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ABSTRACT

An Information System Design Theory (ISDT) is proposed for use in the development of Spatial Decision Support Systems (SDSS). First, a review of SDSS is presented along with the problems specific to end-users of these systems. Next, a brief overview of ISDT is presented along with a specific example of an ISDT for SDSS that addresses the question of how to establish relationships between components of a Proximate Commuting System. The International Organization for Standardization Technical Committee 211 and the Open GIS Consortium Service Architecture is then discussed. Drawing on this discussion, an ISDT that addresses the question of how to establish relationships between components of a SDSS, in general, is detailed. Finally, a specific example is presented demonstrating how the ISDT for SDSS was utilized in the development of a system of this type.

Keywords

Information System Design Theory, Spatial Decision Support Systems, GIS

INTRODUCTION

Spatial Decision Support Systems

Decision support systems (DSS) are "interactive, computer-based systems that aid users in judgment and choice activities. They provide data storage and retrieval but enhance the traditional information access and retrieval functions with support for model building and model-based reasoning. They support framing, modeling, and problem solving" (Druzdzel & Flynn, 2000). Spatial decision support systems (SDSS) are decision support systems where the spatial properties of the data to be analyzed play a major role in decision-making (Seffino, Medeiros, Rocha, & Yi, 1999). A SDSS can also be defined as an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem (Malczewski, 1997).

A SDSS then, is a specialized class of DSS that allows users to capture, analyze, and display spatial data in addition to traditional attribute data. "As with many information technologies, however, presenting these capabilities to end-users for ad hoc system development, direct data manipulation, or decision support requires specialized planning to reduce user effort, protect vital data, and reduce costs" p. 14 (West, 2000). Furthermore, while the use of computer-generated maps has the potential to enhance analysis and improve decision-making performance, research into the factors impacting these issues has been extremely limited. In fact, research in computer-assisted spatial problem solving has been all but ignored in the information systems literature (Crossland, Herschel, Perkins, & Scudder, 2000).

One type of information system that is particularly suited to spatial problem solving is the geographic information system (GIS). A GIS is a group of procedures that provide data input, storage and retrieval, mapping and spatial analysis for both spatial and attribute data to support the decision-making activities of the organization (Grimshaw, 2000). However, although GIS are valuable information systems particularly suited to spatial decision support and end-user applications, their complexity, use of complex data, and utilization of cartographic principles makes their direct use by end-users problematic (West, 2000). Consequently, an information system design approach for the development of a SDSS that supports end-users and the decision-making activities of the organization is needed. Information System Design Theory (ISDT) provides guidelines for developing and testing such a system by specifying a design approach that will support organizational goals (West & Hess, 2002). The next section describes an ISDT that would be utilized for the development of a SDSS.

Information System Design Theory

As presented by Walls et al. (Walls, Widmeyer, & El Sawy, 1992), the concern of researchers in the Information Systems discipline is the design of systems and the development of system design theories that address the question of how to establish relationships between components of a system to achieve a specific result. An Information System Design Theory (ISDT), then, refers to an integrated prescription consisting of a particular class of user requirements, a type of system solution (with distinctive features), and a set of effective development practices (Markus, Majchrzak, & Gasser, 2002). Here, Walls et al. refer to Meta-Requirements (user requirements), which describe the specific goals that are applicable to any system of the type to which the theory relates. Meta-Design (system solution) describes the specific artifacts that are applicable to the Meta-Requirements, while the Design Method (effective development practices) describes the procedures to be utilized in building a system of the type to which the theory relates. Underlying these three features (Meta-Requirements, Meta-Design, Design Method) of an ISDT are kernel theories that enable the formulation of empirically testable hypotheses relating the design theory to expected outcomes. These design theory characteristics help to establish why the application of one particular ISDT to a specific situation yields better results than the application of a different ISDT. For example, "it should be possible to establish empirically that the application of Decision Support System design theory to a particular set of requirements produces better results than applying Transaction Processing System design theory to the same requirements" p. 181 (Markus et al., 2002). Figure 1 illustrates the relationships between the components of an ISDT where the Meta-Requirements and Meta-Design form the foundation of the Design Product, while the Design Method forms the foundation of the Design Process.

