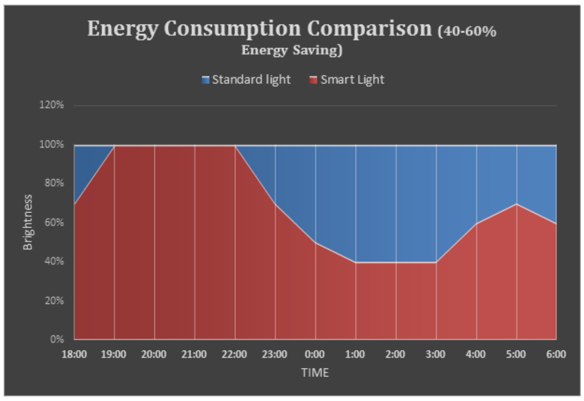


Figure 7: Energy Consumption Comparison

Some segmented controls are used nowadays, but they mostly work as a timer to turn the streetlight ON and OFF and do not offer any information about Light failure or flickering and do not support dimming capabilities. With individual modules, we can monitor and collect a lot of parameters to reduce energy usage and enhance public safety by using a lot of presets that can be applied to the streetlights. For smart street lighting, we have solutions that utilize both Wi-SUN and LoRaWAN technologies for communication.

6.1.6. Health

Remote monitoring of patient health from home has rapidly become a key component of telehealth services, allowing healthcare providers to effectively manage acute and chronic conditions without needing in-person visits. This technology eliminates the need for patients to travel and significantly reduces their risk of exposure to infections, especially in a hospital setting. Integrating such technologies into the healthcare system is crucial in fostering a more sustainable, efficient, and high-quality urban living environment.

By using smart infrastructure, healthcare services can be more efficiently delivered to individuals in underserved communities, ensuring more equitable access to care. The following are several ways that the health sector thrives within a smart city ecosystem:

1. **Telemedicine and Virtual Health Services**—Expanding access to care through remote consultations and virtual doctor-patient interactions.
2. **Smart Health Monitoring Devices** – Using connected wearables and IoT-enabled devices to track patient health in real-time.
3. **AI-Driven Diagnostics and Personalized Care** – Leveraging artificial intelligence to enhance diagnostics and create customized care plans.
4. **Big Data for Public Health Management**—Analyzing vast amounts of health data to optimize resources, prevent diseases, and improve overall health outcomes.
5. **Smart Hospitals and Clinics** – Implementing advanced technologies to streamline operations, reduce errors, and improve patient care.
6. **Emergency Response Systems** – Utilizing connected infrastructure to improve response times and efficiency during medical emergencies.
7. **Healthcare Accessibility and Equity** – Ensuring that all individuals have access to high-quality health services regardless of their background.
8. **Health Information Systems and Data Privacy** – Secure, interoperable digital health records that protect patient privacy while enabling seamless care coordination.
9. **Predictive Analytics for Disease Prevention** – Using data analytics to predict health trends and prevent disease outbreaks before they occur.
10. **Health and Wellness Integration in Urban Design** – Designing cities prioritising citizens' physical and mental health by integrating green spaces and encouraging active lifestyles.
11. **Mental Health Support** – Incorporating digital mental health services and support systems to address the growing need for mental health care.
12. **Health Education and Awareness** – Using digital platforms and public health campaigns to educate citizens on wellness, prevention, and healthy living.

When cities embrace these innovations, they improve the healthcare system and enhance the overall quality of life for residents. Innovative health technologies help provide more efficient, personalized, and equitable care, leading to healthier, more resilient communities. Therefore, it is crucial to conduct a thorough investigation to understand the diverse applications of health sector solutions in Smart Cities.

6.1.7. Waste Management

6.1.7.1. Waste Monitoring

Waste bin status needs to be monitored regularly, and proper intimation of waste pickup needs to be streamlined. Studies can also be undertaken to understand people’s behaviour, dumping patterns using cameras as sensors may not be ideal for the same.

6.1.7.2. Waste segregation

Waste segregation is one of the key aspects of waste management. It requires motivating people to segregate and dump the waste accordingly and ensure that the wrong waste is not dumped into the wrong bin. The other aspect which is crucial is the management of Garbage vehicles movement.

6.1.8. Mobility

All Roads currently in use in the country need an interaction with a system for detecting surface damage conditions, like road surface damage due to poor construction, digging of roads by various other agencies, utility damage, water etc. At present road surface damage is mostly assessed by periodic site surveys where huge manpower is involved which is a costly affair.

Surface damage monitoring can be improved by using cameras installed along the road with image recording, and by image processing, generation of road damage reports., Image processing results may vary depending on the light conditions of the road. It is estimated that 20 cameras are required for a 1000-meter-long road, with one camera at every 100 meters for upstream and downstream. Installing cameras along the road to monitor every square meter area for image processing is presently an expensive proposition as it requires a huge storage device to store the images and communication overhead due to high bandwidth requirements. All roads are mapped using surveillance and roadside units and in between if any incident happens that is to be tracked, an alarm is to be generated on the central server. Also, it can be done using sensor-based solutions to detect road surface damage in real time and generate surface damage status reports using inexpensive road damage sensors and damage detection module hardware.

Surface damage monitoring, smart parking, adaptive traffic control systems, adherence to safety guidelines, and detection of accidents/unwanted activities are some of the areas where smartness becomes crucial. Data privacy and Security becomes crucial in this aspect.

6.1.9. Remote Education

The various points that reiterate the need for remote education are listed below:

- India has over 1.4 million schools and 40,000 higher education institutions.
- Quality of education in India is a major concern.
- Factors contributing to poor education quality include inadequate funding and a shortage of trained teachers.
- Lack of access to laboratory facilities, especially in rural areas, is a significant issue.
- Many educational institutions cannot afford complete laboratory equipment due to financial constraints and limited resources.
- Accessibility is further hindered by political instability, armed conflicts, natural disasters, and pandemics.
- The COVID-19 pandemic worsened the situation as lockdowns prevented access to lab facilities, particularly affecting science-based education.

Hence making education available to remote places is one of the major challenges faced today which surfaced during the covid times. Remote labs where experiments are done remotely with the live setup is one of the use cases.

6.1.10. Finance

Fintech in smart cities is an exciting intersection of technology, finance, and urban development. As cities become more intelligent by integrating IoT, AI, and big data, solutions are becoming increasingly important in managing financial services, improving efficiency, and fostering innovation. use cases can be studied from various perspectives, i.e., a) end user (customer, citizen or enterprise), b) incumbent players (banks and related regulated entities); c) tech-innovators or disruptors (who leverage technological breakthroughs and agile execution to offer new solutions, some of which may have unknown risks); and d) regulators and government.

Here are a few ways can contribute to smart cities:

1. Cashless Transactions
2. Verifiable digital IDs for citizens
3. Smart Infrastructure Financing
4. Better access to financial tools
5. Data-driven Insights for Urban Development
6. Mobility as a Service
7. Transparent and secure way to manage financial transactions

Fintech offers smart cities the opportunity to create urban environments that are more efficient, inclusive, and sustainable. However, more in-depth research is essential to explore the detailed applications of fintech.

6.1.11. Safety and Surveillance

Live Monitoring of the crowds moving in groups, mask violations etc and keeping surveillance over an area ensures a safer environment to Live.

6.1.11.1. Crowd Management

Various types of devices ranging from wireless cameras, smartphones and drones will be used to continuously capture real-time feeds from crowded spaces (classrooms, events, and open auditoriums). Further, 5G will be leveraged to transfer and process these feeds in near real-time in the cloud server to provide various services.

Crowd management involves the systematic planning and supervision of large groups of people, crucial for ensuring safety and smooth operations in densely populated or high-traffic areas. As cities around the globe evolve into 'smart cities', implementing crowd management solutions has become a critical component of this transformation. These solutions employ advanced technologies and real-time data analysis to manage crowd flow, predict patterns, detect unusual activity, and ensure public safety. In the Indian context, the relevance and need for efficient crowd management are even more pronounced. Given India's substantial population density and the frequency of large-scale public events, from religious gatherings like Kumbh Mela and Durga Puja to political rallies, the importance of effective crowd management cannot be overstated.

Furthermore, India's bustling transportation hubs, teeming markets, and revered religious sites often experience heavy footfall, necessitating systems that can maintain order and ensure public safety. Amidst health crises like the COVID-19 pandemic, these systems can also aid in enforcing social distancing measures and controlling disease spread. As Indian cities strive towards smart city models, integrating robust crowd management systems will play an instrumental role in enhancing urban life's safety, security, and efficiency, making cities more liveable and resilient.

Existing crowd management solutions make use of static cameras deployed at various points (e.g. Kumbh Mela). However, in dense crowd scenarios, there is a need for a combination of static cameras as well as dynamic sources to capture crowd movements such as mobile phones, drones, etc. The feeds available from different sources can be further processed using AI to provide various insights. A smart city crowd management system offers a set of features ranging from real time crowd statistics to suspicious activity detection.

Features

Dense deployment of image-capturing devices (Cameras, Drones, Mobile Phones…) is done to achieve the following:

Real-time Analytics on Captured Images: The real-time processing and analysis of images are crucial for timely decision-making. The captured images are processed using advanced computer vision techniques and machine learning models to extract meaningful insights. The data is analysed in real-time to support immediate action when required.

People Counting: This feature uses image processing and machine learning algorithms to count the number of people present in the camera's field of view. It helps to monitor crowd size and ensure that it stays within safe limits.

Activity Detection: This feature identifies activities or behaviours in the crowd. It might look for patterns indicating violence, identify signs of distress, or recognize other unusual activities. This can be achieved using machine learning models trained on a dataset of different human activities.

Intrusion Detection (Digital Fence): A virtual boundary or "digital fence" is established, and the system alerts if it detects anyone crossing this boundary. This is useful for preventing unauthorized entry into restricted areas.

Crowd Flow Prediction: This uses historical data and real-time analytics to predict the direction and speed of crowd movement. This can help in managing crowd control measures and can alert managers to potential bottlenecks or overcrowding situations before they become problematic.

Crowd Forecasting: This feature uses historical data, real-time data, and predictive analytics to estimate future crowd sizes. This could help with planning for resources and staff needed at future times.

Real-time Visualization and Analytics: The system provides a live feed of the situation with overlays of the analytics, such as people count, crowd flow directions, heat maps of crowd density, etc. This allows operators to understand the crowd situation immediately. The system might also provide dashboards with key metrics and trends over time. Real-time analytics are critical in enabling timely decisions and interventions.

6.1.12. Assisted Living

Traditionally, the pedestrian crossing time at motorways are maintained to address the normal pedestrians considering the 15th percentile walking speed of a group. They don't consider the 'Divyang' at all; the visually challenged struggle to find out the place to cross. Safety of the visually challenged and other divyang crossing motorway needs to be improved.

6.2. Communication Layer

Connectivity plays a key role in ensuring that the data is communicated and made available. Communication infrastructure plays a crucial role in the success and functioning of smart cities. It serves as the backbone that enables seamless connectivity and data exchange between various components and stakeholders within the smart city ecosystem. The significance of communication infrastructure in smart cities can be understood through the following points:

1. **Data Collection and Integration:** Smart cities rely on the collection of vast amounts of data from sensors, IoT devices, and other sources to monitor and manage various urban systems. Communication

infrastructure allows for real-time data transmission and integration, enabling city authorities to make informed decisions and optimize city services efficiently.

2. **IoT and Connectivity:** The Internet of Things (IoT) forms a critical part of smart cities, with numerous devices and sensors interconnected to gather data and automate processes. A robust communication infrastructure ensures reliable and high-speed connectivity, facilitating the functioning of smart devices and enabling them to communicate with each other and the central system effectively.

3. **Public Safety and Emergency Response:** Smart cities leverage communication infrastructure to enhance public safety measures, including surveillance cameras, emergency alerts, and disaster response systems. Real-time communication ensures a swift response to emergencies and threats.

4. **Citizen Engagement and Participation:** Communication infrastructure enables digital platforms and mobile applications for citizen engagement. Citizens can access information, provide feedback, and participate in decision-making, fostering a more inclusive and participatory governance model.

5. **Efficient Utility Management:** Smart grids and communication networks enable better monitoring and management of utilities such as electricity, water, and waste management. This optimization leads to reduced energy consumption, improved resource allocation, and cost savings.

