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USING A DYNAMIC GIS TO VISUALIZE AND ANALYZE MOBILE SOURCE EMISSIONS

ABSTRACT: Being able to graphically visualize information in a spatial and temporal context can provide insights that may not be possible by other means. Geographic Information Systems (GISs) are an ideal platform for visualizing and analyzing two-dimensional and three-dimensional spatial data. Unfortunately, the temporal aspects of spatial data are difficult to model in current GISs. This paper discusses research that involves implementing a dynamic GIS used in mobile emissions research. In a cooperative research effort with the U.S. Environmental Protection Agency (EPA), Georgia Tech is currently developing a mobile emissions model that will reside in a GIS environment. The major objective of this model is to more accurately estimate mobile source emissions by considering the spatial and temporal characteristics of mobile source data. While a brief overview of this model is included, the major emphasis of this paper is using a customized GIS with sophisticated dynamic graphics capabilities to visualize and analyze emission data collected from instrumented vehicles. Each of the instrumented vehicles in this project is equipped with on-board emission monitoring equipment to record second-by-second emissions and a Global Positioning System (GPS) receiver that monitors the instantaneous position, speed, and acceleration characteristics of the vehicle. Once collected, the data from the instrumented vehicle is post-processed and ported to the GIS for display and analysis. The paper describes how sophisticated dynamic graphics are used within the GIS to monitor a vehicle as it moves through the roadway network. Changes in emissions can be monitored visually and correlated with changes in road characteristics or vehicle performance characteristics (speed, acceleration, etc). It is anticipated that this dynamic system will prove useful in the development of emission factors for the GIS-based model being developed. Insights from this paper should be useful to professionals who analyze spatially referenced data that are constantly changing.

INTRODUCTION

An excellent example of the benefits of graphical presentation of dynamic data is illustrated in Charles Joseph Minard's 1869 portrayal of Napolean's invasion of Russia in 1812 (Figure 1) (Tufte, 1983). The "Grande Armee," consisting of 442,000 men, left the Polish-Russian border near Niemen and proceeded on a path to Moscow. The battles that ensued along the way resulted in great losses to Napoleon's army. The path of Napoleon's retreat from Moscow in the bitterly cold winter reduced the size of the army even more and, by the time the army reached the Polish border where it started, the Grande Armee was down to 10,000 men. Minard's graphic tells a rich coherent story of the movements and losses of the army during this campaign. Several variables are plotted: the size of the army, its two-dimensional position (X,Y), direction of the army's movement, and temperature on various dates during the retreat from Moscow. What makes this graphic so distinctive is its ability to show cause and effect relationships between variables that may not be as apparent if the data were shown in tabular form. For example, in several instances, the map clearly shows the number of men lost as a direct result of crossing a river. The correlation between losses and temperature is also apparent. Another distinctive characteristic of this graphic is that it displays dynamic information, that is, data that change over time and space. The temporal dimension of this graphic is unique, even by today's standards.

More than 100 years after Minard, researchers are rediscovering the benefits of graphical displays of dynamic data available in the computer age. Being able to display information in *both* a spatial and temporal context can provide insights that may not be possible by other means. This paper focuses on using Geographic Information Systems (GISs) and Global Positioning Systems (GPSs) as tools to collect and display spatially referenced mobile emission data that are constantly changing. In a cooperative effort with EPA, Georgia Tech is currently developing a next generation mobile emissions model that will reside in a GIS environment. While a brief overview on this model is included in this paper, along with examples of two-dimensional and three-dimensional maps that can be produced with it, the purpose of the paper is to present a system for analyzing the temporal element of mobile emissions in a dynamic GIS environment. The benefits of the system are discussed as well as future enhancements.

A GIS-BASED MOBILE EMISSIONS MODEL

Vehicle activities and the emissions associated with these activities can be referenced to points in time and space. Being able to identify the spatial and temporal distribution of these activities can add to a greater understanding of emission levels. Most GISs have the ability to develop user interfaces for the easy manipulation and display of project elements. The spatial data manipulation capabilities of a GIS make it well suited for emission estimation and prediction (Bruckman et al., 1992).

The next generation mobile emissions model under development by Georgia Tech and EPA is designed to improve emissions estimates by considering a variety of vehicle activities, environmental factors, vehicle and driver characteristics, and the spatial and temporal distribution of these characteristics. The framework for this model is a modal basis where emission rates are employed for specific modes of vehicle operation. Important vehicle operating modes include engine starts, idle, hot stabilized operation, enrichment conditions (influenced by high acceleration and power demand), and hot soak evaporation. The existing prototype of the model was developed using Environmental Systems Research Institute's ARC/INFO GIS platform (ESRI, 1994).