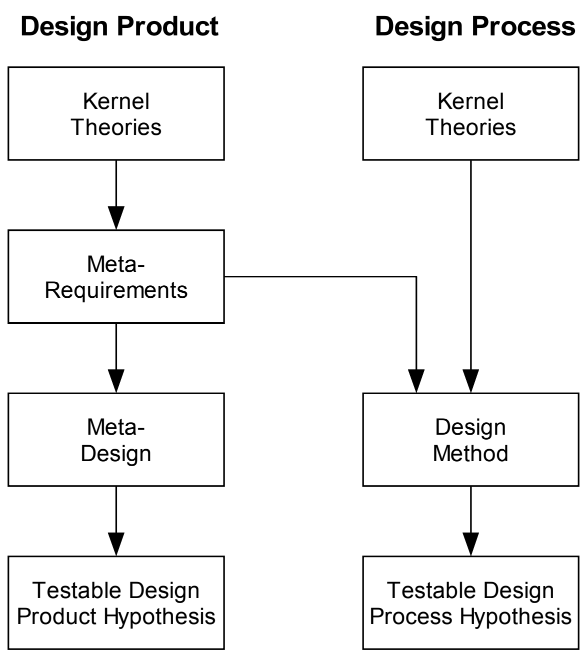

Figure 1. Components of an ISDT

Proximate Commuting

Commute Trip Reduction (CTR) programs give commuters resources and incentives to reduce their automobile trips (Victoria Transport Policy Institute, 2002). These programs, such as Rideshare Matching, Alternative Scheduling, and Telework, may be encouraged or required by local, regional, state, or federal policies. One CTR program, Proximate Commuting, allows employees to shift to work sites that are closest to their homes. Here, spatial analysis is performed that identifies the commutes of employees of multi-location organizations that could be reduced by working at a closer location (Rodriguez, 2001).

Tables 1 and 2 below outline an ISDT for SDSS for the development of a Proximate Commuting system.

Feature	Definition	Realization in SDSS
Kernel Theories	Core theories that support and guide the design.	Decision Support Systems Geographic Information Systems Spatial Cognition Multi-criteria Decision Making
Meta-Requirements	Meta-requirements describe the specific goals that are applicable to any system of the type to which the theory relates.	Geographic human interaction services Geographic model/information management services Geographic processing services Geographic communication services
Meta-Design	Meta-design describes the specific artifacts that are applicable to the meta-requirements.	Geographic viewer Feature access service Coverage access service Coverage access service - sensor Route determination service Proximity analysis service Geographic annotation service Transfer service Messaging service Remote file and execution management
Testable Hypothesis	Hypotheses that are open to empirical testing.	It is possible to develop a Proximate Commuting system using the ISDT for SDSS. Using the ISDT for SDSS, a Proximate Commuting system will be assessed by the user as functional and useful.

Table 1. Design Product

Feature	Definition	Realization in SDSS
Kernel Theories	Core theories that support and guide the design process.	Human-Centered Design
Design Method	Design method describes the procedures to be utilized in building a system of the type to which the theory relates.	Utilize Service Organizer Folder Understand and specify the context of use Specify the user and organizational requirements Produce design solutions Evaluate designs against requirements
Testable Hypothesis	Hypotheses that are open to empirical testing.	Systems built using the ISDT for SDSS will effectively incorporate the needs of both the user and the organization in creating a Proximate Commuting system.

Table 2. Design Process

ISO/TC 211 and the Open GIS Consortium

The International Organization for Standardization has established a structured set of standards for information concerning objects or phenomena that are directly or indirectly associated with a location relative to the Earth (International Organization for Standardization, 2000). The mandate for the International Organization for Standardization Technical Committee (ISO/TC) 211 is to develop an integrated set of standards for geographic information that:

- Increases the understanding and usage of geographic information
- Increases the availability, access, integration, and sharing of geographic information
- Promotes the efficient, effective, and economic use of digital geographic information and associated hardware and software systems
- Contributes to a unified approach to addressing global ecological and humanitarian problems

The ISO/TC 211 expects that innovative, new, and unknown technologies and application domains will present a challenge to the process of geographic standardization. However, where standardization was once a process for recognizing and codifying the status quo of technology, it is now beginning to define the requirements and implementations of new technology (International Organization for Standardization, 2000).

