Using GIS in Strategic Planning and Execution at FedEx Express

Jacquelyn Haas, FedEx Services
Jeff McLeod, FedEx Express
Rick Dezemplen, FedEx Services
Rodney Conger, ESRI

Abstract
ESRI GIS technologies are being used at FedEx Express to solve complex business problems in both the planning and execution of the daily delivery process. The application of spatial data at FedEx is unique in that it is being used to support several mission critical, multi-user applications and processes worldwide. Spatial data is being implemented within the organization for use in decision making for the routing and scheduling of thousands of pickup and delivery vehicles on a daily basis. It is aimed at minimizing costs such as mileage, overtime of workforce, efficient routing, and effective delivery methods, leading to higher productivity and greater customer satisfaction. The dynamic nature of the daily execution as a business problem, when coupled with the analysis of historical events, GIS spatial data, customer data, and resource information can predict best practices for delivery methods and increased productivity.

Introduction

FedEx uses a map-based system to support planning and operations activities for the on-road pickup and delivery operations within the Express operating company. Planners who operate locally and with local knowledge build route plans which guide every stage of the operation from sorting the inbound freight to loading the vans, to driving the routes. Route plans are designed using GIS along with business-specific optimization methods which work together to allow the planners to test the durability of their route plans to accommodate package volumes which may fluctuate higher or lower than those actually planned for. GIS tools are used to display routes on the map and overlay stops on top of those routes. The system calculates and displays statistics based on how those stops and packages relate to routes and then provides editing tools that allow the users to equalize stop and package volume across routes.

One of the keys to successful use of GIS in this system is simplicity in how GIS is implemented. There are no complex business rules or analysis within the GIS tools. The user interface is task driven through menus that guide the user progressively through the planning tasks and expose these tasks via an easy-to-use web application and ArcMap based user interface. Complex analysis is off-boarded to asynchronous algorithms using HTTP level communication. A separation of the planning system and the operational system also exists such that once the plan is complete, validated and tested as 'ready for production', it is loaded in a state where operational systems can access and read it using normal database queries that forego time consuming GIS analysis. Web browser-based mapping tools are also available for non-editing views of route planning data. These tools were built using the ArcGIS Server

Java ADF and are available to a wider group of high level users than the local plan building experts who use the desktop tool to build plans.

This paper presents this FedEx planning system from an implementation perspective by describing the architecture on which it is deployed and the methods that were used to construct it. We also describe major considerations for a system such as this which must communicate with other applications that do not employ GIS concepts and have no knowledge of GIS constructs. Finally, we will describe challenges moving forward from a platform perspective. Rich client capabilities were only available in a Desktop format when this development effort was begun, however the advancement of Web APIs and rich functionality through runtime plug-ins like Flash and Silverlight provide an opportunity to simplify the field deployment architectures for similar applications in the future.

1.0 Goals and objectives for planning

FedEx Express is the world's largest express transportation company, providing fast and reliable delivery to every U.S. address and to more than 220 countries and territories. FedEx Express uses a global air-and-ground network to speed delivery of time-sensitive shipments, usually in one to two business days with the delivery time guaranteed. FedEx Express handles approximately 3.4 million shipments each day in more than 220 countries and territories, including every address in the United States. The transportation fleet at Express consists of 660 aircraft and 42,000 motorized vehicles used for delivery of these shipments. There are 1083 stations (692 U.S. and 391 outside the U.S.) that are responsible for the pickup and delivery of the majority of shipments to and from our customers. Within the U.S., FedEx Express offers a wide range of shipping services for delivery of small packages up to 150 pounds each. Express offers multiple next business day delivery options as well as 2 or 3 business day delivery options. International express delivery is guaranteed to more than 220 countries and territories, with a variety of time-definite services to meet distinct customer needs. FedEx Express offers same day or next business day pickup of customer shipments as well as dropoff points at numerous locations within the FedEx system. Delivery commitment times for all of the express services are based upon the destination zip code. For example, Priority Overnight service commitments for packages shipped within the U.S. can be 10:30 am, noon, or 4:30 pm depending on the destination's service area designated in the most recent edition of the FedEx Express Service Guide.

With all of these statistics and information presented, it is the responsibility of FedEx Express's Planning and Engineering groups to provide efficient and effective plans for our pickup and delivery operations at each of the 1083 stations on a daily basis. These plans are derived using tools such as statistical analysis of historical data and forecast modeling along with the GIS application. The objective of planning is to prescribe the most efficient use of assets, personnel, and time definite windows to pickup and deliver all of the packages that transit through the Express system. As the package volumes fluctuate daily, the Express operations must also be prepared to adjust in order to provide our superior service to our customers at an effective cost. This cycle must be repeated each operating day.

