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GIS Concept of Operations as a First Step towards Total Enterprise Asset Management: Metro-North Commuter Railroad Case Study

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ABSTRACT

For this Enterprise GIS project, Metro-North adopted the Concept of Operations process to define goals and objectives, inventory existing GIS assets, analyze data gaps, determine as-is and to-be business processes, define staffing and resource requirements, project initiatives, and provide a roadmap towards comprehensive companywide GIS deployment. In contrast to the top-down approach typically employed in Total Enterprise Asset Management (TEAM) planning, Metro-North used a dynamic grassroots approach holding fourteen workshops, attended by 92 employees, which were designed to collect GIS goals and objectives. The 122 goals generated from this process were distilled into 8 companywide goals. These goals ranged from increased efficiency to data sharing and decision support. Initiatives were developed for five critical business areas that had the potential to demonstrate how EGIS could help Metro-North accomplish its companywide and broader organizational goals. These pilot applications included: visualizing Straight Line Diagrams, integrating property boundary data, retrieving Capital Plan Room drawings, train tracking and delay visualization, and ridership and demographics.

This paper shows how a ConOps process could be used in railroad environments to think through GIS-related issues and define concrete technology projects that provide tangible benefits to user departments, allowing them to manage their assets and business issues. Although the focus of this study was on non-asset related operations within the railroad, the ConOps offers a user-centric systems planning approach that could be applied to TEAM efforts within the railroad industry or for planning corporate initiatives in any business environment.

INTRODUCTION

The State of New York, Metropolitan Transportation Authority(MTA) Metro-North Commuter Railroad Company (Metro-North) is a full service commuter railroad with engineering responsibilities for track, signals, power equipment, structures, stations, and rolling stock, also contracting and service coordination responsibility for feeder buses, ferries, and parking operations. The goal of this Concept of Operations (ConOps) study was to solicit information from internal users about the existing and desired state of Metro-North's Geographic Information System (GIS). Typically, a ConOps is a high-level document, widely utilized in military and government sectors, which describes a proposed system from perspectives of all individuals who will use that system. The ConOps is also used to inform project planning and decision making by communicating the quantitative and qualitative system characteristics to all stakeholders. The system scope is usually fairly limited and well-defined. However, the ConOps process has also been applied to systems considered highly complex (*1*–*4*).

Metro-North chose to apply the ConOps process to an "Enterprise GIS" (EGIS) system, without any clear constraints on GIS project's reach and extent. The intent of this project was to use the ConOps process as a way to think through:

- Why Enterprise GIS needs to be deployed,
- Goals of the system,
- How various departmental users would interact with it,
- Its impact on current business processes,
- Project initiatives that could be undertaken with EGIS,
- Necessary resources and staffing to support the system, and
- What this system could look like in its end state.

The key output was a companywide EGIS deployment strategy, which defined various project initiatives and described at a high level how users would interact with proposed components of EGIS.

This paper shows how a ConOps process could be used in railroad environments to think through GIS-related issues and define concrete technology projects that provide tangible benefits to user departments, allowing them to manage their assets and business issues. Although the focus of this study was on non-asset related operations within the railroad, the ConOps offers a user-centric systems planning approach that could be applied to Total Enterprise Asset Management (TEAM) efforts, at the same time delivering immediate benefits to users thereby maximizing likelihood of strong buy-in at the supervisor level.

Relationship to Asset Management

A GIS ConOps, whether intentionally or unintentionally, could be one way to jump start TEAM initiatives. This represents a "bottom-up," grassroots, or engineering-driven approach towards TEAM—to build asset inventories, asset tracking system components, and business processes individually by engineering discipline, which are eventually planned to be linked and interfaced together in future to an overarching TEAM system. This grassroots dynamic contrasts with the "top-down" approach towards TEAM. Typically, the "top-down" approach begins with a software package, an overall vision, or a centralized framework that is then disseminated throughout the organization, with departments required to conform their business processes to operate within the new environment.

This GIS-led approach was utilized in recent highway-based pilots (*5*), and GIS has played supporting roles in railway-based asset management implementations (*6-8*). However, within the transit industry, the majority of asset management work to date has focused on long range financial planning, starting with investment needs evaluation during infrastructure separation and restructuring of London Underground (*9*). The Federal Transit Administration (FTA) picked up on this approach based on MAP-21 legislation to address state-of-good-repair issues, resulting in a U.S. Government Accountability Office (GAO) report (*10*), sponsorship of several Transit Cooperative Research Board (TCRP) projects (*11-12*), and a transit asset prioritization tool (*14*).

In terms of current practice in engineering-driven approaches, New York City Transit Authority (NYCT) is in the midst of several asset management projects, including a rail switch inspection pilot based on a bottom-up, linear-referenced approach (*15*), while Long Island Rail Road (LIRR) has implemented an insulated joint inspection program using GIS and a commercial asset management database (*8*). Metro-North has implemented a bridge inventory and periodic inspection program to comply with the 2008 Federal Railroad Safety Improvement Act using a custom-built GIS application (*9*). However, we are not aware of a prior GIS-led companywide approach to TEAM within the rail environment. While we make no claims about this necessarily being an industry best practice, it is an illustrative case study of how overall EGIS and TEAM goals were beginning to be accomplished at the railroad.

Purpose and Need, and Scope of Work

In the early days of EGIS at Metro-North, GIS was a solution looking for a problem. A server-based software package had been purchased by the MTA Information Technology (I.T.) department ostensibly to support emergency management work. However, most senior leaders who were familiar with the technology understood that GIS could have wider applications for a transport and logistics-driven business whose infrastructure and markets are by definition geographical. On the other hand, not all functional directors were fully informed regarding the value of GIS, because the company's engineering business processes were heavily geared towards traditional methods of recording and sharing data (paper maps, large-format blueprint plans and record books). Those that did appreciate its value were somewhat concerned by GIS's implications for the business as a potentially revolutionary and disruptive technology due to its immense data and inventory requirements, its potential to share and expose data to rest of the organization that had previously been exclusive to one department, and changes in business processes required to take full advantage of its capabilities.

While an EGIS Strategic Plan had been developed internally, this was a short document focusing on general steps required to deploy GIS. Each “use case” was no more than a one-line description of an idea supplied by departmental employees in a company-wide email survey. The Business Case for GIS investment was also very generic, with software expenses justified based solely on perceived emergency management benefits. A comprehensive study was required to refine each idea and determine its benefits, costs, required process changes, staffing, and support needed from various departments. More importantly, because staffing and process re-engineering were internally sensitive issues, a management consultant was needed to advance the process. Consequently, the GIS ConOps study was scoped with these needs in mind and comprised of the following major tasks:

1. Goals and Objectives
2. Inventory Existing Location Data Elements and Identify Data Gaps
3. Business and Operational Processes, Policies, and Constraints
4. Develop Project Plans, Early Action Items, and Implementation Roadmap

5. Stakeholder Responsibilities and Staffing Plan
6. Draft and Final Reports

This endeavor was not a traditional ConOps or design study as no detailed technical work such as database design, data model, hardware and software specifications were developed, and no formal functional and technical requirements were included. The intent was to use various project plans produced to initiate design-build-deploy type procurements for software systems, or to implement systems internally using existing GIS servers and agency personnel—depending on each project's complexity and whether resources were available. The ConOps, however, would sketch out future interfaces and workflows such that all projects and subcomponents of EGIS, when fully built out, would function together as a cohesive whole.

