TRB Paper Manuscript #16-2121

Enterprise GIS in a Commuter Rail Environment: State-of-Practice at a Major Northeastern Carrier

Xiaojing Wei, Alex Lu, John Kennard, David Fogel*
** Corresponding author*

Xiaojing Wei, GISP
Manager of Enterprise GIS Program, Metro-North Railroad
420 Lexington Ave., 12th Floor, New York, N.Y. 10170-1200
Tel: (212) 340-4828
Email: *Wei@mnr.org*

Alex Lu
Senior Specialist—Program Analysis, Metro-North Railroad
420 Lexington Ave., 12th Floor, New York, N.Y. 10170-1200
Tel: (212) 340-2684
Email: *Lu@mnr.org*

John E. Kennard
Vice President, Capital Programs, Metro-North Railroad
420 Lexington Ave., 11th Floor, New York, N.Y. 10170-1100
Tel: (212) 340-3982
Email: *JKennard@mnr.org*

David Fogel, AICP
Deputy Director, Capital Planning & Programming, Metro-North Railroad
420 Lexington Ave., 12th Floor, New York, N.Y. 10170-1200
Tel: (212) 340-3327
Email: *DFogel@mnr.org*

Submitted for Consideration for Publication in
Transportation Research Records: Journal of the Transportation Research Board

Word Count: 246 (Abstract) + 5,754 (Text) + 6 * 250 (Figures) = 7,500 Words
Submittal Date: July 31, 2015

Keywords: Geographic Information System, Enterprise GIS, commuter rail, business case, strategy, approach, marketing, staffing, standards, policy, procedures

ABSTRACT

Triggered by both Superstorm Sandy aftermath and a minor operational incident—where accurate and rapid mapping would have been tremendously helpful—Metro-North Commuter Railroad deployed its first Enterprise Geographic Information System (GIS) in 2012 by federating existing departmental systems, creating a companywide Office of GIS Coordination, promulgating GIS policies and standards, and developing and marketing a uniform set of web mapping viewers designed for all employees. This paper describes state-of-practice and a checklist of strategies utilized to promote a new technology that, by its very nature, requires interdisciplinary collaboration and coordination within a proud organization steeped in rich tradition of craft-based engineering excellence. From early beginnings of companywide survey and finding an organizational home for GIS, to later phases of training, holding project managers responsible for consultant data deliverables, refreshing marketing campaigns and monitoring usage, this case study offers a glimpse of how creeping incrementalism and a web-based rapid deployment strategy can overcome institutional inertia, culminating in an ongoing culture transformation where GIS became a common acronym understood by many functional groups and managerial levels within the organization. While there will always be different degree of GIS readiness across departments, many employees at Metro-North now see the value of GIS and proactively seek it out as a resource to improve their daily workflow where circumstances warrant. Mobile device accessibility is the next logical phase of Enterprise GIS development, allowing field forces to reference and share information without printing out hardcopy maps or calling-in to office.

INTRODUCTION

Metropolitan Transportation Authority (MTA), State of New York Metro-North Railroad (Metro-North) operates regional rail service between New York City and its northern and eastern suburbs. Assuming operations from Conrail in 1983 after its Federally-mandated divestment in commuter services, Metro-North today operates about 790 track miles serving 124 stations seven New York counties and two Connecticut counties. With a service territory covering 2,701 square miles, travellers and connecting services originating from adjacent commonwealths of Massachusetts, New Jersey, and Pennsylvania, overhead Amtrak trains operating to key intercity destinations on the Northeast Corridor, Midwest, Vermont, and Canada—and freight services travelling over Metropolitan Region territory on the general system of railroads, Enterprise Geographic Information Systems (EGIS) is a truly nationwide endeavor at Metro-North.

With over 6,000 employees (of which approximately 1,000 are professional, technical, or managerial), Metro-North's Enterprise GIS needs transcends many departments, disciplines, jurisdictions, traditions, and employee backgrounds, demographics, and technical proficiency. At 84.7 million annual riders, Metro-North's 2014 ridership was highest in its 31 year history, requiring a robust Enterprise GIS architecture to serve the needs of its broad, diverse, and generally technically-savvy customer base. With 1,138 bridges, 3,503 drainage structures, 111 grade crossings, more than 1,420 alternating current catenary poles, and 6,500 track inspection “flags” being generated every six months, databases must be tremendously scalable—it currently has 500 feature classes and growing.

Under MTA's umbrella oversight, Metro-North's EGIS must be compatible with, share and exchange data with, not only sister agencies like MTA Long Island Rail Road (LIRR) and MTA Bridges and Tunnels, but also regional emergency management agencies and local governments big and small from New York City Office of Emergency Management (NYC OEM), New York City Police Department (NYPD) to smaller entities such as Village of Hastings-on-Hudson. If it is the transport function and *raison d'être* of commuter rail systems to be the lifeline that connects rural hamlets and townships to the City, nowhere else is variety of scale and differing requirement more vividly illustrated than in the Enterprise GIS program.

As another illustration of tremendous variations in temporal and spatial scale, Metro-North's business needs call for an EGIS capable of tracking precise routing of cable ducts, trays, and drainage wells within our right-of-way using survey-grade GPS—but can also manipulate maps that shows all five lines and regional connections in the entire Northeast Region. Track defect surveys must distinguish between left and right hand running rails, and locate problems to within four feet of a railroad tie (nearest 2-3 ties), but also conduct longitudinal analysis going back as far as data would allow. Train operations need to know in real-time which train is on which track and if crossover moves are being made. Demographics planners visualize population growth of entire service area over 30-50 years.

Metro-North Enterprise GIS, now in its third year of operation, is a success story of creeping incrementalism overcoming institutional inertia at a time of tremendous corporate turbulence due to succession planning challenges and incidents of historic proportions. This paper provides a case study of management practices and ideas used to justify investment in EGIS, generate internal support, increase momentum, implement policies, practices, and new or modified business processes against this background.

BUSINESS CASE FOR ENTERPRISE GIS

In mid-2012, employee seeking geospatial information already had a plethora of resources available throughout the company. However, not all data was available in GIS geodatabase format, data from disparate systems was difficult to overlay, nor was there an organizing framework for making data easier to find and access. Quite frequently, the nascent GIS Office discovered data sources not well known to others, including sometimes employees within the same department! Systems were also variously called BIM, CAD, GPS, or simply known by proprietary names or vendor-creator company names. Although these resources were available, and it was understood by some that information could be shared and made more useful to everybody if the right platform was available, several organizational questions needed to be answered before EGIS could really get underway. In the meantime, trigger events occurred that brought GIS to the forefront of the organization's focus—and highlighted GIS needs that weren't being met by resources then available.

