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Geospatial Analysis and Modeling in Korea: A Literature Review

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Abstract : The main objective of this paper is to provide an adequate and comprehensive review of what has been done in South Korea in the field of geospatial analysis and modeling. This review focuses on spatial data analysis and spatial statistics, spatial optimization, and geosimulation among various aspects of the field. It is recognized that geospatial analysis and modeling in South Korea got through the initial stage during the 1990s when computer and analytical cartography and GIS were introduced, moved to the growth stage during the first decade of the 21st century when there was a surge of relevant researches, and now is heading for its maturity stage. In spatial data analysis and spatial statistics, various topics have been addressed for spatial point pattern data, areal data, geostatistical data, and spatial interaction data. In spatial optimization, modeling and applications related to facility location problems, districting problems, and routing problems have been mostly researched. Finally, in geosimulation, while most of research has focused on cellular automata, studies on agent-based model and simulation are in beginning stage. Among all these works, some have fostered methodological advances beyond simple applications of the standard techniques.

Key Words : spatial data analysis, spatial statistics, spatial optimization, geosimulation, geography in Korea

요약 : 이 논문의 연구 목적은 한국 지리학계에서 이루어진 지리공간분석 및 모델링 분야의 연구를 개관하는 것이다. 여기에서 지리공간분석과 모델링이라는 분야는 공간데이터분석 및 공간통계학, 공간최적화, 지오시뮬레이션 관련 연구를 의미하는 것으로 한정한다. 한국의 지리공간분석과 모델링 분야는 컴퓨터 혹은 분석 지도학과 GIS가 도입된 1990년대의 초기 단계를 거쳐, 관련 연구 논문이 쏟아진 2000년대의 성장 단계로 이행했으며, 현재 성숙 단계를 향해 진화하고 있다. 공간데이터분석과 공간통계학 분야에서는 공간적 포인트 패턴 데이터, 에이리어 데이터, 지구통계학적 데이터, 공간적 상호작용 데이터에 대한 다양한 연구가 이루어져 왔다. 공간최적화 분야에서는 시설물 입지문제, 구획문제, 경로설정 문제 등에 대한 모델의 개발 및 적용과 관련된 연구가 활발하게 진행되어 왔다. 지오시뮬레이션 분야에서는 셀룰라 오토마타와 관련된 연구가 대부분을 차지하고 있는 것에 비하여, 에이전트 기반 모델링은 이제 시작단계에 있다. 이 모든 연구 성과들 중 몇몇은 표준 기법의 단순한 적용을 넘어 방법론적 진보를 이끌어 낸 것으로 평가된다.

주요어 : 공간데이터분석, 공간통계학, 공간최적화, 지오시뮬레이션, 한국 지리학

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1. Introduction

Rapid advances in geospatial data acquisition and processing technologies, a wide-spread recognition of the importance of GIS (Geographic Information Systems) as a general research platform, and the growing interest in a consilient approach to sciences have collectively precipitated the emergence of a new academic field, geospatial science (or, in more popular but somewhat old term, geographic information science). In the context of geography, the evolution from *Spatial Analysis* to geospatial science (Berry, *et al.*, 2008) may be reflective of an intensive and/or extensive interplay between two revolutions in the field, quantitative and GIS revolutions (Lee, S.-I., 2005; Murayama, 2012). This implies that the term of spatial analysis has greatly lost its adequacy in describing what has been done and how it has been done in the interdisciplinary geospatial science and thus needs to be replaced by a new one in order to cover and provide a unity to its whole gamut.

We choose the term, 'geospatial analysis and modeling' since we believe that it has increasingly been gaining the popularity in accordance with nearly the same intention as we have here (Jiang, 2007; de Smith, 2007; Murayama, 2012). We also believe that 'geographic information analysis' as defined by O'Sullivan and Unwin (2010) is almost synonymous with our term. In a sense, geospatial analysis and modeling can be defined as a GIS-based approach to analyze and model geographic data and information (Murayama, 2012). However, we do not think that the GIS-friendliness is a necessary condition for a membership. Rather, geospatial analysis and modeling encompasses the whole gamut of research practices aiming at "extracting knowledge from geospatial information" (Jiang, 2007:478).