The authors' intent in publishing details of these results and project plans is to provide ideas and share with the industry our methods and best practices in terms of GIS issues and applications (Figure 1(a)). The methodology and results of the ConOps are described at a high level, maximizing the applicability of our findings to other organizations. Specifics relating to Metro-North are addressed only as examples to illustrate typical conditions that may be faced by industry practitioners.

COMPANYWIDE GOALS AND OBJECTIVES

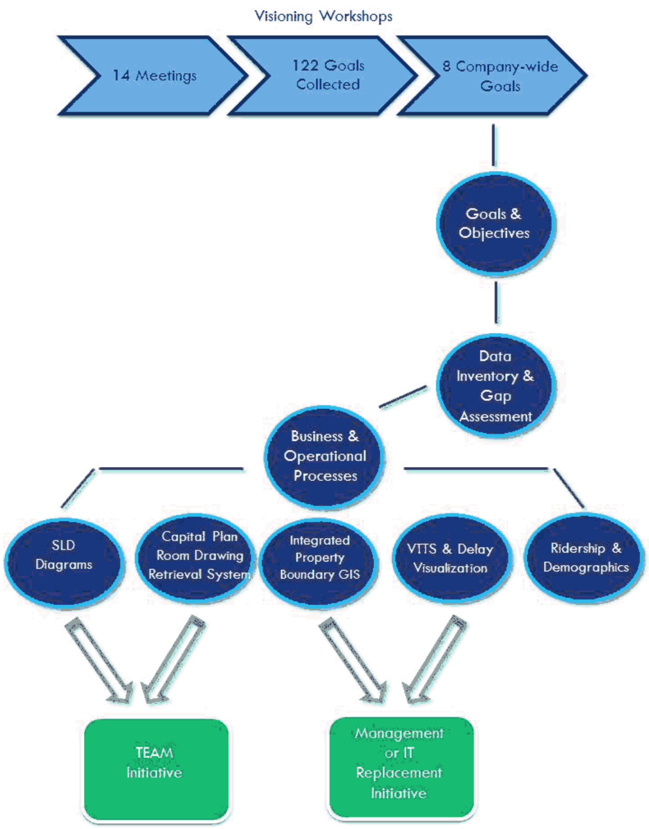
Step 1 of the ConOps involved holding a series of fourteen separate Visioning Workshops with discipline-focused stakeholders to collect their departmental GIS goals and objectives from which the companywide Goals and Objectives would be defined. These meetings, attended by 92 individual employees and managers as well as senior leadership at the Vice President level, included demonstrating examples of GIS-type systems, discussion of current work practices, and desired future work practices to create a framework for the goals discussion.

These groups made no distinction between the Operating and Maintenance sides of the railroad and Capital Programs employees, fostering an inclusive discussion of GIS data centered around specific engineering disciplines, business areas, or asset groups. This approach is unusual in railroads which have traditionally made a strong distinction between two types of construction—those focused on immediate maintenance and repairs and funded out of Operating budget, and those focused on periodic or long-term rehabilitation and replacement, funded by the Capital budget. The meetings were organized by discipline (Figure 1(b)) rather than by grade level, allowing senior leadership within a specific division or department to interact directly with their subordinates several levels down during the discussion of Goals and Objectives.

Visioning Workshop Responses

A total of 122 departmental goals were collected at these meetings. Generally, the meetings elicited responses that reflected the challenges of working within “a pencil and paper process” framework. Feedback included:

(a)



(b) Stakeholder Groups

Group 1	Environmental Compliance, Facilities, and Sustainability
Group 2	Rolling Stock Equipment (Maintenance and Capital)
Group 3	Structures, Grand Central Terminal, and Parking
Group 4	Planning Division (Operations, Capital, and Long Range)
Group 5	Maintenance of Way, Track, and Operating Capital (Force Account)
Group 6	Operations Services and Operations Administration
Group 7	Communications and Signals (CTC, Radio, and PTC groups)
Group 8	Power Infrastructure (A.C. and D.C. Traction, Signal Power, and Power Control Groups)
Group 9	Safety and Security
Group 10	Corporate Functions (Customer Service, Public Affairs, Business Development, EEO, Corporate Compliance, Training and Development, Chief of Staff's Office)
Group 11	Systemwide Policy Issues (Real Estate, Construction Management, Entry Permits, Technical Services and Plan Room)
Group 12	Enterprise Asset Management (including coordination with other MTA agencies)
Group 13	Information Technology
Group 14	Make-up Session (to accommodate those who missed a previous meeting)

(c) **Goals**	**Objectives**
Increase Efficiency *By streamlining access to data and pinpointing locations.*	• Provide Enterprise GIS (EGIS) web portal, adequate staffing, and training. • Migrate existing diagrams to EGIS views.
Facilitate Project Planning *Through displaying asset locations, their proximity to ROW, and other project limits.*	• Show project plans on EGIS to improve employee location awareness. • Record old and new asset locations whenever Force Account or contractors relocate assets.
Improve Asset Management *Through common portal for location and condition data.*	• Define maintenance and condition data to be collected; create logical asset model. • Integrate EGIS with asset management systems.
Provide Shared Mapping *Improve cross-departmental coordination and collaboration by showing spatial relationships amongst assets.*	• View all fixed infrastructure assets on EGIS. • Create standard process to import and update GIS data from outside agencies. • Create security framework to regulate display, export, and flow of company GIS data.
Better Information Access *Provide a single portal for data in multiple formats, and across departments and locations.*	• Specify companywide common standards. • Make EGIS available on mobile device. • Organize visual records and electronic data in a system-wide library.
Enhance Incident Management *Faster and better pre-event planning, post-event response.*	• Display incident location to identify access points for emergency services.
Upgrade Customer Service *Improving range, variety, and quality of public data and complaint resolution.*	• Connect EGIS with scheduling and VTTS systems to drill-down (ridership, work, etc.). • Clarify asset ownership and maintenance responsibilities by displaying on EGIS.
Decision Support *Analyze location and temporal trends to drive investment, project planning.*	• Develop an improved track outage planning and foul time mapping process on EGIS. • Interface EGIS with Enterprise systems for drill-down employee data and location attributes.

Figure 1. Scope and Goal and Objectives Exercise: (a) Flowchart showing the various steps of the GIS ConOps project; (b) List of stakeholder groups invited to participate; (c) Results of Companywide EGIS Goals and Objectives.

We need to spend less time looking and more time verifying. Eliminate search-and-destroy missions."
"You just can't do it on a spreadsheet anymore."
"We need to breakdown the silos. We know where our own assets are, but GIS will help other departments to find our stuff."
"After 30 years, people who know the assets will be retiring. What is the new staff going to do?"

A number of themes ranging from productivity to visualization and decision support emerged from the Visioning Workshops which formed the basis for eight company-wide goals. These themes formed the basis for eight company-wide goals that are shown in Figure 1(c) along with their corresponding objectives. In several instances, shared goals between departments were broadened into a companywide goal. Additionally, goals specific to one area of company operations (e.g., customer service, incident management) sometimes became a company goal if deemed critical or in alignment with Metro-North's strategic goals. These findings informed remainder of the ConOps process and provided a foundational framework and design criteria for the entire project.