Trigger Event—Hurricane Sandy

Hurricane Sandy made landfall at 8pm on October 29, 2012 near Brigantine, N.J. with maximum sustained winds of 80mph. Shortly thereafter, a maximum storm surge of 9.4 feet (above mean lower low water) was recorded at NOAA station at The Battery, N.Y. (southern tip of Manhattan Island). Although Governor Cuomo took unprecedented steps in preparation to close all transit systems beginning 8pm on October 28, flooding nonetheless caused widespread destruction to New York's transit systems, including severe water damage to New York City Transit Authority's numerous underwater tunnels between Manhattan and Brooklyn, LIRR's electric power, signal, and yard infrastructure in the Rockaways, Long Beach, Manhattan's west side, and Metro-North's Harlem River Lift Bridge and Hudson Line south of Croton-Harmon—formerly known as New York Central "Water Level Route", much of which was constructed on land reclaimed from the Hudson River, with parts barely 6-8 feet above water level (Figure 1(a)-(d)).

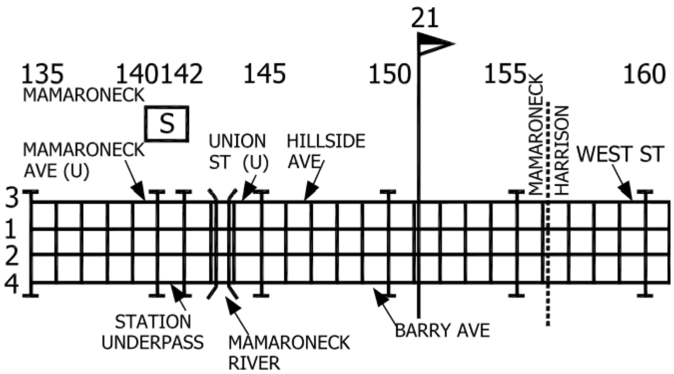
In the aftermath, insurance claim maps were required to show exact geographical location of key infrastructure assets in relation to Federal Emergency Management Agency (FEMA) base flood elevations (Figure 1(f)); flood maps were needed to assess risks to existing infrastructure and to determine design standards for replacement infrastructure (Figure 1(e)). Many other maps were requested, sometimes at short notice, to provide visuals for discussions with outside stakeholders and assessors. At that time, it became obvious that other agencies had a "GIS contact" and a department to coordinate sharing and mapping of geographic data, whereas Metro-North was reliant on many outside contractors each with different expertise and dataset, yet had no internal capability to quickly turn around map products. As in other railways (*5*), flood mapping is very much a key competency offered by mature GIS programs.

Trigger Event—Westport 1532

On July 22, 2011, an electric train stopped between Westport and Green's Farms stations, in a rural part of Connecticut, due to sagging electric catenary wire being snagged by a pantograph during an unusual heat wave. While catenary was powered-off and under repair, several passengers onboard called 911 to report that traincar interior temperature was rising and uncomfortable for some.

(Figure 1 continues on next page)

(g)



(h)

(j)

How often do you or your Department need to communicate or describe the location of something to someone else within the company?

[ ] Constantly [ ] Several times a day [ ] Once a day
[x] Few times a week [ ] Few times a month [ ] Rarely

How would you typically describe the location? (e.g. 1,750 ft. N. of CP 244)

By CP, station or catenary pole

How much time do you or your Department spend manually counting the number of instances something or some incident occupies a given space? (e.g., Station platform gap incidents; how many track circuits are between CP 216 and CP 223? How many Northbound Amtrak trains were delayed entering New Rochelle in 2011? How many people live within 2.5 miles of this station?)

[ ] All day long [ ] Half of my day [ ] An hour a day
[x] An hour a week [ ] Few mins per month [ ] Never do it

What reference sources would you use to figure that out?

The on car data reports incidents with GPS locations. This has to be analyzed when one kind of incident becomes frequent.

(k)

GIS Need	% Respondents
Precisely describing a location (at least monthly)	90%
Communicating a location (e.g. geocodes) to an outside entity	66%
Locate a fixed asset in the field	62%
Print out a map for sharing, reporting, etc.	34%
Count number of features within a geographic area	62%-66%

Figure 1. Enterprise GIS Trigger Events and Early Strategy: (a) Boat Removal—To restore Hudson Line service after Hurricane Sandy, a crane was needed to remove a boat that had washed up on the tracks near milepost 31 at Ossining, N.Y. (Photo: MTA/Al Cecere); (b) Metro-North Right-of-Way (ROW) between Philipse Manor and Scarborough shows N.Y. Central "Water Level Route" at barely 6-8 ft above the Hudson River, with Tappan Zee Bridge in the background; (c) ROW in the vicinity of Bear Mountain Bridge is surrounded by water on both sides; (d) Topographical Contours near Kemey's Cove in Scarborough, N.Y.; (e) Track and Asset Inundation Map Book (*3*) generated in the wake of Hurricane Irene; (f) Map showing substation A-25 bisected by FEMA 500-year flood limit but was nevertheless inundated by Sandy (Map: Day Environmental/Chris Smelt); (g) Traditional engineering diagrams showing catenary locations do not relate well to outside features and are not easily understood by emergency personnel; (h) GIS-based representations makes clear the relationship between catenary poles and other features like stations and overpasses; (j) GIS survey instrument with sample response; (k) GIS survey results.

While this might otherwise be described as a routine incident, when Westport emergency services attempted to provide assistance, they were unable to locate the train because Metro-North internally tracks locations using interlockings, mileposts (not well known outside the railroad), and "catenary pole numbers" (Figure 1(g)-(h)) that forms in essence a proprietary linear-referencing system (south to north) along New Haven Line—whereas emergency services typically use cross streets and longitude-latitude geocodes. With difficulty in geo-translation, it took 45 minutes for emergency services to ascertain train's location near Beachside Ave. overpass in Westport.

Once arrived, emergency services was unable to determine how best to access right-of-way—by the time a plan was figured out, power had been restored and so train started up and moved into Green's Farms station, ½ mile away. While this incident resulted in no serious lingering effects, it highlighted importance of coordination and joint drills between local emergency responders and Metro-North, and ensuring compatible means of communicating geographical locations exist. GIS is an accepted emergency management practice in air (*6*), highway (*7*), and hazmat transport (*8*), but application to passenger railway appears to be a novel practice within extant literature.

EARLY STRATEGY

Early strategy adopted by Planning group was one of education and outreach. While background GIS level-of-comfort existed amongst some technical managers, this did not extend to executive chambers at first. Targeted discussions and early products were critical to achieving buy-in at highest levels.

Companywide GIS Survey

While employees agreed that better GIS would advance company's mission, divergence of opinions existed as to how best to deliver it and relative priorities. To help achieve consensus on defining and scoping EGIS, a companywide survey was used as a strategy. It gathered some quantitative data, but was really designed for educating stakeholders, and generating support and publicity. Few questions (and sample answers) are reproduced in Figure 1(j) to illustrate type of questions that educate stakeholders on value of GIS, and less for data gathering. Results are shown in Figure 1(k), which helped to provide "ammunition" for budget justification.

Another benefit was to help generate ideas for EGIS pilot projects. Some departments have heretofore not been on GIS Office's radar as requiring GIS support, but actually articulated such convincing answers that they received higher priority as EGIS was rolled out. For instance, engineers throughout the company found it difficult to locate as-built record drawings of infrastructure, and wanted an interface where online maps would offer access to drawings by location. This idea, first identified in companywide GIS survey, eventually became an EGIS management initiative.