6. **E-Governance and Service Delivery:** Communication infrastructure supports e-governance initiatives, making government services accessible online. This simplifies administrative processes, reduces bureaucracy, and enhances service delivery to citizens.

7. **Data Privacy and Security:** A well-designed communication infrastructure incorporates robust security measures to protect sensitive data and ensure privacy for citizens. As data exchange occurs between various entities, safeguarding information becomes paramount.

8. **Resilience and Reliability:** Smart cities need reliable, redundant communication networks to ensure continuous operations. In case of network failures, redundant communication channels can help maintain critical services.

9. **Future-Readiness:** As technology continues to advance, a scalable communication infrastructure ensures that the smart city is well-prepared to adopt emerging technologies and innovations in the future.

In summary, communication infrastructure acts as the nervous system of a smart city, enabling the smooth flow of information and facilitating the integration of various technologies and services. It is an essential enabler that empowers smart cities to achieve their goals of efficiency, sustainability, citizen engagement, and improved quality of life.

Last-mile connectivity is always a major requirement in getting the sensor data to the end destination in the required time. Hence it is required to have a hybrid network comprising all types of communication to ensure safe and secure delivery. Various options available for communication are listed below.

6.2.1. Wi-Fi

Wi-Fi, short for Wireless Fidelity, is a wireless networking technology that allows devices to connect and communicate over a local area network (LAN) without the need for physical wired connections. It operates on the principles of radio waves, enabling devices such as smartphones, laptops, and IoT devices to access the internet and share data wirelessly. Wi-Fi has become widely popular in homes, offices, public spaces, and various industries due to its convenience, high-speed data transfer capabilities, and wide device compatibility.

6.2.2. 4G

4G, or fourth generation, is a mobile network technology that provides high-speed wireless communication for mobile devices. It offers significantly faster data transfer speeds compared to its predecessor, 3G, enabling users to enjoy seamless browsing, video streaming, and online gaming experiences on their smartphones and tablets. With 4G, users can access the internet on the go, make video calls, and download/upload large files quickly. It has revolutionized the mobile telecommunications industry and paved the way for advanced mobile services and applications.

6.2.3. eSIM

eSIM, short for embedded SIM, is a small chip embedded directly into devices such as smartphones, tablets, smartwatches, and IoT devices. It replaces the traditional physical SIM card and allows users to switch between different mobile network operators without changing the SIM card physically. eSIM technology provides flexibility and convenience, as users can remotely activate or change their mobile network subscriptions through digital means. It also enables devices to have multiple profiles, allowing users to switch between personal and business accounts seamlessly.

6.2.4. Wi-SUN

Wi-SUN, which stands for Wireless Smart Ubiquitous Network, is a wireless communication technology designed specifically for large-scale IoT deployments in utility and smart city applications. It operates on a low-power, long-range mesh network, allowing devices to communicate over extended distances while consuming minimal energy. Wi-SUN is optimized for smart metering, street lighting, and other utility-based applications that require reliable and secure connectivity over a wide area. It provides robust, scalable and self-healing connectivity solutions for managing and monitoring IoT devices in urban environments.

6.2.5. LoRaWAN

LoRaWAN, short for Long Range Wide Area Network, is a low-power, wide-area network protocol designed for long-range communication in IoT applications. It utilizes the LoRa modulation technique, which enables devices to transmit data over several kilometers while operating on low power. LoRaWAN is ideal for applications that require long battery life and extended connectivity, such as smart agriculture, asset tracking, and environmental monitoring. It provides a scalable and cost-effective solution for connecting multiple low-power IoT devices in both urban and rural areas.

6.2.6. 5G & its Impact

5G, the fifth-generation mobile network, is the latest advancement in wireless communication technology. It offers significantly faster data transfer speeds, lower latency, and higher network capacity compared to previous generations. 5G aims to revolutionize the way we connect and communicate by enabling advanced applications such as autonomous vehicles, virtual reality, augmented reality, and smart cities. With its ultra-fast speeds and low latency, 5G will unlock new possibilities in areas such as telemedicine, industrial automation, and immersive multimedia experiences. It will provide the foundation for a highly connected and digitized world, supporting the exponential growth of IoT devices and the increasing demand for high-bandwidth applications.

The selection of the communication protocol/network should be based on the location where nodes must be deployed, and the network reachability. It should be a hybrid network where all the networks can work together to achieve seamless connectivity.

6.3. Data Storage Layer: Middleware for Organizing IoT Data

In the ever-expanding landscape of Smart Cities, ensuring the seamless exchange of data among a plethora of IoT devices and systems is paramount. This calls for robust middleware solutions that not only enable interoperability but also simplify the complex web of IoT technologies, protocols, and manufacturers. At the forefront of this endeavour stands the oneM2M standard, developed collaboratively by leading organizations in the IoT domain.

Data warehousing plays a pivotal role in Smart Cities by facilitating the collection and analysis of copious amounts of information.

The oneM2M standard is a global initiative driven by the imperative to support interoperable and scalable IoT solutions. It functions as a common middleware technology, situated as a horizontal layer between IoT devices, communication networks, and applications. Its mission is to standardize the intricate links between connected devices, gateways, communication networks, and cloud infrastructure, empowering developers to seamlessly integrate components from diverse vendors.

Interoperability: Imperative Interoperability, within the IoT context, embodies the ability of diverse systems, devices, and components to harmoniously collaborate and efficiently share data. This concept is of paramount importance as Smart Cities witness the proliferation of a vast array of interconnected devices. Here are three key reasons why interoperability is a cornerstone of Smart Cities:

- **Heterogeneity:** Smart Cities encompass a multitude of devices, each with its unique protocols and technologies. Interoperability acts as the unifying force that bridges these disparate elements, fostering seamless integration and cooperation.
- **Scalability:** The growth of Smart Cities is inexorable, with IoT devices and services multiplying exponentially. Interoperability ensures that these expanding systems can seamlessly adapt and scale without creating isolated data silos.
- **Sustainability:** Smart Cities aim to optimize resource utilization, enhance efficiency, and improve residents' quality of life. Interoperability is pivotal in achieving these sustainability goals by streamlining data flows, promoting innovation, and minimizing waste.

6.3.1. Interoperability platforms compliant with oneM2M standards

A few representative oneM2M compliant platforms are listed below:

6.3.1.1. OM2M

Standing for "oneM2M-based Open-source Machine-to-Machine," OM2M is an open-source embodiment of the oneM2M global standard. It serves as a middleware platform, facilitating the integration and communication among a heterogeneous array of IoT devices and applications. With standardized APIs, protocols, and services, OM2M simplifies data exchange, device management, and application development within the IoT ecosystem.

6.3.1.2. Mobius

Mobius, an open-source IoT server platform aligned with the oneM2M standard, provides essential service functions, such as registration, data management, subscription/notification, and security. Importantly, it accommodates not only oneM2M devices but also non-oneM2M devices, ensuring broad connectivity. Mobius has earned certification as a 'oneM2M standard' product by TTA (Telecommunications Technology Association), underscoring its commitment to interoperability.

6.3.1.3. ACME

ACME, an open-source platform compliant with the oneM2M standard, focuses on delivering a subset of oneM2M functionality. Designed for ease of installation, extensibility, and user-friendliness, ACME serves as a valuable educational resource.

6.3.1.4. CCSP (C-DOT Common Service Platform)

Positioned as an interoperability enabler for IoT/M2M based on oneM2M Release3 Standards, the C-DOT CCSP is designed to provide a common service layer for IN, MN, and ASN nodes. It aligns with oneM2M's commitment to interoperability and scalability.

6.3.1.5. Common SMart IoT Connectivity (CoSMiC)

Common SMart IoT Connectivity (CoSMiC) is a versatile software middleware that deploys IoT solutions in adherence to the global oneM2M standard. CoSMiC empowers users and application service providers across diverse vertical domains by offering application-agnostic open standards and interfaces. It fosters end-to-end communication with well-defined common service functionalities, all in compliance with the oneM2M standard. Notably, CoSMiC's management console simplifies the addition of IoT products and establishes secure, standardized communication, making it an invaluable asset for Smart City Domains.

6.3.2. Interworking with oneM2M

oneM2M actively collaborates with sector specific bodies to reuse existing standards and promote interworking. A key example of this interworking is the OCF-oneM2M bridge.

Open Connectivity Foundation (OCF) has developed standards to enable interoperable communication between devices and applications. The OCF-oneM2M bridge enables seamless interworking between their environments through a proxy which acts as an adapter to translate between oneM2M and non-oneM2M protocols and data models.

6.4. Data Exchange Layer

Data warehousing plays a pivotal role in Smart Cities by facilitating collecting and analysing copious amounts of information. Data availability is one requirement, whereas data sharing with the relevant authorized stakeholders is another. AI/ML platforms for smart cities in India, particularly those focused on data and model sharing, are crucial for enabling collaboration, enhancing data-driven decision-making, and promoting sustainable urban development. Here are some key platforms that facilitate the exchange and sharing of data in urban environments and initiatives in this space:

1. India Urban Data Exchange (IUDX)
    - **Overview:** Developed by the Indian Institute of Science (IISc) in partnership with the Ministry of Housing and Urban Affairs, IUDX is an open-source data exchange platform that enables the sharing of urban data across various stakeholders, including government bodies, private companies, and citizens. The platform promotes transparency, innovation, and collaboration in urban governance and decision-making processes. It enables data providers to create innovative services and generate value. It aims to support smart city administrations by facilitating the data exchange between various civic bodies, municipal departments, application developers and data consumers.
    - **Key Features:**
        - Seamless integration with oneM2M APIs
        - Facilitates secure and efficient data sharing between different urban data providers.
        - Supports AI/ML model sharing by providing a common platform for testing and deploying algorithms on real-world urban data.

    - Encourages the development of innovative smart city solutions by making data accessible to startups and researchers.

2. Smart City Mission Data Portal
    - **Overview:** Under the Smart Cities Mission, the Indian government has created a data portal that serves as a centralized repository for smart city-related data across India.
    - **Key Features:**
        - Provides access to data from various smart city projects across India, enabling analysis and model development.
        - Supports the sharing of AI/ML models that can be applied to different urban scenarios, such as traffic management, waste management, and energy efficiency.

3. City Data for India Initiative
    - **Overview:** Led by the World Council on City Data (WCCD) and the Tata Trusts, this initiative focuses on developing standardized city data across India, which can be leveraged for AI/ML applications.
    - **Key Features:**
        - Encourages cities to adopt the ISO 37120 standard for city data, ensuring consistency and comparability.
        - Facilitates the sharing of data and models across cities, promoting the replication of successful smart city solutions.

4. NIC Smart City Data Platform
    - **Overview:** The National Informatics Centre (NIC) provides a data platform that integrates data from various smart city initiatives across India.
    - **Key Features:**
        - Offers a secure environment for data sharing between municipal authorities, researchers, and technology providers.
        - Supports AI/ML model deployment for real-time analysis and decision-making.

5. SmartNet
    - **Overview:** SmartNet is a knowledge-sharing platform developed by the Ministry of Housing and Urban Affairs to foster collaboration among smart cities in India.
    - **Key Features:**
        - Provides a space for cities to share best practices, data, and AI/ML models.
        - Encourages peer-to-peer learning and the dissemination of innovative smart city solutions.

6. NITI Aayog's AI for All Initiative
    - **Overview:** As part of its broader AI strategy, NITI Aayog has been working on initiatives to integrate AI into urban governance and smart city planning.
    - **Key Features:**
        - Promotes the development of AI/ML models for urban applications and encourages collaboration between cities and the private sector.
        - Focuses on ethical AI, ensuring that models used in smart cities are transparent, fair, and accountable.

