White Paper – GIS for Smart Cities

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Objective

GIS integrates hardware, software and data for capturing, managing, analyzing and displaying all forms of geographically referenced information for a city. GIS technology allows a city to view, query and understand data in many ways. It is very easy to see relationships, patterns and trends in the form of GIS-based maps, reports and charts. GIS helps answer questions and solve problems. When viewed in the context of geography, a city's data is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework of a city.

GIS has the unique ability to a) Integrate data from multiple sources b) Present them visually using geography as a common element of these various data sources, and c) Help understand patterns and relationships between these data elements. Informed decision making enabled by this would be very helpful while converting existing cities to smart cities or while developing new green-field smart cities.

Apart from enabling cities to be more efficient and "green", GIS can play a critical role in enabling government interface where citizens can share grievances, comment on the status of city infrastructure and understand the corrective measure taken by the city authorities. Citizens can also access the city master plans and share their views on the proposed development activities.

This white paper describes the way GIS can help in planning, designing, execution and management of various functions of a smart city. A few examples have been taken to describe the concepts, the opportunities are wide-ranging.

Introduction

A city, by definition, is a geographic entity and hence using GIS as one of the key "system of records" for a city would help various city agencies to work in tandem and collaboratively at all stages – planning, design, engineering, construction, asset management, operations and development, managing outage situations and during emergencies.

A GIS based framework can track a set of indicators including total energy use, water demand, waste produced, vehicle miles traveled and total greenhouse gas (GHG) emissions that can be modeled to show the impact of a single building, block of buildings or entire community. Various energy or water conservation strategies can be recombined and modeled to show the immediate carbon or water footprint, as well as initial development costs or ongoing maintenance and management costs of a given scheme for any point in the future.

GIS is also being increasingly used in the construction of Smart, Green Buildings as GIS easily interfaces with BIM solutions. Latest developments in 3D GIS and Indoor GIS allow creation of intelligent and interactive digital city models that makes it easy for the city planners to create "what-if" scenarios. This helps them in understanding short and long term impact of various planning decision they take.

While GIS can be used in many areas of a Smart City, some areas where the benefits of unique capabilities of GIS can be quickly leveraged are:

- Smart Urban Planning
- Smart Utilities
- Smart Transportation
- Smart Public Works
- Citizen Engagement

Smart Urban Planning

The urban plan and design of a city, including land use and circulation patterns—has the largest impact on a city's energy use and GHG emissions. A city organization seeks to identify the best mix of urban form, land-use density, and transportation network to achieve the reduction in carbon emissions at the lowest cost.

The success of planners in combating chronic urban problems is largely determined by their ability to utilize effective tools and planning support systems that allow them to make informed decisions based on actionable intelligence.

GIS can be used by planners as a platform – to help them reach their goal of creating livable "smart" communities and improving the overall quality of life while protecting environment and promoting economic development. GIS can provide the necessary planning platform for visualization, modeling, analysis and collaboration.

Land Use Planning

Traditionally, GIS has been used for land use management – to keep track of zoning and related data on building, taxes and occupancy. For a Smart City, however, it would be essential to use GIS for land use planning to support and enhance community viability.

A GIS used for classic planning activities will help planners consider, understand and manage the following:

- The amount of land to be left undeveloped so as to provide green space, cluster development and storm water drainage
- The density of development in relation to the existing and planned infrastructure
- The amount of land needed for parking, given a particular land use
- The proportion of land set aside for various uses, zoning classifications or design standard requirements
- Land uses within zoning classifications (e.g. amount of green or open space per residential unit within residential zones)
- The minimum/maximum size for parks and their ideal locations with regard to encouraging use
- The length of city blocks and the buffering of sidewalks (e.g. so as to encourage sidewalk use)

GIS facilitates Multiple Criteria Evaluation (MCE) allocating weights to assessment criteria for suggesting and ranking alternatives. GIS planning support tools – based on spatial analysis – have an important advantage: it is convenient and easy to change the valuation criteria to visually illustrate and depict the implications of different spatial decisions and alternatives. The capabilities needed for decision making readily available in a single system makes GIS a great tool for integrating in planning processes. GIS spatial analytical tools can be used to effectively shape decisions that foster urban growth management, e.g., while identifying suitable locations for residential purpose, economic perspective would be to minimize the cost of development whereas the environmental perspective would be to ensure that agricultural and forest lands are protected and the integrity of the environment is maintained.