Hire GIS Specialist

One theme coming out of the survey was, while GIS is everybody's job at some level, it is also nobody's job. Dedicated resources were needed in GIS Office to manage the program. Job posting (Figure 2) was drawn up for a GIS specialist to perform all roles related to EGIS—coordination, production, and evangelical roles. Recruitment for such employee was expected to be difficult as it combines high organizational, technical, and people skills requirements all within one position.

To address anticipated recruitment difficulties, a multi-pronged approach was taken. Job was posted to MTA website through normal channels, but copies of posting was also distributed to alumni lists of local

GIS college programs, online GIS network groups, GIS staff amongst vendor communities, and non-traditional channels like mapping and orienteering enthusiast communities, railroad professional networks, etc. This generated a good response; in fact each finalist in selection process came through a different channel; some may not have seen the posting had a wide variety of channels to reach potential candidates not been used.

Where should GIS Live?

Having decided to hire a GIS Specialist, another issue was where GIS Office belongs organizationally. Initially, GIS position was slated for Safety and Security, a large user department, but not ultimate owner of infrastructure or associated data. Finance and I.T. was considered logical, but it was thought important to establish GIS office in the business side rather than support side, to ensure presence of a business champion for the entire affair.

Literature review and benchmarking yielded no consistent patterns (*1,2*), with some organizations putting GIS within large user departments like Planning or Engineering, others putting GIS in support groups like I.T. or Analysis, while some have created special purpose "GIS Department" attached directly to Executive offices or put in corporate functional areas like Graphics or Public Affairs. Indeed, within MTA agencies diversity of placements exist: LIRR put GIS within Strategic Investments, whereas NYCTA had GIS within I.T., and MTA headquarters put it in Planning. In essence, there is no rhyme or reason as to where GIS should reside to maximize effectiveness. Key is obtaining appropriate executive sponsorship.

After discussion, decision was to house the function in Capital Planning department. Historically, Planning unit had been a natural organizational home for analytical functions that required "time to think" and for integration functions requiring close interfaces and a team approach with many departments across the railroad. At that time, Planning is one of few areas within the company that were familiar with this "matrix" organizational structure and thus considered suited to EGIS. However, in other organizations logical home for GIS could be different, and it could have easily gone another way and still be just as successful.

SIZING ENTERPRISE GIS INFRASTRUCTURE

In GIS's early stages, discussions were held between corporate and I.T. regarding hardware and software needs. Conflicts arose because I.T. favored an "Enterprise" model with many software licenses (sufficient to support entire company's eventual requirement) and large-scale resilient and redundant backup servers that could respond to many GIS requests simultaneously and provide for automatic failover in case of server failures—whereas corporate was concerned about demonstrating "return-on-investment" in terms of future headcount reductions (anticipating more efficient work processes that GIS could bring) to justify upfront investment in GIS.

I.T. understood GIS's benefits and criticality, thus they were particularly concerned that once deployed, if insufficient capacity or reliability was installed at the outset, I.T. would come under pressure for having undersized technology infrastructure. On the other hand, budget office was hesitant to commit copious operating revenues to a technology initiative which may or may not actually generate future cash savings, particularly since no single department agreed to commit to headcount or contracting reductions due to GIS investment. This impasse threatened to derail EGIS efforts.

Position Title Geographic Information Systems (GIS) Manager

Position Objective

Develop and lead efforts to expand GIS technology usage within Metro-North. Launch a companywide GIS initiative and manage its ongoing development by acting as point-of-contact and coordinator between departmental users, information technology, vendors, outside consultants and regional agencies. Serve as Metro-North's primary GIS resource for the identification of GIS needs, database construction and maintenance, and analysis requirements, including GIS mapping.

Responsibilities

Act as internal and external point of contact on all corporate GIS and associated data issues; provide functional and analytical expertise as a resource to GIS users within the company; define GIS data formats. Represent Metro-North at MTA and regional clearinghouses and industry trade groups to promote proper data interchange.

Chair the Metro-North GIS Task Force, working with departments to secure implementation of company-wide GIS initiative. Identify and work with designated departmental GIS liaisons to import existing databases into GIS, including GIS-enabled CAD drawings of capital projects. Develop processes and procedures, to ensure GIS data is routinely updated by data owners.

Create and maintain GIS base layers from publicly available material. Continually monitor, develop, and identify available databases (public and internal, AutoCAD, GIS, PDF, paper, etc.), GIS assets and resources, and staff persons with GIS experience or knowledge, to move corporate GIS initiative forward. Perform geospatial analysis as needed for studies, master plans and inquiries. Identify projects/tasks that would benefit from use of GIS applications.

Working with IT and liaisons, develop business needs, functional specifications, hardware and software requirements for the GIS initiative. Plan for integration of existing systems and databases, specifying consultant services where needed. Monitor levels of service on company-wide GIS resources; develop upgrades as required.

Serve as project manager for GIS initiatives establishing a timeline and budget.

Design and execute GIS training and outreach efforts: train liaisons to perform GIS analyses required of their workflows and to access and contribute data.

Continually assist departments in identifying unmet GIS need and new applications; recommend/specify new products to meet business demands. Monitor the rapidly changing GIS technologies marketplace; develop internal standards as necessary.

Provide in-person GIS support to Metro-North situation room in case of a major incident or weather event.

Required Qualifications

- Strong analytical and problem solving skills. Excellent verbal and written communication skills.
- Strong GIS development and database administration skills. Excellent knowledge of underlying technical principles of GIS databases, including data structures, issues, policy considerations, etc.
- Ability to assess GIS-aware data quantitatively.
- Demonstrated ability to specify, develop, formulate, and direct the implementation of, a wide range of GIS products including data exports, maps, and end-user web or desktop applications that relies on GIS databases.
- Project management proficiency.
- Must be organized, detail oriented, with proven ability to motivate and manage ad-hoc teams, and to move projects and initiatives forward. Strong leadership skills.
- Ability to build coalitions to implement initiatives, act as internal advocate, and external point of contact.
- Demonstrated ability to communicate with a wide range of departments and stakeholders with different job functions and varying degrees of subject matter understanding.
- Proficiency with Microsoft Office Suite (Word, Excel, PowerPoint), ArcGIS, TransCAD, and/or comparable applications.

Preferred Qualifications

- Experience running or initiating a companywide or department wide integrated GIS effort is strongly preferred.
- Experience in managing GIS efforts or other complex technical issues in a multi-modal, multi-stakeholder environment.
- Experience with defining and implementing companywide internal standards and protocols, particularly as it relates to GIS.
- Experience in defining or implementing regional ITS, GIS, EDI, or other data exchange architecture is preferred.
- Good knowledge of current GIS marketplace and tools, and current web application development platforms, is preferred.
- Knowledge of data warehousing and archiving practices is preferred.
- Ability to understand railroad operations and engineering organizational cultures is preferred.