6.4.1. Standard Data and Information Models

Multiple data models are existing in the smart city scenario, both from Indian and foreign countries. Making a standard and uniform data model to accommodate various types of users. Some of the existing data models in India are described below:

6.4.1.1. Standard Data models

Sample Air Quality Data Model

S. No	Item
1.	Unique Identifier
2.	"name": Node Name (E.g., AQ-MG00-00)
3.	"label": Node type and the installation area (E.g., "Air Quality Monitoring Sensors in IIIT Hyderabad")
4.	"description": General description of the vertical with the parameters it can measure (E.g., "Air quality monitoring devices and associated sensors in International Institute of Information Technology, Hyderabad"),
5.	"location": This field provides information about the location of the resource. It includes the geographical coordinates (longitude and latitude) and the address of the node.
6.	"tags": Property the node can measure (E.g., environment, air quality, air, aqi, aqm, pollution, ammonia, carbon, carbon monoxide, nitrogen dioxide, co, no2, pm2.5, pm10, humidity, temperature, nh3).
7.	"itemStatus": This field specifies the status of the resource, "ACTIVE," indicating that the resource is currently operational.
8.	pm2p5
9.	description: Instantaneous values of particulate matter 2.5(PM2.5).
10.	dataSchema: Time Series Aggregation
11.	unit Code: GQ
12.	unitText:micro gram per cubic metre
13.	minValue:0
14.	maxValue:999.9
15.	measAccuracy:
16.	maxValue:10
17.	resolution:0.1
18.	pm10
19.	description: Instantaneous values of particulate matter 10(PM10).
20.	dataSchema: Time Series Aggregation
21.	unitCode:GQ

S. No	Item
22.	unitText:micro gram per cubic metre
23.	minValue:0
24.	maxValue:999.9
25.	measAccuracy:
26.	maxValue:10
27.	resolution:0.1
28.	airTemperature
29.	description:Instantaneous values of air temperature.
30.	dataSchema:TimeSeriesAggregation
31.	unitCode:CEL
32.	unitText:degree Celsius
33.	minValue:-40
34.	maxValue:80
35.	measAccuracy:
36.	maxValue:0.5
37.	resolution:0.1
38.	relativeHumidity
39.	description:Instantaneous values of relative humidity (water vapour in air).
40.	unitCode:P1
41.	unitText:percent (%)
42.	dataSchema:TimeSeriesAggregation
43.	minValue:0
44.	maxValue:100
45.	measAccuracy:
46.	maxValue:2
47.	resolution:0.1

S. No	Item
48.	Co
49.	description:Instantaneous values of carbon monoxide(CO).
50.	dataSchema:TimeSeriesAggregation
51.	unitCode:59
52.	unitText:part per million
53.	minValue:1
54.	maxValue:500
55.	resolution:0.01
56.	no2
57.	description:Instantaneous of nitrogen dioxide(NO2).
58.	dataSchema:TimeSeriesAggregation
59.	unitCode:59
60.	unitText:part per million
61.	minValue:0.05
62.	maxValue:10
63.	resolution:0.01
64.	nh3
65.	description:Instantaneous of amonia(NH3).
66.	dataSchema:TimeSeriesAggregation
67.	unitCode:59
68.	unitText:part per million
69.	minValue:1
70.	maxValue:500
71.	resolution:0.01
72.	airQualityIndex
73.	description:Overall Air Quality Index (AQI) observed

S. No	Item
74.	unitCode:C62
75.	unitText:dimensionless
76.	dataSchema:Number
77.	airQualityLevel
78.	description:Air Quality Category Indication. Qualitative level defined according to the local health agencies. For example, 'GOOD', 'MODERATE', 'POOR', 'UNHEALTHY', 'SEVERE', 'HAZARDOUS' etc.
79.	dataSchema:Text
80.	aqiMajorPollutant
81.	description:Major pollutant in the Air Quality Index (AQI).
82.	dataSchema:Text
83.	observationDateTime
84.	description:Last reported time of observation.
85.	dataSchema:DateTime
86.	versionInfo
87.	description: Latest version name corresponding to the device in this observation,
88.	dataSchema: Text

6.4.1.2. Common ontology

This is a common payload ontology standard for the multi-vendor deployment of intelligent transportation systems. Integrating multiple vendor systems with a smart city platform for application data processing is helpful. This would help eliminate compliance delays in deploying different intelligent transportation system applications for public use in smart cities.

The primary objective is to have a common standardized ontology for traffic controllers and all other intelligent transportation products. So, integration between multi-vendor products and dashboards can be deployed in the smart cities easily. The deployable products which that require common standardized ontology are:

- Traffic controller
- Intelligent Parking management system
- Emergency Vehicle pre-emption system
- Street Light Management system
- Variable Messaging System
- Vehicle Detection, Counting and Classification System
- Air Quality Monitoring System
- Sewage status monitoring system

6.4.2. Datasets

Datasets of various verticals need to be created and made available using standard data and information models. This will enable the researchers/startups to generate Indian solutions based on Indian datasets. Standard Vocabulary is to be maintained to enable multiple users to understand the data in a meaningful manner.

6.5. Analytics & Visualization

6.5.1. Analytics

In a smart city framework, the analytical layer is essential for leveraging data and analytics to gain insights, make informed decisions, and optimize city operations and services. The analytical layer aggregates data from various sources within the smart city ecosystem, including IoT sensors, mobile devices, social media, government databases, and utility systems. Data integration processes normalize, clean, and integrate heterogeneous datasets into a unified data repository, enabling cross-domain analysis and correlation.

The analytical layer implements data anonymization, encryption, and access controls to protect sensitive information and ensure compliance with data privacy regulations. Machine learning algorithms analyze data to identify hidden patterns, anomalies, and insights, supporting predictive maintenance, demand forecasting, and anomaly detection in smart city infrastructure. Continuous feedback loops collect user feedback and stakeholder input to refine analytical models, algorithms, and visualization tools, ensuring relevance and usability.

- Descriptive analytics techniques/models analyze historical data to understand past trends, patterns, and events within the city, providing insights into urban dynamics and behaviours.
- Predictive analytics models forecast future trends, events, and outcomes based on historical data and statistical algorithms, enabling proactive decision-making and resource allocation.
- Prescriptive analytics algorithms recommend optimal actions and strategies to achieve desired outcomes, considering constraints, objectives, and uncertainties within the smart city environment.
- Spatial analysis techniques/models analyze geospatial data to identify spatial patterns, relationships, and trends within the city, supporting urban planning, infrastructure development, and land use management.

The analytical layer processes real-time data streams from IoT sensors and other sources to monitor city operations, traffic conditions, environmental parameters, and public safety incidents. Data analytics and visualization plays a crucial role in understanding complex datasets and extracting valuable insights.

6.5.2. Visualization

Visualizing data in a meaningful and interactive way helps in identifying patterns, trends, and outliers, enabling effective decision-making and communication of information. Grafana is a popular open-source platform that specializes in data visualization and analytics, providing powerful tools for creating visually appealing and informative dashboards.

Visualization allows users to connect to various data sources, such as databases, time series databases, cloud platforms, and APIs, to retrieve and visualize data. With a user-friendly interface and extensive library of pre-built visualizations, it empowers users to create customized dashboards tailored to their specific needs.

When visualization is being planned, the following points need to be considered based on the following:

I. Descriptive Analytics

a. What happened?
b. What is happening?

II. Diagnostic Analytics
a. Why did it happen?
b. Why is it happening?

III. Predictive Analytics
a. What might happen in the future?

IV. Prescriptive Analytics
a. What action to take next?

Considering, the above points some of the possible visualizations are listed below:

6.5.2.1. Summary Dashboard

The Summary View offers a comprehensive snapshot of key data metrics, including Carbon Footprint and Air Quality Index, in an easily digestible format. This high-level overview enables users to quickly gauge the monitored network's overall environmental status and health without delving into intricate details. We use Grafana for this.

6.5.2.2. Domain wise geospatial view (both 2-dimensional and 3-dimensional)

This View presents a geographical layout of all interconnected nodes, with the flexibility to apply filters based on node type and location. By displaying live data from each node on the map, users gain an insightful spatial understanding of the network's real-time performance. This view facilitates quick identification of trends and anomalies across different geographical areas.

6.5.2.3. Interactive Dashboard

Users can engage in a captivating virtual environment where they can freely explore the campus and inspect nodes as they navigate. This gamified approach encourages user interaction, making the process of data exploration more engaging and enjoyable.

6.5.2.4. Analytics Dashboard

The analytics dashboard presents the visual representation of key performance indicators (KPIs), metrics, and data received from the various IoT sensors of different verticals.

6.5.2.5. Maintenance Dashboard

A visualization to help maintain the devices deployed becomes crucial in the long run.

6.5.2.6. Mobile App

The comprehensive mobile application is to make it easier to explore and interact with the cutting-edge IoT ecosystem and reach more users. It is intended to track and examine information gathered from various sensors and devices used. The app provides people interested in comprehending and participating in cutting-edge technology and sustainability activities within the urban environment with access to various verticals' vast information, insights, and functions.

Adding configurable/customized widgets will give the users a personalized experience.

6.6. Application Layer

The Application Layer in a smart city is the uppermost tier of the city’s digital infrastructure, where technologies and services are tailored to meet the needs of end-users like citizens, companies, and local authorities. It bridges the gap between advanced technologies and real-world applications, ensuring that innovations in areas like IoT, AI, and data analytics translate into practical solutions. This layer is vital for improving the everyday experience of city dwellers, fostering sustainability, and enhancing the effectiveness of urban management systems. It provides the tools that make smart city services more accessible, responsive, and aligned with the community's needs.

Some of the Application Layer functions are:

- **Citizen Services:** Apps and platforms that allow residents to engage with the city, from paying bills, reporting issues (e.g., potholes, streetlight outages), and accessing public services to participating in decision-making processes.
- **Business Solutions:** Applications that provide businesses with tools for better operations, such as logistics, waste management, energy optimization, and more efficient communication with local authorities.
- **Government and Governance:** Solutions that enable better public administration, such as digital platforms for efficient resource management, traffic monitoring, environmental tracking, and responsive policy development.
- **Data Interactions:** This layer also helps transform raw data generated by IoT sensors and smart devices into useful information and actionable insights. These insights are then used to enhance daily experiences, improve urban planning, or inform public policy decisions.

Some examples of smart city applications include:

- Smart Utility Networks (water, Energy, Waste management, Street lights etc.) management
- Smart Transportation Systems: Real-time traffic updates, smart parking, or route optimization.
- E-Government Services: Digital platforms for interacting with local government services.
- Environmental Monitoring: Apps that monitor air quality, water quality, and energy usage.
- Public Health: Telemedicine, health monitoring, or emergency response systems.
- Generating ESG Metrics.

These applications are pivotal in creating a seamless and integrated urban environment that supports sustainability, efficiency, and a higher quality of life for all citizens.

7. Data Security and Data Privacy

In the rapidly evolving landscape of smart cities and IoT nodes, data security and privacy emerge as paramount concerns. The foundation of this approach lies in the meticulous authentication of users, nodes, and applications to ensure access is exclusively granted to authorized entities. Simultaneously, the implementation of secure data transmission measures effectively prevents any interception or manipulation during data exchanges. Embracing the principles of data minimization and purpose limitation, the system collects only essential information, thereby avoiding unnecessary exposure of personal data.

Strong access control mechanisms are thoughtfully integrated to diligently manage user permissions, thereby significantly reducing the risk of data breaches or unauthorized access. Moreover, encryption and hashing techniques are thoughtfully integrated to bolster the system's defenses and ensure the protection of sensitive information. Throughout the development process, the team adheres to privacy by design principles, by placing privacy-aware settings are prioritized to safeguard user privacy from the outset.

The solutions devised are skilfully crafted to accommodate the inherent heterogeneity and complexity of the ecosystem while steadfastly upholding data protection. Emphasizing a security-by-design approach, the integration of security measures occurs throughout the development life cycle, thereby proactively addressing potential vulnerabilities.

Despite the challenges posed by fragmented standards and regulations, unwavering compliance is to be maintained to uphold a high level of security and data privacy. The principles of transparency and accountability take centre stage in data sharing and usage practices, empowering users with valuable insights into the utilization of their data. This holistic approach is geared towards fostering innovation within the smart city ecosystem while preserving the security and privacy of its inhabitants' data and digital interactions.