A major impetus for new design thinking in GIS comes from the advent of open geoprocessing interoperability computing standards. The Open GIS Consortium (OGC) recently released The OpenGIS Service Architecture (Open GIS Consortium Inc., 2002) which provides a platform for creating diverse, open standards-based GIS solutions. They state that, based on advances in information technology, geographic datasets are increasingly being shared, exchanged, and used for purposes other than their producers' intended ones. As a result, GIS, remote sensing, automated mapping and facilities management, traffic analysis, geo-positioning systems, and other technologies for geographic information are entering a period of radical integration. The following section draws on these ideas and details an ISDT that addresses the question of how to establish relationships between components of a SDSS.

ISDT FOR SDSS

Meta-Requirements

Accordingly, the OGC, in conjunction with the ISO/TC 211, has developed an international standard that provides a framework for developers to create software that enables users to access and process geographic data from a variety of sources across a generic computing interface within an open information technology environment (Open GIS Consortium Inc., 2002). The geographic services architecture specified in this international standard contains six classes of GIS technology services. Drawing on the information system design theory framework, it is proposed that these six classes form the Meta-Requirements of an ISDT for SDSS. These Meta-requirements describe the specific goals that are applicable to any system of the type to which the theory relates, and in this instance should be necessary aspects of supporting spatial decision-making. The six SDSS Meta-Requirements are illustrated in Table 3.

Meta-Requirement	Goals
Geographic human interaction services	A SDSS should provide geographic human interaction services for the management of user interfaces, graphics, multimedia, and for presentation of compound documents.
Geographic model/information management services	A SDSS should provide geographic model / information management services for the management of the development, manipulation, and storage of metadata, conceptual schemas, and datasets.
Geographic workflow/task management services	A SDSS should provide geographic workflow/task services for the support of specific tasks or work-related activities conducted by humans. These services support use of resources and development of products involving a sequence of activities or steps that may be conducted by different persons.
Geographic processing services – spatial, thematic, temporal, metadata	A SDSS should provide geographic processing services that perform large-scale computations involving substantial amounts of data. A processing service does not include capabilities for providing persistent storage of data or transfer of data over networks.
Geographic communication services	A SDSS should provide geographic communication services for the encoding and transfer of data across communications networks.
Geographic system management services	A SDSS should provide geographic system management services for the management of system components, applications, and networks. These services also include management of user accounts and user access privileges.

Table 3. SDSS Meta-Requirements

The OGC expects that geographic information system and software developers will use these standards to provide general and specialized services for all geographic information. In fact, the geographic services architecture specified in this international standard was developed to meet the following purposes:

- Provide an abstract framework to allow coordinated development of specific services
- Enable interoperable data services through interface standardization
- Support development of a service catalogue through the definition of service metadata
- Allow separation of data instances and service instances
- Enable use of one provider's service on another provider's data, and
- Define an abstract framework, which can be implemented in multiple ways.

Thus, it is fitting that this international standard serves as the starting point for the development of an ISDT for SDSS.

Meta-Design

Table 4 contains examples of specific GIS Meta-Design elements contained within each of the six SDSS Meta-Requirements described above. Here, each Meta-Design element describes the specific artifacts that are applicable to the Meta-Requirements. It should be noted that the following is a representative list of geographic services as outlined by the OGC – the entire, non-exhaustive, OpenGIS listing can be found in (Open GIS Consortium Inc., 2002).