Required Education/Experience

Bachelor's Degree in Geography, GIS, Computer Science, Engineering, City and Regional Planning, Transportation Planning, Technology Management, or related field.

Minimum five (5) years of progressively responsible experience in a GIS administration, project management, or management consulting function, including two years production and/or project management experience in GIS or other related surveying and mapping operations.

Preferred Education/Experience

Experience launching and implementing a comprehensive GIS initiative at a large public sector operations or engineering organization.

Figure 2 Sample GIS specialist job description, for first dedicated GIS employee in an organization.

Small-Scale but Expandable Infrastructure

A strategy was devised addressing everyone's concerns. At an initial stage, many employees' GIS roles are limited to visualizing map data (similar to Google Maps), a function easily fulfilled with web-based GIS viewers. Only advanced GIS users with specific software skills (including those in GIS Office) require desktop software licenses. Thus, initial deployment focuses on creating an Enterprise GIS web-server providing mapping services to employees, with very few desktop software licenses available only to those with advanced GIS skills. Individual licenses can be added incrementally as needs are identified—and more importantly budget for licenses can be allocated to specific departments based on utilization and business justification.

Leverage Enterprise Virtual Servers

Regarding EGIS web server, redundancy and resiliency was sacrificed in the short-run to reduce upfront investment, but technical architecture was designed for future scalability and expandability. Initial plan provided only a single server chain each for development and production environments (Figure 3(a)), but additional production servers could easily be added in a load-sharing configuration. Furthermore, EGIS web servers were built as “virtual servers”, not physical computers but boxes running under emulation on mainframe computers. Advantages of using “virtual server” technology is that, should needs arise, size of each server can be quickly increased simply by reconfiguring emulation set-up instead of physically adding processing units or memory modules. This design addressed I.T. 's concerns about potential need to quickly scale up GIS deployment in unforeseen situations, particularly when used for emergency management purposes.

FEDERATED APPROACH—SHARING OF RESPONSIBILITIES

One critical decision faced by the nascent GIS Office was whether to centralize GIS systems and functions or to federalize by sharing responsibility and control. Historically, government authorities in the Northeast approached technologies by creating large agencywide service offices and then consolidating technology functions to reduce duplication, increase specialization, and thereby theoretically reducing costs—i.e. attempting to do more with less by taking advantage of supposed economies of scale, most recently for payroll and general I.T. functions.

However, as EGIS developed, concerns arose from departments already using GIS regarding potentially disruptive consolidation impacts. Both Environmental Compliance and Bridge departments already had vendor-developed and proprietary GISes installed, both were used for critical business functions including aspects of asset management. When these systems were assessed in detail, it became clear that to replicate and transition these systems to new EGIS platform is both cost-prohibitive and potentially counter-productive. “Mother-of-all-systems” approach was neither technically feasible nor desirable, particularly due to different pre-existing user interfaces designed carefully to very closely mirror each department's business processes.

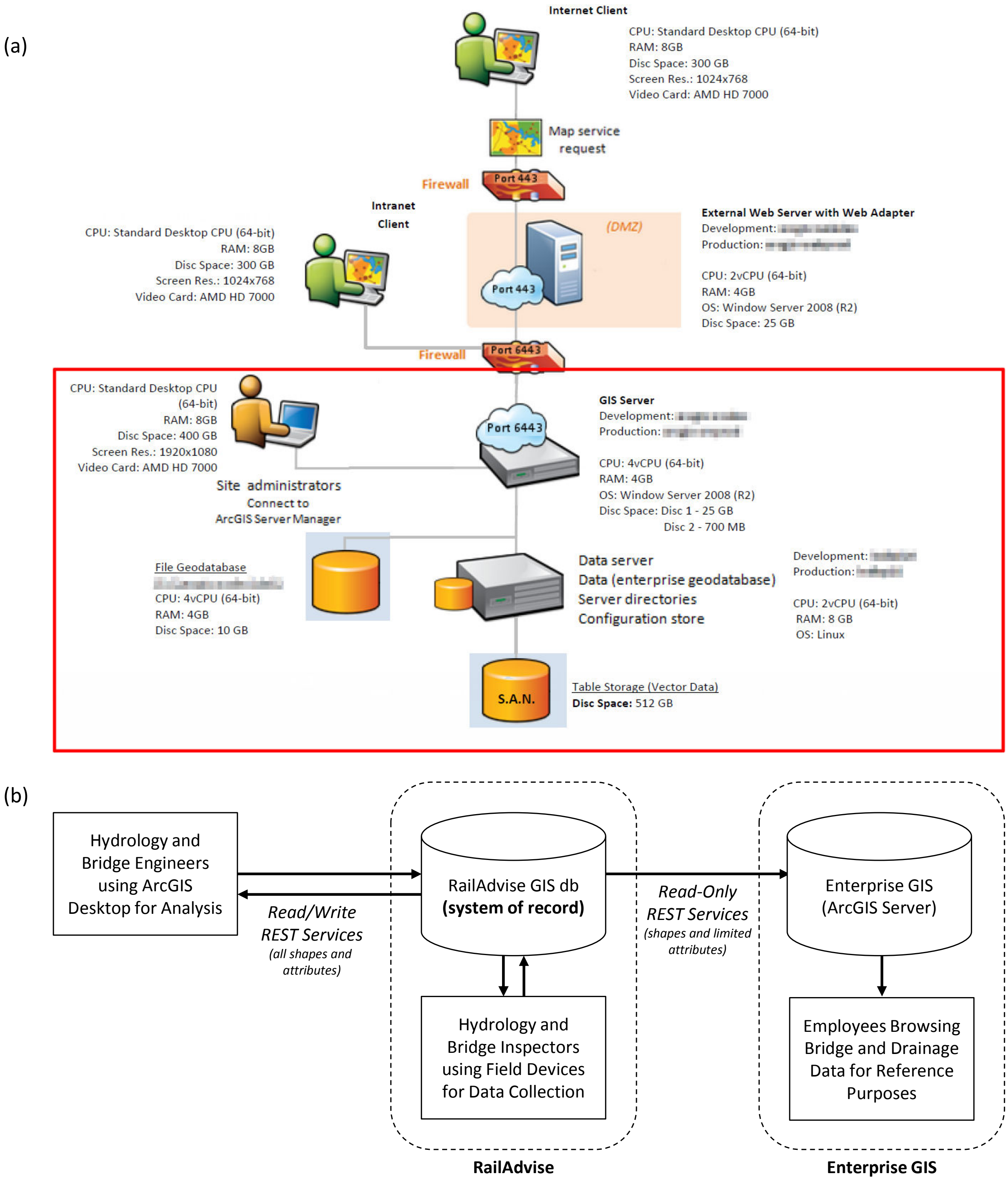


Figure 3. Enterprise GIS Architecture: (a) Initial server configuration was based on providing no redundancy but could support future resiliency upgrades; (b) Departmental systems would be the system of record while EGIS would fulfill a portal role with read-only access to departmental geodata.

