Spatiotemporal interaction modelling and simulation for transport system based on a geosensor network

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1. Introduction

The transport system is a crucial infrastructure in the urban area characterized by its spatiotemporal phenomena. With the advent of Information and Communication Technology (ICT), the transport system has been evolving towards an Intelligent Transport System (ITS) based on the communication components providing traffic information to moving vehicles in real time. The problem is that current GIS data models are limited in handling moving objects and the events between them.

In the transportation field, dynamic segmentation and link-node topology have been used to manage transport infrastructures and to provide navigation functions; however a suitable model is needed to represent mobile objects (Goodchild 2000). The goal of this research is to develop a reliable conceptual framework for the GIS data model to support ITS and its communication component. In particular, the emphasis is set on communication between vehicles and road facilities under the assumption that they can interact with each other as a node of a geosensor network.

2. Literature review

Recently, considerable research efforts have been aimed at the representation of dynamic geographical phenomena as well as interaction with each geo-object in the spatiotemporal phenomena in real time. All of them provide valuable techniques to extend traditional GIS data models for supporting spatio-temporal phenomena in diverse application domains.

Several researchers have tried to represent temporal variation in the geographic domain. Hornsby and Egenhofer (2000) proposed the identity-based model which can model changes of objects based on their own identity. The concept of geospatial lifelines was also proposed to present moving objects as ordered points in space and time (Hornsby & Egenhofer 2002). This research provided the multi-granularity model for moving objects using approximations of lifelines and it may be useful for processing in very large datasets. Recently, Goodchild et al. (2007) proposed a model of dynamic geo-objects through time using three conditions: movement (stationary or moving), shape (elastic or rigid), and internal structure (uniform, evolving).

Ontological approaches have been developed for geographical objects, events and processes as well as dynamic representations for moving objects (Worboys 2005). Gernon and Smith (2004) presented a framework for geographical representation of objects, events, and processes using SNAP-SPAN ontology. Moreover, ontological views have been used to examine the semantic relationship between different geographical categories (Agarwal 2005).

Geosensor network analysis has been used to support dynamic phenomena with monitoring and interaction based on a Mobile Ad-hoc Network (MANET) in real time (Nittel et al. 2004).

This research showed that interaction with moving geo-objects as a sensor node can contribute to reduce their redundancies throughout information dissemination related to their locations and settings using geosensor networks.. In order to support ad-hoc shared-ride trip planning using geosensor networks, simulation was performed based on grid environment (Winter & Nittel 2006). They showed that mid-range negotiation is more effective and efficient than unconstrained negotiation and short-range negotiation for communication among sensors. Raubal et al. (2007) considerably reduced communication costs for ad-hoc shared-ride trip planning with different way-finding strategies using time geography in a real street network environment. .

3. A scenario for interaction modelling and simulation

This research extends on the other current research in geo-sensor networks by proposing a model for an ubiquitous geospatial environment in which different nodes can communicate with each other. The scenario employed for developing a model is an intelligent transport infrastructure with dynamics among the geo-objects focused on a data model and an interaction model (Figure 1) in which vehicles and road facilities collaborate with each other within a geosensor network. .

A driver is going to Manchester to attend a conference, so he inputs his destination into an intelligent vehicle. The intelligent vehicle will find a suitable route to the destination and interact with other objects along the route. When the vehicle joins the highway, it becomes a member of a stream of cars. It would then interact with remaining cars in the stream to maintain vehicles speeds and intervals. In addition, the first car of the stream will keep communicating with road facilities and signal controllers to recognize various and dynamic road situations such as road pavement, and car accidents.
Now, twenty cars are leaving the stream on the highway to go to the conference site in Edinburgh. These cars are a member of smaller stream going to the same destination. The first car communicates with the signal controller to inform that cars are member of the stream, so that the signal controller deals with cars like a long lorry. This means that the controller will not change the signal until all the cars have passed. Finally, they arrive at their destination.

