A Prototype Cooperative Effort to Enhance TIGER

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Abstract: *Data sharing and coordination between the US Census Bureau and the Vermont Center for Geographic Information (VCGI) has propelled new advances and possibilities in the update and maintenance of the nation's Topological Integrated Encoding and Referencing (TIGER) database. Utilizing existing local and state resources, internally developed spatial matching and update software, and an effective working partnership with the VCGI, the Census Bureau incorporated, for the first time, GPS[1]-level accuracy to its street centerline network. This statewide prototype demonstrates how the Census Bureau can utilize local data to improve both positional and attribute accuracy while reducing redundancy of effort between federal, state, and local government. This initiative and related data sharing efforts offer important lessons and opportunities for the Census Bureau as well as for the evolution of the National Spatial Data Infrastructure (NSDI).*

Background

The diffusion and use of geographic information systems (GIS) in state and local government and throughout the private sector during the 1990s has been well documented. While the Census Bureau anticipated and, to some extent, precipitated this growth, the development of an operational system to capture local map updates from a wide variety of files and data formats was slow to emerge. Although pieces of the system have been in place for several years, digital exchange remained unproductive; that is, the efforts to process digital files often required more resources than the existing clerical means to update the Topologically Integrated Geographic Encoding & Referencing (TIGER) database. In the absence of a formal digital exchange program and digital exchange standards, Census Bureau regional office staff manually plotted and used locally provided digital files as paper reference sources.

This environment, sparked by Census Bureau requests to help update the TIGER data base via manual annotation of census maps, led to frustration on the part of many local and state officials. These responses came predominantly from local and state governments that had spent considerable time and resources developing their own geographic database using a GIS, an activity that has been growing rapidly across the country. In essence, the Census Bureau was requesting local governments to repeat work in paper format they had already done digitally. This meant duplication of effort, an increased burden on state and local resources, and the creation of data at a lower level of accuracy; not a happy solution for either party, particularly with "partnerships" being a major theme for Census 2000.

This was the situation encountered in Vermont when each municipality was requested by the Census Bureau to manually update paper census maps. At this time, Vermont had invested heavily in state of the art GIS, had developed highly accurate street centerline files for the entire State, and was nearly geographically complete with an enhanced E-911 project, which included the capture of GPS points for structures in most towns. VCGI also maintained current and complete on-line data and metadata that was critical in facilitating communication and use of available resources. Fortunately, the elements to move forward were in place and key staff from the Census Bureau and the VCGI

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made an effort to understand each others resources, requirements, and needs.

Vermont's Enhanced TIGER

The tools and resources to digitally enhance the spatial and attribute accuracy of the portion of the TIGER data base covering Vermont for Census 2000 were provided by recent technical and organizational advances in spatial data exchange at the Census Bureau (Sperling 1997), state coordination of GIS database development by the VCGI, and E-911-related developments in Vermont (Elliot 1997). The TIGER database update for Vermont evolved in two phases.

Phase I: Initial Processing and Integration with TIGER

The first phase required Vermont's road centerline files to be manipulated prior to integration with the TIGER network. Initial processing included a number of conversion, editing, and quality assurance procedures. Town-based layers were combined into county coverages (255 towns, gores, grants). Georeference and datum were converted to Geographic NAD83. Street prefix, name, and suffix items were transferred from related files into the centerline attribute table. Non-TIGER attributes were dropped. ZIP Code values were transferred automatically from polygon coverage into the centerline attribute table. Street names were enhanced to conform to TIGER/postal standards (including cleanup of truncated names, non-standard abbreviations, and inconsistent highway naming); and street names, address ranges, and ZIP Codes were edited to ensure coverage and consistency.

A number of issues arose during the course of this initial preparatory work, some requiring immediate resolution. Many of these issues are common barriers to data sharing and exchange in relation to road centerline data sets.

- What is the definition of a "road network" or "road feature"? What is a road? Does the road network include trails, driveways, parking lots, etc? Is there a common definition? For example, the State of Vermont E-911 Board defines "private roads" as a privately owned roadway leading to three or more sites. A "driveway" is defined as a private roadway leading to one or two sites. However, these definitions are specific to Vermont and may not apply to other areas of the country, and do not apply to the TIGER data base, which considers as a road any roadway leading to two or more dwellings.
- What defines the starting and stopping point of a "road segment/entity"? Is it intersection to intersection, or is it based on changes in attribution? How does this impact data exchange? Should a "generic" Linear Referencing Scheme be included? Can concepts such as "Framework Transportation Reference Segments" and "Transportation Reference Points"[2] facilitate data exchange and integration?
- How should feature networks (e.g., roads, rivers, railroads) of varying levels of spatial accuracy be reconciled and integrated? For example, VCGI provided hydrography files (1:5,000) which were much more detailed than the hydrography features in the TIGER data base (1:100,000).
- How should the feature network be attributed? How should addresses and ZIP Codes be modeled (Sperling 1993)?