2.0 Goals and Objectives for Execution

A GIS description of FedEx Express routes

Pickup and delivery plans are called route plans, but they do not actually describe a linear point-to-point driving plan. Route plans are more accurately route areas and describe the area within which a courier operates to pickup and deliver packages. The locations of pickup and delivery sites within the route area are called stops. In the simplest terms, a stop that falls within a given area on a given day of the week and for a given time period will be assigned to a specific courier. Route plans are broken up a bit further by specifying locations inside the truck where delivery packages are placed. These locations are called load positions and the collection of all load positions constitute the route. In mapping terms, each piece of geography is a member of a load position and each load position is a member of a route.

In GIS terms, route plans are described in terms of the street segments that are members of load positions and routes. A street segment is the linear feature which connects one intersection to the next or connects to the street network at only one end. So a load position and hence a route is made up of one or more street segments. Load positions and routes are areas, but they are not stored as physical polygons except for map display purposes. The polygons are used by the mapping display to allow the user to discern one route or load position from another and to easily see the boundaries between two different route or load position areas.

Addresses and stops

Stops were described above as locations where pickup and delivery occur. But these stops are not physical points that float in space, they are actually locations along a street segment and in fact an address must resolve to a street segment to be considered part of a route from the perspective of planning and execution. Resolving a stop to an address and an address to a street segment is one of the more complex and challenging aspects of this or any similar system due to data quality, address quality as supplied by the package sender, and the quality and accuracy of the geocoding processes that parse addresses and resolve them to locations. The methods for dealing with geocoding issues are too large a topic to describe in this paper, but the challenges continually evolve as more international locations are added to any address geocoding system. For the purposes of building a plan with the system described in this paper; a stop has an address and that address resolves to a street segment in the streets feature class. More specifically, that address resolves to either the left or right side of a street feature.

Plan "definitions" and storing GIS data

Route and load position plans are comprised of street segments and the GIS representation of those are groups of street features which are unioned together. Since address points resolve to the base street features that make up the routes and load positions and since the systems responsible for sorting packages and loading trucks have no concept of GIS, the GIS actually stores route features in two ways: first, routes are stored using specialized line buffers which build polygons around unioned line features. This storage scheme is used for visual display only while using the planning application or on printed maps. Second, the system stores definitions which are tabular representations of the street lines on which the polygon features are based. These definitions describe each route and load position with a series of records that identify the street segments that make them up, so other systems which need to read and understand a route plan for operational sorting and loading do not require a GIS interface. Furthermore, the sorting and loading operations are not impacted by the processing time it might take to discover the spatial relationship of a point to a route feature. To summarize, route definition tables store a tabular description of the route and buffer polygons store the mapping representation. This storage scheme allows the buffered polygons to be reconstructed at any time using the definitions and provides assurance that the information that is shown on the map will be accurately translated into the package sort.

GIS-plan to package-delivery

The end result of this storage scheme is a straightforward set of mapping instructions that resolve addresses to street segments and street segments to routes and load positions as shown in Figure 1.

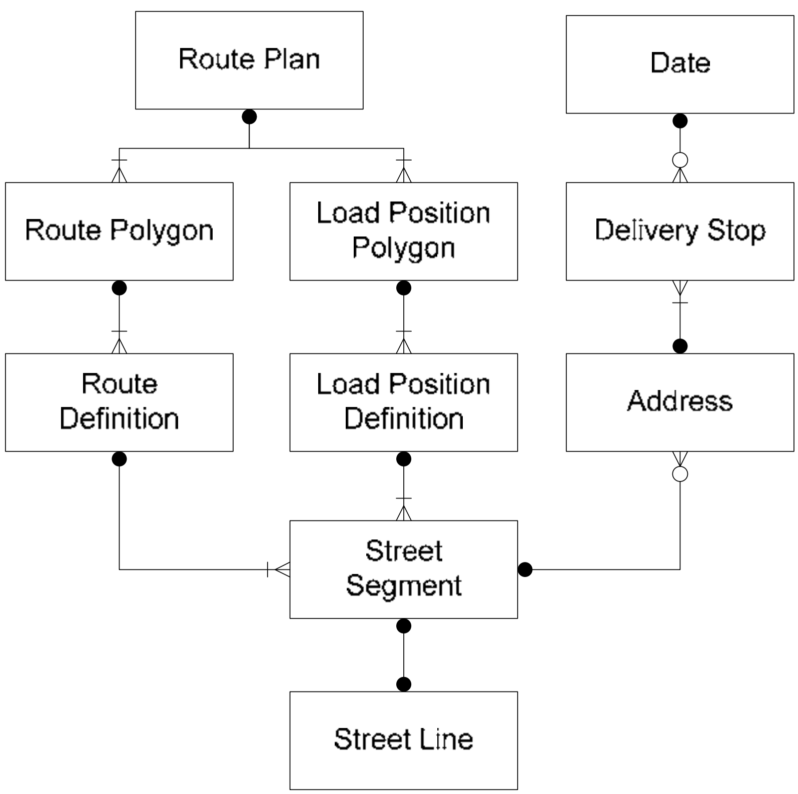

Figure 1. From address to position on the truck. This is how a package is sorted using abstracted GIS planning data for any date and any street address.