We believe that there exists spatial data analysis at the heart of geospatial analysis and modeling, because it is a well-established interdisciplinary field (Bailey and Gatrell, 1995; Haining, 2003) and the efforts of integrating it with GIS in the 1990s are believed to have founded the emergence of geospatial analysis and modeling (among others, Goodchild *et al.*, 1992). In addition, spatial data analysis is often regarded as exchangeable with spatial statistics when focuses are on testing and modeling (Bailey and Gatrell, 1995; Getis, 1999). Thus, geospatial analysis and modeling here is viewed as composed of spatial data analysis (and spatial statistics) and other more GIS-friendly and/or more computationally intensive analytics such as spatial optimization, spatial data mining, geocomputation, geosimulation, geovisualization, and so on. This definition is well consonant to what is in the spatial analysis section in the GIS big book (Longley *et al.*, 1999) and that of a popular geospatial analysis textbook (de Smith *et al.*, 2007).

Although a few primitive works in geospatial analysis and modeling in South Korea were found in the 1970s and 1980s when some scholars inspired by the quantitative revolution sought to carry out sophisticated quantitative researches, its practical foundations were established during the 1990s when computer and analytical cartography and GIS were introduced (Yu, K. B., 1996) (the initial stage). However, it was not until the mid-2000s that the Korean society of geography witnessed a surge of works pertaining to geospatial analysis and modeling and began to recognize it as a distinct field. Geospatial analysis and modeling in South Korea lied in its growth stage during the fist decade of the 21st century and now is evolving into its maturity stage.

This paper aims at providing an adequate and comprehensive review of what has been done in South Korea in the field of geospatial analysis and modeling. Given a limited space for the review, we had to accept two arbitrary restrictions. First, the review focuses on works done in such fields as spatial data analysis and spatial statistics, spatial optimization, and geosimulation. Second, the review is confined to the works done by Korean geographers (at least partly) and published in Korean journals, which rules out the works done by Korean geographers but published in international journals.

2. Spatial Data Analysis and Spatial Statistics

Following Bailey and Gatrell (1995), spatial data analysis is divided according to different types of spatial data: spatial point pattern data, areal data, geostatistical data, and spatial interaction data. For each data type, the review will be separately done.

It should be noted that some pioneering works in spatial data analysis and spatial statistics have been done by graduate students for their master's degrees in Seoul National University even though almost all the works have never been published in academic journals (Yoo, E.-H., 1999; Cho, D., 2001; Kim, K., 2001, Chun, Y., 2002; Hwang, M., 2002; Lee, G., 2003). Yoo (1999), for example, developed a GIS-based spatial data analysis tool named SAAD (Statistical Analysis of Area Data) which was equipped with some ESDA (exploratory spatial data analysis) functionalities for areal data analysis. Other students also made initial contributions to various sub-fields such as spatial point pattern data analysis (Chun, Y., 2002), areal data analysis (Cho, D., 2001), spatial data mining (Hwang, D., 2002; Lee, G., 2003), and geovisualizaiton (Kim, K., 2001).

1) Spatial Point Pattern Data Analysis

The first and most comprehensive works on exploring and modeling spatial point pattern data were done by S.-K. Hong (1998a; 1998b) and K.-H. Park (1999). Hong provided a way of exploring space-temporal phenomena and applied Knox's and Mantel's approaches to model space-time clustering. Park conducted a full-fledged ESDA for shigellosis by utilizing kernel density estimation, *G*, *K*, and *L* functions for univariate analysis, and difference *K* or *D* functions for bivariate case-control analysis. The simple, direct applications of the standard techniques were also found in other practical researches such as crime analysis (Hwang, S.-Y. and Hwang, C.-S., 2003) and bank branch network evaluation (Lee, B.-K., 2006).