After reviewing and implementing solutions to some of the issues mentioned above, the files were converted into TIGER-db format files (different than the TIGER/Lineâ public extracts) matched, and then "rubbersheeted" to the TIGER feature base using census developed routines that work in the TIGER data base environment (Rosenson 1997). This process automatically transferred new road segments that did not conflict with existing TIGER topology and automatically transferred attributes (street names, address ranges, ZIP Codes) from the Vermont file if they did not conflict with existing attribute information.

As many in the GIS community know, the automated matching and transfer of features and attributes (often called "conflation") from one geo-spatial database into another is problematic at best. Extensive research has been conducted within the GIS community with regard to the optimization of "conflation" routines, but the differences in coordinate representation continue to limit match rates. Census "conflation" routines were designed primarily to enable the electronic and interactive transfer of new road features and postal attributes from locally provided files to support its TIGER/Master Address File (MAF) integration goals.[3] Routines are intersection-based and employ a combination of name and feature-based matching programs with topological relationship checking for verification. The percentage of successfully matched features varies widely depending on the similarity of the two databases. Successful coordinate matching is dependent upon the degree to which TIGER feature and name representations match the local data.

Once all the automated operations were complete, the files were available to Census Bureau geographic staff to interactively add/enhance features and attributes not resolved from the automated match. As stated above, this latter step can be quite extensive if the feature network between TIGER and the local files are significantly different. Since the base for most of the feature network in the TIGER database for Vermont was based on the USGS 1:100,000-scale files, the discrepancies and the amount of interactive work required was relatively minimal.

For the State of Vermont, which had just undergone E-911 conversion, the automated process transferred thousands of new streets, street names, address ranges, and ZIP Codes from the local files to TIGER in a few hours of computer time with minimal staff time required for interactive update. This initial automated update capability led to increased productivity, large cost savings, enhanced data quality, and an effective partnership. This process, however, did not enhance the positional accuracy of TIGER.

Phase 2: Enhanced Positional Accuracy

VCGI and the Census Bureau extended the developments achieved in Phase 1 by moving TIGER to the coordinate accuracy of the Vermont files. The Census Bureau rubbersheeted the

TIGER road network using the local road centerlines and added roads from the Vermont files not in TIGER. Although enhancing the coordinate accuracy of TIGER was not a funded mandate for Census 2000, it became obvious that the existing resources in the Census Bureau and the VCGI provided an opportunity to further enhance quality and save hundreds of thousands of dollars more by possibly eliminating a major labor-intensive, precensus field address-listing operation and creating an initial geocoded address list for Census 2000.

VCGI and the Census Bureau leveraged their individual resources to accomplish this task. Vermont provided a 1:5,000-scale orthophoto-based and GPS-enhanced road network, 1:5,000-scale digital orthophotos of the hydrography network, a town boundary file based on best available data, and GPS points and attributes for all residential, commercial, and industrial structures. The Census Bureau provided the ability to convert the local GIS files to a TIGER-like format for electronic/ interactive update and TIGER coordinate enhancement software programs.

Only road features received coordinate enhancement; non-road features (e.g., hydrography, governmental unit boundaries) were rubbersheeted to the new road network using defined algorithms with some interactive adjustments to maintain topological consistency in the TIGER data base. While hydrography files based on digital orthophotos were available for most of the state, they were used only as reference sources to quality check the rubbersheeting process. Adding the more accurate and larger scale 1:5,000 digital hydrography to the TIGER data base would add a significant number of new features and intersections and raise a number of modeling issues (e.g., area vs. line representation, data generalization) that would need to be resolved.

Using minimal but highly focused efforts, all preparatory work was completed in a relatively short period of time. The road networks in 9 of the 14 counties in Vermont were spatially enhanced in TIGER with minimal interactive effort. Census 2000 operational deadlines precluded completing the entire State. Pending additional resources, the remaining five county road centerline files will be spatially enhanced for year 2000 data products.

