Geospatial Analyses and System Architectures for the Next Generation of Radioactive Materials Risk Assessment and Routing*

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INTRODUCTION

The emergence of a post-industrial information society has a number of implications for those working on transportation risk assessment and routing of radioactive and hazardous materials. Citizens consume more material goods and energy, while also demanding environmental protection and showing minimal tolerance for individual or group risk. The result is increasing regional, state, national, and international regulation. Regulation is carried out at finer levels of geographic detail, and environmental and/or risk analyses at seemingly microscopic scales (e.g., neighborhoods) are common, especially in legal challenges. Meanwhile, both commercial and governmental provision of information and information technology is growing exponentially. The key goal of programs such as the U.S. National Information Infrastructure (NII) is citizen access to Federal records that may affect them. World Wide Web (WWW) sites provide voluminous databases on everything from early radiation experiment records to the Toxic Release Inventory (TRI) to every 'Yellow Pages' entry in the United States. The result of these social and technological trends is that today's citizen demands more regulation and is in a position to invoke, and monitor, that regulation through information technology. How will the radioactive and hazardous materials risk and routing community serve these information-savvy citizens? This paper will suggest a number of consequences for our development of information technologies, especially in the area of geographic information systems (GIS). By cooperatively managing geospatial (map-oriented) data and taking advantage of consumer-driven technologies (e.g., recordable CD-ROM), we can serve, engage, and educate the public in the next generation of risk assessment and routing methods and studies.

THE NEW SOCIAL AND TECHNOLOGICAL CLIMATE OF TRANSPORTATION RISK ASSESSMENT

Transportation risk assessment is taking place amid steady or growing environmental interest and concern in an information-rich society. Thus, citizens can quickly communicate with others having similar concerns, and gather supporting information with unprecedented ease and speed. Two executive orders reflect these trends: environmental equity (Clinton 1994a) and the national spatial data infrastructure (NSDI) (Clinton 1994b). The environmental equity order requires that all U.S. Federal activities analyze whether they distribute risk equally among racial and ethnic groups. The NSDI requires that agencies manage their geospatial data in a cooperative manner that treats it as a national treasure. These executive orders have legitimized two cutting-edge social and technical issues: the relative spatial distributions of race and environmental risk, and our national ability to map phenomena over long time periods and to share these databases with ease. Even if these executive orders are rescinded, they have already created a critical mass of interest and influence which will persist.

Meanwhile, the business and consumer software markets are providing GIS technologies at rapidly declining prices. The major spreadsheet products (Lotus, Excel) now include basic mapping capabilities. U.S. Census Bureau 'TIGER' map data are available in hundreds of derivative forms at low cost. Business mapping is increasing exponentially and it will attract a new influx of scientific, technical, and marketing talent into the field of GIS. The result will be easier, faster, and lower-cost mapping and analysis for existing and wholly novel purposes, including environmental and risk assessment.

The net result of these trends is a climate in which many citizens feel personally involved in environmental issues, and they are capable of gathering and sharing information among allies with unprecedented ease. In particular, the inquisitive citizen will be able to map what occurs where and when with a relatively small investment. Clearly, government agencies will find themselves increasingly questioned and challenged by such taxpayers.

What are some of the consequences of this "participative electronic democracy" in a time of steady or declining budgets for many agencies? First, we need to include the public early in risk and routing analyses. No other gesture or technology will yield comparable returns in goodwill and buy-in. No other step is as antithetical in some bureaucracies. Second, we need to develop new analytical techniques to avoid or respond to legal intervention. Intervention, when it occurs, is going to utilize new, low-cost technology. Third, we must participate in the NSDI. We have an obligation to make taxpayer-funded data as accurate, accessible, and cost-effective as possible.