Initially there was considerable difficulty explaining this finding to executives, who perhaps expected savings associated with bringing many systems into one. This approach gathered more support when it was cast in terms of a "federated" or "distributed" approach, where each department is responsible for maintaining its own GIS data and systems—but agrees to centralized standards and oversight, including data sharing. Data ownership is particularly important because GIS Office could never acquire sufficient resources or expertise to maintain specialized data associated with every railroad department. GIS Office's role is coordination and facilitating sharing—breaking down data silos where they exist—and not an outsourced configuration management function for everyone.

EGIS fulfills a portal-like function—most basic data is gathered from all departments and displayed on maps suitable for general audience of all employees and company executives. Clicking on assets belonging to specific departments (e.g. undergrade bridge) provides click-thrus to departmental GIS or asset management site, allowing those with proper access rights to view detailed drill-down. Updates of EGIS data is provided via interfaces like REST Services, allowing proprietary departmental applications to exchange data with EGIS (e.g. Figure 3(b)).

Decision rules determine how new GIS data is stored. Pragmatic, commonsense approach suggests that if user department already has GIS-like systems which employees are comfortable with, and has current vendor support, new data and functionalities are added to departmental systems (with relevant read-only EGIS interface). If user department doesn't have current installations, decision is based on whether current EGIS can support proposed data volume and functionality. Specialized functionalities or large data volumes (e.g. GIS data from track geometry cars) require specialized solutions installed departmentally; otherwise, data is hosted on EGIS, and GIS Office provides off-the-shelf application functionalities directly.

GIS Policies and Standards

One critical early action item in comprehensive EGIS programs at passenger railways are GIS policies and standards. GIS touches many corners of the organization, and can result in inter-departmental issues, particularly in an environment with horizontally isolated semi-autonomous functional units or districts often present in railways. GIS Office promulgated policies in six areas and attempted standardization in two areas with varying degrees of success.

Policies

1. **Software**—At time of EGIS inception, software budgets weren't centralized and each department held its own licenses. GIS software often offered possibility of "floating licenses," it was necessary to develop methods for allocating available software capacity and providing charging mechanism to user departments for purchasing add-ons and extensions, yet making licenses available for companywide use. Figure 4(a) shows example policy.

2. **Procurement (Boilerplate)**—In a full-service passenger railway infrastructure owner, capital projects are managed in-house with third-party contractors doing design and construction under railway personnel supervision. When capital projects are "delivered" to customer (i.e. Transportation or other user departments), "as-built" drawings and GIS/BIM models must be turned over, quality checked, and kept up-to-date as maintenance forces make repairs or alterations over time. GIS Office developed two separate policies, one governing construction

projects, and another governing consulting projects or equipment purchases, to ensure data and deliverables generated by projects pass through GIS quality check and appropriate georeferencing information is collected. Figure 4(b) shows important elements of these procurement policies. These policies don't apply to projects built entirely by in-house railway employee forces (i.e. Force Account); GIS updates for Force Account work must be dealt with by creating a configuration management group (potentially part of asset management efforts).

(a)

1. Software is a precious business resource and requests must be backed up by business justification.
2. Web-based GIS functionalities are preferred for all employees; desktop GIS is provided to advanced users.
3. Initial request should fill out form providing user name, job title, job description, rank, an example use case, and training needs.
4. GIS office will evaluate request based on whether example use case can be fulfilled by web service or if software is needed. Additional software procurements may be charged to the department budget.
5. Normally, the employee with GIS software will also serve as departmental GIS liaison.

(b)

1. All georeferenced deliverables shall specify coordinate system datum and projection, WGS84 or NYS State Plane is preferred. For vertical datum use NAVD88 or indicate "ground level".
2. Layers shall consist of different asset classes based on standard asset hierarchies. Asset attributes (e.g. install date, part number, etc.) shall be provided. Each asset shall have an unique ID.
3. Annotation and notes on CAD drawings shall be available as spreadsheet keyed to asset ID or as GIS attributes.
4. Data deliverables of measured values shall contain longitudes and latitudes for each data record and have properly defined units. Data shall be delivered in open formats such as CSV.
5. Contractor shall obtain any necessary clarification from project manager, whose sole discretion is binding and final.

(c)

Level 1 Public Access: Any GIS data already released to the public or easily observable from publicly accessible areas. No restrictions.
Level 2A Employee Access: Proprietary GIS data describing assets knowable to employees but not by general public without railroad knowledge (e.g. interlockings, culverts). Access restricted to employees only, or contractors with signed non-disclosure agreement.
Level 2B Departmental Access: Data designated by owner dept. as not available to employees without their approval (e.g. signal design charts). Access restricted to data owner department employees only.
Level 2C Confidential, Personal, or Private: Datasets accessible only to H.R., Legal, or Safety depts. with business justification.
Level 3 Sensitive Security Information (SSI): Classified by Security Dept. in accordance with FTA SSI guidelines. Must not be stored on networked computers or general-use GIS systems.

(d)

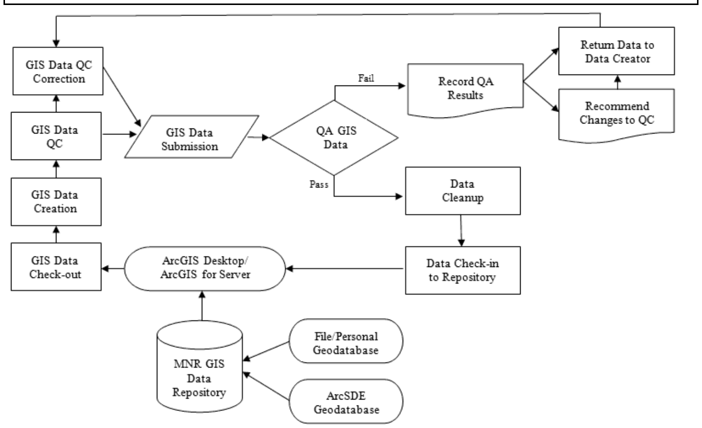


Figure 4. Enterprise GIS Policy and Standards: (a) skeletal framework of a sample software policy; (b) generic CAD drawing/data deliverable boilerplate language; (c) example data classification scheme; (d) sample check in/out and data QA/QC process.

3. **Data Security**—During EGIS process, it was discovered that no data classification guidelines existed within the organization for distinguishing between sensitive infrastructure data (e.g. load ratings of key structural members) and publicly-observable GIS information (e.g. passenger stations locations). Through meetings with Security department, data owners, and infrastructure asset owner groups facilitated by Security consultant (*4*), detailed guideline was developed to classify GIS data sources. Figure 4(c) shows these classifications.

4. **Data Hygiene Procedures**—Otherwise known as "check-in/-out process", its design intent is to ensure contractors and third parties can get access to railway's baseline data to perform updates without re-creating base maps or overwriting changes made by others. Ideally, in-house changes gets handled with multi-user geodatabases while third-party changes must be reviewed and QA/QC-ed by GIS specialists. Figure 4(d) shows an example process. Our efforts

in this area wasn't as successful due to early decision to federalize the EGIS framework, resulting in each department essentially keeping data exchange procedures existing prior to EGIS.