Data Sharing, Data Maintenance, and the NSDI

Now that TIGER contains 1:5,000-scale road accuracy for several counties in Vermont, how can the Census Bureau maintain the same level of accuracy as TIGER is updated? Field operations and other inputs from non-census sources continually add updates to TIGER; however, these often are based on inconsistent sources (e.g., sketches by field staff) and scales. The Census Bureau is currently exploring short and long-term methodologies such as use of digital orthophotography quads or satellite imagery (Broome 1998) to deal with these issues as it incrementally develops more spatially accurate county partitions in the TIGER database.

Similar problems posed at the national level exist at the local level. The State of Vermont (the VCGI specifically) has been grappling with the complexities of integrating road centerline files maintained in a distributed environment that includes updates from Regional Planning Commissions, the Vermont Agency of Transportation, and E-911. This kind of situation can be found in many other parts of the country. Fortunately these Vermont organizations, with support from the VCGI, are attempting to develop data sharing and integration solutions that will minimize duplication and redundancy.

The VCGI's "area integration"[4] role is a vital link between Federal organizations (such as the U.S. Geological Survey and the Census Bureau) and Vermont's local, regional, and state agencies. These organizational relationships establish the foundation for NSDI Framework data development in the State of Vermont, and a robust maintenance regime for TIGER. The establishment of "area integrators" provides the opportunity to establish formal data sharing agreements for ongoing updates.

The understandings gained from this work may provide lessons for the ongoing development of the NSDI. The NSDI is based on the vision of creating a *spatial data infrastructure* supported from the bottom-up: the best available data establishing the NSDI "framework". Significant resources have been allocated at the federal, tribal, state, and local levels in an attempt to develop road centerline networks designed to meet specific application requirements. However, many of these initiatives have not attempted to resolve the sharing of data between organizations and across map scales for the purposes of update, especially at a national level.

A wide range of technical and organizational constraints continues to make the NSDI concept elusive. Technical constraints which limit the sharing and integration of transportation databases have been explored by many in the GIS-T community, including the Federal Geographic Data Committee (FGDC), Oak Ridge National Laboratory (ORNL), and federal organizations such as Bureau of Transportation Statistics (BTS). Detailed discussion of some of the modeling issues that affect data sharing can be found in Butler and Dueker (1998) and Dueker and Butler (1997).

Road data models have been proposed which attempt to eliminate traditional "conflation" problems by assigning a stable and unique identifier to each geo-spatial feature in the source and target databases. Once established, unique identifiers can be used to match features between databases without any reliance on coordinate or name matching. However, unique feature identifiers fail in instances where the geo-spatial representation of a feature varies. For example, roads can be segmented in many ways, depending on specific application requirements. This is often what cooperating organizations encounter in their attempts to share information.

The FGDC Ground Transportation Subcommittee (1998) has sponsored the development of a NSDI Framework Road Data Model. The current draft document attempts to "define a road segment in such as way that it is independent of cartographic scale or network topology."[5] This standard is currently in its second phase of development, and will likely be piloted in several