A STATIC WAY TO MODEL DYNAMIC DATA

Conventional GISs tend to deal with static information at a set instant in time. Spatial features such as points, lines, and polygons are used to represent intersections, roads, and census tracts. Since mobile emissions are temporal, a conventional GIS is limited to displaying emissions at a single instant in time or total quantities over a fixed time period. Figure 2 illustrates a two-dimensional map of modeled hot stabilized carbon monoxide (CO) emissions in Atlanta during the AM peak hour traffic period. This thematic map uses shades to indicate different levels of CO in a uniform grid cell format that is compatible with regional airshed models. Figure 3 presents a three-dimensional surface of the Atlanta Metropolitan area. The third dimension shown here represents cold start emissions. Peaks in the graphic represent extremes in CO. Being able to see CO displayed in three dimensions presents a clear picture of how CO is distributed spatially in Atlanta. Another benefit of a three dimensional map is that the user doesn't have to rely on a legend to understand the meaning of different shades on a thematic map. It is very clear, for example, in the figure that flat areas represent low CO levels while the large peaks represent much higher CO levels.

In summary, what is common about both maps is that they represent a typical method for incorporating the "fourth dimension" into a GIS analysis by aggregating data over a time period; in this case the AM peak hour. Unfortunately, many important details may be lost in trying to model dynamic data such as mobile emissions in a static fashion. For example, spikes in emissions that may occur over short time periods are not reflected in the model estimates. While it is possible to model any single instantaneous period of time (assuming that the data are available), the research mobile emissions model cannot show continuous changes in emission patterns dynamically. Analyzing the dynamic nature of mobile emissions within a GIS presents a new challenge.

DYNAMIC GRAPHICS: ENTERING THE FOURTH DIMENSION

Georgia Tech is currently conducting research into the benefits of using dynamic graphics as part of a mobile emissions modeling regime. The objective of this research was to design and develop a dynamic GIS system that could be used to display and analyze emission data collected by a vehicle that was instrumented with emission monitoring equipment. One of the anticipated benefits of a dynamic GIS system is that it will be useful in the development of emission factors for the GIS-based model described above. Being able to display and analyze emission data continuously may provide insights that would be difficult to identify otherwise. The research project has evaluated emissions versus operations for several instrumented vehicles (cars, trucks, minivans, etc). Each of these vehicles was found to behave very differently on the same stretch of road. There are variables which affect emissions which have a dynamic component and some variables which do not. Static variables may include factors such as fuel characteristics and maintenance effects. Using a dynamic graphic system would provide a means to visually correlate changes in emissions from the different vehicles with potential dynamic causal variables, such as vehicle performance characteristics [revolutions per minute (RPMs), throttle position, speed, etc], and physical roadway/traffic characteristics (e.g., grade and congestion).

Conceptual Framework of a Mobile Emissions Dynamic GIS

Figure 4 illustrates the conceptual framework of the dynamic GIS being developed at Georgia Tech that will be used to display and analyze mobile emissions data collected by instrumented vehicles.

There are three procedural areas in this framework: 1) vehicle instrumentation; 2) data processing; and 3) dynamic GIS tools.

Vehicle Instrumentation. To analyze data from the instrumented vehicles within a GIS, it is necessary to link the emissions data to the actual spatial position where the emissions occurred. This can be accomplished by using either dead reckoning (relative positioning) equipment or Global Positioning System (GPS) technology. Extensive setup and post-processing would be required to bring relative positioning data from a dead reckoning device into a GIS. Because a GPS can provide geographic coordinates that can be brought directly into a GIS without extensive post-processing, it was the most appropriate choice. Another reason for choosing GPS is that Georgia Tech is already making extensive use of the technology in its mobile emissions research. For example, Georgia Tech is using a specialized attitude GPS to collect grade information. Grade has been found to contribute to a vehicle's tendency to go into a high emission state (Cicero-Fernandez, 1995). This vehicle "enrichment" occurs during a rich air-to-fuel ratio operating mode.

Data Processing. Ideally, all of the vehicle's monitoring equipment should be linked directly to the GPS to ensure that data are synchronized precisely with the two-dimensional position of the vehicle. An alternative method is to synchronize the spatial and emission data through post-processing by linking the time stamps that are recorded by both the GPS and the emissions monitoring equipment. To facilitate this research, post-processing was used. However, this will eventually be replaced by a direct linkage between the GPS, the emissions and engine parameter monitoring equipment, and a single notebook computer which records inputs from all devices simultaneously.