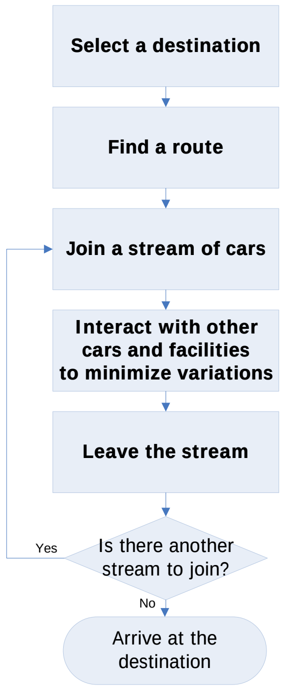

Figure 1. A scenario within which vehicles and road facilities collaborate and communicate with each other within a ubiquitous information space

Based on the above scenario which was made under the assumption that vehicles and road facilities are nodes of a geosensor network, methods such as conceptual modelling and ontologies will be used to model categories and communication networks in a real-time ubiquitous information infrastructure in the transportation domain. Also, agent-based simulations will be used to model specific parts of communication, and test categories and their interactions.

4. Spatio-temporal interaction modelling

The basic underlying theoretical idea of the model is that interaction among geo-objects in real time can have positive influences on transport system itself. Therefore, we divided the setting of the scenario into three parts in the view of service consumer, service provider, and

other environmental parameters. And then, we tried to find relations between these categories based on determined variables, predictable variables, and unpredictable variables.
First, objects and events of this setting were categorized into infrastructure, traffic flow, and others. Traffic flow category can be characterized as moving objects and its events, while most of infrastructure category was populated by services based on their location. In addition, there is another environmental category which affects infrastructure and traffic flow.
Second, variables of spatiotemporal setting were divided into three parts – determined variables, predictable variables, and unpredictable variables (Figure 2). Determined variables relate to known information before the journey such as origin, destination, pavement status, planned events and maintenances. Predictable variables describe variables which can be anticipated like the weather condition or traffic signal, but it can change. Unpredictable variables can not be known before its occurrence such as car accidents, signal failure, and unexpected road closure.

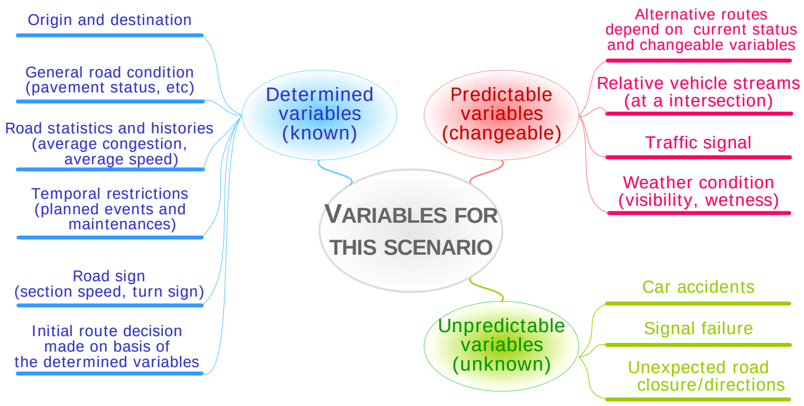

Figure 2. Three kinds of variables for this scenario (determined variables, predictable variables, and unpredictable variables)

Third, each variable is matched to an appropriate semantic category. The transport infrastructure as well as the traffic flow contains determined, predictable, and unpredictable variables (Figure 3). Basically, most variables are related to the transport infrastructure and moving objects (the traffic flow) on the infrastructure. However, there are other variables such as weather condition and emergencies which are unpredictable, and they have an effect on this setting directly and indirectly.