Meta-Design	Description
Catalog viewer	Client service that allows a user to interact with a catalog to locate, browse, and manage metadata about geographic data or geographic services.
Feature access service	Service that provides a client access to and management of a feature store. An access service may include a query that filters the data returned to the client.
Chain definition service	Service to define a chain and to enable it to be executed by the workflow enactment service. This includes information about its starting and completion conditions, constituent activities and rules for navigating between them, user tasks to be undertaken, references to applications which may need to be invoked, definition of any workflow relevant data which may need to be referenced, etc. Chain definition service may also provide a chain validation service.
Coordinate conversion service	Service to change coordinates from one coordinate system to another coordinate system that is related to the same datum. In a coordinate conversion the parameters' values are exact. Coordinate conversion services include map projection services.
Thematic classification service	Service to classify regions of geographic data based on thematic attributes. Classification of coverage (including images); subdivides a coverage into regions based on attribute values. Classification of features; sorts features into groups based on attribute values or feature associations.
Temporal reference system transformation service	Service to change the values of temporal instances from one temporal reference system to another temporal reference system.
Statistical calculation service	Service to calculate the statistics of a data set, e.g., mean, median, mode, and standard deviation; histogram statistics and histogram calculation; minimum and maximum of an image; multi-band cross correlation matrix; spectral statistics; spatial statistics; other statistical calculations.
Encoding service	Service that provides implementation of an encoding rule and provides an interface to encoding and decoding functionality.

Table 4. SDSS Meta-Design

Design Method

A Design Method describes the procedures to be utilized in building a system of the type to which the theory relates. Here, two procedures are outlined for the development of a SDSS. The first considers the use of the Service Organizer Folder as a method to organize specific Meta-Design elements, while the second outlines the Human-Centered Design processes used to construct a system of this type.

Service Organizer Folder

The OGC has proposed a method of organizing the geographic services described above that are to be employed for a specific task – the Service Organizer Folder (Open GIS Consortium Inc., 2002). A Service Organizer Folder is:

- A persistent, sharable data structure containing references to a set of services applicable to a given situation
- A subset of available services applicable to a specific situation, e.g., image analysis
- An aid for analysts in finding services applicable to their situation

Though many types of geographic services may be available for use – see Table 4 and (Open GIS Consortium Inc., 2002), only a subset of these services would be applicable to any specific situation. A Service Organizer Folder would therefore assist users in finding a specific grouping of services applicable to their particular situation.

Human-Centered Design

As defined by the International Standards Organization, human-centered design is an approach to interactive system development that focuses specifically on making systems usable (International Organization for Standardization, 1997). While there are many approaches and methods for the design of interactive computer-based systems (e.g. process-oriented versus data-oriented approaches; systems development life cycle and prototyping methods), these approaches and methods generally focus on ensuring that the systems meet specific business and/or performance objectives. The human-centered design approach enhances existing approaches and methods by providing a human-centered perspective to the overall system design process. Human-centered design activities include:

- Understanding and specifying the context of use
- Specifying the user and organizational requirements
- Producing design solutions
- Evaluating designs against requirements

The human-centered design process iterates through these activities until the system meets specified functional, user, and organizational requirements.

CASE IMPLEMENTATION: PROXIMATE COMMUTING

As discussed earlier, CTR programs provide commuters with resources and incentives to reduce their automobile trips and many of the benefits of CTR programs can be calculated quite precisely. For instance, RIDES for Bay Area Commuters provides a Commute Calculator on their website (RIDES For Bay Area Commuters, 2003). Using this calculator a commuter can determine the cost of their current drive-alone commute. Figure 2 is an example of the use of this calculator.

Using the Commute Calculator, a commuter can compute the costs and benefits associated with a reduced commute. For example, if a person driving 50 miles (round-trip) reduces their commute by 25%, their benefits would be:

Economic Cost / Benefit (Dollars)	**Daily**	**Monthly**	**Yearly**
Commuting Cost: 50 Miles (Round Trip)	$19.50	$409.50	$4,914.00
Commuting Cost: 37.5 Miles (25% Reduction)	$14.63	$307.13	$3,685.50
Commuting Benefit: Reduced Expenditures	**$4.88**	**$102.38**	**$1,228.50**

These are only commute costs. These figures do not include car ownership costs, such as loan or lease payments, and insurance.