3.0 Application usage and architecture

User interfaces and workflows

Route planning begins when the user specifies the parameters for the plan. For example, a plan may be intended to cover only a two-hour delivery period for Monday morning or accommodate special circumstances like a parade or stadium event. Once these parameters are established, planning begins within an ArcGIS Desktop application by checking the plan out for editing. This application is called the T2 Rich Client. Task specific tools are provided within the Rich Client that allow users to quickly aggregate street segments into plan elements such as routes and load positions. A more detailed use case-level description of some of these tools is provided in Section 4.

Once a basic plan structure has been established using interactive tools within the Rich Client, off-board business analysis is executed on the preliminary plan. This analysis runs asynchronously and the user is notified when the analysis has finished. Once finished, results of the analysis are then displayed on the map and the user continues to work within the Rich Client to tune the plan using feedback from the analysis.

After the plan is finished and the validity of the plan has been confirmed using automated validation tools within the Rich Client, the plan is saved by checking it back in. Plans that are in a valid geographic state which have undergone business analysis and are checked-in are available to be viewed by a read-only web mapping viewer that is implemented in the ArcGIS Server Java ADF known as the T2 Map Viewer. The Map Viewer cannot modify the plans, however users can view the plans to help select the appropriate plan for the production sort and initiate a map printing process to communicate the plans to the couriers.

Other web mapping applications that are used for tasks necessary to pre- and post-planning include an address geocoding re-match processor (RJP) where users can view historical stops on a map along with listings of addresses which could not be geocoded automatically. Users are able to select an address and click a point on the map where the address should be located. The application then uses reverse geocoding to tie the non-geocodeable address to the nearest valid address on a street segment for assignment to a route and load position. Also included is a route analysis tool called Planet Station that shows a courier's stops after stops were made and helps identify problem areas which may have affected productivity or caused service failures.

More detail on the use cases of the tools mentioned in this section can be found in Sections 4 and 5.

Technical implementation

Each application in the system is isolated onto its own tier. The ArcGIS Server Java ADF applications are further isolated into sub tiers. Figure 2 shows each tier and how the tiers communicate with one another.