Cluster detection research has also been done. J. Shin (2004b; 2005; 2009) proposed a couple of cluster detection techniques (VCEC and HVCM) which are variants of VCM (variable clumping method). He reported that the techniques allows researchers to detect statistically and economically significant spatial clusters of urban economic activities. Sohn (2008) and Sohn and Park (2008) offered a hybrid cluster detection technique by combining spatial scan statistics and local Moran's I_i to detect hotspots of house price volatility. They contended that the former detects spatial clusters of houses with a positive range of price volatility, while the latter evaluates the homogeneity of direction of price volatility within each cluster.

2) Areal Data Analysis

As in other countries, areal data are the most common type of spatial data in South Korea and, thus, areal data analysis is the most prominent subfield in terms of the publication amount. Tasks are divided into three groups; visualizing areal data, measuring and exploring spatial autocorrelation, and spatial regression.

(1) Visualizing Areal Data

Perhaps the most common way of displaying areal data is the choropleth map. As a geovisualization tool, however, it has several defects (Bailey and Gatrell, 1995). First, physically large areas tend to dominate the pattern. Second, no spatial variation is assumed within each areal unit. Third, any spatial pattern in a choropleth map is always dependent on the spatial configuration of areal units which leads to MAUP (modifiable areal unit problem). Fourth, some statistically informed attribute transformations need to be attempted.

For the first defect, some alternative types of thematic mapping have been proposed and the most viable one could be areal cartogram. In this sense, Y.-H. Kim (2008) developed an ArcView extension for Dorling's circular cartogram and applied it to geographic distribution of demographic attributes stored in administrative areal units in South Korea. For the second defect, various types of spatial estimation techniques have been applied such as areal interpolation (Shin, J., 2004a; Jun, B.-W., 2008), dasymetric mapping (Park, K.-H., 1999; Jun, B.-W., 2006; Lee, S.-I. and Kim, K., 2007; Kim, H., 2007; Kim, H. and Choi, J., 2011), and small area population estimation (Ku, C. Y., 2008; Kim, B.-S. *et al*., 2010).

For the third defect, some intensive works have been done to investigate the effects of MAUP. For example, S.-I. Lee (1999) analyzed the scale and zoning effects in variance, correlation coefficient, regression coefficient, coefficient of determination, and global spatial autocorrelation in the context of various types of functional regions in the U.S. In the similar vein, K. Kim (2011a) discussed MAUP in spatial interaction models. He reported that spatial characteristics of residuals, parameter values, and goodness-of-fit of a spatial interaction model are influenced by aggregation scales and schemes. A conceptual elaboration on MAUP from the spatial object perspective has also been done (Lee, G., 2011). For the forth defect, various data transformation techniques such as probability mapping, relative risk transformation, and empirical Bayes estimation have been attempted (Park, K.-H., 1999; Hwang, S.-Y. and Hwang, C.-S., 2003).

(2) Measuring and Exploring Spatial Autocorrelation

A research scheme of measuring and exploring spatial autocorrelation using global and local spatial association measures has been well established in South Korea. A vast majority of works have utilized global and local Moran statistics and the associated ESDA techniques, in particular LISA cluster maps. The framework has been applied to crime analysis (Hwang, S.-Y. and Hwang, C.-S., 2003; Kim, K. and Kim, B. S., 2009), regional income convergence (Lee, S.-I., 2004a), Internet domain distribution (Lee, H.-Y. and Lee, Y.-G., 2004), migration (Kim, K., 2010), and spatial epidemiology (Yang, B.-Y. and Hwang, C.-S., 2010). LISA cluster maps utilizing other local spatial association statistics have also been used: local Geary's c_i and Lee's S_i (Lee, S.-I., 2004a) and Getis-Ord's G_i^* (Kim, K., 2010). Join-count statistics were also used to gauge the degree of spatial autocorrelation of attributes measured at the nominal scale (Byun, B., 2004). All these works are simply to apply a standardized set of techniques to empirical data.