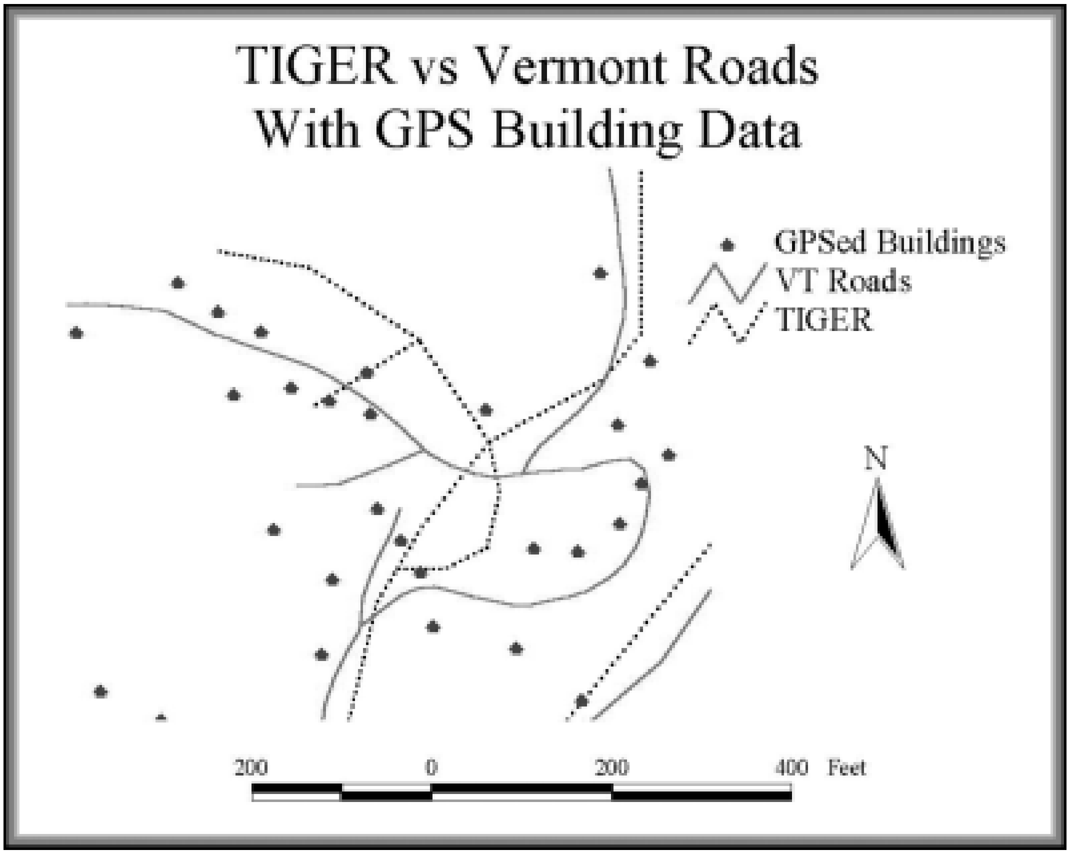

Figure 1

areas. Future plans to modernize and maintain TIGER should integrate the concepts articulated within this standard.

Currently, the Census Bureau is grappling with the technical and organizational (and budget) issues of how to cost-effectively update/maintain, and correct positional accuracy in, its geographic data base in the 21st century. Increased demands for ongoing maintenance of the TIGER/MAF database to support census statistical programs and dissemination efforts provide an impetus to develop more robust data sharing arrangements with public and private partners. These activities coincide with the overall objectives of Executive Order 12906 as being implemented by the FGDC. In fact, part of the Executive Order 12096 initiative was to develop a national geospatial framework to support the 2000 decennial census.

Vermont Initiative Supports a Business Case for Enhancing TIGER

One of the primary criticisms of the TIGER data base during the past ten years has been its poor coordinate accuracy. In a narrow sense, the relative positional accuracy of TIGER has always been “good enough” for census purposes and most social science applications (Sperling, 1995). However, in a broader sense, the increasing requirements for more accurate geospatial databases have begun to tarnish the “good enough” rationale.

The societal need for a more accurate nationwide shared geographic database that can alternately use both address and geographic coordinate as entry points or match keys is being dictated by recent trends. These trends include: the increasing need to integrate environmental, health, and population databases at local, regional, and state levels (Croner, Sperling, Broome, 1996); the rapid advance and availability of GPS technology and high resolution imagery; the concern with developing a framework for the NSDI, and the need to develop an ongoing robust capability to share geographic information.

Although the Census Bureau, at present, has neither the formal mandate nor the resources to correct positional accuracy on a nationwide basis, the experience with Vermont poses a successful model and business case to support similar coordinate enhancement activity nationwide following Census 2000. Agencies generally support the vision of NSDI, but unless short-term agency or mission-specific benefits can be derived, there is little incentive to invest resources that would accelerate the evolution of a robust NSDI.

The TIGER data base is founded on relational rather than absolute accuracy objectives and contains data that vary widely in terms of spatial accuracy, within counties as well as between counties. However, a new environment characterized by GIS, GPS, digital imagery, and data sharing provides the technical and