There are two major tasks involved with post-processing the data. The first is to differentially correct the geographic positions of the GPS data. Because of intentional degradation by the Federal Government (selected availability), non-differentially corrected positions are usually accurate to only 100 meters. Through post-process differential correction using a GPS base station at a known point, accuracy can be improved to within 2 meters. Even better positional data are possible through the use of sophisticated surveying quality (centimeter accuracy or better) GPS units. The second task is to link the GPS positions with the emissions data using the time stamp. This second task is accomplished by merging the two sets of data using custom software. Once synchronized, the data are ready to be brought into the dynamic GIS environment.

Dynamic GIS Tools. The dynamic tools used to display and analyze the emission data temporally are described as follows:

- A dynamic graphic engine that can efficiently manage instrumented vehicle data on a second-by-second basis. This is necessary so that information can be displayed and analyzed in real time or at accelerated rates.

- The various capabilities of the system dictate that the system should be able to conduct dynamic queries (e.g., query vehicle attributes or underlying road attributes at any instant in time) as well as allow for input of attribute information at any given instant. For example, it might be desirable to tag certain events for easy retrieval later.

- The system needs to be able to display a dynamic representation of the instrumented vehicle as it moves through the network along with a legend of what actually is being displayed by the vehicle's graphic.

- Dynamic charting capabilities of the various variables being collected by the instrumented vehicle should be possible. These graphical charts will make it possible to display different variables simultaneously in a format that can be understood quickly. This is preferred to displaying dynamic tabular information because it would be difficult for the analyst to monitor several variables at once that are in tabular format.

- Dynamic color-coded thematic mapping capabilities should be available so that the entire journey of an instrumented vehicle can be displayed on a single map.

Selection of a GIS

As stated previously, the GIS-based mobile emissions model is currently being developed in Environmental Systems Research Institute's ARC/INFO platform. ARC/INFO was chosen for a number of reasons (robust GIS tools, automation capabilities, marketshare, etc). However, ARC/INFO lacks dynamic graphic capabilities which would make it extremely difficult to implement the dynamic system desired. A review of literature and other vendors revealed that GDS, the GIS produced by Graphic Data Systems Corporation (GDSC), does have some dynamic graphic capabilities (GDSC, 1993). For example, GDS has been used to monitor traffic flows along the New Jersey Turnpike. It will also be used to monitor traffic signal indications dynamically as part of Atlanta's Advanced Traffic Management System (ATMS). Furthermore, first-hand evaluation of GDS gave evidence that it would be possible to implement a dynamic mobile emissions analytical environment. The dynamic library of programming tools that is part of GDS provides a foundation to implement very powerful dynamic graphic applications such as the one being discussed here. Other vendors were also evaluated for their dynamic capabilities, but GDS was the clear choice for this application.

The Resulting Dynamic Graphic System

Figure 5 illustrates the interface of the prototype dynamic graphic system that was developed based on the conceptual framework. The prototype provides an example of what is possible by using dynamic graphics to display and analyze mobile emissions data. The system displays information that is updated on a second-by-second basis. The time interval is set by the data collection instruments. Figure 5 shows several things. First, it shows the location of a vehicle at a given instant. Second, it is able to display thematically the current value of an engine parameter or emissions. Third, it provides a dynamic chart (bar graph) of several engine parameters/emission values for comparison purposes. Additionally, the dynamic system can be used to link dynamic information with underlying static information of the roadway such as grade or elevation.

Figure 6 illustrates the function of the system displaying, in this case, the vehicle's enrichment status. As the vehicle moves, its image is left on the screen. This results in a thematic trace of the changes in the vehicle's enrichment status. The associated tabular information of the movements of the vehicle would occupy several pages of text. Figure 6 depicts much of this information in one graphic.

While Figures 5 and 6 display only a single vehicle's movements and attributes, the system is capable of handling any number of vehicles. Certain details, such as those included in the dynamic bar chart, can be displayed for only a single vehicle at a time. Another capability of the system is that it includes a step function where a vehicle can be paused and stepped forward or backward one second at a time so that the changes in attributes can be analyzed in greater detail.

Future Enhancements of the Dynamic Graphic System

Georgia Tech plans to develop additional tools to analyze relationships between dynamic and static objects. These tools will include predictive models used to display a hypothetical emissions trace along a road segment, given vehicle type and inherent driver characteristics. By displaying vehicle objects (including modeled ones) simultaneously within the dynamic GIS, comparisons can be made between the operating performance of different vehicles on the same stretch of road.

Another enhancement is to improve the thematic mapping function (trace function) so that the vehicle path is not "shadowed" as is the case in Figure 6. Further, by using dynamic segmentation to store the emission attributes, strip maps will be possible to display static and dynamic attributes together on one map along with a linear reference.