7.1. Security Concerns – Possible Solutions

S. No	Layer	Security Issue	Possible Solution
1.	Sensor Layer	Physical Tampering of Nodes	Device certificates to authenticate the AEs or CSEs
		Data Tampering	Apply data integrity measures, such as encryption.
2.	Communication Layer	Eavesdropping attack	Firewall Binding and Domain Encryption
		Man-in-the-Middle Attack	Use encryption protocols, such as SSL/TLS, to ensure secure and private communication between devices
		Packet Replay Attack	Adding the Request Time Stamp to the Data and Restrict
		Data Leakage	Encrypt sensitive data at rest and in transit.
		Hijacking	Implement secure communication protocols
	Data Storage Layer-	Brute Force Attacks	Access to view the resource tree

S. No	Layer	Security Issue	Possible Solution
3.	oneM2M		and use of CRUD operations are decoupled.
		Data Repudiation	logging mechanisms to track and record user actions. Use digital signatures or timestamps
		Denial of Service (DoS)	Implement mechanisms to handle network failures and ensure resiliency. Consider scalable infrastructure solutions (e.g., MongoDB) to handle potential DoS attacks.
		Spoofing	Implement authentication mechanisms (e.g., symmetric key-based security, certificate-based security)
4.	Data Storage Layer-Data Lake	Unauthorized Access	Implement strong access controls and authentication mechanism
		Data Corruption	Regularly validate the integrity of stored data.
		Insider Threats	Implement role-based access controls and monitor user activities.
5.	Data Exchange/ Visualization Layer	Unauthorized Access	Implement strong authentication mechanisms and access controls
		Injection Attacks	Validate and sanitize user inputs to prevent code injection
		Cross-Site Request Forgery	Implement CSRF tokens and validation mechanisms
		Session Hijacking	Use secure session management techniques
		Insecure Direct Object References	Validate and authorize all requests for data access
		Lack of Logging and Monitoring	Implement comprehensive logging and monitoring mechanisms
6.	Application Layer	The security concerns in the application layer of smart cities are highly dependent on the specific types of applications and solutions developed.	Hence security at the lower layers plays a crucial role in supporting the security of applications in smart cities. When these foundational layers are securely implemented, they provide a robust foundation for the applications to function securely.

By addressing security in each layer of the system smart cities can create a more resilient, robust, and secure environment for residents, businesses, and city management.

8. Case Studies

8.1. Living Lab

Leveraging the core and domain strengths, IIIT-H established a Centre of Excellence on IoT for Smart Cities in Jan 2019 with support from the India-EU project. IIIT-H together with EBTC and with support from other knowledge partners like LAAS-CNRS as well as Bordeaux Metropole proposed to take this living lab initiative to the next level with support from the Ministry of Electronics and Information Technology (MEITY) and the State Government of Telangana, who have shown interest. The IIIT (International Institute of Information Technology) Campus in Hyderabad applied its smart city approach to make a Living Lab in the campus to create an urban area enhancing three value domains: social, economic, and environmental to lead to a Liveable and renewable area that will be a new urban centre in Hyderabad.

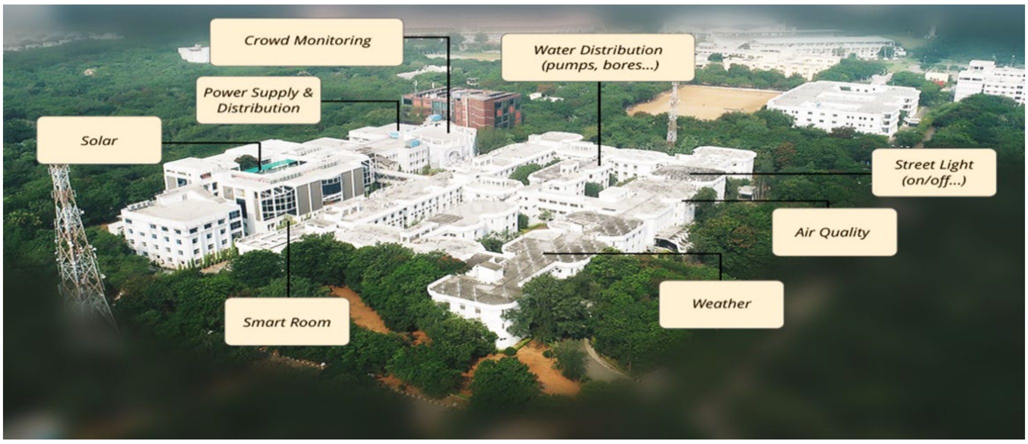


Figure 8:Domains of the Living Lab IIIT Hyderabad

The primary goal of this innovation initiative is to enable the discovering, sourcing, validating, proving, and taking to production, the various Smart City innovations, solutions, and products. This is a one-stop platform which brings in the key stakeholders- governments, research, startups, tech companies, smart city players and policymakers.

8.1.1. Communication Model

This figure presents the various communication infra used for connecting nodes of the different domains of the Living Lab.

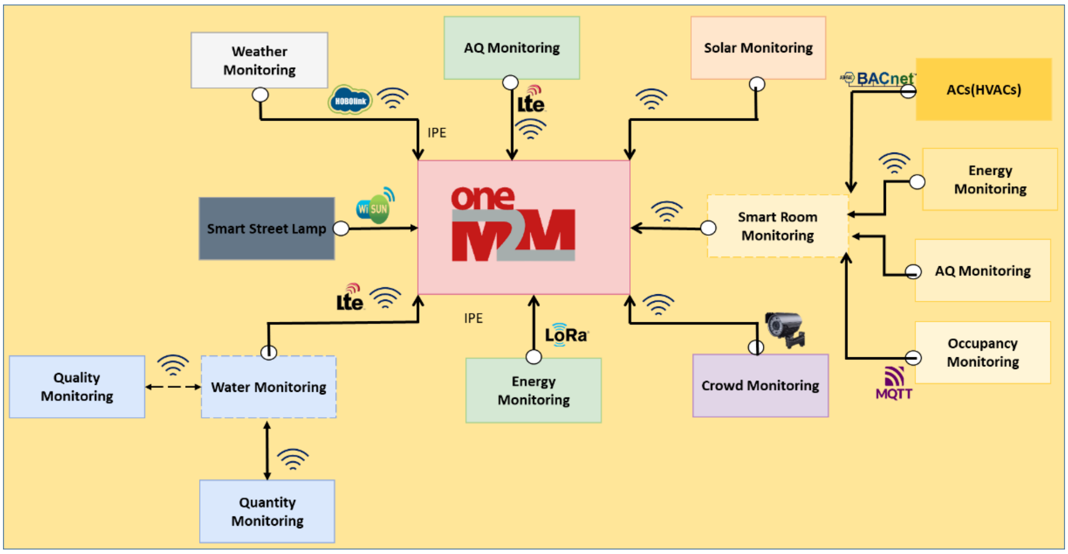


Figure 9: Communication Model

8.1.2. Information model

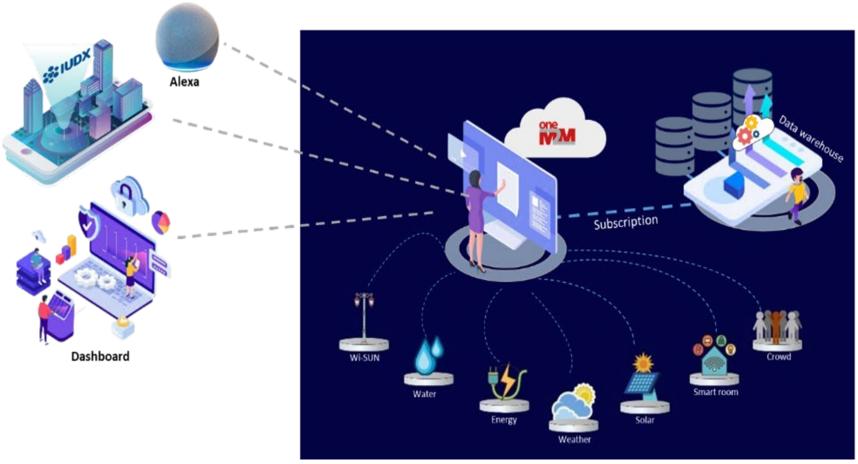


Figure 10: Information Model

Data Flow from various nodes till the end point is clearly represented in the above diagram.

8.1.3. oneM2M implementation

Figure 11: Resource Tree of IIIT-H OM2M

The sample resource tree of oneM2M structure in the living Lab is shown above.

8.1.4. Visualization

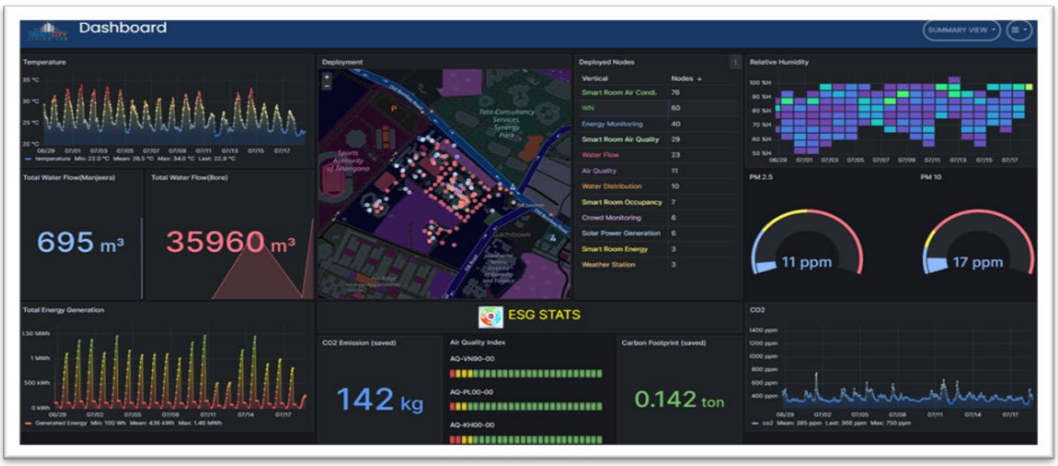


Figure 12: Summary View

This figure shows the overall snapshot of the key parameters of the deployed nodes across the campus.

8.1.5. Domain wise Geospatial View

Figure 14: 3D view

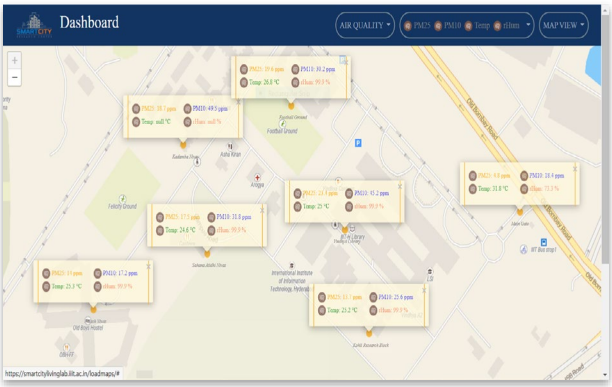


Figure 13: Map View

This figure shoes the 3-dimentional and 2-dimentional view of the campus and the geographical layout of all interconnected nodes.

8.1.6. Analytics

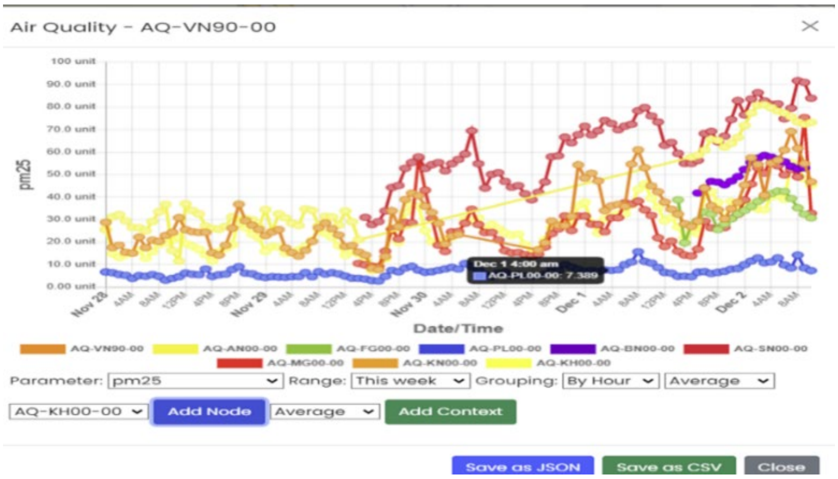


Figure 15:Data Analytics

This Figure shows the flexibility to apply filters based on node type and location. By displaying live data from each node on the map, users gain an insightful spatial understanding of the network's real-time performance.

