



AN ESRI
WHITE PAPER

MAY 2017

A Practical Guide to GIS in Asset Management

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A Practical Guide to GIS in Asset Management

Executive Summary

Historically, best management practices (BMPs) for asset management refer to the 1990 edition of the *International Infrastructure Management Manual (IIMM)* from the New Zealand Asset Management Support (NAMS) group. The next major publication came in the form of Publicly Available Specification 55 (PAS-55) from the British Institute of Standards. The most notable standard today is the International Organization for Standardization 55000 (ISO-55000), under the direction of ISO Technical Committee 251.

Geographic information system (GIS) technology plays a key role in today's BMPs of asset management. This white paper discusses the role of GIS based on lessons learned in this author's experience at his own utility and from customer implementations of the Esri ecosystem.

From a personal perspective, this author's experience dates back to the *IIMM* days, implementing an enterprise asset management program at one of the largest municipal four-service utilities; electric, gas, water, and wastewater in North America. The initial launch took the *IIMM* literally and tried to implement a 48-step program for generation, transmission, distribution, treatment, and collection across the four services. With each service comprising from 5 to 10 major asset classes, more than 7,500 business process improvement opportunities were identified. This was, of course, too daunting. Reacting to this, asset management then boiled down to two questions: What do you have? and What are you doing about it? Conversely, this was too simple. Successful implementation through trial and error landed on a reasonably acceptable seven-step program. The seven steps are

1. Complete an asset inventory.
2. Complete an inventory of programs.
3. Determine levels of service.
4. Define roles and responsibilities.
5. Identify and calculate risk.
6. Extrapolate a forecast.
7. Adjust the budget accordingly

This white paper will provide context for all seven steps while focusing on the role of GIS. The first four steps are mutually independent and can be executed in parallel when beginning an asset management program. Yet all four need to come together as an organization executes steps five through seven.

Complete an Asset Inventory

The most tangible of the seven steps is collecting data for the asset inventory. In asset management, this is also known as an asset registry. In GIS, this is represented as features in various feature classes stored in datasets in the geodatabase. It is relatively straightforward to have a one-to-one relationship between the asset registry and the GIS geodatabase as a physical ledger. However, many financial systems use a general ledger, which is historically aggregated at a much higher level per funding mechanism, causing a many-to-one relationship. GIS can be used to help balance the physical and general ledgers.

There is great debate over what an asset is, and each organization must land on its own definition based on engineering significance, operational strategy, and financial accounting. The concepts of mass assets, units of property, spare parts, and so forth, go into this definition and therefore are beyond the scope of this document. With respect to GIS, the following can be used as an example of asset registry terms:

Asset Term	GIS Term	Example
Asset family	Dataset	Water
Asset class	Feature class	wMains
Asset specification	Attributes	Material = 'Cast Iron'
Asset	Feature	ObjectID = 123

An asset class can be grouped or separated, depending on the organization's preference. For example, the wMains feature class may identify transmission water mains and features via attribution (Trans = 'Y') or via subtype (SubTypeCD 1 = Transmission, SubTypeCD 2 = Distribution), or separated completely such as wMainsTrans and wMainsDist. Best management practices suggest subtyping in one feature class so that all the assets are present and can have unique engineering domains per subtype if necessary. This is especially true in sanitary sewers. Gravity mains of 8-inch diameter and smaller are typically classed as Local Collectors, and anything equal to or greater than 10 inches is classed as a Collector. Yet with sufficiently steep slope, an 8-inch gravity main can be designed to act as a Collector. Therefore, the GIS feature will have a diameter value of 8 inches, with a subtype of Collector. This distinction is critical in developing hydraulic capacity models and reporting to the United States Environmental Protection Agency.

The asset registry is the foundation to an asset management program and is inherently a function of the geodatabase in GIS. Additional information on managing, analyzing, and visualizing data can be found in the following help topics:

- [What is geodata?](#) (managing data)
- [What is geoprocessing?](#) (analyzing data)
- [Mapping and visualization in ArcGIS Desktop](#) (visualizing data)

Complete an Inventory of Programs

This is an inventory of administrative programs associated with the funding mechanisms in the general ledger. At first, it inherently appears to have nothing to do with GIS, yet it is a critical step, as this gives context to what data is collected for any given asset and can thus drive the GIS feature class attribution and data collection architecture. A water utility may have the following programs:

- Tap Water Testing
- Water Main Replacement
- Hydrant Flushing
- Sanitary Sewer Cleaning
- Fats, Oils, and Grease (FOG)

These programs also have a dedicated program manager and line item on the Annual Operating Plan (AOP). The measure of efficacy of the program would be the beneficial use of the funds spent. At times, these programs compete against one another for funding sources, and a utility must be able to prioritize the allocation of funds to optimize the overall beneficial use.