Rather than storing grade statically with the individual road segments and using interpolation tools to identify mid-segment grades, there is a plan to store grade changes on a second-by-second basis and display these data dynamically in conjunction with all of the other dynamic data that are monitored by the instrumented vehicles.

CONCLUSION

Using a conventional GIS, there is capability to describe emission data spatially in the second and third dimensions. Recent advances in the dynamic graphics capabilities available in some GISs make display and analysis in the fourth dimension (time) possible. This capability is especially useful in mobile emissions modeling because of the temporal nature of emissions data. The use of a dynamic GIS along with global positioning systems during activity and emission rate data collection is an example of the application of new technologies to enhance emissions models. Such tools will be a major component of transportation/air quality planning for years to come. The visualization capability of a dynamic GIS is ideally suited for communicating spatial information that is constantly changing. This could lead to a better understanding of the relationships that exist between emissions and the various parameters that affect emissions. Further, the potential applications that could take advantage of dynamic graphic capabilities are endless, because of the vastness of spatial data whose attributes fluctuate with time.

ACKNOWLEDGEMENT

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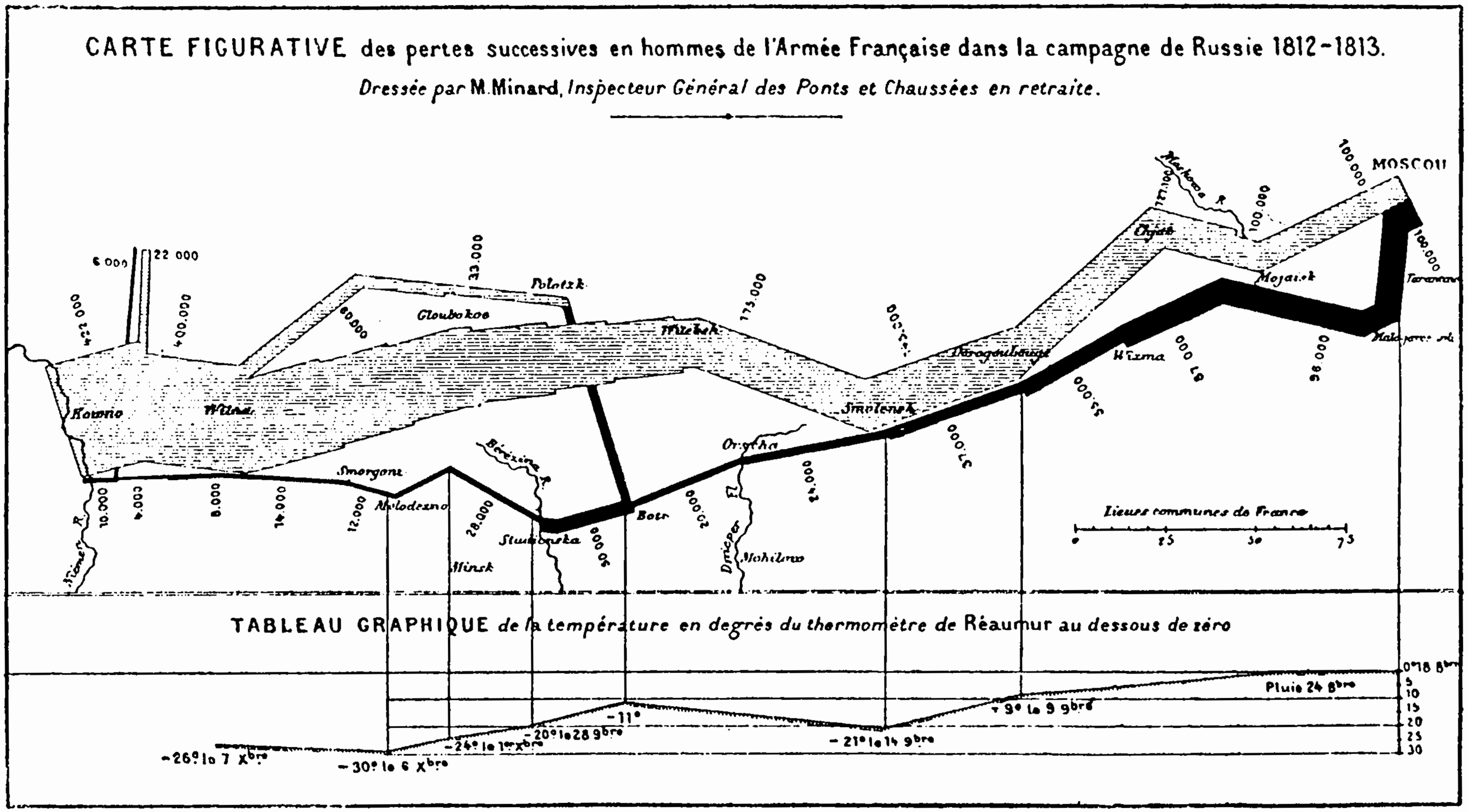

Xbre = December   9bre = November   8bre = October

FIGURE 1 - Charles Joseph Minard's 1896 portrayal of Napolean's invasion of Russia in 1812
Source: Tufte, Edward R. The Visual Display of Quantitative Information. Graphics Press, Cheshire, Connecticut, 1983. Reprinted by permission.