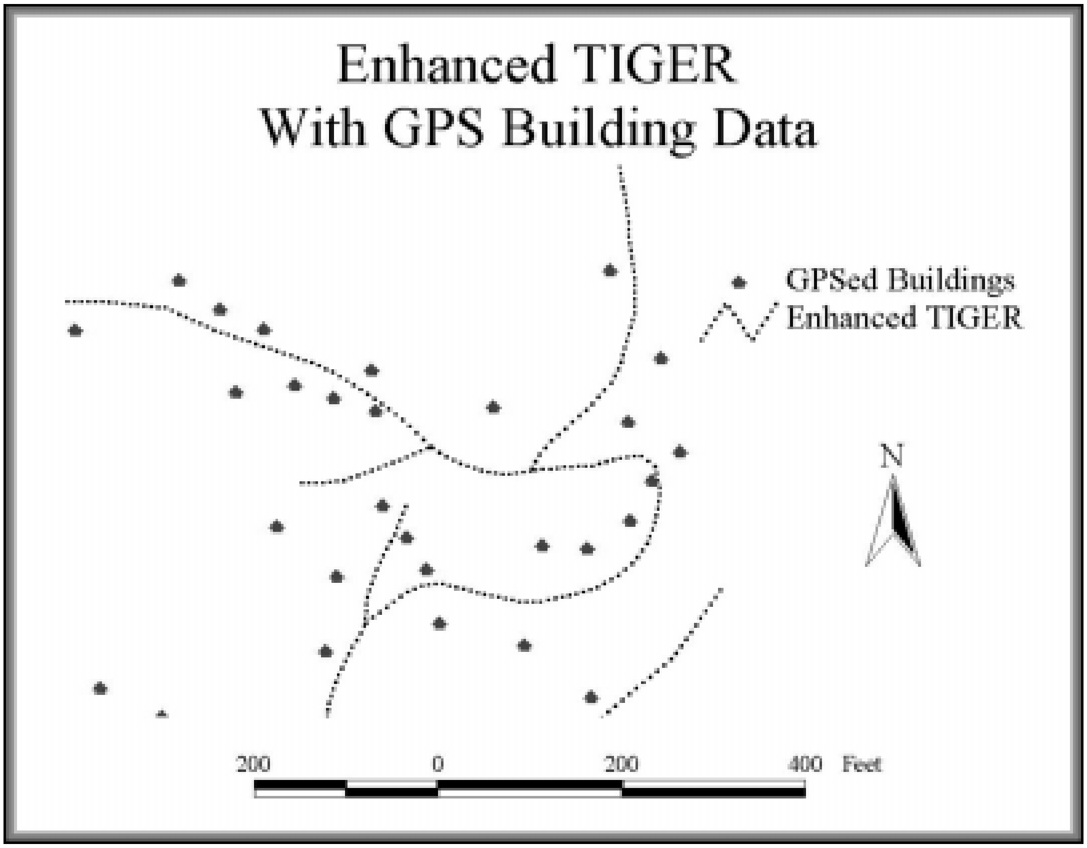

Figure 2

organizational framework for rethinking future database modeling and maintenance strategies. Insertion of basic street address locations also may lead to a more robust capability for data integration, time series analysis, and data tabulations independent of census blocks, the current atomic unit for statistical and geographic processing at the Census Bureau.

The Vermont files show the promise and potential benefits for enhancing coordinate accuracy in TIGER. Figure 1 shows the GPS building locations derived from the State's E-911 work in relationship to TIGER before coordinate enhancement versus the more accurate Vermont road centerline files.[6] This graphic demonstrates the inability of the current TIGER relational accuracy to take full advantage of GPS technology that is increasingly being utilized by the public and private sectors to enhance their geographic databases.

Figure 2 shows TIGER adjusted to accurate coordinates and how GPS building locations can now be automatically and accurately linked to geographic areas and lines in TIGER.

The implications for census operations are profound. For instance, current field operations to create a precensus address list in Vermont, as well as most areas in the United States that do not generally use house number/street name addresses for mail delivery, require the Census Bureau to plot thousands of paper maps, and to rent and staff office space early in the Census 2000 process. Field listers are hired to visit every single housing unit, manually estimate the location of each housing unit with a spot on the paper map, and then hand annotate all address identifiers (or a "location" description if an "address" is not discerned) into an address register. Once this operation is completed, the address registers are mailed to a centralized location where they are clerically keyed and maps are sent to another location where the map spots are scanned, digitized, and inserted into the TIGER data base. Regional office staff members then clerically resolve all discrepancies resulting from the multiple operations described. The availability of high quality attributed GPS data potentially enables the elimination of all these labor-intensive and error-prone operations, particularly in areas undergoing E-911 conversion.