DATA INVENTORY AND GAP ANALYSIS

Step 2 of ConOps summarized the manner in which GIS data is currently used at Metro-North for management, analysis, and decision-making and identifed data gaps relative to the company-wide Goals & Objectives. The inventory component of this effort documented all known existing location data sources and applications. An assessment of how well each existing data source meets company-wide EGIS goals was also included as part of the inventory. The gap assessment helped to identify data voids in the existing workflows.

This task provided a detailed understanding of how each existing tool supports the stated objectives of EGIS. An example of this type of analysis for a vehicle-borne diagnostic system is shown in Figure 2. The value in conducting this type of exercise is to provide a detailed description of each system within the company. This provides a valuable future reference tool for employees looking for specific types of geospatial data.

This inventory revealed that, as is typical in large organizations formed from mergers of smaller units, data sources and tools are sometimes siloed by division. Moreover, even information within one division can be siloed by office or department. In some cases, multiple departments were forced to maintain information related to the same assets, leading to conflicting data and information that are not standardized (e.g., different file formats with different attributes and unique methods of identifying and describing specific assets).

The gap analysis identified data gaps in the current workflow. For example, a common standard did not exist for identifying and classifying assets or for georeferencing data. As a result, overlaying information from multiple data sources is difficult even if the data contain associated location information (e.g., one source may use latitudes and longitudes, while another may use a linear referencing system like milepost). Some data sources were maintained by contractors rather than by in-house staff. Typically, a phone chain is necessary to get access to accurate information. Often data is available somewhere, but identifying the "owner" (or even having data owners acknowledge the existence of information) can be the result of happenstance rather than by a logical process of discovery. In some cases, data was not recorded and staff relied on experience and local knowledge to manage assets. In other cases, as-built drawings have been lost during multiple transitions from prior asset owners (e.g., Erie Railroad, Erie-Lackawanna, Conrail, Norfolk Southern, then Metro-North) resulting in the need to conduct costly field surveys or "tone out" buried cables. A lack of remote access to data was repeatedly cited as a gap in current systems. Engineers are unable to access data in the field and must carry hard copies of drawings with them or make multiple trips to the field to survey existing conditions and compare to various data sources.

Data Source or Tool	**Wayside Monitoring and Diagnostic Systems (WMDS) and Real-Time Data Monitoring (RTDM) System (Data Source and Tool)**
Description	M8 and M7 electric multiple-unit cars transmit train "heartbeats," critical faults, ERS and RTDM (Real Time Data Monitoring) files over Cellular Network to their respective databases. M8 cars generate 4 GB of data per day about various conditions, which can then be used to diagnose maintenance issues. For M7 units, IMS and AMS automates the recordings of train incidents and shop orders for certain critical fault codes, including low adhesion incidents. This system has mapping with attribute data associated with it, such as: • Train • Car • Fault description • System • Count • First set • Last set • Last reset • Zones • Location
Degree of Support for EGIS Goals	Productivity ○ Data and Standardization ○ Visualization ○ Customer Service ○ Decision Support ◒ Project Planning ○ Incident Management ◒ Asset Management ◒
Comments/ Assessment	• Locations tracked but not mapped currently

Figure 2. Example Data Sheet from the Gap Analysis Effort for Wayside Monitoring and Diagnostic System

Priority Areas Identified

A number of recommendations were made to improve the state of GIS and asset data at Metro-North based on the inventory and gap analysis findings. Key recommendations included:

1. **Define GIS/CAD/Asset Hierarchy Standards.** Metro-North is developing GIS/AutoCAD standards for positional accuracy, naming conventions, as well as database formats, but these standards have not been widely adopted. GIS and AutoCAD standards should be completed, disseminated, and adopted throughout the organization. Provisions should be included in consultant contracts to ensure all deliverables adhere to these standards. Coordination with outside stakeholders including other MTA operating agencies and Connecticut Department of Transportation (CTDOT) should be undertaken to ensure interoperability of systems and to facilitate sharing of information.
2. **Handheld Field Device GIS Strategy.** Existing web-based viewers are not used on mobile devices such as tablets, and mobile smartphones. These mobile devices have become the

preferred data access points for field workers. Accordingly, opportunities to use mobile devices to facilitate access to and the capture of data in the field should be explored.

3. **Make Non-Sensitive Data Available on MTA OpenData.** Data made available via the current intranet systems are not accessible outside of Metro-North. In order to improve access to data and enhance data accuracy outside of Metro-North, opportunities to augment access to non-sensitive data sets consistent with MTA's open data and security policies should be explored.
4. **Enhance Incident Management GIS Capabilities.** Several applications have elements that could support enhanced incident management, but are not easily accessible to first responders in real-time. GIS could enhance incident management capabilities (e.g., development of better train-location system that would enhance the geospatial accuracy of train locations on maps as well as allowing data from multiple sources to be displayed along with the train attribute data).
5. **Develop Procedure for Data Updates.** Establish and maintain a workflow process for capturing location data, updating asset data, and keeping relevant data current. Organizational responsibilities with regard to database maintenance should be established. Workflow processes should be developed for updating asset locations in real time as they are modified in the field. Verify the accuracy of location and asset data that is submitted by contractors should be verified. Staffing needs to support updates should also be identified.

BUSINESS AND OPERATIONAL PROCESSES

Five critical business areas were selected for detailed business and operational process analyses as they had the potential to demonstrate how EGIS could help Metro-North accomplish both its company-wide GIS goals as well as broader organizational goals. The pilot applications, identified below, were viewed as relatively high impact, with a clear improvement over existing business processes, and comparatively achievable in the medium-term based on the gap analysis.

Straight Line Diagrams (SLD)

The track chart is a common rail industry data source that has historically been used by Maintenance of Way to account for track maintenance programs. Over time, the track chart has gained traction as a reference document with other functions within Metro-North including Planning, Training, and Transportation Operations. Other users of the track chart include: Operating Capital staff, Executive-level staff, outside contractors, New York State Department of Transportation (NYSDOT), ConnDOT as well as federal agencies. Currently, Metro-North's track charts (Figure 3(b)) are maintained by Track and Structures staff and updated annually in AutoCAD.

At present, the track chart is updated via a manual process. Track and Structures supervisors query their staff about work that has been completed over the past year. This information is reported to the track chart manager on a hard copy markup of the appropriate page of the current year’s track chart. A staffer, supervised by the track chart manager, revises the track chart page in AutoCAD to reflect the hard copy changes. Typically, the revised track chart is not available to users until a new track chart document is published annually. This process is time consuming for the Track and Structures Department. Additionally, the asset data and locations that are the jurisdiction of other departments are not always updated since each engineering discipline maintains its own drawings of a similar nature covering slightly different information. For example, at Metro-North the Signal Department maintains a block diagram. D.C. Power engineers maintain a sectionalizing diagram, and A.C. Power engineers oversee the catenary chart. An overwhelming amount of geographic information and basic infrastructure data (e.g. mileposts, tunnels, river crossings, and undergrade highway bridges) is replicated or duplicated on charts belonging to different departments.