GIS can help evaluate and identify lands meeting these contradicting criteria by integrating data from different sources and selecting suitable lands based on following criteria:

- Avoid flood plain designated areas and areas having high runoff rates
- Avoid soils with low bearing strength or poor drainage
- Avoid sites having steep terrains
- Select sites connected to existing residential areas
- Sites well connected by transport network – existing or planned
- Sites those are a minimum distance away from landfill and industrial sites
- Sites those are a minimum distance away from airports to reduce noise pollution

Conceptual and Master Plan

GIS is an invaluable tool for creating strategic land use and transportation plan which would be analyzed at regular interval to ensure that there will be sufficient land to meet the anticipated population and economic growth, and provide a good living environment. This can be used to ensure that the future development will balance economic growth with environmental stewardship and social progress.

Likewise, GIS would be extremely useful in creating smart master plans guiding development for 10 to 15 years into the future translating the broad long term strategies of concept plan into detailed plans.

Preparation of both these plans needs several government agencies to work collaboratively and bring information specific to their agency/department. GIS would be the ideal integrator, assimilating this information using location as the common reference point and enabling each agency to see the data pertaining to their city in entirety and understanding interrelationship between different data layers.

GIS would also facilitate publishing the master plan maps on internet and invite public feedback on those.

Storm Water Harvesting

Harvesting storm water reduces the detrimental impact that urban development can have on rivers. It reduces demand for water from water mains, delays the need for major new water resources infrastructure, increases water security and reduces pumping costs.

GIS can be very helpful in :

- Identifying areas suitable for storm water harvesting by analyzing land cover, land use and topography. The suitableness can be defined as:

- o Predominantly impermeable surfaces
- o Land use that does not pollute the quality of the runoff e.g. areas in proximity of roads are prone to contamination from automobiles
- o A natural drainage pattern facilitating collection of storm water from a large area

- GIS can be used to plan storm water harvesting schemes at both a strategic level by way of options appraisal and at a design level via hydraulic simulation

Smart Utilities

GIS can help ensure meet current and future utility demands of a city – water, waste disposal, electricity, gas etc.

A GIS for utility management affords managers the opportunity to advance community viability and environmental quality through the use of the system to:

- Reduce waste of water or energy resources
- Check inflow and infiltration of rainwater and groundwater into sewer systems
- Improve emergency responses to leaks, breaks and downed power lines

Specialized utility-related information systems like SCADA, MIS, AMI, MIS, WMS and CIS can provide data and work with a GIS.

Asset Management

GIS supports the Asset Management of utilities through an authoritative system to store, manage and maintain accurate asset records that can be shared utility wide.

GIS helps maintain and manage up-to-date information about utility's assets, including detailed descriptions about their current location, condition and operating status. It can also help create performance information about facilities such as customer complaints, main breaks, leaks, meter readings and SCADA data.

Utility asset management starts with compiling a geographic database of utility network from source documents such as as-built drawings, construction plans, field observations, and GPS data collectors.

It is common at utilities for the complete information about an asset to be stored in multiple systems, e.g., GIS stores the location, connectivity to other assets and basic descriptive information (material, size, install date, operational status, etc.) about an asset, a work order management system may store extended information about the work history for an asset, a financial system may store depreciation and valuation information, a customer information system may store complaints about the function of an asset, etc. Optimally, all the systems that store information about an asset should be integrated so that the utility staff can access data stored across multiple systems enabling a comprehensive view of the location, connectivity, status, history and description of an asset.