8.1.7. Maintenance Dashboard

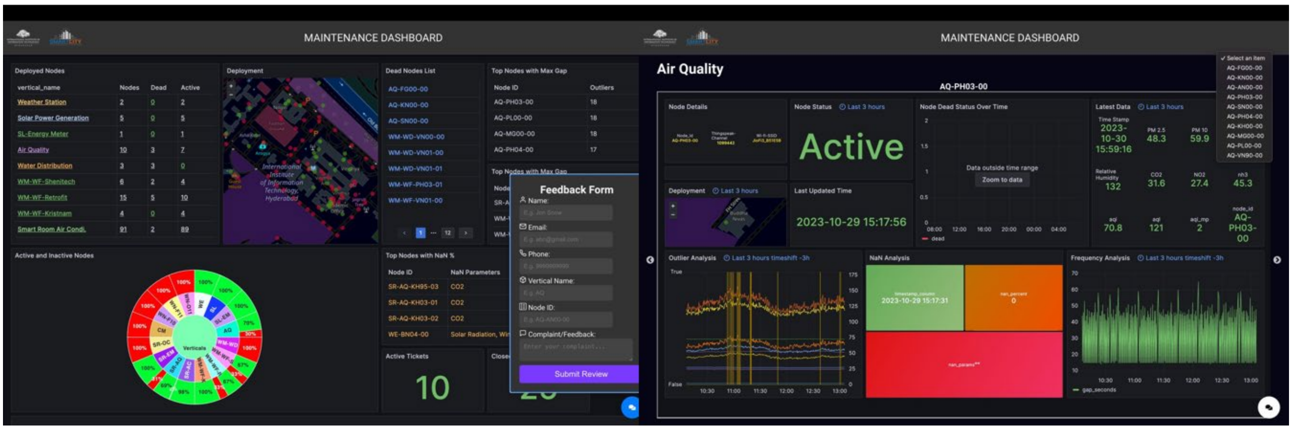
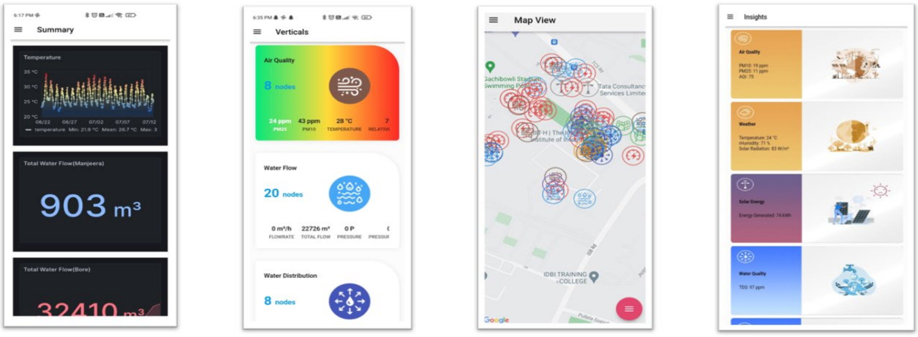


Figure 16: Maintenance Dashboard

This figure shows the active/inactive status of the deployed nodes and other important parameters to make the maintenance process easy.

8.1.8. Living Lab Mobile Application



Summary view | Detail view | Map view | Insights

Figure 17: Living Lab Mobile Application

8.1.9. Sensor Hardware

8.1.9.1. Air Quality (Outdoor)

Figure 18: Air Quality (Outdoor)

At IIIT-H, an end-to-end, low-cost IoT system has been developed for monitoring particulate matter (PM) with fine spatio-temporal resolution using dense deployment. The AirIoT system includes hardware design, calibration of low-cost sensors, cloud interfacing, and the development of a web-based dashboard. The devices are deployed at 49 outdoor locations covering a 4 km^2 area in Gachibowli, Hyderabad, India. The field locations were selected to include urban, semi-urban, and green regions. Few devices were deployed at busy traffic junctions and roadsides. A web-based dashboard has been developed and deployed to visualize the data in real time. This kind of deployment provides a huge opportunity to verify, fine-tune or improve the existing ambient air quality models. Both governments and citizens can use this data to identify pollution hotspots and make timely, localized decisions to reduce and prevent air pollution.

Features

- Monitor the quality of air in and around the campus by measuring the following parameters.
    - PM2.5, PM10 in $\mu g/m^3$
    - Temperature in °C and RH in%
    - CO_2 concentrations in ppm
    - AQI (Air Quality indicator)
- Issue alerts in case the quality deteriorates below acceptable levels.
- Data logging is available for every 30 seconds.
- Denser deployment identifying pollution at a minute level.
- Identifying and mapping corridors of pathogens that cause health hazards/epidemics.

8.1.9.2. Air quality (Indoor)

Figure 19: Air Quality (Indoor)

Features

- Monitor the quality of air indoors by measuring the following parameters
    - Temperature in °C and RH in %
    - CO2 concentrations in ppm
    - PM2.5, PM10 in µg/m³
    - VOC
    - AQI (Air Quality indicator)
- Issue alerts in case the quality deteriorates below/above acceptable levels.
- Data logging is available at one-minute intervals.
- Denser deployment identifying pollution at a minute level.
- Identifying and mapping ~~of~~ corridors of pathogens that cause health hazards/epidemics.

8.1.9.3. Water Quality

Figure 20: Water Quality

Features

- Monitor the quality and quantity of water in and around the campus by measuring the following parameters in a non-intrusive manner
    - pH in standard unit(SU)
    - Turbidity in NTU
    - Salinity (TDS) in ppm
    - Water flow
- Issue alerts in case the quality deteriorates below or above acceptable levels.
- Data logging is available every 2 hours.

8.1.9.4. Water Quantity

Figure 21: Water Quantity

Figure 18: Water Level

Figure 19: Water level Monitoring

Features

- Monitor the quantity of water used in the campus by measuring the following parameters
  - Flow Rate
  - Total Flow
  - Pressure
  - Pressure Voltage
  - Water level in Borewells/Sumps
- Issue alerts in case of water leakages or zero flow
- Data logging is available every 1 minute .
- Water saving by controlling the water supply as per the consumption requirement

8.1.9.5. Energy (Conventional)

Figure 22: Conventional Energy Monitoring

Features

- Monitor the energy consumption in the campus by measuring the following parameters using the LoRaWAN network
  - Current
  - Voltage
  - Power
  - Energy Consumption
  - Frequency
- Monitor the energy generated and consumed in the campus.
- Data logging time programmable from 1 minute to 18 hours.

- This data enables predictive analytics and energy consumption patterns.
- DLMS protocol is mostly used on these meters.

8.1.9.6. Smart Room Energy Monitoring

Figure 23: Smart Room Energy Monitoring

Features

- Monitor and measure the following energy related parameters for the AC installations using smart energy meters.
    - Energy
    - Power
    - Current
- Monitor the smart room energy generated in and around the campus.
- Issue alerts as per the requirements.

8.1.9.7. Solar Energy Monitoring

Figure 24: Solar Energy Monitoring

Features

- Monitor and measure the following energy-related parameters for the solar installations using smart energy meters.
    - Voltage & Current in each phase
    - Power factor
    - Frequency in Hz
    - Signed active power (KW)
    - Energy consumption in KW & KVA
    - Maximum demand (peak load) in KWh
- Fault identification and diagnostics based on the predicted energy and actual power generated.

8.1.9.8. Weather Monitoring

Figure 25: Weather Station

Features

- Monitor the quality of the environment in and around the campus by measuring the following parameters
  - Humidity in %
  - Temperature in °C
  - Global Horizontal Solar Radiation in W/m2
  - Wind Speed in mph
  - Wind Direction in degrees
  - Wind Direction
  - Rainfall
- Issue alerts as per the requirements.
- Data logging time programmable from 1 minute to 18 hours.
- Identifying and mapping of corridors of pathogens that cause health hazards/epidemics by correlating micro climatic & pollution data with the weather data.

8.1.9.9. Smart Room AC

Figure 26: Smart Room AC

Features

- Smart room AC deployed using BACnet protocol.
- Monitor and measure the following smart room AC-related parameters in and around the campus
  - Room Temp
  - Temp Adjust
  - Start/Stop Status
  - Air Con Mode Status

  - Air Flow Rate Status
  - Filter Sign
  - Gas Total Power
  - Air Direction Status Energy Efficiency Status
- Monitor the smart room ACs in the research labs and meeting rooms and control based on the existing temperature etc.

8.1.9.10. Smart Room OC (Occupancy)

Figure 27: Smart Room OC (Occupancy)

Features

- Monitor the occupancy of the room by measuring the following parameters.
  - Occupancy
  - Temperature
  - Relative Humidity
- Data logging is available at ten -minutes interval

8.1.9.11. Crowd Monitoring

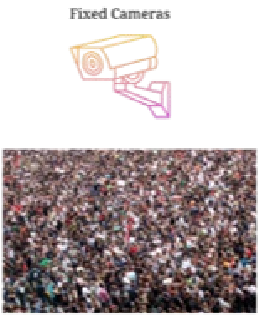


Figure 28: Crowd Monitoring

One of the systems used for monitoring people with mask and safe distance violation conditions measures geo tagged information of No. of safe distance violations, No. of mask violations with time stamp.

For other crowd monitoring solutions like digital fence, emotion identification, streamlining the crowds etc. various deployment models can be planned as listed below:

Type Of Deployment Models

Fixed Cameras: These are installed in a stationary location and cover a set field of view. They are most effective when placed in high-traffic areas, such as entrances, exits, and main pathways.

PTZ (Pan-Tilt-Zoom) Cameras: PTZ cameras can be remotely controlled to change their field of view, either to pan (move left or right), tilt (move up or down), or zoom (focus on a particular point or area). These are particularly useful in crowd management for dynamic monitoring of different areas as needed.

360-Degree Cameras: These cameras provide a panoramic view of the surroundings, useful for monitoring large crowds as they allow wide area coverage with a single device. They often use fish-eye lenses and require special software to correct the distortion and provide a flat view.

Drone Cameras: Drones equipped with cameras provide aerial views and can be useful in managing large outdoor crowds. They allow flexible, mobile surveillance and can quickly cover a large area.

Body-Worn Cameras/hand-held smartphones: Typically used by security personnel, these cameras provide a first-person perspective on crowd situations and can help document incidents and behaviours within the crowd.

8.1.9.12. Home Automation

Figure 29: Home Automation Dashboard

Features

- All the fans and lights can be controlled from the dashboard.
- Controls appliances with Alexa commands.
- Monitors the on/off status of the appliances.
- Energy consumption of the appliances can be monitored.
- Turning On/Off the corridor lights based on motion detection.
- Floor map to directly identify the activity status in the lab.
- Indoor Air quality can be monitored.
- Fan Speed can be Controlled.
- Brightness of light can be controlled.

8.1.9.13. Waste Management

Figure 30: Smart Waste Management Bin

Features

- Incorporating sensors for hands-free operation, our IoT-enabled dustbin detects nearby individuals and commands the motor to open the lid.
- Utilizing a motor-driven metallic string, this innovative system ensures touchless access, enhancing user convenience and hygiene.
- With an integrated display, users can monitor real-time data, including fill level, lid status, and battery level, promoting efficient waste management.

8.1.9.14. Smart LED Display

Figure 31: Smart LED Display

Features

- Visualize information from different nodes, in the form of data in a scrolling line.
- App based control to display the data as selected by the user.

8.1.9.15. Echo Explorer

Figure 32: Eco Explorer

Features

- A handy portable device to carry around wherever a person goes

- Measures
    - PM2.5
    - PM10 - Air quality parameters
    - CO22 level
    - Temperature
    - Humidity
    - light intensity
    - sound level
- Moves
    - In straight line
    - In circles

8.1.9.16. Smart Street Lights (Wi-SUN Based Solution (IIIT-H))

Streetlights would be one of the areas in cities where proper lighting, connectivity and information can be provided as most of the Indian cities are populated with streetlights.