There have been some methodological advances in this field. S.-I. Lee (2004a; 2004b) proposed bivariate ESDA techniques utilizing his L_i statistics and r_i, a localized version of Pearson's correlation coefficient. He contended that the proposed method is expected to effectively reveal spatial heterogeneity in bivariate association and help detect bivariate spatial hotspots or spatio-temporal hotspots. S.-I. Lee (2007; 2008a) also devised a set of global and local spatial separation measures by integrating the bivariate Geary statistic and spatial chi-square statistic and provided a set of ESDA techniques allowing for exploring spatial dependence and heterogeneity in residential differentiation. Similarly, J. Shin and G. Lee (2007) proposed a new set of global and local statistics for spatio-temporal surveillance. They combined the *J* statistic with *CUSUM* (cumulative sum) statistic and provided a significance testing procedure based on the Monte Carlo simulation. They argued that the proposed method allows researchers to effectively explore continual and cumulative changes in spatial patterns.

Some other tasks have also been tackled. A generalized statistical testing procedure for univariate spatial association measures based on the normality assumption has been presented (Lee, S.-I., 2008b). A modified AMOEBA (A Multidirectional Optimal Ecotope-Based Algorithm) technique has been proposed to delineate spatial clusters (Lee, S.-I. *et al.*, 2010). This approach was successfully applied to detect the boundaries of business centers in a metropolitan area (Kim, K., 2011b). Some extended the AMOEBA framework by providing a discussion on the possibilities of either Geary's local statistic (Kim, J.-H., 2012) or Mahalanobis distance for multivariate situations (Lee, M., 2012).

(3) Spatial Regression

Spatial regression refers to all kinds of regression-type modeling techniques which have been developed to overcome OLS regression's inability to deal with spatial autocorrelation in residuals. There are two types of spatial regression approaches; global and local.

For the global approach, traditional spatial autoregressive models such as SAR (simultaneous autoregressive), CAR (conditional autoregressive), and MA (moving average) models have been utilized. H.-Y. Lee and Y.-G. Lee (2004) fitted a CAR model. S.-I. Lee (2004b) compared OLS and SAR models and showed the latter's superiority in modeling β-convergence. Similarly, Y. Chun and Y. Park (2008) compared OLS, SAR, and CAR models and suggested that the lack of consideration for spatial aspects may result in the bias of parameter estimation and inefficient standard errors for the parameters in a regression analysis. Y. Kim (2008) presented the exact mechanism and effects of spatial autocorrelation in OLS regression. He also introduced new regression schemes such as a Bayesian hierarchical modeling (2007) and an eigenvector spatial filtering framework (2009).

For the local approach, GWR (geographically weighted regression) has solely been chosen. While S.-I. Lee (2004b) used GWR in the context of simple regression to exploring spatial heterogeneity of beta-coefficients, all the others did in the context of multivariate regression (Kim, I.-H., 2005; Yang, B.-Y. and Hwang, C.-S., 2010; Kim, K., 2011b).

3) Geostatistical Data Analysis

Geostatistical data, also called spatial continuous data, refer to a set of points to each of which a sample attribute is attached. Unlike spatial point pattern data, locations are fixed and attributes attached on them constitute random variables. They are almost the same as areal data; the only difference is the dimensionality of spatial objects possessing attributes. Geostatistical data analysis usually employs certain forms of spatial interpolation. The review focuses on applications of various types of kriging.

Some applications utilized simple, ordinary, or universal kriging to recover physical features (Choi, K.-H. *et al.*, 2006); others to create the surfaces on the spatial distributions of the engaged variables for next step usage (Lee, J. and Hwang, C.-S., 2002; Park, Y.-M. and Kim, Y., 2011). More sophisticated kriging techniques such as cokriging and regression-kriging have also been utilized. N.-W. Park and D.-H. Jang (2008) reported that collocated cokriging shows much improved prediction capability compared to that of ordinary kriging. Furthermore, N.-W. Park and D.-H. Jang (2009) illustrated that kriging could provide an effective framework both for integrating remote sensing data and for uncertainty modeling through a case study of sediment grain size mapping with remote sensing data. S. Park (2009) also contended that cokriging significantly improves interpolation accuracy compared to IDW to estimate air temperature over mountainous terrain. B.-S. Kim *et al*. (2010) obtained an improved estimation of population distribution by adopting a regression-kriging method. Similarly, H.-J. Park *et al*. (2012) showed the superiority of regression-kriging methods over ordinary kriging in estimating aboveground biomass carbon stocks.