The proposed application and associated business processes are designed to consolidate the numerous departmental drawings within Metro-North. The application would provide a single, uniform, up-to-date source of engineering data, as well as one electronic platform to maintain such data. The system would:

- Automatically plot linearly-referenced geodata (GPS coordinates or milepost/stationing/chaining locations) by computer on a straight line diagram (SLD), with data driven from a GIS database.
- Provide a platform to manage and maintain track charts without manually plotting each page in AutoCAD.
- Provide a process to regularly update the data.
- Allow a user to zoom in/out to any specific geographic area or section of track, seeing information at whatever scale appropriate for the linearly referenced data being visualized.
- Overlay information from different GIS layers (e.g. streams, power lines, municipal boundaries, geology, etc.), engineering disciplines (track, signal, power, real estate such as cable runs, duct banks, central instrument locations, property lines, etc.), and operating timetable information (e.g. speed, height, and clearance restrictions), integrating data sources and allowing intelligence sharing.
- Visualize inspection data (manual inspections, automated tie inspection, ultrasonic rail inspection, track geometry inspection, etc., e.g. Figure 3(c))
- Provide a "Track View" using a Track Geometry Car (TGC) attachment or a separate video truck (Figure 3(f)).
- Allow users to turn each layer or chart section on/off depending on needs.
- Visual interface to integrate GIS and TEAM data.
- Serve as an employee reference of Metro-North infrastructure and operations.

This system would provide a platform to visualize data that is not easily displayed on a scale map (e.g. track-by-track information) in a format that engineers and planners are used to seeing. The platform would allow operating restrictions and infrastructure data from different disciplines to be visualized and integrated into one view which is not possible with the traditional paper track charts. This application could also serve as a training aid for physical characteristics of the railroad. It could also improve capability and speed in identifying maintenance issues through overlays of infrastructure condition and using custom analytical algorithms. Numerous off-the-shelf applications and custom solutions are available in the marketplace (*17-20*).

Implementation of this project would required that the engineering data of each technical department be stored, combined in the same database and made viewable within the same system. A business process re-engineering activity would be required to achieve the “buy-in” of each technical department, eventually culminating in switching the master copy of the data (maintained by each technical department) from the manual paper/CAD-based process over to the new combined system. This last goal may be difficult to achieve and may take 5 to 10 years for the technical departments to become fully comfortable. To achieve this, careful control of each data element is required, and the editing of each item must be restricted to the responsible department.

The planned implementation steps for this application would progress through the various application components, starting with the most commonly used items:

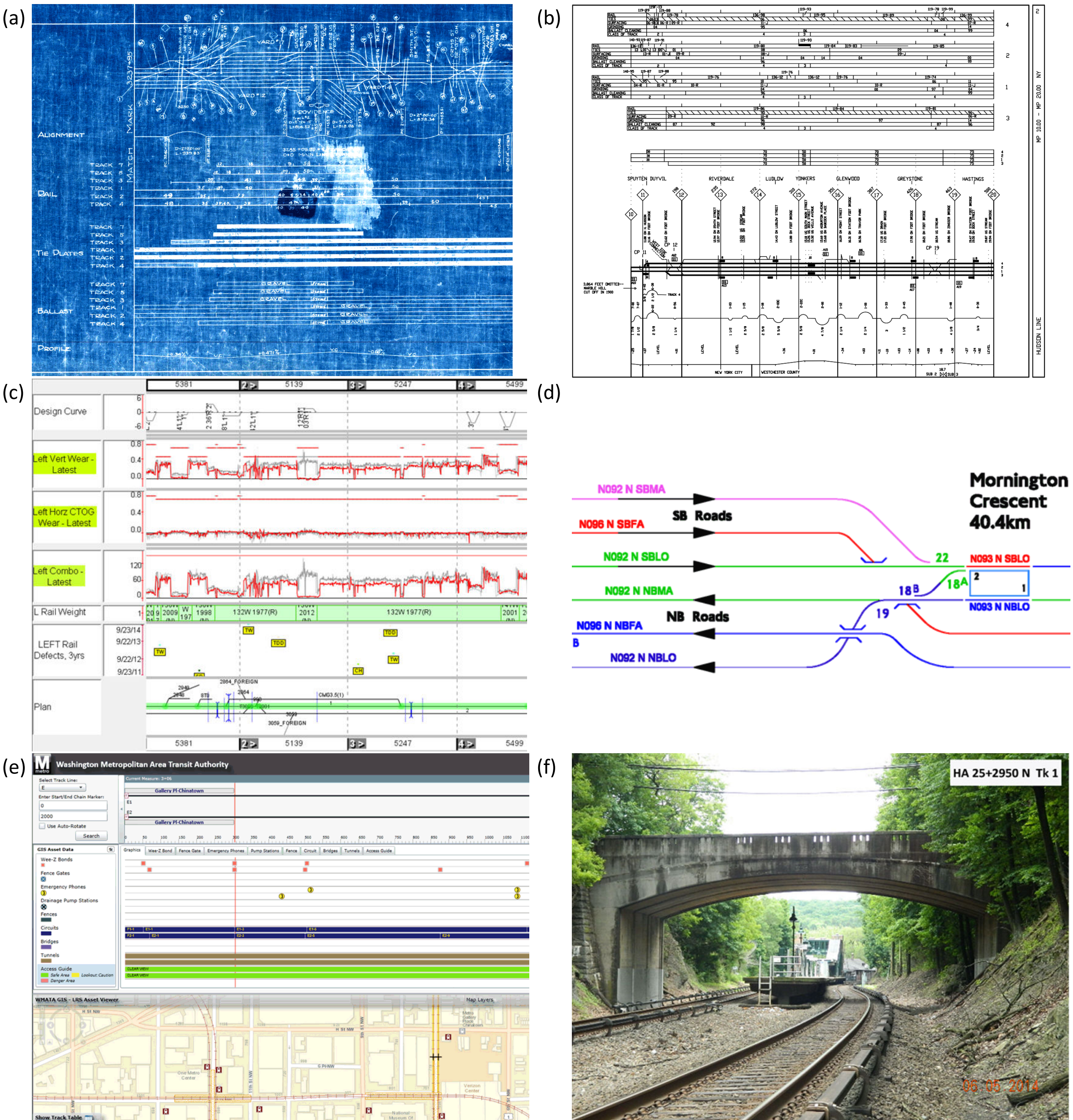


Figure 3. Single Line Diagrams and Views: (a) New Haven, Hartford, and Springfield Railroad Track Chart, Boston Division, Providence District, Updated October 29, 1947; (b) Metro-North Track Chart, Hudson Line, Milepost 10-20, Updated 2014; (c) Bentley Optram software displaying a data-driven straight line diagram (*17*); (d) Intergraph software displaying a route diagram (*18*); (e) Washington Metropolitan Area Transit Authority GIS-based rail line asset viewer (*19*); (f) Simulated track-level view with linear referencing.

1. Develop or purchase GIS application to generate SLDs & display track chart data
2. Overlay & integrate linear asset information from various disciplines (Communications & Signals, Traction Power) onto a user-configurable track chart
3. Visualize routine inspection data
4. Visualize operating restrictions contained within Employee Timetables
5. Provide "Track View" (requires video recording truck)
6. Provide mobile device accessibility

Visualization of infrastructure data would allow better informed, more quantitative, and potentially improved decision-making for project planning and infrastructure maintenance, such as prioritizing repairs, better planning track outages, better anticipation of on-site conditions, improved situational awareness by field personnel, and corporate-level planning and training benefits. Mobile accessibility could provide decision makers with the ability to make informed and critical operating decisions, which from an operations standpoint, is a major benefit of asset management.