Various use cases of Street lights can be listed as follows:

- Lighting (controlled lighting based on the need)
- Connectivity
- Traffic streamlining
- Emergency response
- City Stats
- Warnings/Announcements etc

Some of the example implementations are listed below:

Figure 34: Wi-SUN Router Node

Figure 33: Wi-SUN Dashboard

Features

- A multi-connected Light analytics platform offers an early warning system,
- RF mesh enables the last mile connectivity for the IoT data.
- Self-Healing Network
- Automatic light control based on the sun light, movement and luminosity.
- Real-time Monitoring and controlling of the Individual light and bunch of lights using a web-based platform.
- Wireless network saves a lot of wiring cost
- Low-power radio network
- Different light profiles can be added to different places like parks, streets, highways, etc

8.2. Other Case Studies

8.2.1. LoRaWAN Based Smart Street Lights (UniConverge Solutions)

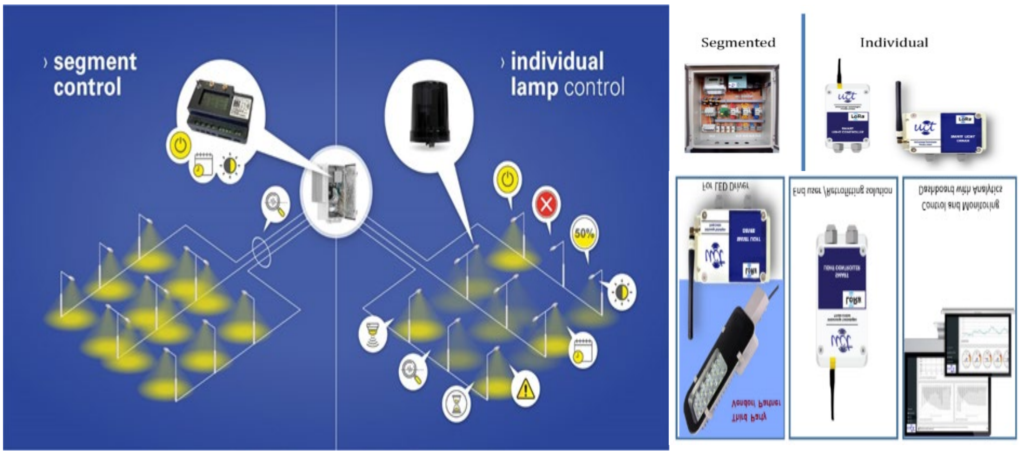


Figure 35: LoRaWAN Based Smart Street Lights

Features

- Internet Only needed at the gateway.
- The range is 3 km Radius.
- Can be controlled using Cloud app/ Mobile app
- Integration with field Sensors
- Reduce wiring in the field.
- Easy to install.

8.3. Mobility

8.3.1. Smart Road Network

Sensors are installed below the road surface and ~~a~~ power is provided to power the sensor unit, and a communications device is provided for remote monitoring and generates surface damage reports in real-time. It monitors pollution parameters, gasses, and particulate monitoring in particular stretches.

- Monitors of Road Condition
- Interface to Weigh in motion sensor for enforcement.
- Detection of violated parking of vehicles.
- Detection of Wet surface (water/ oil) and information generated for action.
- Monitoring of Air Quality
- Records Measurement of Temperature, Humidity, Noise, Vibration (accelerometer), Wind speed, Wind direction, Rain detection
- Detects any ~~of~~ Gases like – CO (Carbon Monoxide), NO (Nitric oxide), NO2 (Nitrogen dioxide), So2 (Sulphur dioxide), H2S (hydrogen sulphide), CL (Chlorine)
- Records PM10 and PM2.5 levels at the roadside.
- Monitors Incident Detection as below
    - Accidents
    - Unwanted activities
    - Public Abuse.

- unauthorized Intrusion in a protected area.
- Traffic rule adherence.

- Speed of vehicles monitoring unit
- Data logged, monitored, Real-time view and Report generation from the control centre.

8.3.2. Traffic Control System

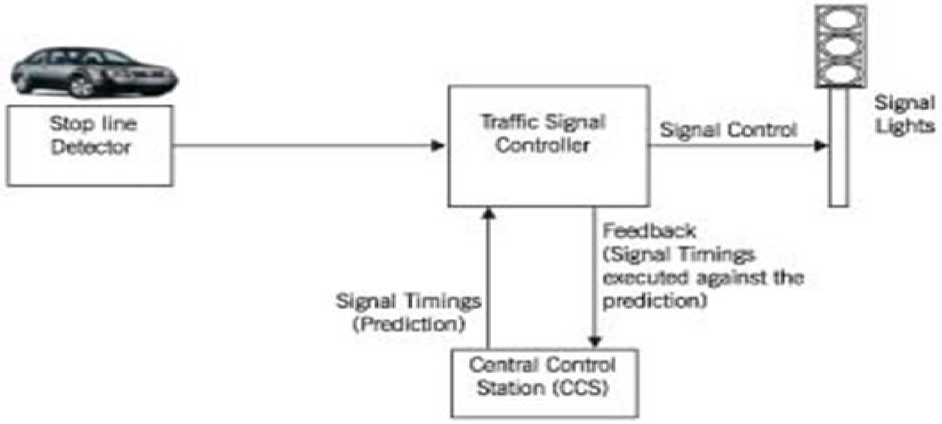


Figure 36: Traffic Control System

Traffic control system

The Adaptive Traffic Control System (ATCS) is a traffic management, monitoring, and control system. It is a fully adaptive traffic control system that uses data from vehicle detectors and optimizes traffic signal timings in an area to reduce vehicle delays and stops. The traffic management and monitoring monitor a green signal actuation time for each approach of the intersection based on an analysis of the demand trends at the approaches. Also, it analyses and computes the next green signal time based on vehicle actuation and proposes to the traffic signal controller to execute. An Adaptive Traffic Control System built on the VA controller can provide better network timings as the VA controllers operate on optimum signal timing. The Area Traffic Control Systems (ATCS) divide the area into corridors and separately optimize the traffic flow on the corridor by way of coordinated traffic in real-time. To achieve this coordinated traffic, the Composite Signal Control Strategy (CoSi CoSt) plays a major role in the adaptive traffic control system to achieve coordinated control to maximize the throughput by minimizing the stops and delays of the major corridor. The Control Strategy is the approach adopted to optimize the signal plans at different intersections in a corridor. Optimization of signal plans includes optimization of signal timings and the coordination of stages between intersections in a corridor. Input for the control strategy is the utilized green at every stage which is varied depending on the actual demand. The control strategy analyses the demand distribution at different intersections and proposes optimum signal timings and coordination to the individual intersections in real-time.

The controller then intimates this new green signal time to the Control Centre for update and audit in a feedback loop. The system is scalable, it can operate in different modes ranging from an independent intersection control model to a corridor control model with distributed time synchronization to ATCS.

Features:

- Distributed architecture
- Optimized Solar Power
- 64 Lamp switching and feedback monitoring of optically isolated solid-state lamp driving outputs

- Inbuilt hardware conflict monitor
- Extended Modes of Operation
  - Cable-less Synchronization
  - Pre-timed Vehicle and Semi Actuated
  - Remote Administration
  - Hurry Call, Forced Flash
  - Junction Off
  - Real-time clock (RTC) and Signal Time update
  - Programmable of All Red time, Start Amber time, Red Extension time, Transit Signal priority and Early start in VA mode.
  - Ethernet for Remote Administration and ATCS
  - 16 optically isolated Vehicle detector interface supports inductive loop, camera and microwave-based vehicle detection.
  - Inbuilt GPS module for time synchronization
  - User-friendly human-machine interface
  - Status monitoring and data logging debug port

Traffic control software Features

- Highly Scalable
- Isolated VA to Full-fledged Adaptive Signal Control
- Easy Installation
- User-friendly Configuration interface
- Remote Programming of Junction Controllers
- On-the-fly automatic configuration update
- Configuration Mismatch Alerts
- Configurable Reports, Views, and Charts
- Graphical representation of traffic network, junctions, and signals

Self-calibrating in runtime

- Dynamic identification of Critical Junction
- Dynamic identification of Priority Phase
- Estimation of Critical Cycle lengths
- Estimation and distribution of optimum Phase lengths
- Dynamic selection of Priority Route

Quick and Smooth Offset correction

- Signal coordination achieved without pre-programmed coordinated signal plans
- Dynamic Selection of Transition Modes

Flexible Algorithm Execution

- Signal Time Optimization for Selected Traffic Networks
- Minimum Transition Cost
- Phase Length Updates for Signal Coordination
- Improved Progression with Fair Phase Distribution
- Real-Time Pre-emption of Non-Priority Phases

- Adaptive Signal Control with Dynamic Cycle Adjustment
- Continuous Cycle Optimization and Offset Correction
- Special Features: Logical Quit, Automatic Reversion, Traffic Flow Filters, and Complex Phasing Schemes.

Methods to handle ATCS operation interruption.

- Power interruption
- Communication interruption
- Manual Mode control
- Emergency Service Vehicle Priority Signal
- Green-wave invocation on selected routes from TMC
- Enhanced user management
- Advanced fault reporting and event logging

Traffic Monitoring, Management, and Control Software Features

- User-friendly GUI with Dashboard and Full-Screen Mode
- Comprehensive Management System (User, Application, Privilege, User Group)
- Alarm Management (SMS, Mail, Dashboard Alerts)
- Junction and Corridor Configuration (Active/Passive, On-the-Fly Updates)
- Database Management and Housekeeping
- Traffic Component Editing (Traffic, Process Monitor, Backup, Restore)
- Template-Based Display Configuration
- Data Analysis and Historic Charts
- Time Space Diagram and Scheduler (Permanent/Temporary)
- Various Reports (Corridor, Junction, Timing, Synchronization, Event)
- Video Wall Display (Template-Based)
- Customizable Logos and White-Listing for Remote Access
- Web Service for Smart City Dashboards

8.3.3. Smart Parking

Smart parking helps travellers find parking spots quickly, thereby reducing frustration and enhancing their overall experience. It includes elements ranging from traditional traveller information systems to quick and automated gate control systems, individual bay monitoring electronics, advanced parking management applications, pre-trip web-based information systems, VMS display boards, driver guidance and navigation systems that provide directions to an individual parking space.

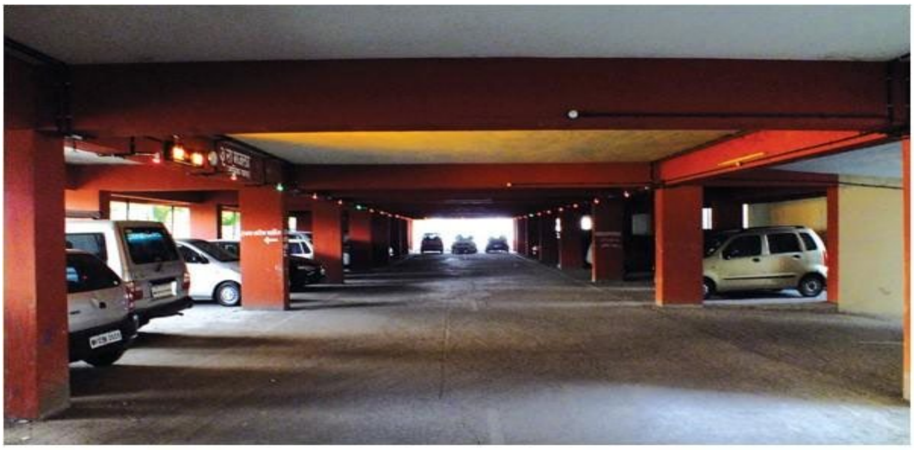


Figure 37: Smart Parking

Features

- Real-time parking information
- Quick Identification of parking spots
- Enhanced capacity utilization
- Modular design and architecture
- Suitable for Multilevel parking
- Driver Guidance and Navigation Aids
- Reports and revenue management

Entry Gate System Features

- Manned and unmanned operation
- Entry based on parking availability.
- Driver and vehicle registration number image capture
- Bar code-based entry token
- Automated boom barrier control
- Web-based application.