Maybe, one of the most advanced studies on kriging methods in South Korea has been done by N. W. Park and D.-H. Jang (2011). They introduced and applied space-time variogram modeling and space-time kriging, and demonstrated that space-time kriging outperforms both conventional space only ordinary kriging and regression-kriging.

4) Spatial Interaction Data Analysis

Spatial interaction data refer to relational attributes for pairs of points or areas, usually measured as certain forms of flows from a set of origins to a set of destinations. Thus, spatial interaction data are unique in comparison to other spatial data types in many ways (Kim, K. and Lee, S.-I., 2012; Lee, S-I., 2012). Spatial interaction data analysis can be categorized into four themes; (1) statistical modeling, (2) spatial autocorrelation analysis, (3) spatial accessibility analysis, and (4) functional regionalization.

For statistical modeling, log-linear models or Poisson regression models have been utilized for migration data. S.-I. Lee (2001) conducted a kind of ESDA by extracting place-specific distance parameters under the Poisson regression framework. He showed that Poisson regression with an adequately specified design matrix yields a set of either origin- or destination-specific distance parameters and found that place-specific distance parameters are spatially heterogeneous as well as spatially clustered. Y. Chun (2004) fitted a doubly constrained model to explain migration patterns.

Some works have been done to cope with the misspecification problem which results mainly from the spatial structure effects. A migration study based on the competing destinations model has been done with exemplifying an ESDA for spatial interaction data (Choi, D.-S., 2011). A more sophisticated approach has been attempted by Y. Chun (2007) who proposed a Bayesian hierarchical approach and showed that it provides an efficient way to deal with the misspecification problem by taking spatial random effects into consideration.

Spatial autocorrelation analysis for spatial interaction data is a relatively new field. Some local analyses to detect spatial clusters in spatial interaction have been done by applying Getis-Ord's G_i and G_i^* to geographical flows under the notion of network autocorrelation (Park, Y., 2010; Kim, Y., 2010). The latter study utilized the bootstrap permutation for significance testing. Y. Kim (2011) extended the framework to bivariate situations by accommodating the concept and techniques of bivariate LISA. In a slightly different way, G. Lee (2008c) proposed a vector spatial autocorrelation as an alternative way of identifying spatially autocorrelated paired-location events at a local level. He proposed a statistical algorithm combining univariate point pattern analysis for evaluating local clustering of origin-points and similarity measure of corresponding vectors.

Much attention in spatial accessibility analysis has been given to how to measure it, whether individual-based or location-based. For the individual-based spatial accessibility, a GIS-based geocomputational approach has been attempted (Kim, H.-M., 2005a; 2005b). She critically examined conventional spatial measures of individual accessibility, proposed an enhanced space-time accessibility measure predicated on space-time prism of time geography, and then implemented the notion in a GIS-based geocomputational framework. For the location-based spatial accessibility, various measures for various situations have been proposed (among others, Cho, H.-J. and Kim, K.-S., 2007; Lee, G., 2008a; Cho, D. *et al*., 2010). Since the latter conception of spatial accessibility is connected to the notion of location-allocation, many more works relevant to it will be found in the spatial optimization section later on.

Lastly, a relatively new research topic is functional regionalization based on spatial interaction data. It identifies functional regions by aggregating basic areal units on the basis of fundamental spatial structures found in inter-areal flows. Hierarchical aggregation procedures such as Intramax have been utilized to obtain a set of commuting zones (Koo, H., 2012) and housing market areas (Jaegal, Y., 2012) in the Seoul metropolitan area. However, a genuine geocomputational approach in this field entails spatial optimization procedures which will be seen later (Kim, K. *et al*., 2009; Kim, K., 2010).