Integrated Property Boundary GIS

Currently, the Real Estate Department of the MTA uses a proprietary property management software package (*21*) to track all MTA property interests within its service area. MTA real estate interests are uniquely complex both in the number of tenants, the nature of the asset types, and the vast geography in which they are located. While the software package is popular with property managers in the real estate industry, until recently it did not offer a map interface as most clients are managing individual buildings or pad sites as opposed to corridors containing a complex collection of accessory parcels, concessions within buildings, air rights, and utility easements.

The proposed application is a web-based GIS tool intended to integrate the tenant management system (TMS) with an interactive, web-based map viewer to show the location of each property asset relative to railroad infrastructure and adjacencies. This map viewer would allow staff to find and identify real estate holdings and easements based on location, allowing users to drill-down into contract details and available survey plans. This approach has been used in a highway context by Florida DOT (*22*) and by VicTrack in a rail corridor environment in Melbourne, Australia (*23*). The objectives are to:

- Create GIS shapes (via georeferencing, digitizing, or field verification when necessary) of each authority property in Metro-North's service area and link them to TMS via an unique property ID, and commit to regularly updating shapes due to conveyances.
- Provide visualization of linear assets, property boundaries, and easements situations such as:
    1. Underground spaces and overbuild air rights
    2. Utility crossings, and PPW (pole, pipe and wire)
    3. Multiple tenants sharing retail space within a station
    4. Other miscellaneous structures on railroad property: access roads, billboards, communications towers, etc.
- Integrate other layers such as zoning information, tax parcel information, valuation maps, etc.
- Allow two-way click-thru links between TMS (with a “show map” button) and the GIS viewer (with a “show TMS data” button) providing seamless user experience.
- Enable geospatial analyses and queries: What properties are co-located or adjacent? What utilities are present in a track construction zone? Where are property access points?

(a) (b) (c) (d) (e)

Figure 4. Real Estate Management GIS Integration: (a) Typical text-based tenant management system screen (*10*); (b) Railroad valuation maps showing property boundary and infrastructure detail, but updates to which have been spotty; (c) Grand Central Terminal building model screen, showing floorplan and each room; (d) Esri software displaying tax parcel boundaries using municipal data may not always correspond with surveyed property lines; (e) Intergraph software displaying a property map.

- Provide accurate, surveyed property lines of Metro-North rights of way, yards, etc. on GIS to support capital project planning, asset maintenance, operations, & emergency management. Also support engineering needs in the entry permit process, rent collection, renewal, etc.

The primary beneficiaries of this application would be Metro-North staff who would have access to accurate and continuously updated information on both real estate locations and key attribute data kept on TMS. Timely access to property information allows: proper planning of improvements that may impact leases or easements; incident management where timely access to contact information of nearby owners and tenants is critical; maintenance and operations activities requiring property access or notification of affected tenants. Current TMS users would be able to identify and locate properties, and visualize geospatial relationships amongst them.

The linkage between mapping and TMS will produce many benefits for both property managers and the engineering department. The current work flow to discover this information involves a significant amount of manual research through hard copy paper or PDF based drawings. The future work flow will use the mapping interface to overlay information from different sources and enable click-thrus to TMS. The planned implementation steps would start by georeferencing and digitizing all relevant valuation maps, conveyancing surveys, and lease agreements. In parallel, progress through prototyping and testing the visualization application, populating test data, and ending with agreement on a business process to ensure new information is captured on the system going forward.

Capital Plan Room Drawing Retrieval System

Metro-North has recently completed a major project to digitize all paper as-built drawings, consisting of over 180,000 record drawings including linen blueprints dating to the original construction of Grand Central Terminal (GCT) in 1913. The drawings were scanned, and non-GCT portions were uploaded onto a web-based drawing retrieval system for use by employees and contractors. This replaced the previous business process that required telephoning or physically travelling to the Capital Programs Plan Room to look up specific file drawer numbers and contracting out large-format reproduction with the associated potential chain-of-custody and security issues. The website allows authorized users to search for drawings by a variety of key fields such as Line, Location Name, Structure, Milepost, etc.

The proposed application would advance the search interface one step further by geo-referencing each drawing to allow employees to look for all drawings in a particular vicinity "by map" rather than having to search using numerous combinations of key fields. This practice for as-built drawings would be similar to the process already in place for valuation maps and other engineering drawings. Under this process, the EGIS system would show "pushpins" on map, color-coded by engineering discipline, to alert the user to the availability of a PDF drawing showing the immediate vicinity.

The "pushpin" approach strikes a balance between the laborious process of fully digitizing and converting 100 years' worth of record drawings into GIS line work, and having the drawings filed by location descriptions but not searchable "by map". Due to the enormous volumes of drawings, not all metadata associated with each drawing are 100% accurate. This makes the process of drawing research more of an art than a science where institutional knowledge of the railroad infrastructure and drawing sources is paramount. While a good drawing retrieval system could never replace a good engineering librarian or archivist, it can provide self-service functionality and assist the process of resource discovery, handling most requests while allowing the archivist to focus on specialized tasks. The retrieval system objectives are:

(a) (b) (c) (e) (f)