Exit Gate System Features

- Entry token scanned
- Entry-exit details displayed
- Live streaming of vehicle registration number
- Generate receipt & print bill
- Web-based application

Bay Sensor Features

- Real-time bay status update
- Trigger bay indicator lamp
- Ultrasonic sensor
- Wi-Fi or RS485 communication
- Status indicator

8.4. The Garbage Vehicle Management System

The Garbage vehicle management system is an online monitoring system and two-way voice communication with the driver. The system shall provide a memory device with a tamper-proof mounting mechanism that shall hold the trip information for at least 10 days. Transferring the trip information from the memory device in the vehicle to a handheld device/mobile/laptop PC shall be possible by either wired or wireless methods. Further, it shall be possible to transfer the data from the handheld device/mobile/laptop PC to a Server / Computer at the Central Control (CC) and generate reports. Playback of the route traversed by the vehicle shall be possible on scanned/digitized map. Selection of this playback shall be possible by setting the calendar and time for the period. Upgrading to the online system real-time route display also shall be possible at the CC. The system shall generate the reports like Vehicle arrival/departure at specified garbage collection points, Duration of halt more than a user defined period, Speed violation of more than a user-defined speed, Duration of the vehicle in use, Distance traversed by the vehicle in a day, Route the vehicle travelled, Halt at predefined locations.

All the reports shall be with a vehicle number, type of vehicle, driver's name, date, time, and location name wherever applicable. Developing the location database shall be the responsibility of the vendor. It shall be possible to plot multiple vehicles on a single scanned/digitized map. Mouse over the vehicle image shall display the vehicle number, time, date, location, and speed of the vehicle at that time. Playback of the route traversed by the vehicle may be one at a time. The driver database shall be maintained at the CC with the driver's name, address, license, and expiry date. It shall be possible to generate and print reports by the driver's name that may be used as duty reports for the driver. The Garbage vehicle Management System offered shall allow for continuous upgrades of technology to support current and future core functional needs.

- Online monitoring of garbage vehicles and two-way voice communication with the driver.
- Connected to Smart Bin.
- Generates Vehicle arrival/departure reports at specified garbage collection points.
- Generates Duration of halt, speed, route travelled, distance travelled and duration report for a user-defined period.

8.5. Remote Labs for Education

- Remote labs are online environments accessible to students, providing virtual access to real laboratory equipment for conducting experiments.
- They offer hands-on experience, allowing students to manipulate equipment and observe outcomes as if they were in a traditional lab.
- Students can analyze experiment outputs through tables, plots, and diagrams, developing valuable data analysis and visualization skills.
- Live streams from the lab enable real-time observation and learning from instructors or lab assistants.
- Remote labs break geographical barriers, granting global access to science education and promoting equality.
- During pandemics or emergencies, remote labs ensure continuous practical learning and engagement.
- Internet of Things (IoT) technology facilitates seamless connectivity and real-time data transmission.

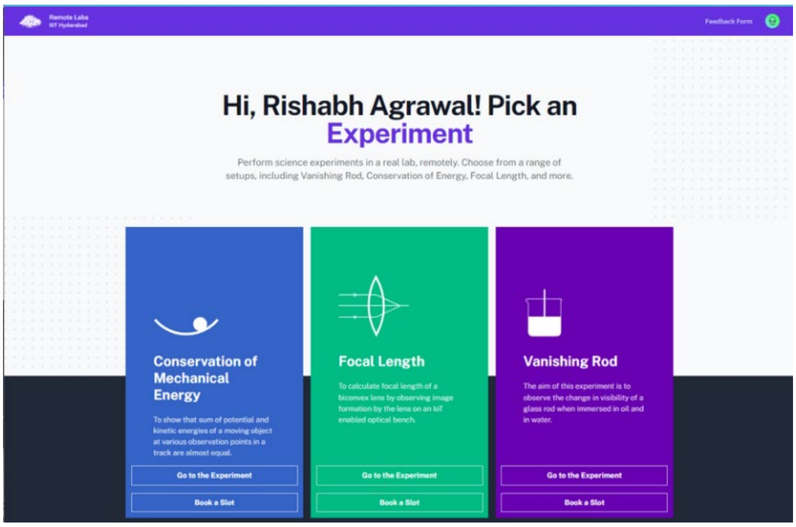


Figure 38: Remote Labs Experiment Website

8.6. Assisted Living - Pedestrian Safety Enhancement Controller (PeSCo)

It is an Accessible Pedestrian Signal (APS) capable of identifying different classes of pedestrians such as (1) normal (2) differently abled (3) visually challenged and (4) other needy people like the elderly, children and women crossing the motorway and regulates the crossing time (Pedestrian Green Time) according to their requirement. It also helps the visually challenged in locating the 'zebra crossing' through the 'Pole Locator' tone generated through a hooter mounted on the Pedestrian Signal Pole. 'Safe Crossing' time, 'Do not Cross' and 'Wait for Signal' to cross are also indicated through audio/visual signals to help the visually challenged and other pedestrians.

The APS can automatically identify the presence of visually challenged waiting to cross the road by reading the signal from their 'Smart Cane.' The needy people are provided with RFID cards through NGOs and other authorized agencies to demand additional crossing time at the motorway. Flashing the RFID card near the APS will regulate the crossing time based on the degree of disability recorded in the RFID card.

Traditionally, the pedestrian crossing time at motorways are maintained to address the normal pedestrians considering the 15^{th} percentile walking speed of a group. The visually challenged struggle to find out the place to cross. The safety of the visually challenged and other Divyanga crossing motorways are improved by this innovation. PeSCo is also provided with a large size 'Push Button' for easy accessibility for differently able and Braille inscriptions to help the visually challenged.

The needy pedestrian can demand more time to cross the motorway by flashing an RFID card near PeSCo. The audio signals help the visually challenged to locate the 'zebra crossing,' and identify the 'waiting time for signal,' 'safe crossing time' and 'do not cross' time through different tones. The visual indications also help the pedestrians to respond to various scenarios effectively.

Figure 39: Assisted Living - Pedestrian Safety Enhancement Controller

Features

- Categories of pedestrian supported: Visually challenged – with a smart cane
    - Visually challenged – with RFID Tag
    - Physically challenged – with RFID Tag
    - Children– with RFID Tag
    - Any Pedestrian – Push Button Press
- Pedestrian Detection Inputs: Push Button Switch, RFID Reader, and Ultrasonic Sensor
- Pedestrian Tone Types: Locater, Wait, Safe Cross and Alert
    - Tone Base frequency: 2 kHz
    - Tone Volume Level: Variable from 0 to 5 dB
    - Tone output device: Horn Speaker (8 Ohms 30W power)
- Labelling for visually challenged: By Braille Labels
- Pedestrian Sensor Box (PSB) to PSB communication: Wireless 2.4GHz / CAN interface
- RFID card Supported: 125 KHz with EM4102 protocol.
- Smart cane supported: Any smart cane with a 40 KHz ultrasonic pulse.
- Web Server based configuration of Pedestrian categories Vs Walk time, RF ID card No Vs Pedestrian categories, Pedestrian Safe Walk time, and timings.
- Data logging

9. Potential Evaluation metrics For Smart City projects

- Efficiency
- Environmental impact- ESG metrics
- Resource saving (Water/Energy)
- Evaluation at three levels.
  - Technology
  - Infrastructure services
  - Citizen benefit
- The four metrics in evaluation metrics are
  - Alignment of citizen priorities across smart city products
  - Density of data/information flow
  - Quality of infrastructure services
  - Citizen benefits.
- Impact comparison based on pre and post-deployment study.

10. Challenges and Gaps

The various challenges which need attention, gaps to be addressed and actions suggested to move ahead to address the futuristic problems are discussed

- Data Security & Privacy
  - Data Security and Privacy for huge data collected.
- Indian Dat set Availability
  - Availability of Indian Datasets for Indian Solutions is the need of the hour.
- Citizen Awareness
  - Bringing awareness to people and enabling people to understand the usability and enable anti-tampering.
- Standards and Policy Definition
  - Standards/Policies to be laid down on various aspects like Data Models, payload, security etc. to enable uniform and scalable implementations.
- Common platform to connect
  - Tailoring solutions to multiple scenarios in India to meet the diversity would be a tough task.
  - Parallel development of the same solution by different individuals due to a lack of approach to a common platform. The application layer and Service layer will be proprietary in each case. Any addition of either device or application is complex, as a new protocol specific to both is to be formulated and integrated every time. This makes the interoperability of the system complex. A common ontology along with a common city platform that can integrate these solutions is the only option to connect to multiple vendors and bring it to a standardized platform suitable for both data providers and data consumers.

    For eg. Different types of Traffic Management devices and Application layer software are commercially available these days for different requirements in the field of Traffic Management. Varied ITS solutions use different and specific hardware and software. It becomes difficult to integrate the solutions in various scenarios individually. Hence a common platform is required.
- Scalability
  - Architecture to support huge deployment of devices.
- Component Availability
  - Sensor's availability and reliability and the sensor parameters validation
- Funding Schemes
  - Opportunities for POCs and Pilot runs to validate the solutions.
  - Lack of goal-oriented funds.
- Diversity in climatic conditions
- Plan for infra maintenance

11. Recommendations and Way Forward

In smart city implementation, standards are indispensable in ensuring that different systems, technologies, and stakeholders interact in a coordinated manner. Smart cities are intricate networks relying on various technologies, data, and infrastructure, and without standardized guidelines, the process can become convoluted, inefficient, and error ridden. A more hands-on approach to implementation and deployment offers a more effective way to provide clear recommendations and navigate the path ahead.

They can be broadly classified into two categories: 1) Policy and 2) Technology Based.

11.1. Some of the Policy-based recommendations to move forward are:

11.1.1. Six Layer Framework:

A six-layer framework is suggested to ensure reliable and effective smart city solutions. These layers include the Sensor/Technology Layer, Communication Layer, Data Storage Layer, Data Exchange Layer, Data Visualization and Analytics Layer, and the Application Layer. The case studies and existing solutions discussed earlier provide a comprehensive understanding of how smart city solutions can be implemented.

11.1.2. Uniform Standards/Data models/Interfaces across the solutions:

Standard Data models need to be made uniform across cities to enable effective utilization of the collected data.

11.1.3. Availability of Indian Datasets:

Making government/public datasets collected so far available to the right people for developing solutions.

11.1.4. Environmental Social Governance:

ESG is an acronym that stands for environmental, social, and governance. It is a framework that helps stakeholders understand how an organization manages risks and opportunities around sustainability issues, supporting both net zero and carbon neutrality goals.

Integrating ESG (Environmental, Social, and Governance) principles is essential for creating sustainable and equitable urban environments in the context of smart cities. Here are some key lines highlighting the importance of ESG in smart cities.

1. **Environmental Sustainability:** Smart cities prioritize environmental sustainability by implementing technologies that reduce energy consumption, minimize waste, and promote eco-friendly transportation solutions, all contributing to a lower carbon footprint. ESG initiatives in smart cities focus on preserving green spaces, improving air quality, and reducing greenhouse gas emissions, fostering a healthier urban ecosystem.
2. **Social Inclusion:** ESG-driven smart cities aim to create a sense of community by enhancing public spaces, supporting cultural diversity, and providing accessible infrastructure for all citizens. By prioritizing ESG principles by investing in resilient infrastructure, early warning systems, and disaster preparedness, protecting citizens from the impacts of climate change and other crises.
3. **Governance and Transparency:** Effective governance in smart cities means making data-driven decisions, enhancing transparency, and engaging citizens in decision-making processes, all aligned with strong ESG principles.

11.1.5. Ethical AI

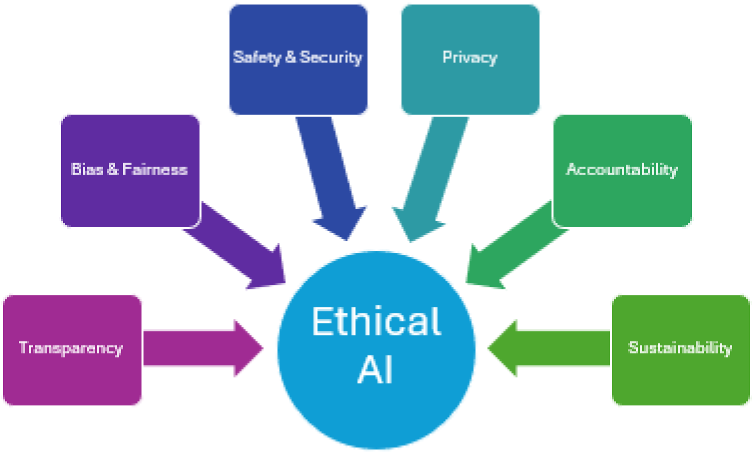


Figure 40: Pillars of Ethical AI

Ethical AI is artificial intelligence that adheres to well-defined ethical guidelines regarding fundamental values, including such things as individual rights, privacy, non-discrimination, and non-manipulation.