5. **Human Capital**—GIS/CAD and data skills are within today's standard engineering, planning, and business school curriculum. However, if not explicitly mentioned in job descriptions of technical and project manager roles, H.R. and hiring managers wouldn't necessarily screen for them, and thence organizational GIS proficiency would be low. Metro-North added under “preferred qualifications” requirements for GIS, CAD, MicroStation, statistical analysis, and database management skills in selected professional/technical positions within Capital Programs, Maintenance of Way, and Operations Administration divisions. Recognizing no single candidate is likely to possess all these skills, but many (but by no means all) recent engineering/planning graduates would have at least one, hiring manager is given latitude to select best candidate for their specific position, and are encouraged to give GIS skills metric due consideration, to support EGIS efforts.

6. **Establish Data Ownership and Update Responsibilities**—This is next logical step in classic Enterprise GIS process, to establish data ownership and devolve data updating responsibility to each department or a configuration management group. In an infrastructure-dominated railway environment, large fraction of GIS data concerns asset locations, thus GIS Office devolved this work item to ongoing asset management project.

Standards

1. **Coordinate System**—A frequent issue with decentralized GIS implementation is GIS products not being properly notated with datum, coordinate system, and projection upon delivery. GIS analysts then must “guess” and try different combinations, which could result in data inaccuracies. Boilerplates require global coordinate system of Project Manager's choice, to allow maximum flexibility for different types of projects while eliminating local coordinate and stationing systems that requires specialized project knowledge and translation before mapping to true locations on earth. One exception is allowed for projects within Grand Central Terminal (GCT), due to difficulty of obtaining GPS fix within tunnels, deliverables are permitted to use historic New York Central Railroad stationing and grid system, well-defined and generally known within the agency.

2. **Milepost Location**—Railroad mileposts are typically measured sequentially from a known point such as a major terminal or junction. However, over time, due to minor changes in alignments and/or movement in mile markers, long and short miles can occur. A project is underway by Maintenance of Way and a consultant to measure and re-mark locations of mileposts based on valuation maps and other sources, providing a clear definition of locations of irregular length miles. (Mileposts are not easily relocated because most infrastructure locations are specified relative to the nearest milepost.) GIS group will complete a linear referencing model once locations of all mileposts are positively reaffirmed and specified using latest GPS technology.

ENTERPRISE GIS WEB VIEWERS

EGIS program aims to make mapping capabilities and data accessible to all employees. Based on web viewer strategy and desire to balance achievable processing speeds and anticipated audiences, several viewers were created to serve data needs of different departments. Tools available on Metro-North's EGIS portal (some link to external sources, most created in-house) are briefly discussed below and shown in Figure 5.

1. **Enterprise GIS Viewer**—Provides most basic general access layers like valuation maps, charts plans and diagrams, stations, mileposts, insulated joints, signal, switches, interlockings, equipment cases and houses, catenary bridges, track centerline, yard, culverts, bridges, grade crossings, platforms, electrical substations, street labels, ferry feeders, tax map parcels, political districts, and civil boundaries. These features are overlaid on default base maps like aerial imagery, street map, USGS topo maps, or light gray canvas. Main objective is quickly relating railroad infrastructure (features identified in LiDAR flyover survey) to outside world (from base map). There is limited integration with outside GIS and information services, for instance clicking on mileposts link to Google Maps at that precise location, and stations link to MTA's station website. Viewer is optimized for rendering speed.

2. **Track Department Automated Sensor Data**—For Maintenance of Way, various GPS-based data streams are loaded onto basic map of track centerlines, stations, and interlockings. Automated sensor data comes from routine infrastructure condition assessment scans like Grex Aurora for assessing tie condition, Sperry car for ultrasonic rail defect scan, and track geometry cars.

3. **Census Demographics**—Designed for planners, this viewer overlays service area and railroad infrastructure on various U.S. Census demographics variables.

4. **Environmental Features**—For environmental engineers and flooding risk assessors, this shows bodies of water together with floodplains, dams, wetlands, natural communities, and geological information like faults, bedrock, soil, etc. Most information comes from publically available source like FEMA maps and Army COE, but because these datasets were generally slow to render, they were not included in the main viewer.

5. **Superstorm Sandy Cable Job**—EGIS program has an explicit strategy to collect infrastructure data by piggybacking on extensive aerial surveying required for ongoing Capital design and construction projects. By accumulating baseline data, future surveying needs may be reduced. First project to afford this opportunity was Sandy Cable Replacement project between Mott Haven Junction, Bronx, and Croton-Harmon in Westchester County. After aerial surveys, data was delivered to Metro-North in AutoCAD format along with design elements (e.g. manhole, pullbox, vault, wall mount, equipment platform, etc.) and imported into web viewers. Although users are effectively limited to project staff, it touches upon major parts of track, communications and signals, and power infrastructure in affected segments. As infrastructure replacement design progresses beyond Sandy affected regions due to normal replacement needs, EGIS goal is to eventually “see” all active buried cable infrastructure.

6. **Quasi-Public Facilities**—Aimed towards planners and public affairs officials, viewer provides publically available locations of universities, schools, emergency services, airports, hospitals, government offices, nursing homes, libraries, cemeteries, churches, recreational areas (beaches, parks, golf courses, shooting ranges), river ports, parking facilities, county fairgrounds, retail centers, military installations, Federal lands, and fire districts. High densities of these facilities in New York City resulted in a very busy map, requiring a separate viewer.

Figure 5. A selection of applications available to all employees on Metro-North's Enterprise GIS Portal.

7. **West-of-Hudson Signal Project As-Built**—This was the first construction project for which GIS-enabled as-built drawings were delivered. Data was loaded into web viewer as proof-of-concept and shows new infrastructure items like interlockings, signals, switches, electric locks, equipment cases and housing, power vaults, C&S vaults, snowmelter boxes, telco demarcation points, cable trays, chain link fences, and detailed attributes for each box, e.g. generator, power

distribution center, central instrument location, etc. This data will prove invaluable for locating and maintaining infrastructure elements in future.

8. **Integrated Google(R) Street View**—Allows Google Street View imagery to be accessed from within EGIS. Although this feature is now integrated into the main viewer, it will eventually permit other video-based data like track-level cab-view videos and CCTV camera footage to be retrieved within EGIS.

9. **Topographical Contours**—Designed for hydrologists, drainage and civil engineers requiring good understanding of specific sites' topological terrain. 2-ft and 10-ft topo lines were downloaded from each county in service area and clipped to within 0.5-mile of right-of-way (to speed up processing time). Although this feature could have been integrated into Environmental Features viewer, the combination was unacceptably slow. As demand increases, this viewer is a candidate for justifying additional disc space for caching techniques or processor/memory upgrades.