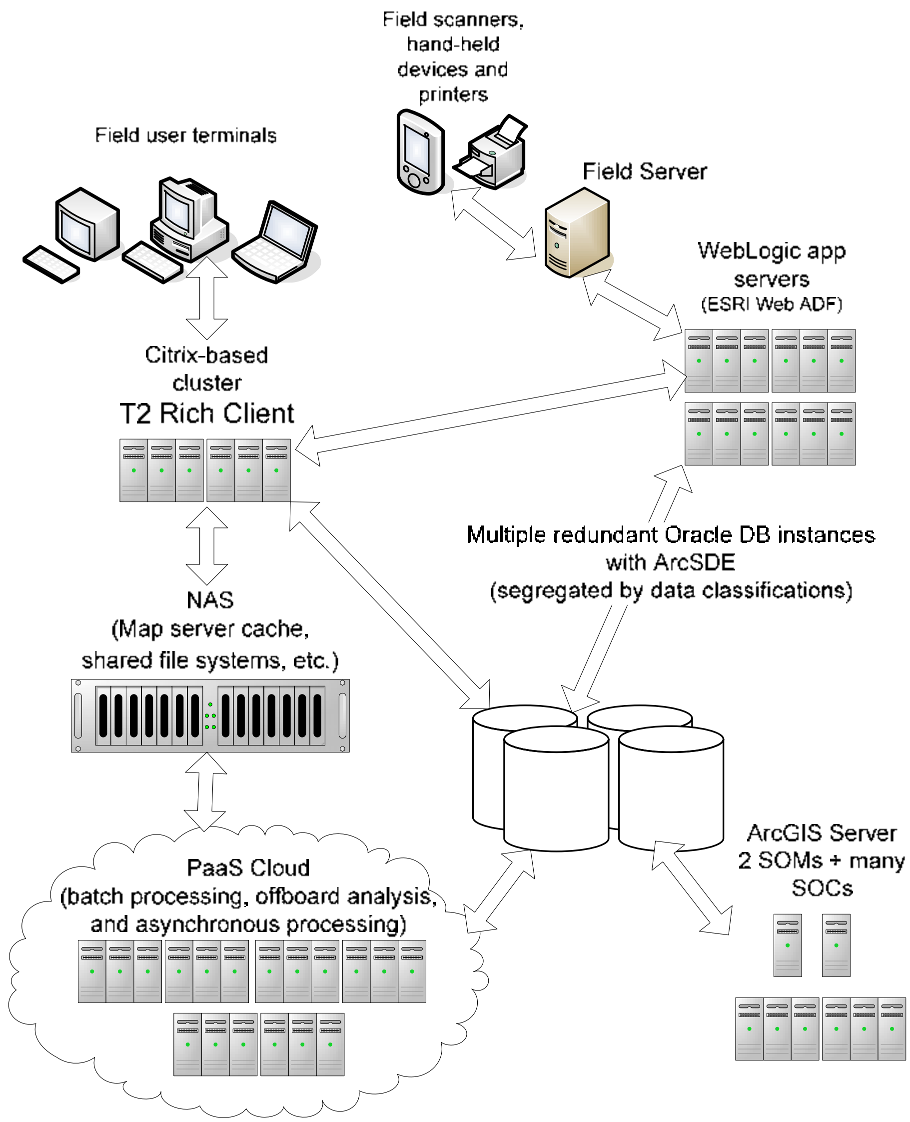

Figure 2. Application component and database storage tiers.

Rich Client

The Rich Client is implemented as an ArcMap extension and is written with ArcObjects using C# .Net and exposed to end users throughout the U.S. via Citrix application streaming. This configuration supports hundreds of simultaneous editors. Implementing the application as an ArcMap extension allows the startup behavior to be controlled and for a custom startup menu to be shown to the users rather than the COTS startup menu. The extension also allows for environment checks to be preformed prior to allowing the user to continue using the application. For example, if the database connection were found to be unhealthy at startup, the user is notified, the issue logged and the application automatically terminated. All custom planning-specific functions are also contained within the extension. Users are given a choice of whether to load a plan at startup or just to start ArcMap in COTS mode. If COTS mode is selected, all custom planning functions are disabled.

Portions of plans that are edited in the rich client reside in a file geodatabase while they are checked out. Checking a plan out for editing involves copying some features from the ArcSDE Oracle instance to a file geodatabase that is dedicated to that checked-out plan only. The plan is also marked as being checked-out in the oracle instance and is not available to be checked-out by another user while in this state. It is important to note that the term 'check out' does not imply a geodatabase check out. The FedEx planning system does not use geodatabase versioning in any sense. Rather, a much simpler versioning model was devised that meets the business requirement of versioned plan data while eliminating all of the management overhead geodatabase versioning.

Off-board business analysis functions are called from the Rich Client via HTTP to a service request listener. The listener then posts analysis job status information to database tables which are maintained in common between the Rich Client and the analysis engine. The system architecture and the methodology used to process off-board business analysis functions are shown in more detail in Figure 3.

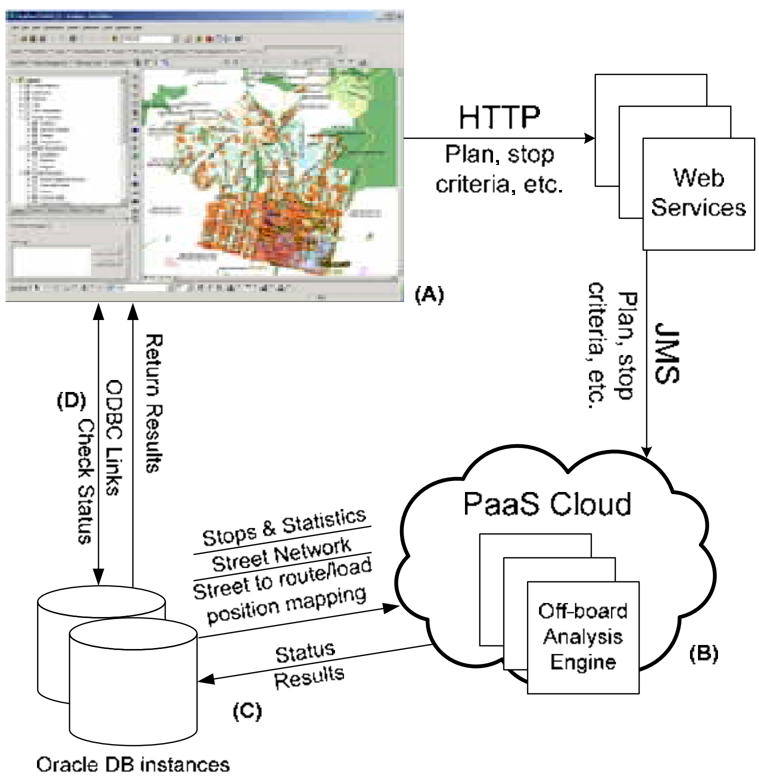

Figure 3. Rich Client component detail for off-board analysis. The ArcMap extension is used for planning and grouping geographies (A). When a portion of the plan is finished, the user submits a business analysis run request through an HTTP listener. The run request is published on a JMS queue and brokered through the analysis engine which runs within a PaaS cloud (B). The analysis engine uses the information provided with the run request to retrieve the data needed for the analysis from the common Oracle database (C). The Rich client monitors run request progress and retrieves analysis results through an ODBC connection to the Oracle database (D).