UNESCO recommends that Getting AI governance right is one of the most consequential challenges of our time, calling for mutual learning based on the lessons and good practices emerging from the different jurisdictions around the world.

As AI is being used in multiple domains, ethical AI may soon become one of the major requirements/concerns in the future. Ethical AI policies can be implemented at various stages and in different contexts. Here's when and how these policies can occur:

1. **Development Stage**
   - Design and Planning: Policies should guide how AI systems are designed, ensuring they align with ethical standards such as fairness, transparency, and privacy.
   - Data Collection: Ethical policies should govern how data is collected, ensuring consent, privacy, and representation.

2. **Deployment Stage**
   - Testing and Validation: Before deploying AI, ethical policies should ensure the system is tested for biases, accuracy, and unintended consequences.
   - User Interaction: Policies should guide how users interact with AI, ensuring transparency about how AI makes decisions and what data it uses.

3. **Post-Deployment Stage**
   - Monitoring and Accountability: Continuous monitoring to ensure AI systems remain ethical over time. Policies should include mechanisms for auditing and addressing issues that arise.
   - Feedback and Iteration: Policies should support mechanisms for user feedback and iterative improvements to AI systems based on ethical considerations.

4. **Regulatory and Compliance Stage**
   - Legal Frameworks: Policies can be implemented through laws and regulations that mandate ethical AI practices, such as data protection laws or AI-specific regulations.
   - Industry Standards: Professional organizations and industry groups can create and enforce standards for ethical AI.

5. Organizational and Cultural Stage

- Corporate Governance: Companies can implement policies at the organizational level to ensure all AI development adheres to ethical guidelines.
- Training and Awareness: Policies should include training for employees on ethical AI practices to foster a culture of responsibility.

Ethical AI policies should be integrated throughout the entire lifecycle of AI development, from initial design to post-deployment monitoring, to ensure the technology is used responsibly and beneficially.

11.2. Some of the Technology based Recommendations and Way-Forward are:

11.2.1. Hyper scalability

The dense network of devices and high latency of data results in large amounts of data that need to be collected, transformed, and stored in near-real time. This calls for highly scalable software architecture that can provide support for big data processing and analytics. However, creating an architecture that can operate on such a scale requires going beyond the resource limitations of traditional hardware (servers, GPUs, etc.). To this end, this work proposes a novel approach that uses a combination of techniques inspired by optimization theory, machine learning and software architectures to dynamically scale the software to support the increasing demands imposed by 5G.

11.2.2. AI based models using cameras to avoid huge deployment of sensors

Large scale deployment of sensor nodes would be difficult for maintenance. Hence if the data can be correlated with the camera images and predict parameters using AI models based on the available datasets without the actual deployment of the nodes.AI / ML platforms for smart cities - especially on data and model sharing for diversity in India

11.2.3. AI/ML platforms for smart cities in India

Models, particularly those focused on data and model sharing, enable collaboration, enhance data-driven decision-making, and promote sustainable urban development.

These platforms are pivotal in driving the next wave of smart city innovations in India, particularly by sharing data and AI/ML models that can be adapted to diverse urban challenges.

11.2.4. Digital Twin

A Digital Twin (DT) is a digital version of a process or physical object based on a two-way data exchange between digital and physical entities in real-time. A digital twin is a virtual representation of a physical object which represents collected information from the real environment, validates and simulates the process of physical objects present and future behaviour. It enables monitoring of complex systems, decision making based on data, validates products, and simulates scenario and object lifecycle management. Digital Twin based smart city solutions is the emerging trend.

The development of Digital twins for smart cities is a critical need in today's rapidly evolving technology landscape especially with the emergence of 5G coupled with the challenges induced by 5G networks. This further calls for architectures that can support the large-scale requirements of 5G and Digital Twins.

Some of the existing examples are:

- Digital Twin for Utility networks
- Digital twin-based air monitoring system is a digital replica of a deployed sensors, analyzes collected data in real time and predicts future trends.

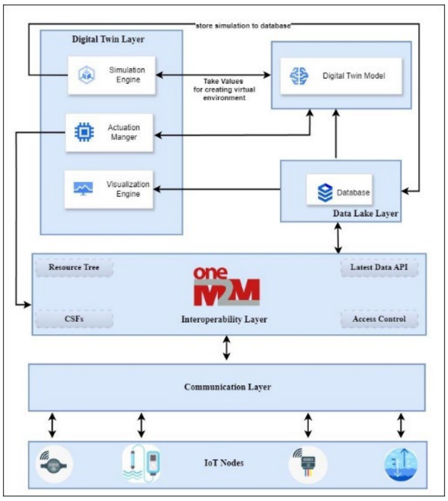


Figure 41: Digital Twin for utility network

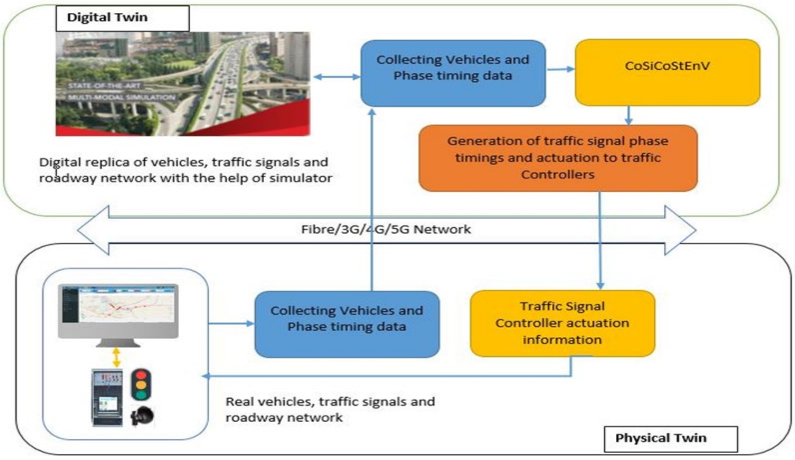


Figure 42: Digital Twin for ATMS

- Digital Twin based Adaptive Traffic Management System (ATMS-DT) consists of a microscopic traffic simulation (SUMO or VISSIM) for developing a digital replica of a roadway network with signalized intersections in an urban traffic condition where vehicle and traffic signal data are collected in real-time.
- Digital Twin based Adaptive Traffic Management System (ATMS-DT) consists of a microscopic traffic simulation (SUMO or VISSIM) for developing a digital replica of a roadway network with signalized intersections in an urban traffic condition where vehicle and traffic signal data are collected in real-time.

11.2.5. City Operating System (COS)

It is an operating System for cities to use and interface with multiple stakeholders, thus enabling the streamlining of the process for smart city solutions, getting seamlessly integrated into Integrated Command Control Centre and User Applications. It will be a standard platform where multiple data providers and data consumers can easily interface. For IoT data, The City IoT operating Platform is used.

11.2.6. City IoT operating Platform (ctOP)

The City IoT Operating Platform is designed to improve interoperability and simplify the integration of IoT devices for smart city deployments. It aims to make the IoT ecosystem more streamlined, facilitating the creation of smarter and more efficient cities. The ctOP serves as an intermediary system that provides user authentication and access control for IoT ecosystems based on oneM2M. It offers an intuitive interface for users to manage their IoT devices and network security. Additionally, it supports multiple vendors and aims to revolutionize IoT device deployment in smart cities by promoting standardized data exchange through a user-friendly interface.

Figure 43: ctOP Features

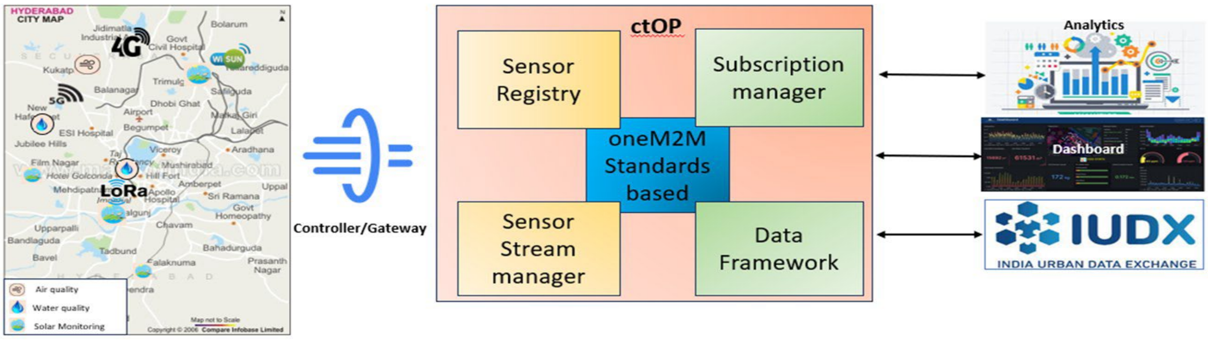


Figure 44: City IoT Operating Platform

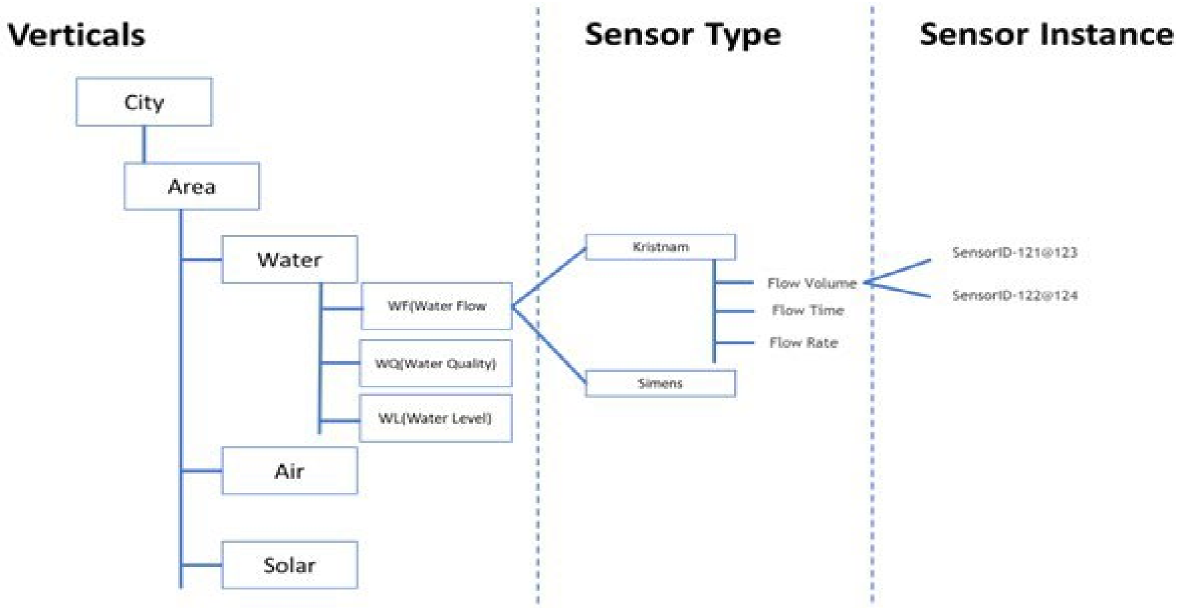


Figure 45: Data flow of ctOP platform

12. Conclusion

This paper outlines some of the recommendations for smart city solutions based on the actual implementation on a small scale and understanding the operating issues and from the inputs of the various contributors based on their experience. This recommendation cannot be claimed as the final recommendation considering the diversity found in Indian cities. However, this recommendation can be used as a reference and tailored to the requirements and needs of a particular city.

TSDSI is working on finalizing white papers on FinTech and the health sector, acknowledging the need for a deeper study.

13. References

This white paper draws on insights from various related works in the field based on articles authored by the whitepaper contributors in various conferences, symposia and publications: and information available in the public domain.

While individual references are not cited at specific points, a list of key sources informing our analysis is provided for further reading.

a. Papers co- authored by contributors to this whitepaper:

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