IMPLICATIONS FOR GEOSPATIAL ANALYSIS

Changes in regulations, and in some cases the supply of geospatial data, have tended to far outstrip analytical techniques. Searching for the nearest emergency response unit, or overlaying a release plume on a population map are examples of mature techniques in spatial analysis. In other areas of spatial analysis even the problems to be solved have not been fully defined. Environmental equity provides several examples of the gulf between equity as a social goal and equity in geographic space and the tools we use to explore that space. What is equity in spatial terms? Cases to date have involved areas of low land value and high minority population that are selected as sites for industrial polluters or other undesirable industries (e.g., Burke 1993). The implications of environmental equity for siting of Federal radioactive waste facilities has been recognized (Easterling and Poles 1994), but many scientific and methodological issues remain. What is risk equity for a shipment passing through rural, suburban, and urban population densities across a country like the United States? What are the units of equity? How is it measured? How is it optimized? How are judgments arrived at? How are the process and the results communicated to the citizen? We need to research and develop fundamental scientific and quantitative analysis techniques in order to design for equity in shipment campaigns and to inform the debates that will typically ensue. One role for the U.S. national laboratories may be in synthesizing and systematizing developments in academic institutions (e.g., Wyman and Kuby, in press) and commercial hazardous materials (HazMat) operations.
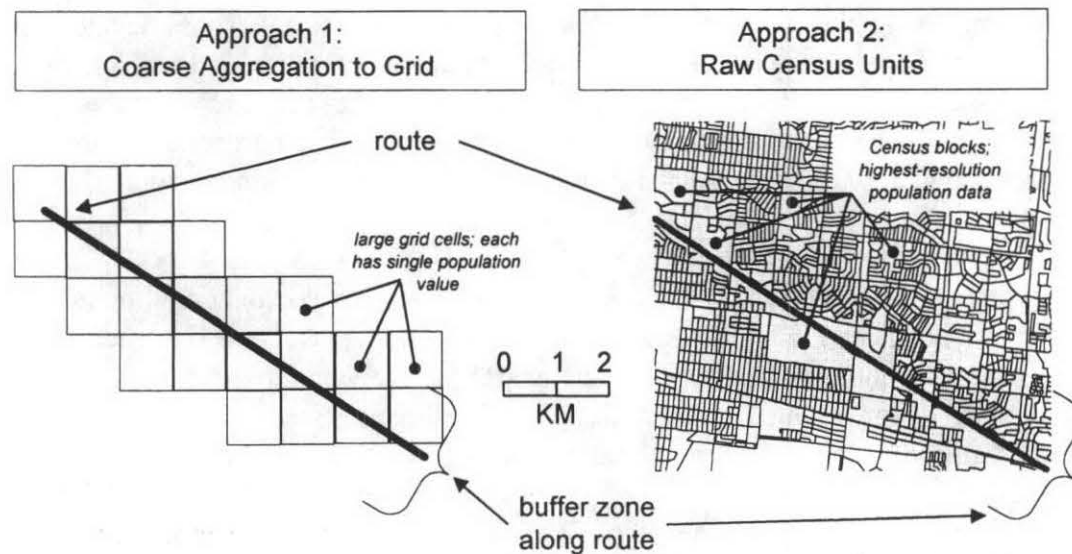

Figure 1 Approaches to population modeling along transportation routes. Approach 1 is computationally easier and faster than Approach 2, but it tends to smooth the detail available in the underlying census 'block level' geography.

A key ingredient in the overall geospatial modeling process is better and more defensible population modeling. With consumer access to TIGER data at 'block level' resolution (nominally 50 people), it will no longer be possible to claim that aggregated (coarsely

gridded) population data are the best that we can do (Figure 1). While most GIS-using organizations can perform block level modeling for a small area with ease (site-specific analysis), the ability to do so at any place in the United States or for any possible route remains a significant challenge.

Because developing new techniques (and data collections to support them) is expensive, we must also consider their overall significance in assessing risk. Do dose models produce significantly different results when supplied with more refined population data? Why or why not? The transportation risk assessment and routing community needs to address these issues, since they will inevitably be used in legal challenges if left unresolved.

The new analytical techniques just mentioned need to be implemented in user-friendly, participative tools on low-cost platforms. This will ensure that citizens can test and run these tools themselves, thus increasing the credibility of the tool developers. An example of such software is the MPATHav prototype developed at Sandia National Laboratories (Ganter and Smith, in press). While MPATHav only begins to address the spatial analysis and data problems discussed herein, it does serve as an interactive tool for exploring the options and tradeoffs that emerge in multiobjective routing problems.

IMPLICATIONS FOR SOFTWARE AND DATA ARCHITECTURES

We have observed that the emerging social and technical climate requires public participation, new analytical techniques, and participation in the NSDI. Those developing information technology for the risk assessment and routing community are like highway engineers compelled to develop new and better infrastructure that meets more of the population's needs at less cost. New requirements combined with a burgeoning market of new construction materials (software and data) suggests a number of architectural implications:

Commercial Off-The-Shelf (COTS) software and software development environments will be the main ingredient in building new systems. Developers can now buy enormous GIS functionality (millions of lines of computer code) for a few hundred dollars. These economies of scale are possible because the coding investment is amortized over thousands or millions of buyers. Transportation analysts can thus apply their efforts to inventing new analytical techniques (above) rather than reinventing basic GIS functionality. The TRAGIS system developed at Oak Ridge National Laboratory (Johnson, in press) and MPATHav (Ganter and Smith, in press) are examples of systems developed using the COTS development approach (both use the ArcView® GIS).