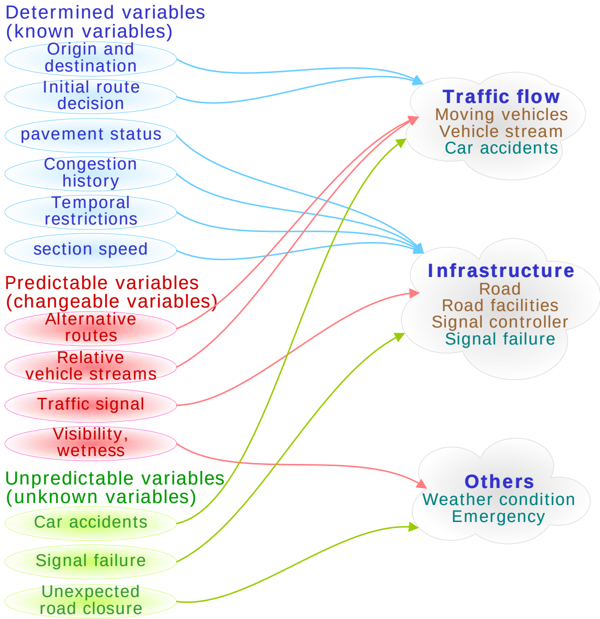

Figure 3. Relations between three kinds of variables and categories

Lastly, we extracted six types of interaction among categories because these variables belonging to each category can affect other variables based on their relations (Figure 4). Although through analysis it was deduced that there are nine types of two-way communication, this research focused on six interactions which have a direct influence on infrastructure and traffic flow.. The infrastructure and the traffic flow can have four-ways effects (infrastructure to infrastructure, traffic flow to traffic flow, infrastructure to traffic flow, traffic flow to infrastructure). Other environmental variables also have an influence on the infrastructure and the traffic flow (two types: other variables to infrastructure, other variables to traffic flow). For example, some precipitation may cause a wet road condition so that vehicles reduce their speed. Also, it can evaluate congestion and intelligent signal controller may try to find a suitable signal pattern for the congestion.

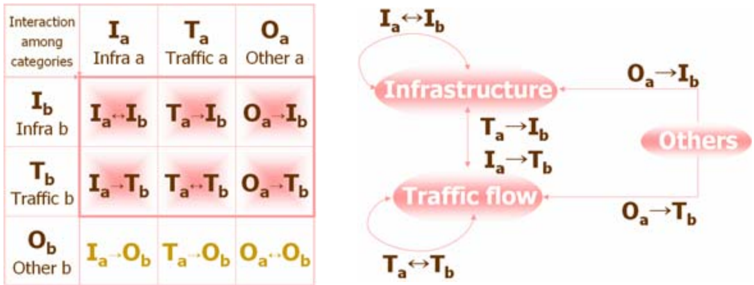

Figure 4. Direct interaction with infrastructure and traffic flow among sensor networks
for transport infrastructure

5. Development of a simulation environment

Further to development of the theoretical model and ontological deployment, we implemented a simulation environment relating to six types of interaction which can reduce various temporal variations during the journey on the road network. The simulation focused on Traffic flow-to-Infrastructure interactions ($T_a \rightarrow I_b$, $I_a \rightarrow T_b$ of figure 4) between vehicles and traffic signal controllers. If signal controllers can make signal schedule considering road status about the traffic flow in real time, traffic efficiency will be improved. The simulation environment was developed with a vector-based grid network to consider scalability towards real street networks.

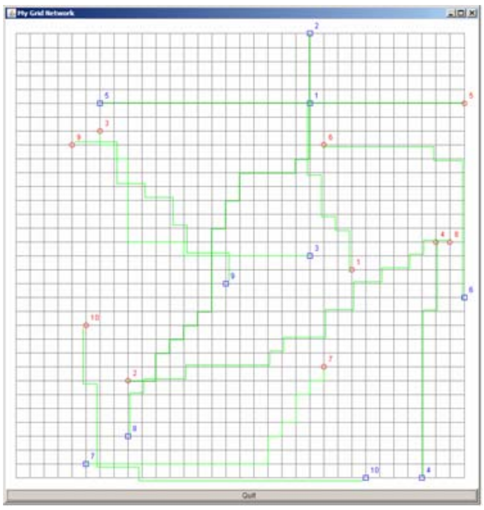

Figure 5. Simulation environment (grid network)

We conducted three types of simulation with different settings relating to signal controllers to measure average travel time from departure to destination: travel without signal, travel with signal; and interactive travel with signal. When we consider the signal, we have to calculate delay time at signals so that three kinds of time domain are needed: absolute time (STimer class), accumulated travel time of each vehicle (SCar class) and circular time for signal controller (SSignal class). If a vehicle arrived at an intersection as soon as the signal turned red, the delay of the vehicle at the intersection is maximized. Signal schedule can be made flexible to minimize the delay throughout the interaction between vehicles and signal controllers. This is the purpose of the simulation to examine whether or not interactions minimize the delay at intersections. For the multi-agent based simulation, several agent classes are created (sample shown in Figure 6). There are many dependency relations among classes so that it can be argued that the simulation for interaction is well directed.