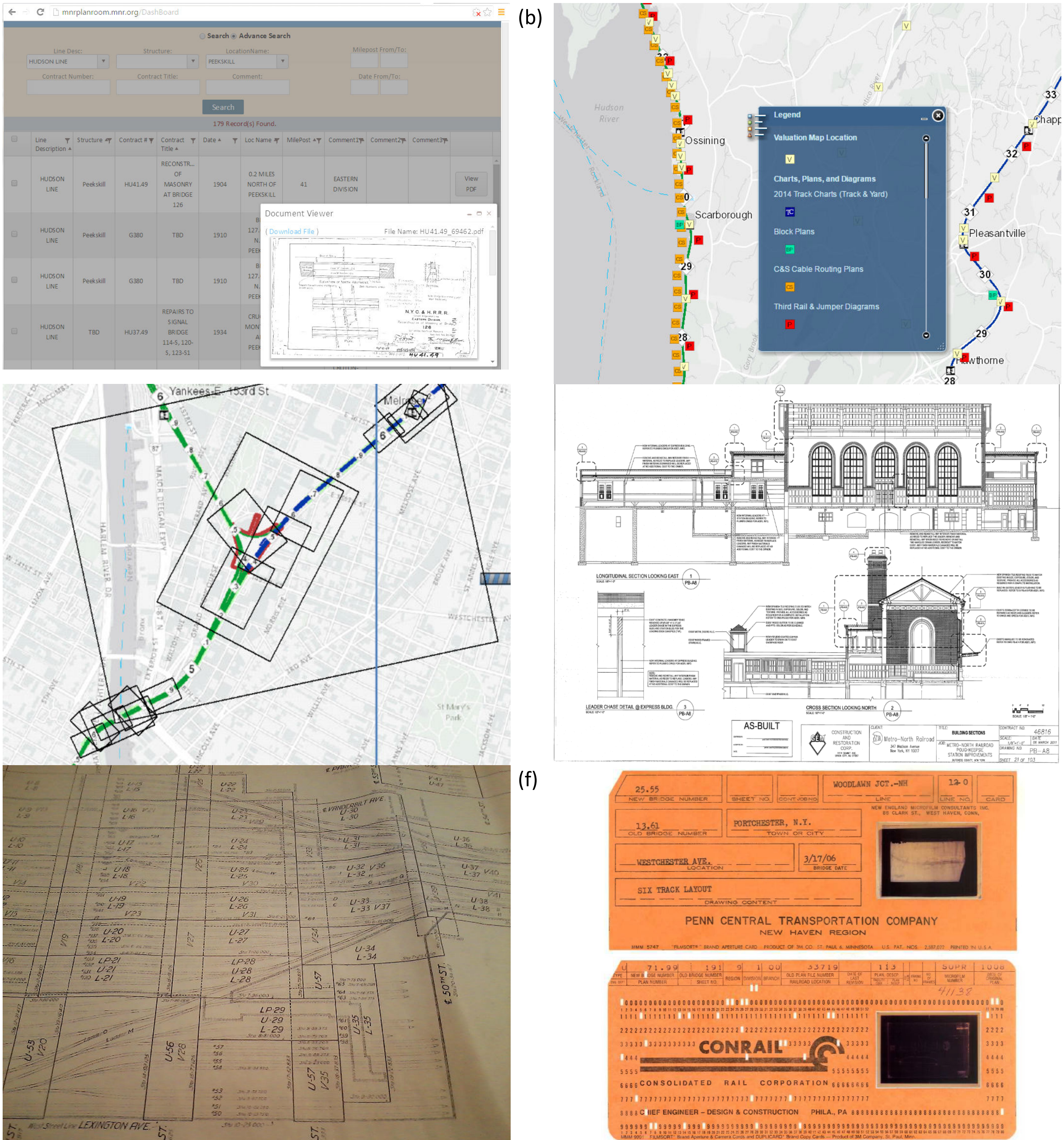


Figure 5. Plan Room Drawing Retrieval System: (a) Existing plan room system allows keyword searches in a text-based interface; (b) Enterprise GIS system showing "pushpins" associated with various drawings; (c) One possible view of approximate record drawing extents shown "by map"; (d) One example of 678 as-built drawings showing parts of station building in Poughkeepsie, N.Y.; (e) Large format paper index sheet with file numbers currently used to retrieve GCT drawings; (f) Examples of Penn Central and Conrail aperture cards still stored in Plan Room drawers.

- Configuring existing EGIS to provide drawing retrieval functionality, creating necessary GIS features, such as "pushpins" or polygons showing approximate drawing extent, associated with each drawing.
- Populate and/or verify metadata in the drawing retrieval system database, organizing drawings not by historic file number but by location, type of drawing, milepost, common name, engineering discipline, and other relevant parameters.

As part of the scoping process for this project, an additional 44,000 structural drawings stored on microfilm aperture cards by predecessor railroads were discovered in the Plan Room archives. The final scope for the project included four main parts:

1. Interface between GIS and the existing Plan Room database,
2. New specialized GIS/BIM application for intranet access to GCT drawings, which had not been available online,
3. Scanning and cataloguing of remaining drawings stored on aperture cards,
4. Based on gap analysis recommendation:
    a. Refresh GIS and CAD standards for the drawing submittals, and
    b. Create a facilities management asset hierarchy to support the GCT components of drawing retrieval application

Train Tracking System Replacement and Delay Visualization

Metro-North uses an internal application called the Visual Train Tracking System (VTTS) that displays live train locations in near real-time on a diagrammatic map (Figure 6(a)) and also on a line chart (Figure 6(b)). The VTTS platform is currently on an outdated software platform that is no longer supported. The technology is now antiquated with known security issues. Accordingly, MTA Information Technology has proposed replacing it with a modern GIS platform that would permit easier expansion of its capabilities to meet changing needs of the business and to support mobile devices.

The VTTS Replacement will display live train locations in near real-time on a diagrammatic map (allowing users to zoom and pan at will), on a line chart, as a colorized delay diagram, and allowing drill-downs into additional and historical data. The objectives are to:

- Visualize train movements and delays on a modern web-based GIS platform, including mobile devices.
- Visualize train movements on a straight line diagram (similar to track chart) showing train locations accurately relative to platforms and interlockings.
- Provide real-time interactive tabular displays of lateness based on color-coded charts (Figure 6(d)), and improve historical data query capability.
- Interface with the existing fleet assignment system (called Terminal Management System) and the Crew Management System to provide data via click-thru for trainmasters making real-time assignments. Provide the following information in a pop-up box:
    1. Current consist assignment and crew assignment, and
    2. Next job (turn) for the consist and crew—also separate countdown timers for time remaining until next turn for consist, and next turn for crew.
- Refine the accuracy of real-time data by enabling additional track circuits to report occupancy information to the corporate network.

- In the longer term, the map view could be made available to the public showing only publicly-visible information (Figure 6(c)).
- Further improve query functionality to generate and visualize train sheets, and train delays by location, performance by terminal, etc.