Common NSDI-compliant data sources will have to be made available. Executive Order 12906 requires that agencies and the public share data collected and maintained with public funds. We believe that the risk and routing community has been constrained by the lack of a common, open U.S.-wide highway network dataset that can be used by

any analytical system. Organization of a common node and link-naming system for a shared dataset would allow models and analyses to be compared (Figure 2). The emerging National Highway Planning Network (NHPN) (FHWA 1995) may provide such a framework if the needs of the risk and routing community can be addressed and incorporated. Handling of data such as traffic accident records is particularly challenging due to the historical differences in the way they are collected. We believe that there is a need for a national-level standards-setting process (Bespalko et al., in press) to help guide this development.
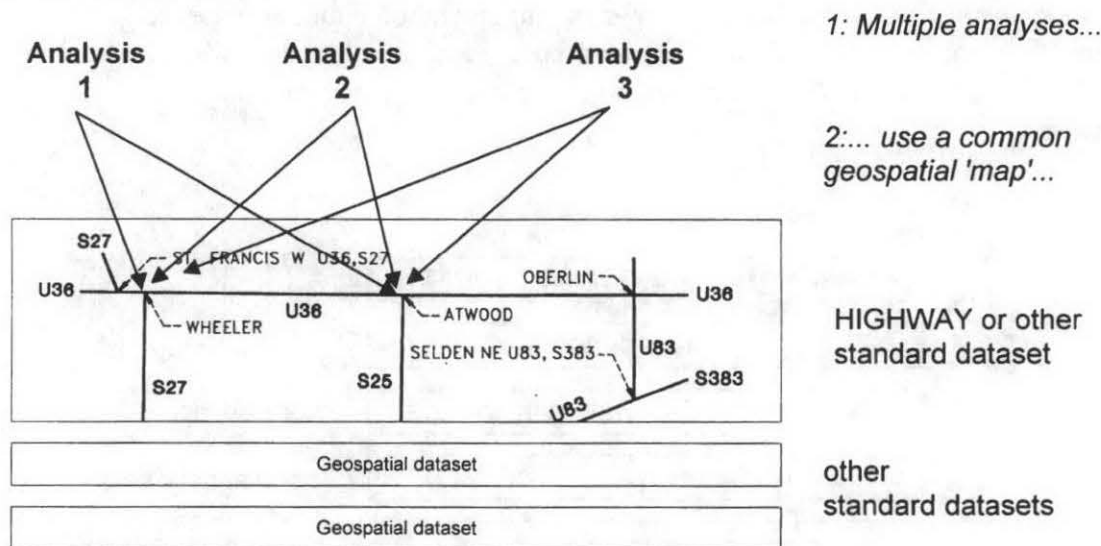
Figure 2 Multiple analyses using a common link/node geospatial dataset. This permits comparison of results, since the geospatial framework is held constant. HIGHWAY illustration extracted from Johnson, et al., 1993, p. 4.

Internet and World Wide Web (WWW): While network speeds tend to preclude on-line use of GIS tools, the Internet and WWW are extremely important for connecting the members of the risk assessment and routing community with each other and the public. The WWW can be used for general information, database searches, bibliographies, and easily-accessible publications. Examples can be seen at **http://www.sandia .gov/ GIS/gis.html** and linked sites. Modest programming can provide 'lite' demos of GIS software which include simple maps. The WWW is also ideal for on-line help and technical support, and for requesting or ordering full versions of software.

Bundled distribution: One of the most immediate architectural implications is in bundled distribution of routing and risk assessment systems. Because of the technical and organizational affinity among the community members, it is logical to have one or more common ways of making software and data available. One example is TRANSNET, a long-term cooperative effort between the national laboratories working in U.S. Department of Energy (DOE) technology development (Cashwell 1991). TRANSNET is a dial-up modem system that provides access to several databases and models through an ASCII-character user interface. Because graphical user interfaces (GUIs) and GIS are so