Web Applications
The web mapping toolset contains the Web Viewer, RJP, and Planet Station applications described above. These applications provide web mapping capability to users through ArcGIS Server, the Java Web ADF, and fine-grained ArcObjects applications written in Java. All web applications share common deployment tiers. The web application client code is extensive in terms of capability and all business logic for the mapping application is contained in the Java ADF tier and deployed using WebLogic application server. The application server tier makes client use of ArcGIS Server which resides on a separate tier. Map rendering and fine-grain ArcObjects processing services are provided to the ADF tier through a SOC/SOM cluster that is distributed across several hosts to provide load balancing and redundancy.

Data Services
All of the applications make use of an Oracle database instance for persisting data and this repository serves as a communication mechanism between applications which mostly make no use of services-based architecture methods. Permanent route plan and address data are stored in Oracle and evolve through a versioning and data updating scheme on a daily basis. Vendor data such as streets and postal code polygons are also stored in Oracle and changes are made to vendor data through a regular scheduled update process. File based data is also used in the planning process to support versioned data requirements when planning data is checked out for editing. A cached tile representation of basemap data is also stored on the file system and provides vendor and business data map tiles to web clients and mapping applications for data which does not change very often.

Figure 4 shows an example of one of the data services workflow patterns used in the system. In this example, the web application is used to request a set of exported PDF maps representing a pickup and delivery service area. Data services are used to provide the map export process with plan data describing the routes. The oracle database is then used to store the output of the map export process for later on-demand retrieval by the user.

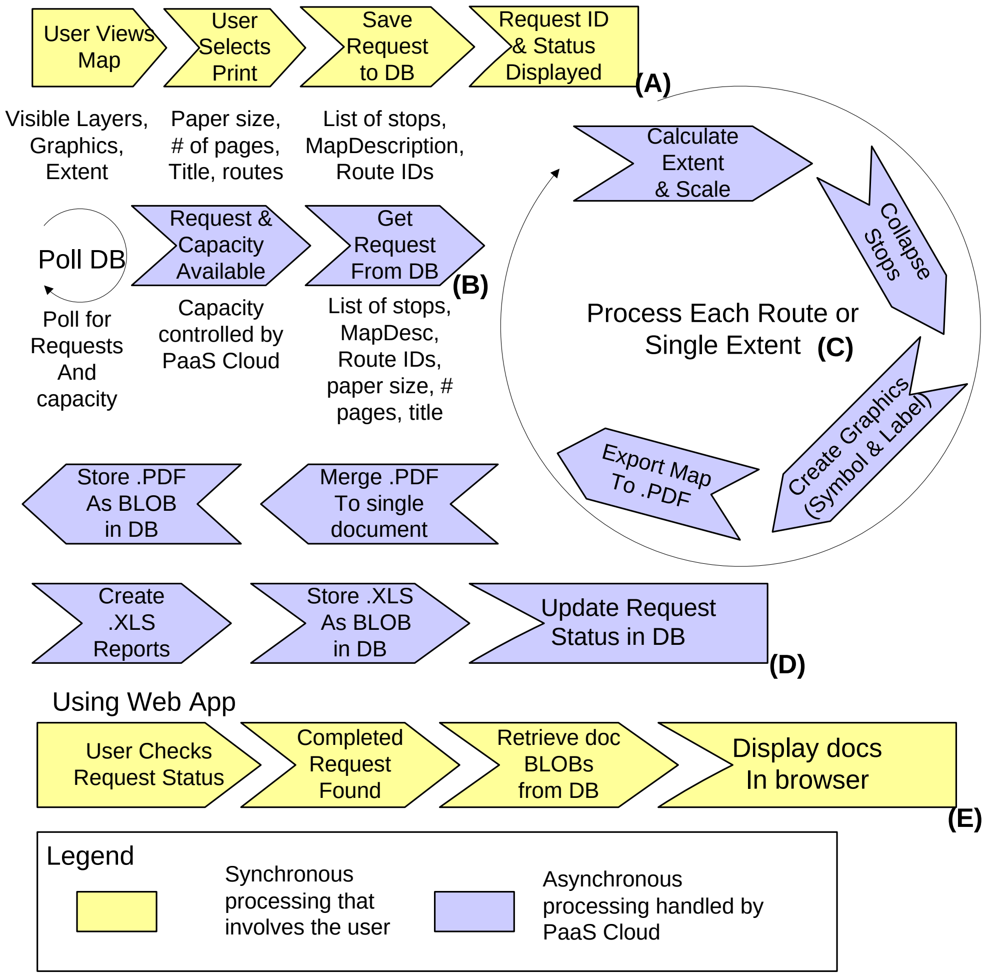

Figure 4. An example of a process that uses data services. Users are able to view maps in the web browser application and request printed maps (A). The system saves the map print request to the database. A process running in a PaaS cloud monitors the queue for map export requests and meters the requests into the map processing service (B). The spatial extent of each route in the map request is used to generate a PDF export covering the extent of that route (C). After all individual map exports have been exported, a process merges all PDFs created by the export into a single document and serializes the export into a BLOB in the Oracle database. Metadata for the exported map is created also as well as job request status information (D). The user monitors the export progress using the web browser application and is notified when an export completes. The user can then display the exported map in the browser and print it locally if desired (E).