One example, from a customer utility, refers to a water main replacement program funded at \$2 million a year to replace aging infrastructure. An analysis of water main breaks highlighted the corrosion of cast-iron pipe that was from 35 to 45 years old as being the most significant cause. GIS was used to report over 150 miles of this vintage pipe in the system. Based on current funding in the program, it would have taken nearly 75 years just to remove the cast iron. Facing customer dissatisfaction of weekly water main breaks, the utility was able to successfully promote a rate increase for additional funding directed into the program for an accelerated replacement schedule.

Determine Levels of Service

The Level of Service (LOS), or what is sometimes simply referred to as service level, is a performance criteria of what the organization wants the asset to achieve. Multiple criteria are often reported as Key Performance Indicators (KPIs). This can be one of the most difficult aspects of asset management, as many organizations do not take a hard look at this. Many overachieve and want the assets to perform at maximum levels, indifferent to the cost.

In electric distribution, reliability is generally reported as 99.x percent. The more 9's — as in 99.99 versus 99.9999 or 99.999999 — the more exponentially expensive reliability gets, due to increased system investment. A common electric performance indicator is the System Average Interruption Duration Index (SAIDI), which is relatively low in the United States at roughly 1.5 hours per year. The lower the number, the higher the reliability and, many times, the electricity rate. Effective asset management practitioners will have a conversation with their ratepayers and ask if this service level is optimized. A negotiated electricity rate may be able to offer a lower electricity bill if customers were willing to let the SAIDI be increased to four hours (a reduction in reliability) with the possibility of its resulting in fewer overtime labor hours, reduced warehousing of parts, curtailed maintenance activities, and so forth.

In lieu of outage minutes, water utilities have common service-level KPIs with respect to line pressure in pounds per square inch (psi), number of water main breaks per 100 miles of pipe, percentage of operable fire hydrants, and so forth. The number one KPI in wastewater is the total number of Sanitary Sewer Overflows (SSOs). Preferably, this number is zero.

GIS can play a role in LOS by carrying the appropriate attributes for network system analysis, or it can help in the engineering design. Many times, overall system reliability can be improved by sectionalizing or isolating problem-prone areas. The GIS network can be used to optimize those assets and devices for segmentation. Water loss, or more specifically, Non-Revenue Water, can be reduced by implementing District Metered Areas (DMAs). Managing DMAs can be achieved with the [Nighttime Flow Analysis](#) configuration of ArcGIS® for Water Utilities.

Define Roles and Responsibilities

Roles and responsibilities are more than items on an organizational chart. Indeed, many organizations align work groups and program budgets based on people instead of assets. Asset management best practices suggest aligning functional roles based on asset classes. This way, a specific program, managed by a specific group of people with specific skill sets, is designed to optimize the life and performance of specific assets. For example, a water operations crew performs maintenance on fire hydrants funded by the hydrant flushing program in order to meet the KPI of 95 percent of operable fire hydrants.

Determining the number of resources in any given work group can directly be supported by GIS by analyzing work efforts for a given set of assets, and then calculating the overall effort when applied to the entire asset registry, including drive time. For example, if a two-person fire hydrant flushing crew can flush 25 hydrants a day and there are 10,000 hydrants in the asset registry, then an organization would need 2.0 crews to flush every hydrant in one year:

- 10,000 total hydrants in GIS
- 25 hydrants per crew per day
- 2 Full-Time Employees (FTEs) per crew
- 8 hours per FTE (16 hours per crew)
- 2,080 hours per year (after vacations, holidays, sick leave, etc.)
- 1.25 travel factor calculated from GIS (more accurate with actual routes)

$$10,000 \text{ hyd} * \left(\frac{16 \text{ hrs}}{25 \text{ hyd}}\right) * 1.25 * \left(\frac{1 \text{ FTE}}{2,080 \text{ hrs/yr}}\right) * \left(\frac{1 \text{ crew}}{2 \text{ FTEs}}\right) = 1.92 \text{ crews}$$

These calculations can be applied for all work groups for all asset classes to approximate the necessary staffing requirements. These data-driven staffing requirements can be useful when budget cuts necessitate doing more with less.

Identify and Calculate Risk

Calculating risk is the number one analytical benefit of using GIS in asset management. A data-driven, reproducible method of calculating risk demonstrates fiscal accountability and transparency to an organization's citizens, customers, and stakeholders. Using GIS to calculate risk converts institutional experience into the codified business rules from which to make decisions.