RIDES also provides an Environmental Calculator to compute the impact of a commute on the environment. The cost of a commute on the environment includes the emission of reactive organic gases, carbon monoxide, nitrogen oxide, PM10, and sulfur dioxides. Using this calculator, the benefits to the environment associated with this 25% shorter commute are:

Environmental Cost / Benefit (Pounds)	**Daily**	**Monthly**	**Yearly**
Commuting Cost: 50 Miles (Round Trip)	2.00	42.00	504.00
Commuting Cost: 37.5 Miles (25% Reduction)	1.50	31.50	378.00
Commuting Benefit: Reduced Emissions	**0.50**	**10.50**	**126.00**

Figure 2. Commute / Environmental Calculator Example

The application of the ISDT for SDSS for Proximate Commuting, illustrated in Tables 1 and 2, as it relates to the development of a prototype information system, is detailed below. In this case, an information system for a quasi-governmental organization consisting of a Proximate Commuting system was designed, developed, implemented, and evaluated. Table 5 details the specific ISDT elements contained in the Proximate Commuting Service Organizer Folder that were used to guide the development and implementation of the initial prototype. As presented here, Proximate Commuting is a combination of services for the purpose of end-user spatial analysis whose goal is to reduce commuting distances.

Meta-Requirements	**Meta-Design**
Geographic human interaction services	Geographic viewer
Geographic model/information management services	Feature access service Coverage access service Coverage access service – sensor
Geographic workflow/task services	NA
Geographic processing services – spatial	Route determination service Proximity analysis service
Geographic processing services – thematic	NA
Geographic processing services – temporal	NA
Geographic processing services – metadata	Geographic annotation service

Geographic communication services	Transfer service Messaging service Remote file and execution management
Geographic system management services	NA

Table 5. Proximate Commuting Service Organizer Folder

The following example demonstrates the various activities and functions of this system. In Figure 3, the user clicks on a City / Zip Code map feature (e.g. Berkeley, California) sending a request to a GeoLocator Web Service (proximity analysis service) where the user is then presented with a new window displaying a listing of all Commute-Friendly Jobs within a specified radius of the City / Zip Code. At this point in time, the user can either browse through this list for a new job location, perform a new spatial search by entering in a new search radius, or perform a new spatial search with additional attribute parameters entered, e.g. Job Type, Address, City.