Specific Technical Challenges

GIS Data Challenges

One of the GIS challenges with this system is due to the 32-bit limitation of an ArcSDE feature class OBJECTID. Ideally, stop address data would have been stored in a feature class for easy client display and ready availability for GIS analysis. However, FedEx Express daily package volumes generate enough stops nationwide to exceed the 2.1 billion row limitation in a relatively short amount of time. The solution to this challenge was to store the stop data in non-spatial tables and include the latitude and longitude as fields, without geodatabase columns or registration. When stop data is required for analysis or display, the appropriate stops are queried using standard SQL and then the client either persists the results into temporary feature classes (as in the rich client) or into graphic elements that contain symbology and text elements for the labels (as in the ADF web applications). This solution is not ideal because of much of the complexity and business logic to support this functionality resides at the client and is re-implemented differently within each client based on the architecture.

Another challenge is the nationwide map cache. The map cache that supports the web applications is about 600 GB in size for the U.S. and the cached map scales meet a large percentage of the business need. However, there are some scenarios where users need to zoom into scales that are larger than the largest cached scale. For those cases, the web applications automatically switch to dynamically rendered maps. This scenario offers a better compromise between not using caching at all and caching at very large scales when considering the time required to generate the cache during regular data updates and the low likelihood that many of the tiles that were cached at the highest resolution would ever be accessed. More recent options for caching on-demand and perhaps a map service that is sufficiently performant to eliminate the need for caching entirely are currently under consideration. Building and managing an appropriate cache that is complete and can be generated in a reasonable amount of time have been considerable challenges.

Functional and system challenges

An inherent challenge in any mapping application that displays dense point data is communicating point locations accurately, but not allowing stacked points at small scales to overrun one another. There are several FedEx data scenarios that can cause multiple stops to be at the exact same latitude and longitude or very close together at normal map viewing scales. The challenge of displaying only relevant information for each overrun location was overcome by spatially clustering the stops before the graphic elements are created. Point stop features are collapsed and the representative symbol on the map is changed to indicate a cluster location based in the scale that the map is being rendered. Furthermore, the text label in this scenario is changed to show information about all of the features in the cluster. The logic for clustering runs with the other logic in the ADF tier and performance is always a consideration. A possible future solution to the performance issue may be moving the logic into a Java Server Object Extension or perhaps clustering on a new-generation client using the FLEX API. New architecture options which did not exist when the current application was designed could help to more effectively overcome the limitations of an application server architectures to deliver better performance and more interactivity to the end user.

Another challenge is map printing. Users of the web applications can request that map views be exported to PDF. Some of these maps can be very intense maps with lots of features and street-level details displayed at relatively large scales. Therefore, the exporting of these maps to .PDF is handled asynchronously and queued based upon hardware availability. For these maps, speed of getting the final product is not a primary concern and map requests are processed through the queue as demand for resources permits.

A same-day mapping which shows a courier's route area and stops for the day is another printing challenge. Speed is the main concern for the daily map export process and a special dedicated map server cache is used to produce these maps since relying on ArcGIS Server to process them would have represented a bottleneck. A custom application with tile edge matching logic was developed for this purpose. The application edge-matches tiles from the tile library and places graphic symbols on the maps using java graphics libraries before outputting the end product to PDF.

4.0 Planning operations

Specific planning groups at FedEx Express are responsible for analyzing, developing, communicating, and distributing plans to the operations personnel at the stations across the U.S. and other countries for the pickup and delivery portions of the process. The planning groups use customer and business information from past dates along with the GIS application to assign addresses from a street segment or multiple streets to routes for delivery assignment. As the volume changes across different weekdays within the Express system, the plans need to change as well in order to achieve the most efficient operation of the business. Planners must review vast amounts of data and develop plans for every day that dictates changes in the operation. Saturdays, holiday periods, and Christmas peak season represent some examples of periods when the pickup and delivery operations change dramatically. Almost every day of the week requires some level of fluctuation within the plans to ensure the Express business meets its commitments to customers' needs and operates in the most efficient manner as well. Operations personnel are provided different operating plans based upon the changing needs of these examples. The GIS tool allows planners to review these changes on a daily basis and adjust route areas or metrics so that the pickup and delivery operations can execute efficiently with each variation. Adjustments can be based upon volume changes, changes in stop density, more or less routes, or schedules. All of this information can be viewed within the GIS application to determine optimal plans. Figure 5 shows an example of some of the information that is available to the planning analyst while using the application.