In the case of Vermont, and other areas with similar resources around the country, the coordinate enhancement of TIGER, coupled with the availability of good quality GPS attribute data, enables potential savings of millions of dollars, increased productivity, elimination of redundant field operations, and increased accuracy. Partnerships become even more strategic at this level of local/state/tribal/federal cooperation. It has become increasingly apparent that other local jurisdictions are following similar paths to Vermont's and have similar resources available (NSGIC 1998). In some areas, the Census Bureau may even initiate this GPS collection work (Medina and Pfeiffer, 1996). Currently, the Census Bureau is initiating plans to pilot more automated and GPS field collection methodologies to support the American Community Survey (ACS).[7]

Improving the positional accuracy of the TIGER data base also would significantly enhance the automated capability to exchange spatial data between agencies. The current spatial data exchange process at the Census Bureau still involves significant back-end interactive work. The automated process cannot handle many situations where the features between TIGER and non-census spatial data files are significantly different and topological relationships in TIGER are affected. If TIGER coordinates were more accurate, the amount of post-processing interactive work in the future would be significantly minimized. This development would better enable a nationwide automated and ongoing TIGER update capability.

Non-census partners also stand to reap benefits from this process. Constituents within the state of Vermont realized some short and long-term benefits from this initiative. Partnership efforts between the Census Bureau and the VCGI led to positive feedback for the ongoing E-911 effort in Vermont. The Census Bureau was able to communicate concerns and potential data problems to the VCGI which, in turn, was able to pass this information to the E-911 Board and contractors. In the long-term, updating TIGER from local digital data sources reduces the burden on local municipalities by reducing labor cost incurred when municipalities annotate paper TIGER maps with new roads, road names, and address range information. Additionally, the improved spatial accuracy of TIGER will reduce the amount of "rubber-sheeting" required when TIGER 2000 is released, a process that is time consuming and costly for organizations that wish to use TIGER with their existing data. A more accurate TIGER/MAF also helps ensure coverage and quality of census data collection activities, and ultimately, the quality of census statistics for local communities.

Conclusions and Recommendations

Recent innovations in updating the TIGER data base with local, state, tribal, and private GIS databases will continue to be an increasingly important component of TIGER maintenance, because it enables timely and cost-effective updates. Organizational and technical advances in spatial data sharing will create the framework for continuous local partnerships and more

accurate decennial and economic censuses.[8] This process will enable ongoing updates to be transferred to the Census Bureau on an ongoing or as-needed basis throughout the decade. Continuous update will support an integrated TIGER/MAF, the ACS, Administrative Records, the American Factfinder (AFF), and the Integrated Information Solutions (IIS) program (Wallace et. al. 1999); the primary vehicles, along with a corporate metadata repository, for re-engineering the collection, processing, dissemination, and sharing of data after 2000.[9]

These innovations will enable the Census Bureau to spend significantly less time and resources to plot and mail maps, and to digitize updates. Local and tribal governments will not be "burdened" with clerically updating census maps (i.e., duplicating work at lower levels of spatial accuracy) from their own increasingly accurate databases. Overall, taxpayers will receive increased value as the Census Bureau collects and disseminates updates that are more accurate and timely, with minimal overhead and public expenditures required.

Collaborative efforts between the Census Bureau and the VCGI provide evidence to demonstrate the short-term cost-effectiveness of moving to a more accurate street centerline base. This initiative demonstrates the potential for cost reductions, quality enhancements, and a re-engineering of geographic support for the collection, processing, and tabulation of census data for Census 2000 and beyond. As stated previously, this work also coincides with the overall objectives of Executive Order 12906 as being implemented by the FGDC.

This Vermont initiative provides a needed business model and demonstration for enhancing the spatial and attribute accuracy in the TIGER data base and promoting a modernization of the TIGER/MAF data base and processing environment. GPS technology has demonstrated that it can replace/enhance traditional field listing operations. The development of a more common and shared spatially accurate database will help facilitate data exchange and data collection capabilities. Most importantly, this initiative shows the critical importance of "area integrators" to provide the bottom-up flow of data to support agencies, such as the Census Bureau, and the emerging NSDI.

The electronic exchange of spatial data can significantly lessen the burden for all levels of government, enhance partnerships, and provide the formal and informal means to communicate the needs for standards and metadata to all levels of government and the private sector. These are essential prerequisites to building and maintaining the NSDI. Ideally this process will lead to less duplication of effort, more effective use of limited resources within the public sector, and the promotion of mutually beneficial cooperative ventures between the public and private sector. As spatial and attribute data becomes increasingly accurate and available, the full benefits of data sharing will depend increasingly on clear, consistent, and shared confidentiality and privacy guidelines.