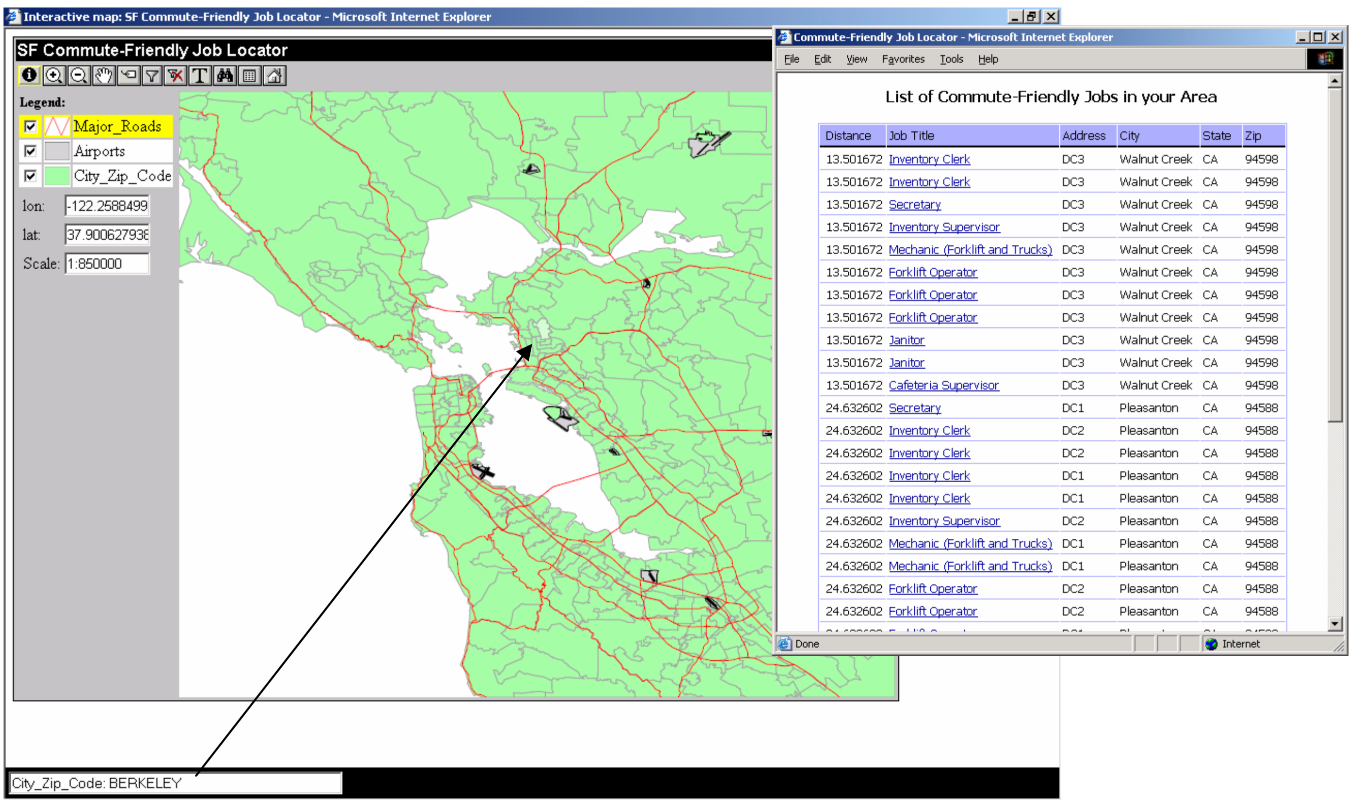

Figure 3. GeoLocator Web Service

DISCUSSION

It has been observed (Green, Kennedy, & McGown, 2002) that increasing international competitiveness and technological advances have prompted the need for organizations to:

- Exploit emerging technologies more rapidly
- Reduce design time-scales
- Provide "right first time" design

- Innovate more frequently and produce more innovative products
- Improve the reliability of products and systems

In an effort to address these needs, industry and academia have been directing research towards developing ways to automate and guide the design process while at the same time improving the quality of the process along with its outputs (Green et al., 2002). To that end, the ISDT proposed herein could be used to guide the development of any SDSS. As a case in point, this research-based methodology was effectively used for the design of a specific instance of a SDSS – a Proximate Commuting system. Continued research in developing an ISDT for SDSS represents an opportunity to build upon and expand the contributions of this initial research effort.

For example, one drawback to the use of the ISDT framework for the design of information systems is that as the number of requirements and design elements grows, the use and management of these artifacts may become unwieldy, and hence, problematic. For example, the Meta-Design elements presented above, based on the geographic services outlined in the OpenGIS Service Architecture, total approximately 100. As additional geographic services are developed, this number will only grow.

One method to mitigate this potential problem is through application of an ontology. To that end, the development of an ontology using Protégé-2000; an integrated software tool used by system developers and domain experts to develop knowledge-based systems (Stanford Medical Informatics, 2003) would extend this research. An ontology defines a common vocabulary for researchers who need to share information in a domain and includes machine-interpretable definitions of basic concepts in the domain and relations among them (Noy & McGuinness, 2003). Noy and McGuinness (Noy & McGuinness, 2003) identified five major reasons for developing an ontology. They are:

1. Sharing common understanding of the structure of information among people or software agents
2. Enabling reuse of domain knowledge
3. Making explicit domain assumptions
4. Separating the domain knowledge from the operational knowledge
5. Analyzing domain knowledge

Noy and McGuinness further state that problem-solving methods, domain-independent applications, and software agents use ontologies and knowledge bases built from ontologies for problem-solving and decision-making within particular domains. Figure 4 is an example of an initial research effort by the authors to address these needs and illustrates an ontology developed for SDSS using Protégé-2000. The SDSS Main Class with Application Domain and Geographic Service Subclasses can be seen on the left-hand side of the figure. On the right-hand side, the design for a Proximate Commuting system can be seen with each of its specific design elements outlined, e.g. proximity analysis service.