Planning and Analysis

GIS supports utility planning and analysis by transforming asset and operational data into actionable information. Operational data for utilities is customer complaints, service requests, historic work order locations, etc.

For short term planning, GIS is typically used to support creating and optimizing work orders. Answering questions such as what is the best route to accomplish daily work tasks and where can some proactive work be done in close proximity to assets that need reactive work. GIS is also used to understand what assets you should do proactive work on and when you should do it.

For long term planning, asset data, performance data and GIS analysis is used to help utilities understand how their utility networks are performing. Then to identify the best replacement and rehabilitation projects to undertake and to estimate project costs to support project evaluation and budgeting. For example, water utilities use repeatable geoprocessing models that take into account many weighted factors to rate their assets on condition, reliability, criticality, performance, etc. This information is then used to help guide where to best spend capital budget to maximize the value of investments in a utility's assets.

Field-worker Mobility

Mobile field workers at utilities need information that is current, optimized for their needs to help them carry out their work and delivered in an easy to use format. Mobile field workers also generate much information that needs to be passed back into the office and managed in enterprise business systems.

The field mobility patterns includes both work the field crews are performing as well as the processes used in the office to support and manage field crews. There is recognition across the industry that field work is a large part of utility operating budget and for many utilities there is not enough field crew labor available to meet the needs of the utility. Utilities are always looking for ways to decrease the time it takes to share information bi-directionally with the field and increase the reliability and accuracy of data coming back from the field. GIS provides utility field crews with maps and map centric applications on a mobile device that can be rapidly updated and are easy to use. GIS also supports the Field Mobility pattern by enabling field crews to capture GIS data in the field and efficiently pass it back into the office.

Operational Awareness

The Operational Awareness pattern is about having an understanding of the current state of operations at a utility, so this is a real time or near real time understanding of how assets, utility networks and personnel are performing and how they are affecting each other. Being operationally aware empowers utility managers to confidently make decisions based on accurate and up to date information.

GIS supports utility operational awareness by enabling utilities to have a web map based view into the current state of operations. A map based view into their organization is the easiest way for them to understand at a glance what is currently happening at their utility. An interactive map is also an easy way for utilities to take information from multiple business systems and present it through a common application.

A utility manager empowered with GIS can quickly answer questions such as:

- How is our water network performing?
- Where and what types of pipes have leaked over the last year?
- What customers are currently out-of-service due to an unplanned interruption?
- Where our work crews are and which tasks have they completed today?
- What is the status of each of my Capital Improvement Projects for this fiscal year?

Stakeholder Engagement

Utilities have many external stakeholders such as customers, elected officials, regulatory agencies, other utilities in their service area, etc. The Stakeholder Engagement pattern encapsulates how utilities interact with external entities that are affected by the utility.

The trend is for utilities to more proactively engage with stakeholders through public outreach programs, providing more transparency while delivering information in a way that minimizes the possibility of misinterpretation. Modern utilities recognize the need to utilize the internet and social media to communicate with their stakeholders. Presenting up to date information via interactive maps is a powerful medium to communicate.

Utilities use GIS to support Stakeholder Engagement by creating and delivering static and interactive maps. GIS has been used by utilities to make maps that were submitted either electronically or as a hardcopy for regulatory agencies. Utilities have also used GIS to make static maps available as an image file or PDFs on their websites.

GIS is commonly used to support stake holder engagement activities such as:

- Dynamic web mapping applications for customer self-service and service requests
- Transparency into utility operations and spending
- Capital improvement project coordination
- Web mapping Applications to support customer service representatives and utility call center personnel
- Web mapping applications for service interruption

- Spatial analysis for emergency notifications of customers
- Spatial analysis for key performance indicators (KPIs)
- Spatially enabling customer information systems (CIS) and work order management systems

Smart Transportation

The ability to visualize assets and the surrounding environment - while building, upgrading or repairing transportation infrastructure - helps transport organizations prioritize their work and make the right decisions.