Start with the simplified equation for risk:

$$\text{risk} = (\text{probability of failure}) * (\text{impact of failure})$$

Calculating the probability of failure for assets deals with maintenance activities, material degradation, construction methodologies, manufacturing defects, and so forth. The probability of failure is a function of the asset condition. There are many [mobile tools](#) that GIS can provide to collect asset condition data, but they do not directly calculate the probability of failure. Further discussion of the probabilities of failure is beyond the scope of this white paper, but the use of GIS analysis to better understand the cause of the failure will be highlighted.

GIS can often help explain why an asset has failed in a given environment. Based on the premise that a 100-foot-long, 6-inch-diameter steel pipe will perform differently when placed in a dry sandy soil versus in a groundwater saturated corrosive clay, GIS brings together environmental data that explains potential premature failure conditions.

In lieu of asset condition, probability of failure can be estimated from asset age. With a complete asset inventory in the GIS, reporting on the total count, sum of miles, and so forth, per asset vintage is an easy calculation. Histograms of assets based on age are known as age curves or humps, since most communities have growth spurts over time that create groupings of aged assets. These curves can be indicative of technology advancement in materials, such as the eras in water pipes: the earliest of cast iron (CIP), then ductile iron (DIP), then polyvinyl chloride (PVC), and the latest high density polyethylene (HDPE).

A basic asset management principle is that assets can fail from a lack of integrity and/or capacity overload. All assets have an intent to serve, thus a 6-inch sanitary sewer main—designed to collect sewage from 100 homes—can fail when an entirely new constructed subdivision upstream adds another 100 homes without said sanitary sewer main being upsized to 8 inches or 10 inches to carry the additional effluent. Additionally, GIS can be used to identify potential risks of failure from external causes such as easement encroachment on a major pipeline. Failure can sometimes be a result of homes or industries being built near assets and engaging in daily activities that can physically damage an asset and are beyond the control of the infrastructure owner-operator.

Here are some examples of GIS data used to assess failure:

Failure Mechanisms

Integrity

- Material degradation
 - Corrosion from soil mineralogy and/or groundwater infiltration
 - Dynamic loads from arterial roads
- Physical damage
 - Moving soils defined within geologic hazards
 - Zones of excavation
 - Right of way and/or easement enforcement

Capacity

- Network parameters that affect flow in electron potential, fluid hydraulics, traffic movement, and so forth
- Demographics that may change over time, enhancing or negating the intent of the asset
- Land-use changes over time that alter the original design criteria for the asset

Calculating the impact of failure is directly applicable to GIS, as impact is a function of location whether by criticality of an asset within a collection of assets or by simple proximity to critical things. Therefore, impact of failure can be rewritten as follows:

$$criticality = f(location)$$

Thus location or position calculated from the GIS can be used to determine criticality and the ultimate impact of failure.

Here are some examples of GIS data used to assess impact based on criticality:

- Physical
 - Critical infrastructure defined by attribution or asset class (i.e., transmission mains versus distribution mains or service laterals)
 - Criticality to other assets, either physical or human (i.e., electricity service to hospitals, schools, and manufacturing plants; fire hydrants for fighting fires)
- Environmental
 - Critical habitats of endangered species, wetlands, coastal reefs, and so forth
- Society
 - Hazardous materials' transport through populated areas, noise pollution, light pollution, scenic aesthetics, and so forth
 - Customer satisfaction assessed from the tone of social media posts, georeferenced Twitter feeds, and so forth

There are specific GIS analytical functions that can be used in addition to the data above for calculating the impact of failure. Sample ArcGIS syntax is used to illustrate these functions. These include, but are not limited to, the following:

Criticality based on proximity

- Buffer_analysis (wHydrants, wHydrants_Buffer, 500) creates a buffer of 500 feet around every hydrant.
- Intersect_analysis (wHydrants_Buffer, Hospitals) identifies critical hydrants that are within 500 feet of a hospital.

Note: This can be applied to any critical facility layer.

Failure due to corrosion

- MakeQueryLayer_management (SDE, Corrosive_Soils, select * from USA_Soil_Map_Units_2011 where SteelCorrosion = 'High') creates a soil polygon layer of highly corrosive soils.
- MakeQueryLayer_management (SDE, Steel_Mains, select * from wMains where Material = 'Steel') creates a line layer of steel pipe.
- Intersect_analysis (Steel_Mains, Corrosive_Soils) identifies sections of steel pipe that are within corrosive soils.

Note: This can be applied to any geologic hazard or road vibrations from heavy traffic.