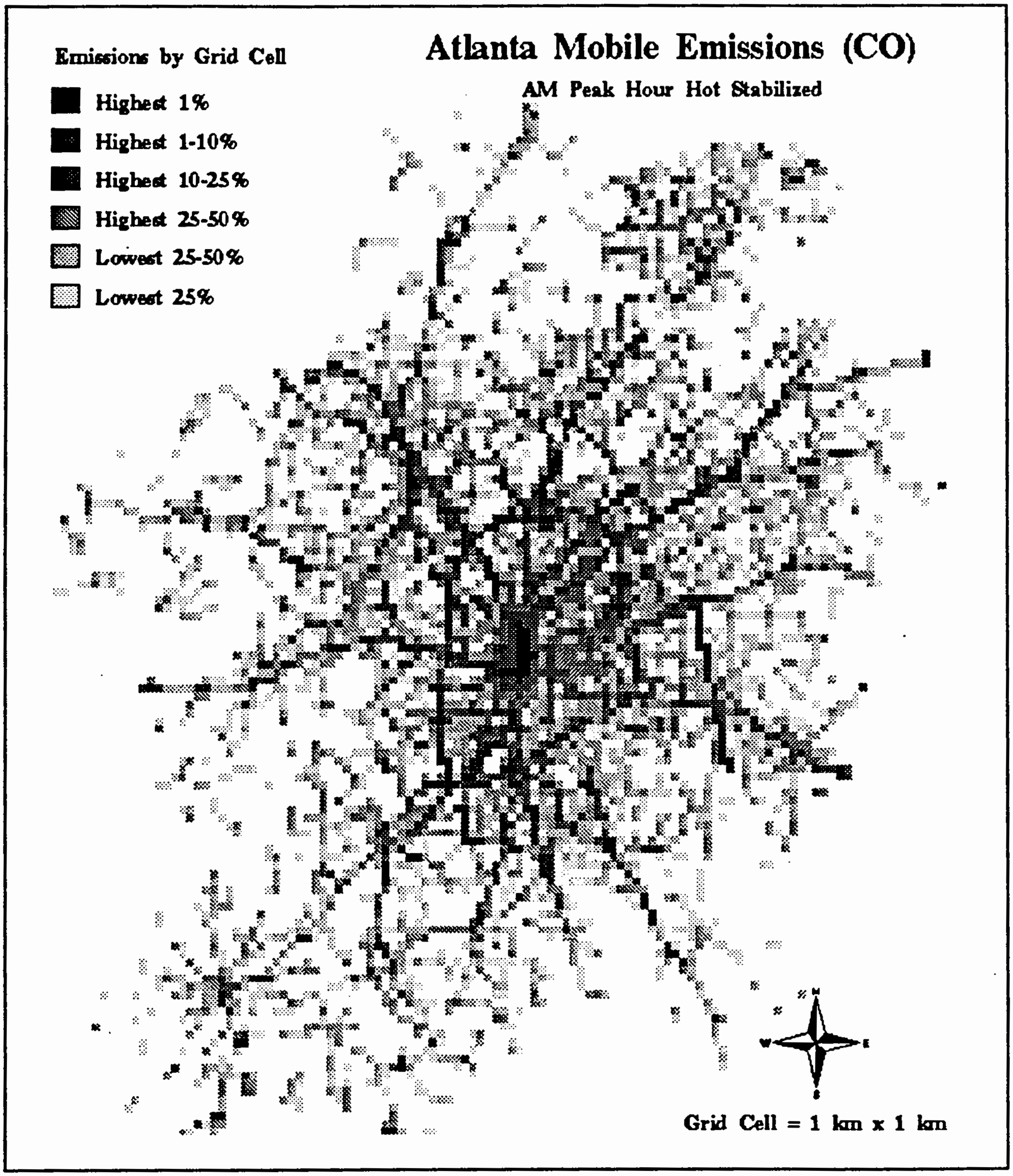

FIGURE 2 - Two-dimensional graphic of estimated CO hot-stabilized emissions in Atlanta