GIS supports the Transportation Infrastructure life cycle:

Throughout the transportation infrastructure life cycle, GIS technology helps create a seamless flow of information from one stage to the next. With GIS, information from planning process can be brought into the design process and easily carried over into other areas like as-built drawings, operations and maintenance. Gains in both employee productivity and transportation system performance are made possible by the unique ability of GIS to integrate with a wide variety of technologies. Transportation organizations benefit by making use of the resultant information throughout their enterprise for better decision making.

Planning

Transportation agencies face an enormous challenge in keeping their infrastructure operating smoothly and efficiently. Increasingly, transportation planners are integrating land-use, environmental and greenhouse gas considerations, along with energy consumption factors, into their planning processes. In doing so, they have discovered that GIS can bring all these factors together in the type of comprehensive planning models that will be required to help effectively plan the future.

Environmental Management

Transportation infrastructure management requires careful consideration of the environment. GIS is uniquely capable of assisting transportation professionals in understanding these issues and selecting the most environmentally sensitive solution. With GIS, they can understand the impact of land-use decisions and evaluate smart-growth alternatives. GIS integrates environmental factors with land-use, housing and employment density analysis to help communities address growth issues. The ability to visualize alternatives on a common GIS platform allows parties that differ to reach a consensus when dealing with environmentally sensitive matters.

Construction Management

When integrated with construction management and financial software, GIS can help track the performance of one or multiple infrastructure projects. GIS makes a wealth of information, such as schedules, estimates and contracts, easily available from a spatial interface. For project tracking, GIS can help organize all relevant information, from survey data, soils, and geotechnical studies to planning, environmental studies and engineering drawings. Having quick and easy access to data during construction can greatly increase efficiency and reduce time spent searching for needed information.

This type of project transparency and reduced risk can lead to a greater return on investment.

Asset and Maintenance Management

GIS integrates asset mapping with project management and budgeting tools so that construction and maintenance expenses can be accounted for and centrally managed. A GIS-based maintenance management system promotes efficient scheduling of activities and tracking of work tasks, personnel, equipment and material usage so managers can track and report accurately. Simultaneously, field-workers can record information, perform inspections and locate assets with GIS-equipped mobile devices. Deficiencies identified in the field during inspections can automatically prompt the GIS to generate new work orders for maintenance and repair.

Operations

The demand for operational efficiency and increased safety in modern transportation systems requires access to detailed and real-time information. GIS provides management solutions that integrate data from all aspects of operations. GIS can track and analyze assets over space and time, and provide insights through visualization of information via maps and easy-to-understand reports. GIS gives the ability to integrate disparate information sources into a common operational picture of all facilities and transportation systems, with greater power to control operations.

Security Management

Comprehensive transportation facility protection requires the cooperation and close coordination of various agencies, the integration of different technologies and information sources. GIS can integrate multiple sources of information, display them on a map or satellite image, and deliver the resultant situational awareness on a secure network. One can combine real-time tracking of assets and vehicles with sources such as live closed-circuit television cameras to deliver a real-time security view of transportation facilities. These capabilities make GIS an essential technology for managing a transportation security framework.

Safety Management

Accurate records of accident locations frequently hold the key to improving safety for motorists, freight carriers, railways and even pedestrians. GIS maps can display crash records paired with spatial analysis of congestion, construction zones and weather; making obvious what can easily be missed in simple tabular data. Spatial analysis, combined with statistical and business intelligence tools, can help pinpoint the root causes of accidents and determine effective counter-measures. Departments of transportation can identify trends, such as increases in oversized vehicle traffic, permit violations and general commercial traffic route information, using GIS tools—all leading to significant improvements in transportation safety.