Moving beyond "ad hoc" projects, and into a robust operational environment characterized by bi-directional exchange of data between the Census Bureau and State/Tribal/Regional/Local entities requires the establishment of organizational and technical "blueprints" which define the methods and mechanisms to facilitate this activity. Organizational blueprints include the need to define appropriate exchange protocols (e.g., Memorandums of Understanding, contracts) to establish formal relationships between the Census Bureau and cooperating organizations. Technical blueprints would specify or reference the standards and protocols defining the "language of data exchange". Existing standards and ongoing standards development initiatives should be referenced during the development of technical requirements, insuring compatibility with existing investments.

Establishing a formal digital data exchange program, one with enough organizational and technical resources to make data exchange manageable and cost effective, will require extraordinary leadership, communication, and flexibility among agencies. As demonstrated by this and other initiatives, data exchange will be most successful when such ventures can be justified by short-term results, verified cost reductions, improved operations, and minimal problems of data ownership. While significant work remains to be done, this prototype effort between the Census Bureau and the Vermont Center for Geographic Information offers a viable model of local-state-federal partnership as the nation builds a National Spatial Data Infrastructure.

Acknowledgement

The opinions expressed in this article do not necessarily represent the views of the U.S. Census Bureau or the Vermont Center for Geographic Information.

Notes

1. Primary data sources for Vermont's road centerline include Global Positioning system (GPS) and 1:5,000 scale orthophotography.
2. Framework Transportation Reference Segments and Points are conceptual "entities" comprising a "network datum." The FGDC Ground Transportation Subcommittee is currently reviewing the potential of this concept in its attempt to develop a "NSDI Framework Road Data Model." Refer to HYPERLINK http://www.fgdc.gov for documents and related reference articles.
3. TIGER, a nationwide digital geographic database that links all the Census Bureau's extensive social, demographic, and economic data sets and the Master Address File, a nationwide inventory of all residential and, eventually, commercial units are key integrated components of the Census Bureau's data infrastructure. Extracts of the TIGER data base are publicly available as TIGER/Line® files while the MAF is confidential and protected by US Code Title 13.
4. As defined in the FDGC "Bluebook" (Development of a National Digital Geospatial Data Framework, Federal Geographic Data Committee. April 1995), an Area Integrator "incorporates the contributions of data producers into the framework" for a given geographic area. "The framework is a basic, consistent set of digital geospatial data…"
5. Refer to HYPERLINK http://www.fgdc.gov http://www.fgdc.gov for links to the "NSDI Framework Road Data Model" and related reference articles.
6. Vermont's new E-911 address data, including structure number and GPS-identified location, are publicly available. The public record law which established the State E-911 Board includes specific confidentiality provisions relating to "individually identifiable information contained in the system data base". The E-911 Board's interpretation and VCGI's implementation of this law has been to remove names, phone numbers, and older rural route identifiers from, yet maintain public access to, the buildings data base. Interestingly, this information, if shared with the Census Bureau, would become confidential under the more restrictive interpretation of confidentiality provisions in Title 13, U.S.C.
7. The ACS is a large, continuous demographic survey that will provide annual and multi-year estimates of social, economic, and housing characteristics for legal/administrative and statistical geographies. The ACS is a response to customer demands for more timely data and may replace the traditional census long-form questionnaire for 2010.
8. TIGER was created, primarily, for decennial purposes and contains minimal non-residential address information. One of the major problems for coding employer and place-of-work addresses for the Economic and Decennial Censuses has been the low geocoding rate and need for extensive clerical and labor-intensive work to resolve uncoded place-of-work locations. The electronic transfer of all address ranges, including non-residential, from local files to TIGER will improve geocoding rates and data quality for the Economic Census and decennial place-of-work coding operations and census products.
9. The IIS program is a new initiative at the Census Bureau that will better integrate the Bureau's many systems, processes, and products and possibly, data from other statistical agencies. IIS supports an organizational framework for conceiving, developing, disseminating and supporting customer-driven Bureau-wide information access and dissemination. Within this context, TIGER/MAF modernization and the emergence of an increasingly accurate national geo-spatial framework, more automated data collection (including GPS), and on-the-fly data services and visualization will fuel advancements not only at the Census Bureau but for society and the economy as a whole in the early 21st century.

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