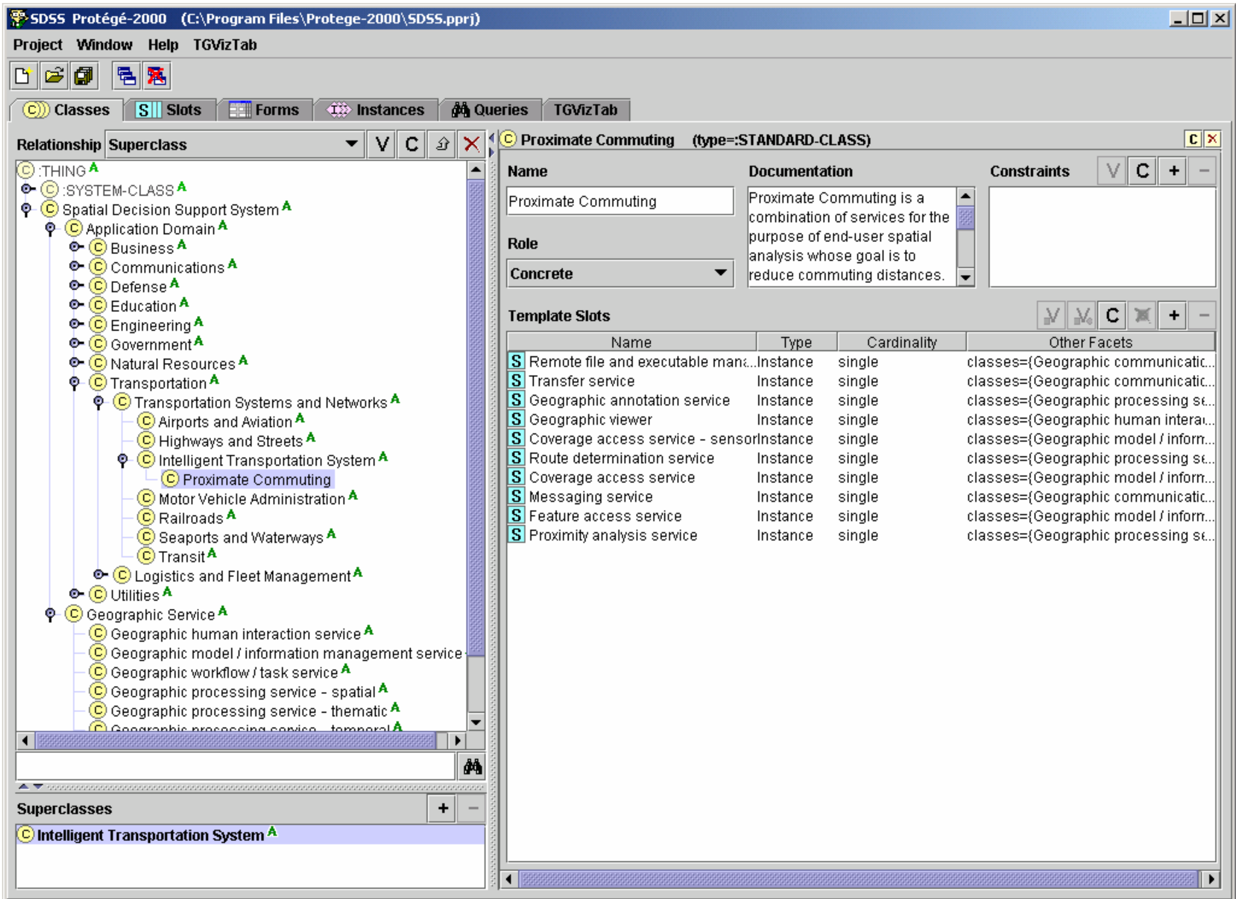

Figure 4. Spatial Decision Support System Ontology

Within the context of GIS, the role of a Spatial Decision Support System Ontology is to classify the dimensions of design available for developing tailored GIS systems. With the continued growth of open standards-based solutions, there may be less of a premium on new integrated systems and more pressure to customize generic solutions for use in specific applications (such as Proximate Commuting) where an ontology-based ISDT can provide the framework for such an approach.

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