Rights-of-Way Management

From property acquisition for new alignments to the disposal of unneeded properties, understanding the extent of rights-of-way is a task enhanced by GIS. By linking parcel, survey and assessor information, GIS can give rights-of-way managers a better understanding of their properties and a better way of analyzing which properties may no longer be required. GIS can capture the location of various utilities within the rights-of-way, simplifying future construction and relocation activities, and preventing unforeseen construction accidents. Rights-of-way leases can be managed by a GIS linked to a database-driven lease management solution for more effective property management.

Smart Public Works

Public works makes sure that a city is running smoothly. Increasing number of departments related to public works internationally now rely on GIS platform to integrate their dissimilar systems because of its ability to provide a common, geo-enabled view of their entire city organization.

The resultant synergy supports a dynamic system that allows the PWD to function smoothly across its full range of responsibilities including roadways inventories, facilities maintenance, water system optimization, solid waste disposal, fleet management and infrastructure construction and maintenance.

Asset Management

Creating, storing, managing and sharing accurate and updated asset inventory is the foundation of any PWD. GIS is the ideal system for ensuring this. GIS enabled sharing of this data on a map across the organization saves time and money, allows collaborative functioning and increases efficiency and productivity.

Taking the example of asset inventory of city's sewer system, there is a need to regularly update city wide sewer maps as there is a need of current record of assets for maintenance and inspections.

GIS is used to create an asset database on maps and it can provide online maps of the city's sewer system to contractors, city engineers and general public. The officials then use this information to determine where to connect private sewer pipes to public sewer mains.

The sewer system may show all the connected assets with attributes like sewer pipes, flow direction, manholes, related imagery, parcels, pump stations, pumps and wet wells. For sewer pipes information like construction material, footage, year installed, tributary etc. can be accessed directly from the map on desktop, web or on a mobile device.

Planning and Analysis

Public works officials need to balance investment in infrastructure against an asset's expected life span. In most existing cities, aging infrastructure combined with increase in population puts a strain on sewer system resulting in sanitary overflows and sewer stoppages.

Using GIS, lines requiring frequent cleanings can be easily identified giving the department specific areas to target and improve. GIS maps can also be interfaced with CCTV feeds to better understand the situation for timely and effective decision-making.

Another area of effective utilization of GIS is tracking capital projects. Capital projects like new sanitary sewers, storm sewers, roads and widening of roads, concretization of existing roads can be tracked and monitored with the help of GIS.

GIS can also be very effective in residential built-out analysis. This predicts how many units will be developed in undeveloped areas. Based on this, water, sewerage and power utilities can plan where to put new water, sewage and power distribution supply and water and sewage treatment facilities and how large should those be.

Field Mobility

This gives field staff tools to remotely collect and confirm information about asset locations and conditions. From the office data can be sent to the field for validation and then returned to operation's centralized database for distribution in near real-time, providing timely and accurate information throughout the organization.

Citizen Engagement

The Citizen as a Sensor

GIS-based online applications can be developed to engage the citizens. These applications will help the public easily connect with the government and in turn help government better understand the citizenry it serves. Web and mobile apps can allow government organizations to receive immediate feedback from citizens including reports of incidents, suggestions and general comments. A person walking through a park can pull out a smartphone and provide a realtime report on problems or ideas for improvement. Casting a wider net for citizen input, these apps help government know what's happening on the ground in a community so it can try to improve the services.

Smart Cities

Smart cities recognize citizens as important data sources. As such, these cities are making it easy for the public to deliver real-time comments online or via mobile devices, which is a stark contrast to the time-consuming processes of calling or visiting city office. Adding citizens to vast network of sensors, cameras, smart meters and other data-collection systems gives government a more detailed understanding of a community. Inputs can be automatically fed into a GIS to help agencies improve processes and analyses.

The Geographic Connection

Geography connects citizens and the people who serve in government and GIS naturally facilitates communication about place-based issues. With a steady stream of public input, governments have an increased ability to base operations on the needs of the community, whether it involves repairing a broken streetlight or potholes. As citizen-generated data becomes part of the government workflow, operations become smoother and more responsive. Ongoing connection between citizens and government also helps organizations achieve accountability and transparency.