data-intensive, we do not believe that adequate modem or Internet speeds for a "new TRANSNET" will be available for several years. However, many personal computers now are fast enough to run GIS software and include a CD-ROM drive. We believe that CD-ROMs containing several risk and routing models, and associated data, could be created at very low per-piece cost (Figure 3). The U.S. Census Bureau, US Bureau of Transportation Statistics, and other agencies routinely give away CD-ROMs at meetings and conferences. Because of the use of common COTS software development tools (see above), it would also be possible to create a single system that incorporates 'plug-ins' contributed by several parties. For example, one organization could provide the general user interface and dataset, while another would provide the routing capability, and a third the risk assessment capability. Such symbiotic arrangements are becoming popular in commercial software.
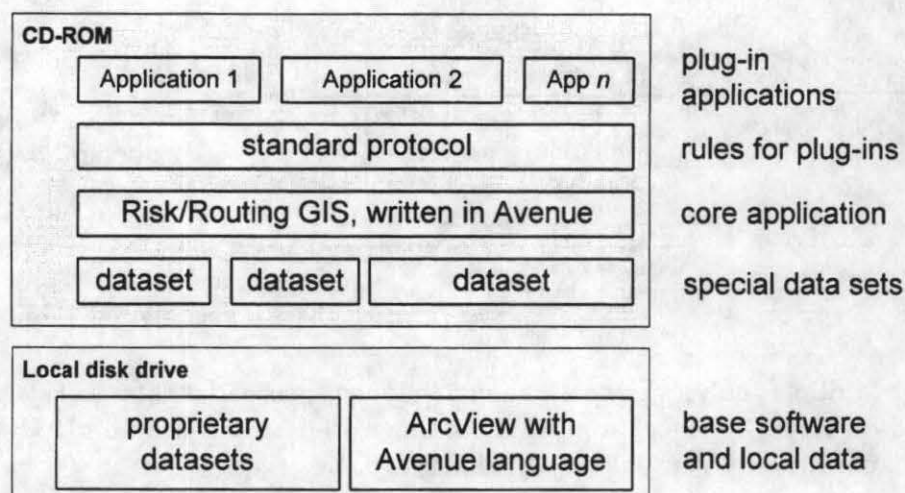
CD-ROM		
Application 1	Application 2	App *n*
standard protocol		
Risk/Routing GIS, written in Avenue		
dataset	dataset	dataset

plug-in applications
rules for plug-ins
core application
special data sets

Local disk drive	
proprietary datasets	ArcView with Avenue language

base software and local data

Figure 3 Concept of a risk/routing GIS package distributed on CD-ROM. The end user would supply 'base' software (in this case ArcView), and any proprietary datasets that they might wish to register to the datasets on the CD-ROM. These resources would reside on the user's relatively fast local disk drive. The 'risk/routing GIS' would provide a user interface. Other applications, such as the Sandia MPATHav code for multiobjective routing, would utilize the risk GIS through a standard protocol.

Interoperabilty technologies (open GIS) are now under development in the commercial GIS market. These technologies should result in compatible data and analytical tools which will break down the present proprietary barriers between systems. Thus, data collections such as the NHPN could incorporate data with different histories, and be made usable by different systems and analyses. However, transportation data and routing present unusual requirements that need to be taken into account in this research and development process (see, e.g., Ganter et al. 1995). One example is 'linear referencing' (data tied to mile or kilometer posts), which has numerous incompatible systems in use.

We believe that these architectures should be created in response to incentives consisting of the push of new requirements (what the citizen expects or requires us to consider) and the pull of new means for meeting those requirements (new technologies). The incentive to use COTS comes from a maturing GIS marketplace and our need to be more efficient and effective. The incentive to use common data sources comes from the emerging realization that geospatial data are an enormous expense and natural resource; we must participate in this process rather than duplicate the effort of other parties collecting very similar, but slightly different, data. The incentive to use bundled distribution comes from a tested concept (commercially and in TRANSNET), and the remarkable consumer-driven CD-ROM technology. The incentive to use the WWW comes from its own organic nature and our need to communicate with, and respond to, the citizen.

Taken in sum, pursuing these architectures would have a number of short-term and long-term benefits. In the short term, the architectures would begin to address requirements for public participation, environmental equity analysis, and the NSDI. Use of COTS, common datasets, and shared distribution could reduce costs and increase effectiveness and efficiency in both individual organizations and the larger community. Architectures for shared distribution promote specialization rather than duplication of effort (doing what we each do best), amortization of fixed costs over many users, and the synergy that results when several organizations contribute to a common enterprise. For example, a jointly produced CD-ROM of routing and risk assessment data and software could bring both the contributors and the end-users together to share ideas, critiques, and new products. Innovations which would not be worthwhile for a few users might be justifiable and immensely valuable to a community numbering in the hundreds or thousands. The costs associated with these architectures are largely sociological; the need to concede some 'turf' and begin working within mutually agreed upon software and data architectures.

SUMMARY

This paper suggests that inexorable changes in the society we serve are presenting both challenges and a rich selection of technologies for responding to these challenges. The citizen is more demanding of environmental and personal protection, and of information. Simultaneously, the commercial and government information technologies markets are providing new technologies like COTS software, common datasets, open GIS, recordable CD-ROM, and the World Wide Web. Thus we have the raw ingredients for creating new techniques and tools for spatial analysis, and these tools can support participative study and decision-making. By carrying out a strategy of thorough and demonstrably correct science, design, and development, we can move forward into a new generation of participative risk assessment and routing for radioactive and hazardous materials.

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