Criticality based on availability

- PointDistance_analysis (wHydrants, wHydrants, Hydrant_Density, #) creates a table of distances from one hydrant to the next nearest hydrant.
- MakeQueryLayer_management (SDE, Critical_Hydrants, select * from Hydrant_Density where Distance > 500) creates a list of critical hydrants that have no other hydrant within 500 feet (i.e., if there is a fire, this is the only hydrant within reach of standard fire hoses)

Excessive failures

- HotSpots_stats (WorkOrders, Breaks, Water_Main_Breaks, INVERSE_DISTANCE_SQUARED, EUCLIDEAN_DISTANCE, NONE, #, #, #, NO_FDR) creates a hot spot analysis showing where water main breaks are most significant, indicating a complete replacement under a capital improvement program.

More advanced network tracing tools can be used to identify

- Failure due to weakest link connectivity (i.e., a valve in poor condition can jeopardize the integrity of an entire connected pipeline).

- Criticality based on ordinality (ordinal number) (i.e., first-order valves nearest a treated potable water tank are the most critical in the event of a water main break in case all other isolation valves in the distribution system fail to close around the water main).

A useful geoprocessing function in GIS can help users understand asset behavior at a larger scale than exists in the asset registry. For example, what is a pipe? Some may say it is a single section of manufactured pipe. Best practice asset management principles suggest that a pipe is multiple sections of manufactured pipe terminated by operable devices such as valves, and for gravity mains sections extending from manhole to manhole.

The GIS can consolidate multiple sections into one "superpipe" based on attribution, such as pipes that have the same diameter, material, and installation date. If the valves along this superpipe are normally open, this superpipe hydraulically acts as one pipe, and it can be assumed that failure mechanisms may be the same across this super asset. Affixing water main breaks in a neighborhood to these superpipes will provide a better statistical representation of asset performance.

- Dissolve_management (wMains, C:/output/output.gdb/wMains_dissolved, [DIAMETER,MATERIAL,INSTALL_DATE], "", SINGLE_PART,DISSOLVE_LINES)

Note: The original asset registry is not harmed, and the consolidated features are placed into a new feature class for analysis.

Extrapolate a Forecast

A fundamental goal of an asset management program is to predict the future. As noted, calculating the probability of failure is beyond the scope of this white paper. But once this is determined — or better yet, once asset performance curves are calculated and the useful life percentage for individual assets and asset classes is understood — the asset registry in the GIS can be used to extrapolate overall useful life of the system.

The useful life of an asset is an estimate of the number of years an asset will remain in service. A variety of factors contribute to determining this estimate: usage patterns, maintenance, age, level of service, and so forth. The variation in geography across a service territory can be analyzed for impact to specific useful life observations, as noted above in identifying and calculating risk.

This asset-based level of analysis — using the GIS to extrapolate to the entire system — typically has a higher fidelity than a Weibull analysis, which uses system averages. Using the GIS to understand the *why* of failure allows the use of other GIS layers such as land use, land zoning, soil morphology, groundwater intrusion, and dynamic loading from streets, to overlay zones of impact to useful life for the assets and asset classes in the GIS.

Also, as noted above, useful life can be estimated using the age of an asset through generally accepted degradation curves; calibrating useful life by collecting the asset's actual condition increases the accuracy of the forecast. Mobile tools in GIS are

making the collection of empirically observed condition easier than ever. Mobile forms that quickly guide field personnel to collect the right information improve efficiency and data accuracy. More information about data collection can be found at [Survey123 for ArcGIS](#).

Adjust the Budget Accordingly

The business value of having a forecast is a more realistic, optimized budget. The GIS provides a visual representation of this budget in both a spatial and temporal view. Budgets are typically linked to a general ledger as a record of a company's accounts. A general ledger is used to store a complete record of financial transactions that are used to create financial statements, inclusive of a budget. Many of these transactions are against the very assets themselves. Reconciling the asset registry with the physical records in a GIS gets organizations closer to balancing the general ledger with their physical ledger.

A key component of balancing a budget is accurately determining depreciation of assets. Depreciation is the conversion of the cost of an asset into an operational expense. Depreciation is calculated by taking the cost of an asset and subtracting the end of life (salvage) value and then dispersing the remaining value over the life-span of the asset. Therefore, accurate useful life curves determined by GIS analysis yield accurate depreciation assessments and, ultimately, balanced budgets.

By leveraging accurate useful life calculations based on geography, areas of focused spending can be identified to optimize the overall capital improvement project budget.

Summary

GIS converts asset management standards, best management practices, and institutional knowledge into an operational asset management program. The quantified steps of building inventories with administrative overlays set the stage for predicting outcomes. The single greatest benefit of using GIS is to create a geospatial and temporal model of the built and natural environments to identify, calculate, and predict risk.

There are many other resources on the Internet that demonstrate the use of GIS in optimizing operations and maintenance (O&M) activities; therefore, the content of this white paper focused on the practical use of GIS in asset management.



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