Conclusion

GIS as an enabling technology forms the core of design, development, execution and management of smart cities, whether green-field or brown-field. GIS can be the platform for various departments and services to exchange information and interact with the citizens. Modern technologies including a variety of sensors and high-speed networks can provide the real-time data to the GIS for better management of smart cities.

Examples of GIS Applications in Smart Cities

Land Use Planning

- Parcel inventory of zoning areas, floodplains, industrial parks, land uses, trees, green spaces etc.
- Analysis of percentage of land used in each category, density levels by neighbourhoods, threats to residential amenities, proximity to unwanted land uses
- Modeling of expected residential, commercial and industrial population growth for land use plan, evaluation of land use plan based on demographic characteristics of nearby population

Utilities and Infrastructure

- Inventory of roads, sidewalks, bridges and utility networks with all utility assets
- Attribute information including name, location, condition, most recent maintenance
- Analysis of infrastructure conditions by demographic variables such as income, population change
- Use of analysis to plan and schedule proactive maintenance and expansion based on estimated future load

Transportation and Solid Waste Management

- Identification of bus, MRT and LRT routes, road capacity and condition, signaling system equipment etc.
- Identification of accident sites
- Identification of sanitation truck routes, capacities, and staffing by area
- Identification of landfill and recycling sites
- Analysis of potential capacity strain considering development in certain areas
- Analysis of accident patterns by type of site
- Analysis of sanitation truck routing in relation to area pickup needs, routing efficiency, and destination sites
- Use of analysis to identify ideal high-density development areas based on criteria such as established transportation capacity
- Use of analysis to identify potential alternative traffic flow mechanisms

- Use of analysis to decide where recycling programs or sites should be located

Health

- Identify locations of persons with particular health problems (e.g. asthma)
- Spatial, time-series analysis of the spread of disease
- Analysis of association of disease with environmental conditions (e.g. proximity to heavy traffic roads creating pollution)
- Use of analysis to pinpoint possible sources of disease

Law Enforcement

- Inventory of location of police stations, crimes, arrests, convicted perpetrators, and victims
- Plotting of police beats and patrol car routing
- Security system locations
- Analysis of police visibility and presence
- Officers and police stations available in relation to density of criminal activity
- Victim profiles in relationship to residential populations
- Reallocate police sources and facilities to areas where they are likely to be most effective

Environmental Monitoring

- Inventory of environmental hazards in relation to vital resources such as groundwater
- Pollution sources
- Analysis of spread rates and cumulative pollution levels
- Using multiple overlays of different pollutants to identify areas of potentially negative synergistic effect
- Modeling of potential environmental harm and duration of harm to specific local areas
- Place specific pollution abatement plans

Emergency Management

- Location of key emergency exit routes, their traffic flow capacity, and critical danger points (e.g. weak bridges)
- Analysis of potential effects of emergencies various magnitudes on mobility, traffic flow, inundation, short circuits etc.
- Modeling of effect of placing emergency facilities and response capacities in particular locations

About Esri India

Esri India (NIIT GIS Limited) is an end-to-end Geospatial Information Systems (GIS) based solutions provider and enjoys a leadership position in India with a large customer base of Esri suite of software. Esri India also provides ArcFM Utilities solutions from Schneider Electric (Telvent), Network Engineer Telecom solutions from Ericsson (Telcordia), Cellular Expert from HNIT-Baltic, Cityworks from Azteca Systems and ENVI Image Analysis and Processing solutions from Exelis VIS to its customers.

We offer solutions across various industry verticals such as Land management, Utilities, Infrastructure, Disaster Management, Telecommunications, Urban / Municipal, Transportation, Defence and Natural resources. With more than 15 years of rich experience backed by robust quality processes, we have successfully delivered GIS solutions for more than 5000 customers (including leading Global Fortune 500 companies) across various industries.

Established in 1996, Esri India is a strategic joint venture between Esri Inc., USA and NIIT Technologies Ltd., India.

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