3. Spatial Optimization

Spatial optimization is a methodology used to maximize or minimize a management objective, given the limited area, finite resources, and spatial relationships. Since the late 1980s, spatial optimization has been started in the Korean society of geography. However, there exists a generation gap in the research on this field in Korea. Basic model and ideas of spatial optimization had been established in the period of quantitative revolution, that is, in the 1960s and 1970s. In the late 1980s and the early 1990s, several researchers had tried to introduce the outcome of the quantitative revolution into Korea, but research on this field does not continue during substantial period of time. With GIS revolution, research on this field is in progress recently. One of reason of this generation gap may be that quantitative geography in Korea had been frustrated by anti-positivist movements without a chance to bloom.

Studies on spatial optimization in Korea could be classified into three categories according to decision to be made; facility location problems, districting problems, and routing problems. At the beginning, many researches had focused on applying standard models to examples of Korea. Recent researches began to deal with building models and developing algorithms beyond simple applications.

1) Facility Location Problems

Facility location problems also can be divided into two subgroups; coverage-based (or location) models and location-allocation models. Coverage-based models such as location set covering problem and maximal covering location problem based on predefined coverage optimally determine just the location of facilities. On the other hand, location-allocation models such as *p*-median problem and *p*-center problem locate a given number of facilities in order to minimize the average travel time or distance of users to their closest facility. That is, users are allocated to their closest facility as well as the location of facilities is optimally determined.

(1) Location-allocation Models

Location-allocation models have been applied to various location problems including educational facilities (Seo, T. Y., 1987; Jeon, K.-S., 1992; Choi, W.-S. and Yoon, S.-H., 1995), trade area analysis of retail (Hong, I. Y., 2000), emergency medical services (Yang, B.-Y. and Hwang, C.-S., 2005), estimation of service area of greenspace (Eom, S. K. *et al*., 2008), community service centers (Lee, G., 2010), cultural facilities (Yun, J.-M. and Lee, S. H., 2010), and pickup points (Park, J. S. and Lee, K., 2011). T. Y. Seo (1987) applied a location-allocation model to delineating high school districts in Seoul. K. Jeon (1992) utilized a location-allocation model to find optimal locations of kindergarten in Kwangju City. W.-S. Choi and S.-H. Yoon (1995) located elementary schools and delineated school districts using a location-allocation model. S. K. Eom *et al*.(2008) estimated the service area of greenspace using a location-allocation model.

Equity as well as efficiency is an important consideration when locating public facilities or services. B.-Y. Yang and C.-S. Hwang (2005) determined optimal locations of emergency medical services concerning spatial efficiency and equity using a location-allocation model. J.-M. Yun and S. H. Lee (2010) applied a location-allocation model considering both efficiency and equity to locating cultural facilities. Whereas these two studies had simply employed standard models provided by commercial GIS software (e.g., ESRI ArcInfo network extension), G. Lee (2010) suggested an alternative location model, called *p*-cendian problem which combines *p*-median problem maximizing efficiency with *p*-center problem maximizing equity and applied the model to finding optimal locations of community service centers. On the contrary that so far reviewed studies assumed point-based demands, J. S. Park and K. Lee (2011) determined pickup points maximally capturing flows using a location-allocation model defined with flow-based demands.

Spatial optimization problems can be solved with exact or heuristic approaches. Similar to statistical software, there are software packages specializing in exactly solving optimization models (e.g., Cplex, Lindo/Lingo, SAS, Matlab, etc.). Heuristic is rule of thumb, strategy, or *ad hoc* trick for finding a solution to a problem. It is not guaranteed to produce an optimal solution but often drastically reduces computational processing at the expense of attaining an optimal solution. Heuristic solution algorithms for solving location-allocation models include alternating algorithm, interchange algorithm, Lagrangian relaxation, simulated annealing, tabu search, and genetic algorithms. W.-S. Choi and S.-H. Yoon (1995), I. Y. Hong (2000), B.-Y. Yang. and C.-S. Hwang (2005), S. K. Eom *et al*. (2008), S.-A. Joo and Y.-H. Kim (2007), J.-M. Yun and S. H. Lee (2010) solved their location-allocation models with a commercial GIS package, specifically ESRI ArcInfo (or ArcGIS). ESRI adopted interchange algorithm as a solution method. Therefore, the solutions obtained with ArcInfo could be local rather than global optima. T. Y. Seo (1987) and K. Jeon (1992) utilized alternating algorithm and Lagrangian relaxation developed by existing research, respectively. K. Kim (2004) reviewed various heuristic solution approaches for location-allocation models and Y.-H. Kim (2002) evaluated the performance of heuristic algorithms for solving *p*-median problem using geovisualization techniques. Meanwhile, S.-A Joo and Y.-H. Kim (2007) explored optimization results according to the level of aggregation. J. S. Park. and K. Lee (2011) developed a greedy heuristic algorithm for a location-allocation model determining pickup points maximally capturing flows.