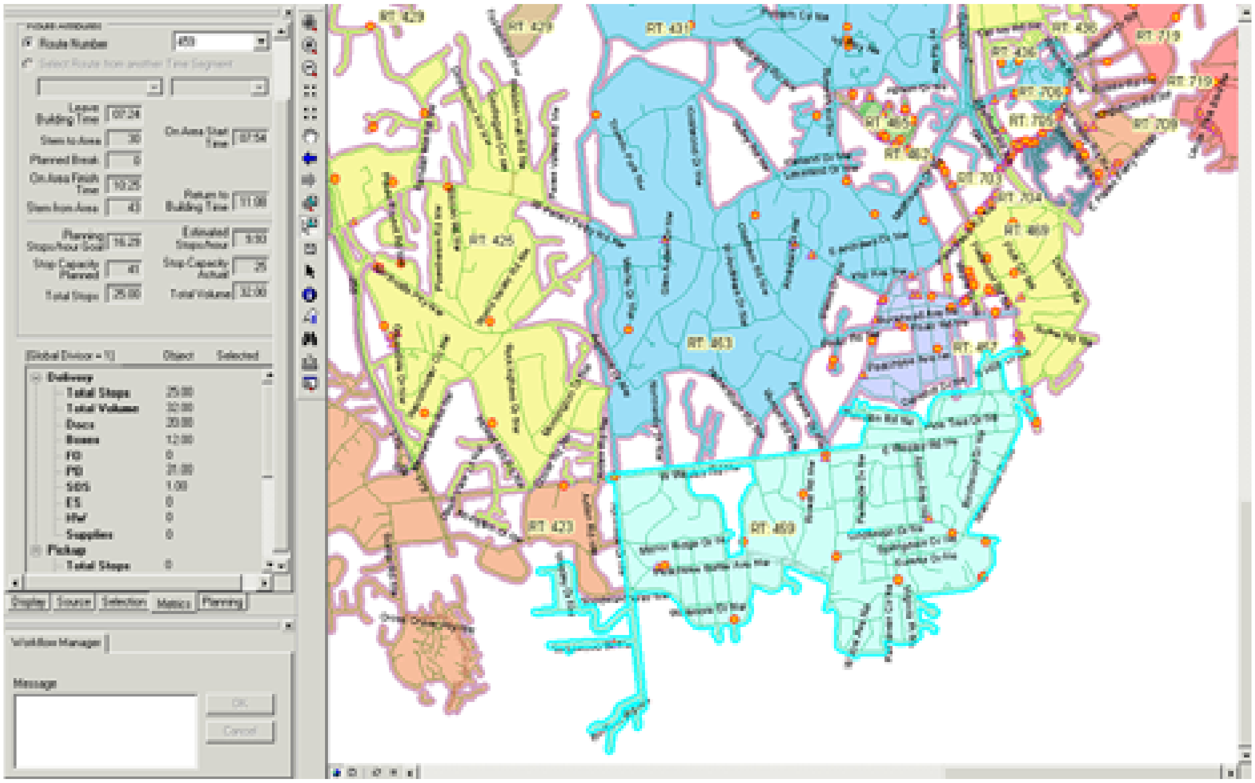

Figure 5. Planning information displayed in the Rich Client application. Users can apply representative stops to a route structure. The application tools summarize stops by route and show the results as metrics for each route. Planners can then use GIS tools to balance stop density across route structures.

GIS Tools can show planners areas of work from historical data. The application also allows planners to see how routes have operated in the past and that information can be used to create new plans. The planner can see which routes have been in geographical areas most recently or frequently and use that information to influence the planning process. The tools can also assist within the plan by automatically grouping the geography into preliminary route areas. The planner can work from these preliminary areas to make adjustments and move geographies between routes using GIS tools that are dedicated to those tasks.

These tools streamline the planning process and allow the pickup and delivery operations to be more flexible and to adapt dynamically to changing business demands.

A delivery service guarantee to every address in the U.S. requires that all addresses are accounted for within every daily plan. The GIS application enforces and validates key business rules during the course of the planning phase and various tools ensure that all geography has been assigned to a route, no addresses have more than one assignment, and that no addresses are unaccounted for within any given plan. This aspect minimizes errors, provides complete and precise information about the plans to operational system which are responsible for package scanning, labeling, and loading according to the plan.

5.0 Tools for execution and using GIS for post-execution analysis

The FedEx Express mapping tools described in Section 3 contain several web-based applications that provide GIS functionality to literally thousands of internal customers who are responsible for all aspects of the business of ensuring that FedEx packages are picked up and delivered on time. The Rich Client is primarily a tool for planning and a relatively small number of experts have access to it. The web applications described in this section have a much larger base of users and are instrumental in supporting the operational GIS needs.

Historical data analysis

One of the very first business use cases for FedEx Express pickup and delivery mapping tools is still relevant today and involves plotting historical stops on a map. Historical stops (as recent as one day in the past) are shown on the map and different labeling and symbology are used to analyze the stops and routes to compare what was planned to occur versus what actually did occur. Package-to-route assignments are compared to the routes that actually delivered each package and variances are highlighted. The purpose of this mapping and analysis is to determine if productivity issues or service failures may be problems with route design. Route boundaries can then be adjusted within the rich client to better distribute the stops among the routes.