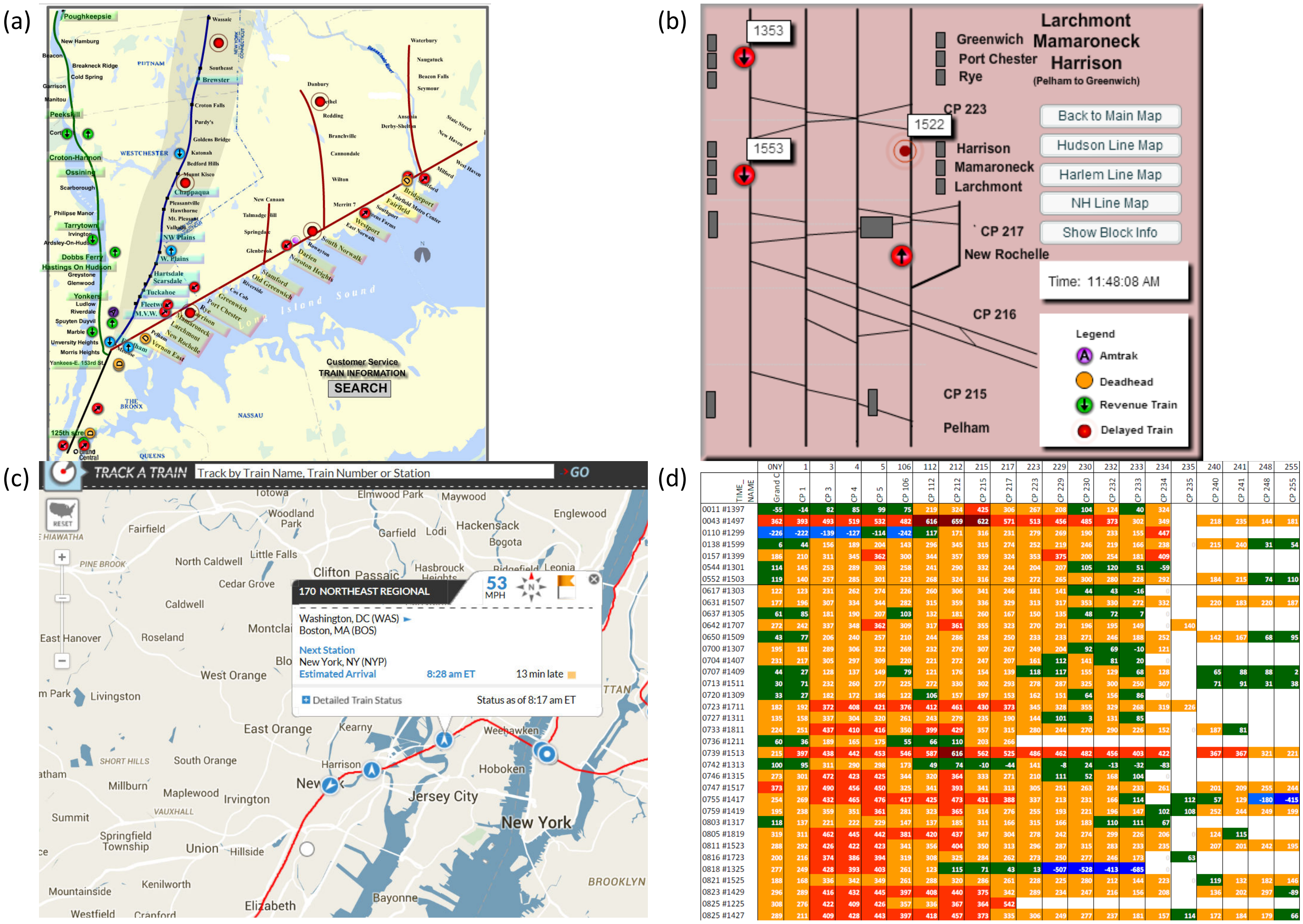


Figure 6. Real-time Train Location and Delay Visualization: (a) Current system showing locations on a diagrammatic map; (b) Train locations shown by straight line diagrams; (c) Amtrak's public system showing train locations and speeds in real time; (d) Delay charts visualizing average delays by train by location.

The replacement application would provide a geographically accurate display, and allow "layers" of other spatial information (e.g., infrastructure, emergency access points, jurisdictional boundaries etc.) to be overlaid. This improved geographic accuracy would allow better prediction of delays and arrival times, particularly during inclement weather trains are running at lower speeds. Schedule planners would be able to better monitor entry and exit times at interlockings and refine scheduled running times. For incidence response, knowing more precisely where a stopped train is located, together with the locations of nearest access points, and other infrastructure elements can reduce incidence response times and help mitigate the impact of a single disabled train on other train movements.

During the scope development for this project, a multitude of systems issues were discovered. The difficulty is not so much the replacement of a not-to-scale mapping platform with GIS, but the interfacing and integration of disparate operational data systems, some of which run on legacy mainframes, with others on enterprise databases combined with custom data processing. An enterprise architecture exercise is underway to fully consider the data flow required to support the new application.

Ridership and Demographics Visualization

Historically at Metro-North, ridership and customer demographics data have not been presented graphically. Graphic visualization of ridership has been a standard tool for operations planning and capacity planning in the transit industry. A number of visualization approaches were reviewed in a recent TCRP Report (*24*). A need was identified to provide a web-based GIS tool to visualize various internally-generated ridership data, demographic data, forecasting models, customer survey data, and ticket sales data. This would allow employees to visualize train loads, where customers are travelling from and to, and their travel patterns. Particular interest was expressed in the ability to visualize estimated ridership by train by location.

This project would would require the construction of a state-of-art database on an Enterprise platform (such as Oracle, DB2, or an open source solution) to capture and house all ridership data, passenger surveys, ticket sales volumes, and automatically collected data streams. This would replace the mainframe-based statistical analysis package and various sundry spreadsheets and single-user desktop databases currently in use. The new application would:

- Visualize ridership, loads, capacity, train counts, on/offs, demographics, and customer survey data using a web-based thematic GIS map viewer.
- Provide new computerized database platform for:
    - Migrating existing ridership and survey data from mainframe database and stand-alone spreadsheets.
    - Storing, processing, and querying automatically collected data, including ticket sales, load weigh sensor/automated passenger counter data, automated station counts, etc.
- Visualize internally generated, consultant-sourced, and automatically collected ridership information, including link-loads by train and overall ridership by line.
- Visualize station or zone boardings and disembarkations by time-of-day, by direction, by service group (express/local), and by line. Visualize train by train/stop by stop counts and display survey-based information on customer residences.
- Provide "on and off" maps with average load as a route planning tool.

This application would provide users with useful, consistent, and visually appealing ridership data that would accommodate the specific needs of different departments. Planning uses this type of maps extensively to forecast demand for service, assess impact of fare adjustments, and determine the appropriate Capital investment. Customer Service uses ridership maps to plan for special events and service disruptions. Operations staff uses boarding counts to plan train consists and schedules. The Control Center uses ridership counts to plan emergency response needs and the Safety Department uses ridership information to assess risks in operations. Engineering uses ridership maps to determine track outage impacts and minimize inconvenience to customers during necessary construction work. The Public Affairs area uses ridership maps when responding to external enquiries and benchmarking requests.

STAFFING PLAN

Based on the business process review conducted as part of the application scoping process described above, detailed resource needs were determined in terms of labor hours. These staffing needs were grouped into numerous full-time equivalents (FTE) based on skill requirements and existing organizational structure. Detailed time and cost estimates are not being published. However, the summary position descriptions below may be of use to railroads or agencies seeking to accomplish similar goals.

In general, each proposed application requires one FTE to act as project manager, advocate, technical point of contact, or data maintenance coordinator for the data within its scope. While the existing level of staffing in each organization will determine whether this is a new position or a rescoping of job responsibilities for existing staff, without a dedicated FTE being responsible for managing the upkeep and planning upgrades to the system, it can be quite easy for this type of “data housekeeping” task to get lost in the typical environment existing within an operating railroad. Systems built at great expense can become of limited value if the data sources within are not updated and technologies are not kept current. One way to future-proof the system and associated business process is to provide an FTE.

Since the level of responsibilities and required knowledge and skills vary, these positions could be assigned different grade levels. The following roles are suggested for previously described applications:

- **SLD Data Librarian:** Responsible for ensuring all maintenance departments update their portion of basic physical characteristics data shown in systemwide SLDs on a periodic and timely basis. Position should reside in the Chief Engineer's office.
- **Real Estate GPS/GIS Surveyor:** Responsible for GPS data collection, field surveying, and working with construction engineers in the field on GIS issues. Position could reside in GIS office, Real Estate, or Construction Management.
- **Drawing Archivist:** Responsible for checking in/out as-built drawings for capital project managers and ensuring they are properly catalogued and accessible in the map-based drawing retrieval system. This position typically resides in the Capital Construction Department.
- **VTTS/GIS Developer:** Position responsible for developing real-time visualization applications and/or putting together packages to outsource such development. Position could reside in MTA I.T., Signals/Telephony Department, or Transportation Operations.
- **System Demographer:** Responsible for organizing, warehousing, and updating demographics and train schedule data in proper database format. Position also conducts geospatial analysis. This position should reside in Operations Planning.