10. **Grand Central Terminal Floorplan**—Provides multi-level GCT building floor plans. It is more Building Information Management (BIM) system than GIS, and used by departments needing to understand spatial relationship between different GCT areas, particularly relationship between different levels. Also included is information regarding tracks, platforms, stairs and passageways, room utilization, emergency exits, HVAC, and certain building infrastructure elements. This will eventually be expanded into full-featured emergency management and security management application for GCT, although access restrictions are required by layer to safeguard sensitive information.

11. **New Haven Railroad Val Maps**—Most valuation maps are provided within EGIS, but internal railroad archives didn't include segments that Metro-North does not own, including all trackage within Connecticut. University of Connecticut library hosts this collection and link is provided from EGIS Portal.

12. **Westchester County GIS**—Many employees were previously using Westchester County GIS for limited service area coverage prior to advent of EGIS; link is provided for employee convenience.

INTERNALLY MARKETING GIS

Railway and other district-based environments often suffer from "not invented here" syndrome, whereby new systemwide tools don't achieve immediate adoption because of unawareness, force of habit, local pride, or legitimate disagreements about standardization benefits. Multi-pronged strategies were devised to combat potential issues and help roll out EGIS in truly companywide fashion.

1. **GIS Portal**—A legitimate complaint often heard when rolling out new technology products is users often can't find it, or don't have access to it. GIS portal was designed with this in mind. Portal consolidates in one place all GIS applications that have complex, hard-to-remember web addresses, and GIS Office purposely didn't require logins for all but most sensitive applications—making assumption that employees using company intranet computers should have access to all GIS information approved for general employee use. A prominent link will go to GIS Portal from company intranet homepage.

2. **REST Services Directory**—REST Service (representational state transfer) is an application programming interface (API) allowing different computer programs to talk to each other and exchange information, including GIS data. Normally, these services are secured to programmers on need-to-know basis. However, EGIS directory of services are purposely left wide open (within company intranet) and advertised to employees with technical skills to use them. Employees in Maintenance of Equipment bases are using REST Services to pull down GIS data from centralized repository for prototype applications being implemented.

3. **Asking Project Managers for Approval**—In fact, no approval of GIS data by infrastructure project managers are really necessary; it is more important for GIS Manager to quality check data deliverables. However, an explicit strategy was put in place requiring project managers to approve GIS deliverables. This created opportunities for GIS Manager to teach each PM use of web-based GIS tools, and allowing PMs opportunities to see EGIS's value to their project. Frequently, in this interaction, PMs spotted errors in contractor-originated data that never would have been picked up by GIS Manager (like minor location errors requiring detailed site knowledge to detect). This strategy generated many EGIS champions within engineering disciplines, created connections for GIS Office, and offered opportunities for learning about specialized capital projects on the railroad.

4. **Relevance of Early Products**—Strategy here is to produce limited number of quick maps dealing with timely topics presented to senior management as demonstration of early progress with EGIS program. Products included maps tracking mudspots in trackbed monthly, and one-off maps tracking third rail bracket incidents (Figure 6(a)), operating employee residence locations (for fatigue modelling), Mail & Ride zipcodes (to track parking demand by stations, Figure 6(b)), and three dimensional visualizations of station ridership. Other rail agencies have done similar mapping with ridership (*10*) and incident locations (*9*).

5. **Infomercial Video**—One idea currently in development is a script offering a QVC or Home Shopping Network style infomercial describing how to use EGIS web interface in somewhat whimsical fashion. It was thought to be a way to reach older employees some of whom are not as comfortable with technology. However, as the organization is currently going through a wave of retirements, video production was put on hold pending further discussion.

6. **Email Blasts**—When EGIS launched, emails were sent out by company executives and managers at different levels to their audiences highlighting availability of web viewer services. Repetition of message by different managerial levels is important: e.g., Senior Director sent short and brief message to Executive Leadership Team, while Deputy Director sent longer introductory message to Corporate Leadership, then GIS Manager sent detailed “how to use EGIS viewer” messages to technical leads within each department.

7. **Roadshows**—GIS Manager made arrangements with department heads to provide half-to-one hour demonstrations of web applications and provide venue to discuss EGIS principles and usage in everyday company functions. Presentations, informal in style, are tailored to specific departments and bridge knowledge gaps for those whose job doesn't require whole-day training classes, but need peripheral awareness of EGIS capabilities and tools.