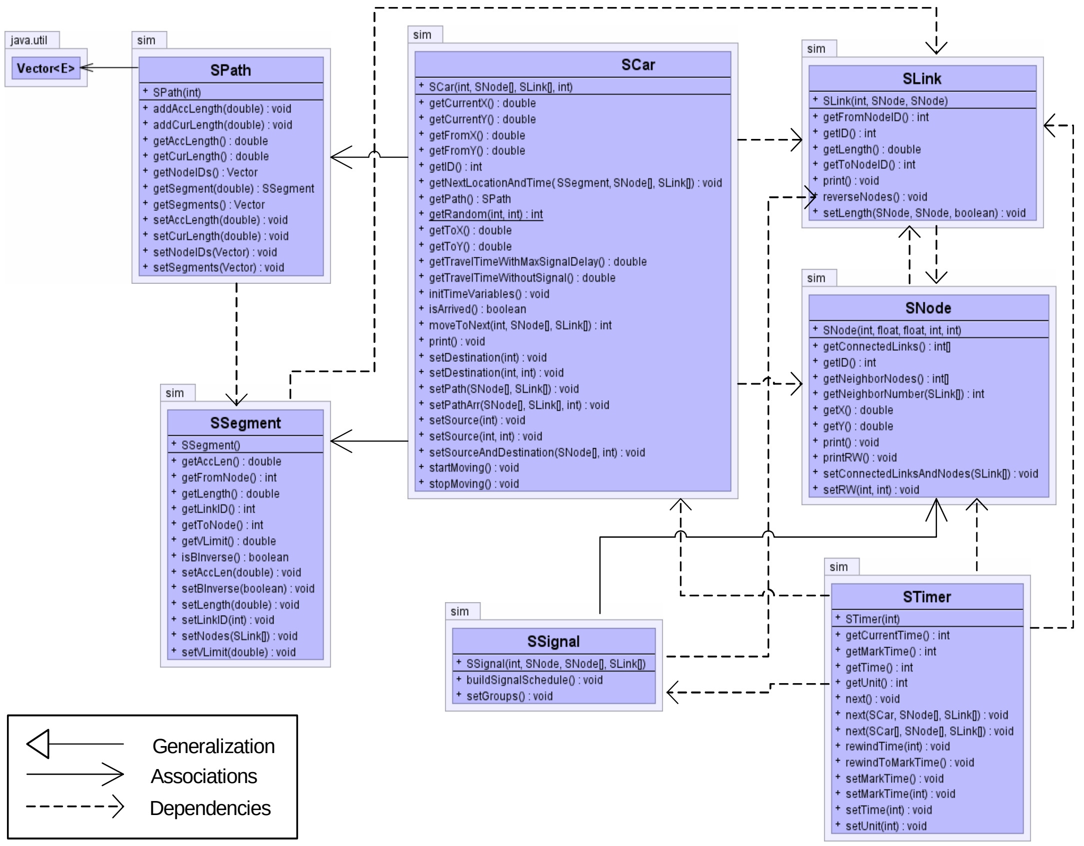

Figure 6. Static class diagram for the simulation

6. Conclusion and future work

This research has been successful in categorizing and modelling interactions between vehicles and road facilities in a road network based on geosensor network and in developing a simulation environment to conduct an experiment for interactions to improve transport system. This research has laid the foundations for future work to examine the efficiency of the simulation of interactions. In order to execute the simulation, some parameters such as number of cars, signal time schedule, length of each segment have to be further examined and defined. In this research, the simulation focused on Traffic flow-to-Infrastructure interactions ($T_a \rightarrow I_b$, $I_a \rightarrow T_b$ of figure 4) between vehicles and traffic signal controllers. However, because

there are four other interactions, the simulation environment will be expanded for more experiments.
This research is aimed at modelling spatio-temporal interactions in real time, and will support research in making geo-objects more interactive and intelligent. Other scenarios besides the one discussed in this paper will be considered in future work, where interaction model may be more useful than representation model. In order to implement GIS functions in a geo-sensor network and ubiquitous information space, ontological methodologies will be useful. For future work, this research will aim for an ontological framework of transport system to support richer simulation and implementation.

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Biography

Seong K. Choi is a first year doctoral student in the department of Civil, Environmental and Geomatic Engineering (UCL). He holds a BSc and an MSc in Geographic information Science from the department of Geoinformatic Engineering (Inha University in South Korea). His PhD research focuses on the interaction modelling and simulation of transport communication in a geo-sensor network.

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