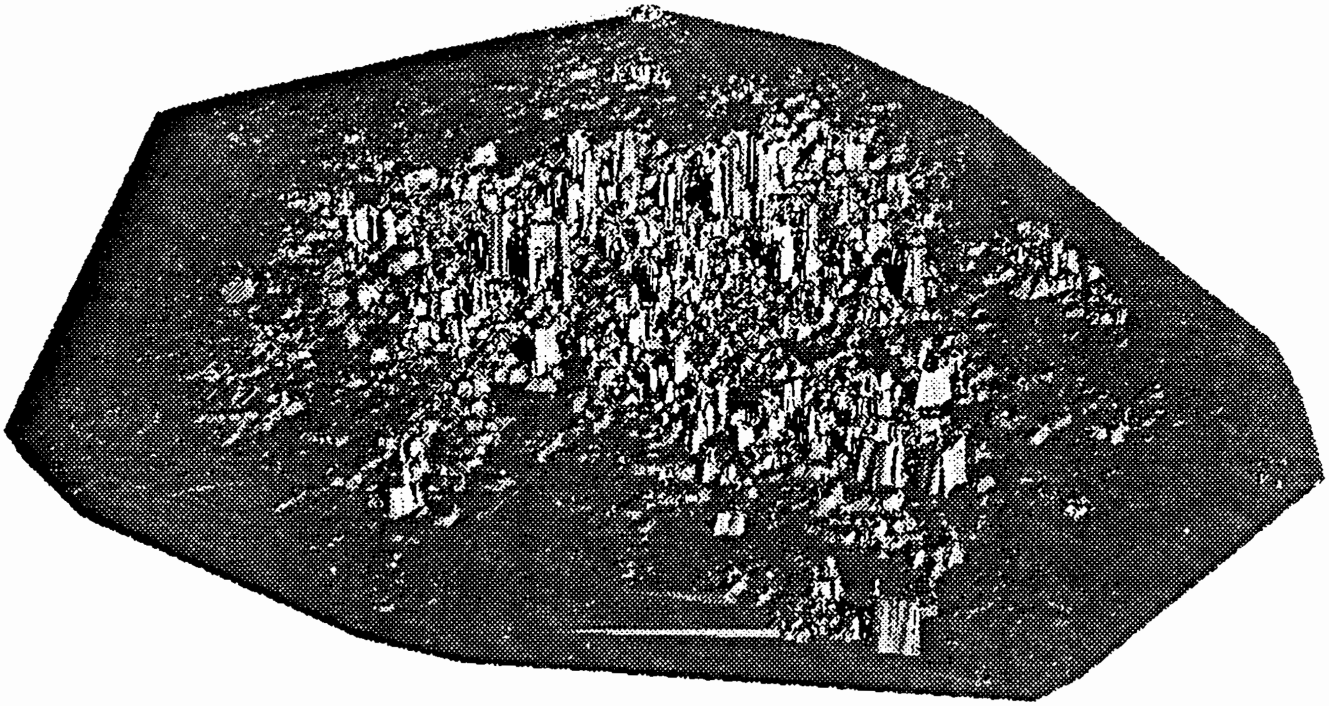

FIGURE 3 - Three-dimensional graphic of CO cold start emissions in the Atlanta Region