Printed maps are an indispensible tool for communicating operational information such the historical stops use case mentioned above. The web application suite contains a map export application where maps are created based on the extents/data viewed on-screen as in the previous use case. PDF documents are exported that show a map area containing at least the on-screen map extent. However, the user has the ability to specify paper size and number of pages across which to break the map up for formatting purposes. The user then has the ability to download that .PDF and store, email, print as necessary.

Another distinct set of use cases center around viewing the planned route structures on a map. These are the route structures that were designed using the ArcMap Rich Client discussed earlier. There are a small number of users who are skilled and authorized to use that particular tool. However, there are thousands of employees affected by the plans those users build. The web mapping toolset includes a Web Viewer product focused upon viewing, communicating, and analyzing those planned structures. The most basic use case for the Web Viewer is to simply display route features that represent the plan on a map and allow people to pan and zoom through the map to see the geography covered by those features. Users can also choose to overlay historical stops on the same map that shows the route plan as well as user defined address points. All of this information together on one map provides the user with information regarding the feasibility of implementing the plan based upon densities of stops.

Same-day operational support

The FedEx Express operational service model allows for flexible and customer focused service offerings such as same-day request for shipment pick up. FedEx Express dispatchers use the web application to see which routes (i.e. FedEx vehicles) have historically handled a given address or neighborhood for the purposes of assigning an on-call pickup request. Dispatchers can enter an address into the system which will be geocoded and the map will zoom to the area around that address. The dispatcher then has the ability to see which couriers have familiarity with the neighborhood and/or customer. The dispatchers can also enter multiple addresses to receive point-to-point driving directions in case a driver is not familiar with a specific address.

The web application framework also provides support for planned execution by exporting and printing map for courier use since there is no practical electronic access to this information while on the road. Each driver can be provided a map that shows their route area along with the planned stops for their pickup and delivery period. Preparing these maps and getting them distributed is quite a time-critical process and a particular IT challenge. More detail about the implementation challenge of this process and queuing and exporting maps in general can be found toward the end of Section3.

6.0 Summary

The implementation and use of GIS in planning and daily operations at FedEx Express has provided many tangible and intangible benefits and has also had its share of challenges. The geographic planning tool has provided an accurate method to predict the daily required number of routes, the stop capacity for each delivery route and recommended delivery stop sequencing. This capability has minimized the number of on-road hours for the workforce and balanced the route and courier capacity. The benefits are saved fuel and improved level of service to the customer through more efficient use of resources.

There have been many challenges in developing systems to accomplish the goals that have been attained – both domestically and internationally. Many independent software tools and systems were integrated to provide the required functionality and software components require distinct hardware and software configurations. For example ArcMap running on Windows/Citrix was used for the Rich Client because many of the required functions in the Planning toolkit were full function ESRI Desktop GIS tools and Windows-based enterprise applications are a deviation from the standard FedEx IT approach of application server-based web clients and service oriented architectures. The system described in this paper consists of both (web and thick Windows clients) and supporting both as well as developing server based applications to "talk" between the tiers and client types has had challenges pertaining to response time, hardcopy printing output, and security issues.

A particular challenge for any company with a service profile such as FedEx is the geocoding required to geo-locate every address necessary for pickup or delivery of a package. Each day, there are new addresses that the system has not encountered previously, changes to postal codes, and the constant variability of customer-supplied address information. Many addresses that come into FedEx on a daily basis are "unresolved" or unmatched after initial automated geocoding processes. Different methods are used to correct these addresses in a small window of time and developing and maintain these methods is a challenge that will continue to grow as we roll out this planning product internationally. Each new country represents challenges due to the limited amount of geocoding and street network data available to the tools.

Time is usually the primary driver of implementing new features or improvements to systems when the commitment to reliable on-time service is as important as it is at FedEx Express. A major hurdle of integrating this system has been the ability to accomplish all of the execution "pieces" in such a small amount of time. Critical shipments can be contracted late into the evening for delivery early the next morning and package processing according to a plan must be done for millions of shipments on a daily basis in a very short timeframe. . Time-saving methods and state of the art technologies (such as cloud computing) have been employed to meet the challenge of minimize response and execution processing times.

Many intangible benefits have resulted directly from precise planning as well. With automatic assignment of packages to geographic areas, the workforce responsible for sorting packages and loading vehicles no longer needs to maintain thorough knowledge of the area for which they are responsible. There is consequently less stress in the mornings during the sort because staff no longer worry that a package for another delivery area will be loaded onto the wrong vehicle. Additionally, the planning tools have enabled route design that equalizes load across all couriers and minimizes conditions where there is too much work for some staff while others do not have enough work to stay busy.