NEXT STEPS

Based on results of this ConOps study, Metro-North is in the process of providing budget justifications for third party efforts required to build or deploy these applications, and position justifications required for staffing these efforts internally. Both the SLD and plan room GIS applications have been deemed to be eligible for asset management funding, and are being progressed as TEAM initiatives. The real estate GIS system is moving forward as an operating-funded management initiative. The train tracking replacement application was deemed an Information Technology systems normal replacement initiative and is being progressed as a platform migration project. The ridership and demographics visualization is the only initiative to emanate from the ConOps process that is not a TEAM project, and will not be progressed for the time being due to other competing priorities within the main user department.

While ultimate implementation and budgeting decisions are somewhat political in nature, the ConOps process was useful and successful in accomplishing several objectives:

1. Educating decision makers regarding latent needs that exist, solutions in the marketplace and yet-to-be developed, and benefits those technologies could bring to the company;
2. Clearly scoping out both data and system needs and allow the established costing process to assign a price both in terms of internal manpower and third party contracting;
3. Examining linkages between different parts of the system and assigning functions to one logical part of the company as to reduce the potential confusion and duplication of efforts, and
4. Providing a rational basis for higher-level discussions on funding prioritization amongst these systems, and versus other initiatives.

LESSONS LEARNED

This user-centric systems planning approach could be used for planning various kinds of corporate initiatives in any business environment. Due to the historically militaristic and siloed culture prevalent in the transit industry, this method is particularly valuable for a project like EGIS or TEAM that literally touches every aspects of the business. By its very nature, this project requires close cooperation and coordination across disciplines and throughout the system. We hope this paper serves as a useful example of industry practice for academics and practitioners alike.

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References

(1) United States Government Printing Office. *Concept of Operations for the Future Digital System* (FDsys). Retrieved from http://www.gpo.gov/pdfs/fdsys-info/documents/FDsys_ConOps_v2.0.pdf on February 13, 2015.

(2) Center for Medicare and Medicaid Services. *Processing of Fee-for-Service Claims for Part A and Part B—Concept of Operations*. August 2007. Retrieved from http://www.cms.gov/Research-Statistics-Data-and-Systems/CMS-Information-Technology/SystemLifecycleFramework/downloads/ConOps.pdf on February 13, 2015.

(3) Linden, Amy, C. Monheim, G. Kocur, E. Paul, L. Greenfield, E. Hines, P. Imbro, and L. Smuglin. *Concept of Operations for MTA New Fare Payment System and NYCT Deployment Phase*. April 21, 2011. Retrieved from http://www.smartcardalliance.org/resources/pdf/MTA_NFPS_Concept_of_Operations_R1.2.pdf on February 13, 2015.

(4) Intelligent Transportation Systems, U.S. Department of Transportation. *Next Generation 9-1-1 (NG911) System Initiative Concept of Operations*. April 6, 2007. Retrieved from http://www.tsag-its.org/media/docs/USDOT_NG911_1.B2_FINAL_Concept_of_Operations_v2.0_04-06-2007.pdf on February 13, 2015.

(5) Harrison, Frances D. et al. *Successful Practices in GIS-Based Asset Management*. NCHRP Report 800. Transportation Research Board, Washington, D.C., 2015.

(6) Taverner, R. and V. Lammerse. Implementing Maximo asset management system for Adelaide's public transport rail assets. Presented at *CORE 2014—Rail Transport for a Vital Economy Conference on Railway Engineering*, Adelaide, South Australia, May, 5-7,2014.

(7) Duffy, Brendan. Direct Integration of ArcGIS with Maximo Asset Management Software on Mobile Platform for Insulated Joint Inspection. Presented at the *2nd Annual NYCArc User Group Symposium*, New York, N.Y., June 17, 2011.

(8) Bleser, Walter. RailAdvise(R)—Industry first technology helps railroad owners comply with FRA bridge safety standards. In *InTransit*, Spring 2012. Retrieved from http://www.hntb.com/sites/default/files/intransit-08-spring2012t.pdf on July 16, 2015.

(9) Adeney, W.E., A. Sinde, and M. Woods. Development of Asset Management Evaluation Framework in Rail Transit Environment: London Underground Public-Private Partnership. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1986 (2006), pp. 21-28.

(10) U.S. Government Accountability Office. *Transit Asset Management: Additional Research on Capital Investment Effects Could Help Transit Agencies Optimize Funding.* Report GAO-13-571, Washington, D.C., July 11, 2013.

(11) Robert, William, K.K. O'Neil, H. Cohen, and J. Barr. *State of Good Repair: Prioritizing the Rehabilitation and Replacement of Existing Capital Assets and Evaluating the Implications for Transit.* TCRP Report 157. Transportation Research Board, Washington, D.C., 2012.

(12) Robert, William, V. Reeder, K. Lawrence, H. Cohen, K.K. O'Neil. *Guidance for Developing a Transit Asset Management Plan.* TCRP Report 172. Transportation Research Board, Washington, D.C., 2014.

(14) Robert, William and H. Cohen. Development and Pilot Testing of the Transit Asset Prioritization Tool for Analysis of Transit State of Good Repair Investment Needs. TRB Paper No. 15-4727. Presented at the *Transportation Research Board 94th Annual Meeting*, Washington, D.C., 2015.

(15) Li, Qing, S. Wong, and S. Rumala. Data Architecture: An Element of Resilient Asset Management System: A Practice of Joint Switch Inspection at New York City Transit. TRB Paper No. 15-1180. Presented at the *Transportation Research Board 94th Annual Meeting*, Washington, D.C., 2015.

(16) Bradley, Kathleen, and S. Maccalous. *Directory of Transportation Data Sources, Bureau of Transportation Statistics, U.S. Department of Transportation.* Report DOT-VNTSC-BTS-96-3 (1996).

(17) Bentley Systems. *Bentley Optram Railway Maintenance Decision Support System*. Retrieved from http://ftp2.bentley.com/dist/collateral/docs/optram/optram_product-family-brochure.pdf on July 14, 2015.

(18) Prosser, Matthew. *Spatial Data Management at Metronet*. Retrieved from http://www.intergraph.com/global/uk/assets/local/SpatialStrategies.pdf on July 14, 2015.

(19) Wang, Minhua. GIS-based Rail Line Asset Viewer. Presented to *TRB GIS in Transit Conference*, Washington D.C., October 16-17, 2013. Retrieved from http://transitgis.org/download/data/Wang%20Presentation.pptx on July 14, 2015.

(20) Environmental Systems Research Institute, Inc. *Esri Roads and Highways—Manage Your Road Network*. Retrieved from http://www.esri.com/software/arcgis/extensions/roads-and-highways on July 14, 2015.

(21) Yardi Systems, Inc. *Voyager Commercial—End to End Property Management*. Retrieved from http://www.yardi.com/products/yardi-voyager-commercial/ on July 14, 2015.

(22) Kraus, E., C. Quiroga, and J. Le. Strategies to Optimize the Management of Right-of-Way Parcel and Utility Information. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2436, pp.119-128, 2014.

(23) Intergraph Corporation. VicTrack Shares Spatial Property Information Online. Retrieved from http://www.intergraph.com/assets/customerstories/pdf/VicTrackAU.pdf on July 16, 2015.

(24) 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.