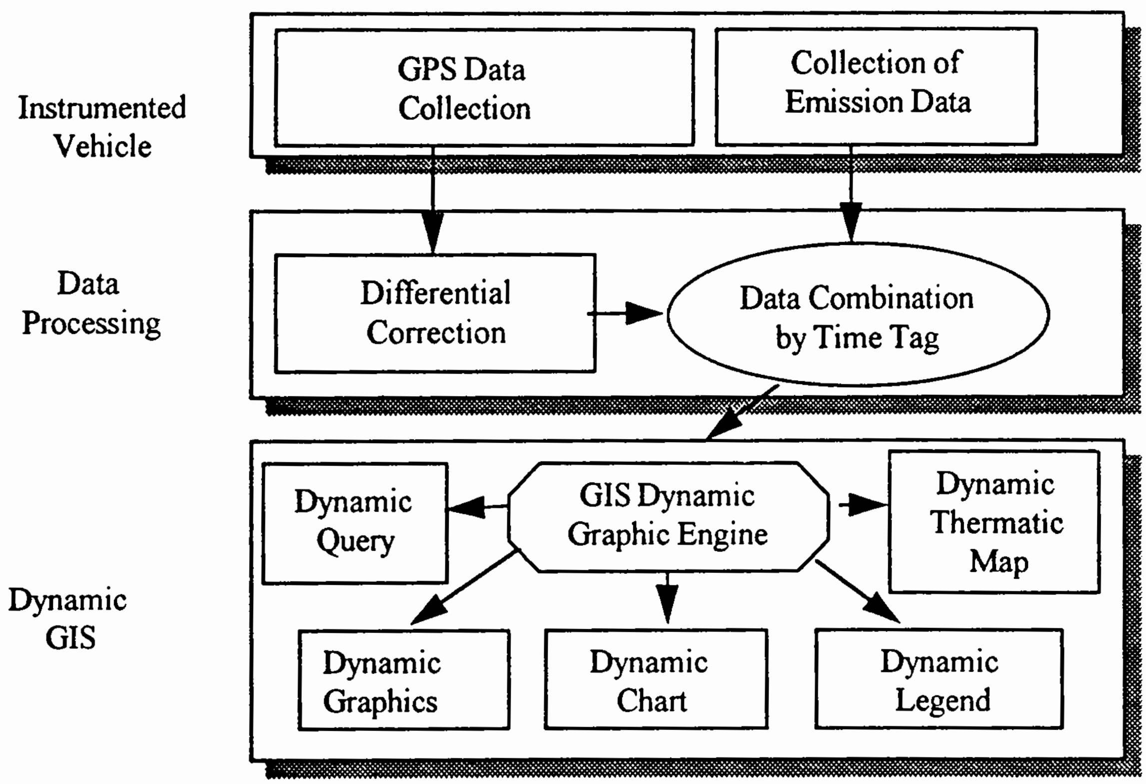

FIGURE 4 - Conceptual framework of the dynamic GIS

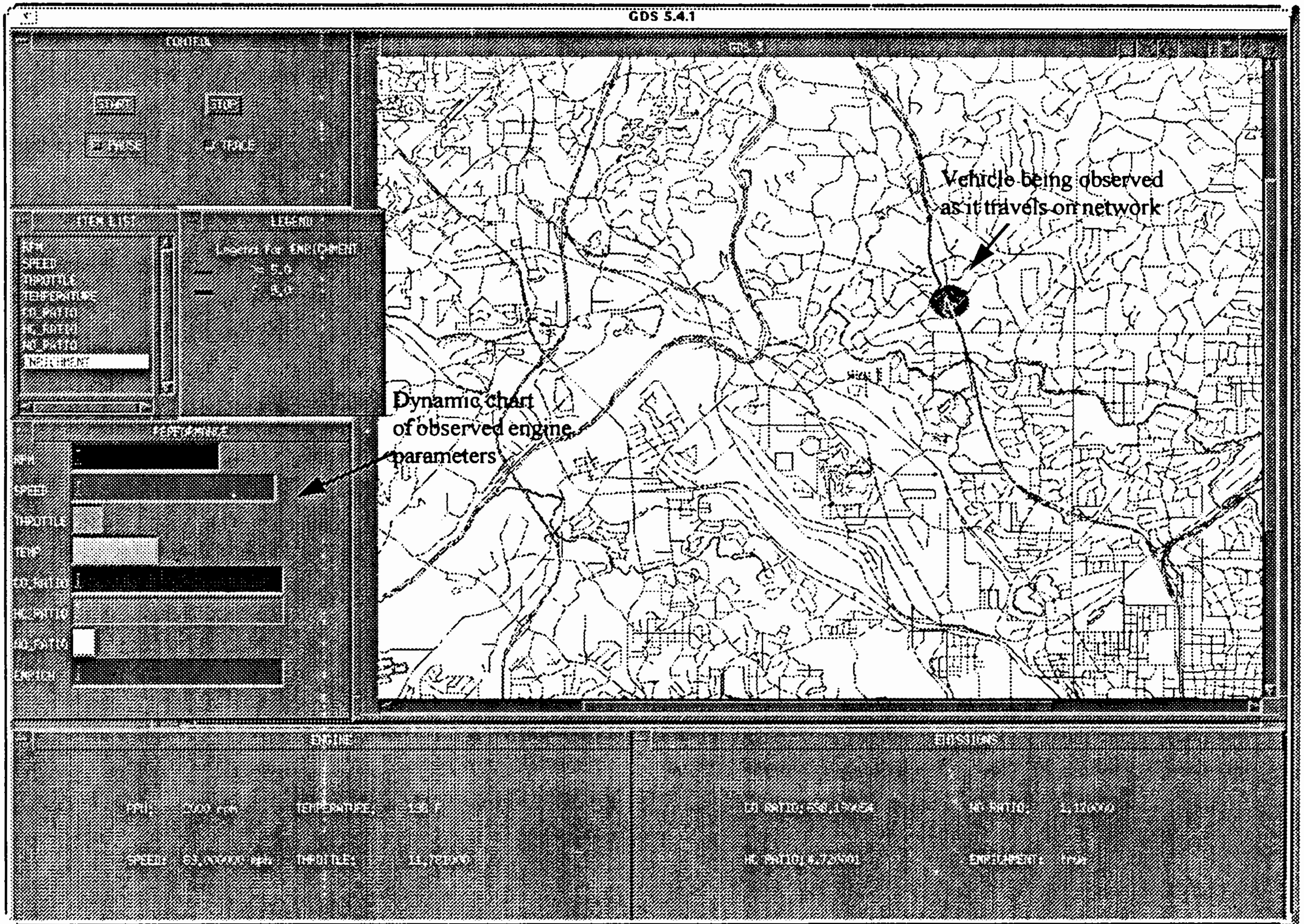

FIGURE 5 - Dynamic graphic display of engine operating parameters

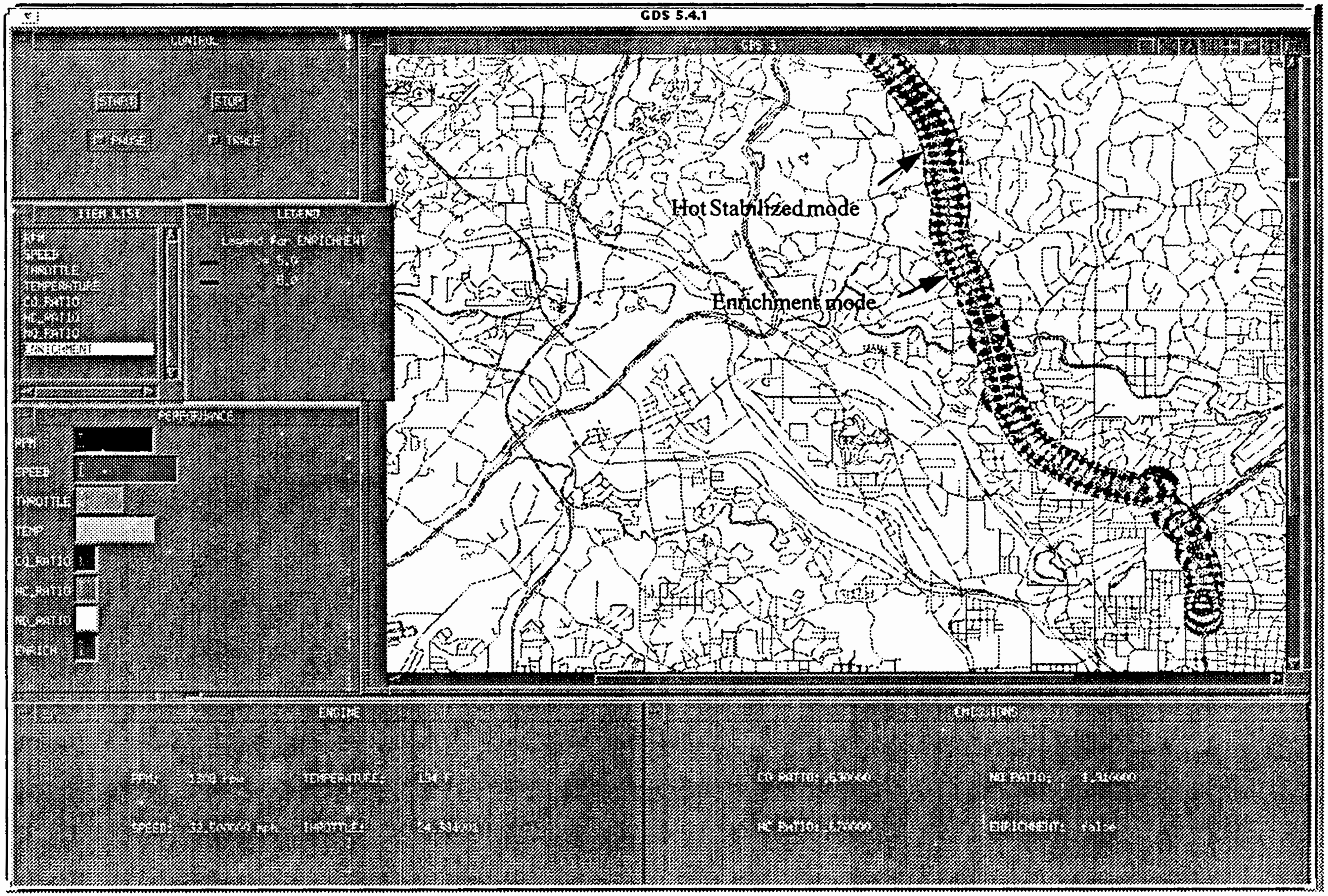

FIGURE 6 - Dynamic graphic of observed enrichment condition

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Fig. 1

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Analyzing		Geographic Information System (GIS)	14B
Monitors			
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