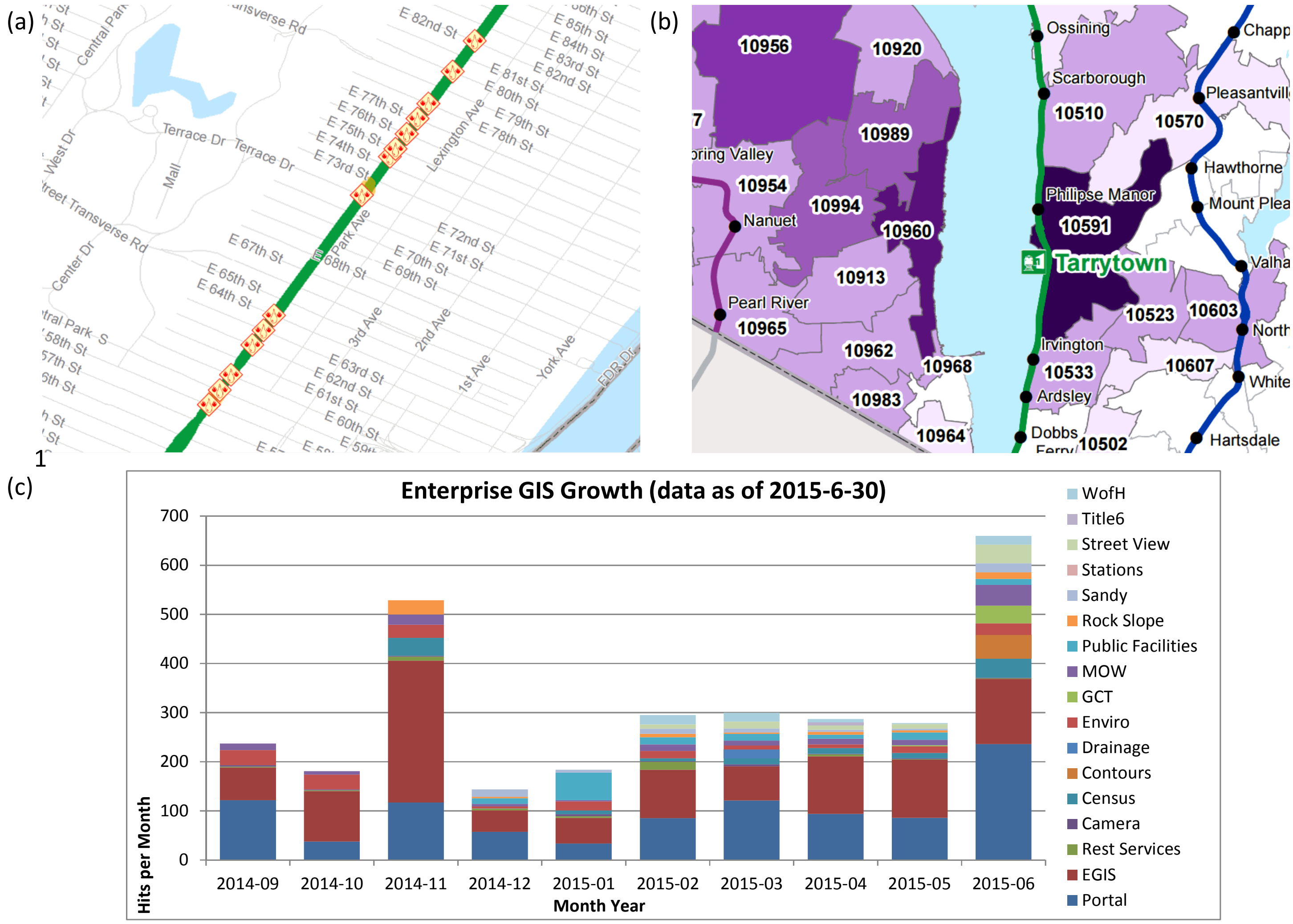


Figure 6. Enterprise GIS Marketing Strategies: (a) an early product showing locations of third rail brackets issues; (b) rider origination patterns by zipcode at Tarrytown station; (c) EGIS web viewer server statistics by category.

8. **Employee Newsletter Article**—Although understood that any given channel would only reach a subsegment of employees, newsletter articles can provided needed buzz to encourage water-cooler conversations and prompt folks to try web applications. Ultimately, employee newsletter was used to publicize training opportunities.

9. **Software Training**—Training is also a strategy to get more buy-in from technical resources throughout the railroad. Not only does a day of training offer reprieve from monotony of operations or technical functions, it also allows employees to feel empowered because the company invested in their careers by providing them knowledge and skills to utilize latest GIS tools. Training should be relevant to railroad's core mission, so if outside course materials are used, railway-specific discussions and customizations of course content can be considered.

Monitoring Enterprise GIS Usage

Using webserver logs, EGIS team can monitor how many employees used web viewers, and which viewers are hit hardest. Figure 6(c) shows during launch month (November 2014), webserver experienced a surge in demand. Subsequently demand stabilized at around 300 uses per month (average of 15 employee users on any given workday). Training activity conducted in June and a concept of operations report being widely distributed resulted in accesses peaking again that month.

General lessons learned here is that GIS office should "keep up the continuing drumbeat" regarding EGIS efforts via any and all channels. Until a geolocation culture catches on, successes in permeating existing business processes are far more likely if GIS is at forefront of employees' minds as they go about their daily routine. Organizational culture changes like cultures of safety, transparency and openness, security, and of course GIS are multi-year efforts that depend on maintenance for continuing improvement.

CONCLUDING OBSERVATIONS

As Metro-North's Enterprise GIS program enters its third year, GIS is becoming a common acronym on the railroad. Software was purchased and installed, staffing is in place, policy and procedures were promulgated and employees were trained. Data was acquired and, for the most part, web strategy was successful as more departments are requesting features they need and also contributing GIS data to the crowd-sourced and federated companywide effort.

For the EGIS team here, one unexpected development that generated some excitement is, unbeknownst to us, Transportation Operations Division had been using EGIS to locate incident trains by telephone—a Trainmaster in the field would call the office and ask question like, "Train 2167 at Cat (catenary) Pole 523 needs attention, nearest cross street and Exit No. on Conn. Tpke., please?" and office personnel use EGIS to find answers—instead of using track book showing catenary numbers and Google Maps showing grade crossings. While obvious next step here is to make EGIS available on mobile smartphones already carried by Trainmasters, clearly the technology is of such value that field personnel discovered and derived an old-fashioned way (voice communications) to gain access to new technology!

While EGIS's success and information-sharing impact it's had on the organization was dependent on many factors outside of GIS Office's direct control, we hope that practices and strategies presented herein provides ideas for other transit properties looking to implement EGIS as a transformative technology for continued teamwork and organizational development.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge support and assistance of Metro-North's Information Technology Team: Ronnie Schaefer (ret.), Charles Nottingham, John Larsen amongst others, and many employees who gave their valuable contributions in the early days of the Enterprise GIS Program: Anne Kirsch, Matt Peloso, Karen Timko, Jian Wang, Anamaria Bonilla. We also would like to thank our vendor representatives Dave Lashell and Caroline Walker for supporting us at every opportunity. Responsibility for errors or omissions remains with the authors. Opinions expressed or implied are the authors' and do not necessarily reflect official policies of any organization.

REFERENCES

(1) Multisystems Inc., Applied Geographics, Inc. Using Geographic Information Systems for Welfare to Work Transportation Planning and Service Delivery. *TCRP Report 60*. Transportation Research Board, National Research Council.

(2) Sutton, John C. Geographic Information Systems Applications in Transit—A Symthesis of Transit Practice. *TCRP Synthesis 55*. Transportation Research Board of the National Academies.

(3) Brilliante, Francisco. *Track and Asset Inundation Map Book for Metro-North Railroad*, HDR Engineering, Pearl River, N.Y. (2012).

(4) Lorrain, Matt. *Metro-North Railroad Enterprise GIS Security Assessment*. Esri Implementation Services, Redlands, Calif. (2014).

(5) Hong, Liu, M. Ouyang, S. Peeta, Y.Z. Yan, and X.Z. He. Vulnerability Assessment and Reduction for the Chinese Railway System Under Floods. TRB Paper #15-2182 in *TRB 94th Annual Meeting Compendium of Papers*, Washington, D.C., 2015.

(6) Barich, Frank, J. Phy, D. Jividen, M. Gartenfield, R. Agnew, R. Meyers, and C. Cofer. *Guidebook on Integrating GIS in Emergency Management at Airports*. ACRP Report 88. Transportation Research Board of the National Academies, Washington, D.C., 2013.

(7) Balijepalli, Chandra, and O. Oppong. Measuring vulnerability of road network considering the extent of serviceability of critical road links in urban areas. In *Journal of Transport Geography*, Vol. 39, pp.145-155, 2014.

(8) Inanloo, Bahareh, B. Tansel, X. Jin, and A. Bernardo-Bricker. Cargo-Specific Air Dispersion and Impact Zone Analysis After Accidental Release of Hazardous Materials. TRB Paper #14-0519. In *TRB 93rd Annual Meeting Compendium of Papers*, Washington D.C., 2014.

(9) Biddle, Scott, A. Kuyumcu, A. Pacheco, G. Yurtseven, and C.J. Taylor. Rails off the Rails: Visualization and Analysis of Railway Safety Incidents. University of Pennsylvania. Retrieved from http://www.seas.upenn.edu/~cse400/CSE400_2012_2013/reports/08_report.pdf on July 17, 2015.

(10) Carol L. Schweiger. *Open Data: Challenges and Opportunities for Transit Agencies*. TCRP Synthesis 115, Transportation Research Board of the National Academies, Washington, D.C., 2015.