(2) Coverage-based Models

The basic form of coverage-based models is location set covering problem (LSCP) finding a minimum cost set of facilities from among a finite set of candidate facilities so that every demand is covered by at least one facility. Maximal covering location problem, which is a variant of LSCP, locates a given number of facilities in order to cover as much demand as possible within a maximal service distance or time standard. In coverage-based models, coverage standard is stipulation or requirement for service within a distance. Coverage-based models have been applied to locate facilities having limited service range such as surveillance facilities

(Kim, Y.-H., 2006; Kim, K., 2008; Kim, J.-T. and Um, J.-S., 2010), Internet broadband (Lee, G., 2008b; 2011), refueling stations for alternative-fuel vehicle (Kim, J.-G., 2011; 2012), etc. K. Kim (2008) developed a coverage-based multi-objective optimization model for siting heterogeneous sensors with difference service coverage. G. Lee (2008b) developed a multi-objective location set covering model minimizing the cost of new broadband facilities and maximizing total connectivity among them. G. Lee (2011) developed a competitive location model for locating broadband facilities. On the contrary that the studies mentioned above assumed point-based demands, J.-G. Kim. (2011; 2012) developed a coverage-based location model with flow-based demands, called Flow Refueling Location Model for finding optimal location of refueling facilities for limited driving range vehicles.

While K. Kim (2008) and G. Lee (2008b) exactly solved optimization models with Cplex, other research utilized heuristic methods. G. Lee (2011) introduced a GIS-based geometric method using a weighted Voronoi diagram for solving a competitive location problem. J.-T. Kim and J.-S. Um (2010) suggested a procedure to minimize redundant route nodes in ubiquitous sensor network considering spatial characteristics of regions such as visibility, proximity, and road and building densities. J.-G. Kim (2011) and J.-G. Kim (2012) solved the suggested model with a greedy algorithm. Meanwhile, Y.-H. Kim (2006) compared the performance of four heuristic algorithms, that is, extensive iteration, Tornqvist algorithm, genetic algorithm, and simulated annealing for a visibility site selection problem maximizing visibility with a given number of observers.

On the other hand, K. Lee (1987) developed an optimization model simultaneously determining new transportation links and the optimal locations of storage facilities and applied it to a grain distribution problem in Korea. This model is a variant of transportation/transshipment problem.

2) Districting Problems

Another topic recently popularly researched is a districting problem partitioning a geographical region into districts or aggregating spatial area units into districts. In this process, each district is spatially contiguous, while optimizing a predefined objective function. The basic form of districting problems is similar to location-allocation models. Therefore, *p*-median problem could be applied to zone design problems (Kim, Y.-H., 2009). Districting problems and location-allocation models share the idea that all spatial units or demands should be exclusively assigned to only one district or one facility. The main difference between two models is that districts established should be contiguous.

Districting problems have been applied to various planning and decision making situations such as delineating delivery area of door-to-door services (Lee, S., 2000), Census output area (Kang, Y. *et al*., 2007; Kang, Y. and Jang, S., 2008), service area of visiting health-care units (Kim, K. *et al*., 2009), local administrative districts (Kim, K. *et al*., 2010), or national basic districts (Kang, Y. and Jo, S., 2012). Y. Kang *et al*. (2007) proposed criteria for establishing statistical area and delineated Census output areas. Y. Kang and S. Jang (2008) asserted that posterior adjustment of districts obtained by an automated procedure is required in order to improve homogeneity of Census output areas. Also, K. Kim *et al*. (2009) suggested a mixed integer programming model considering mobility, workload balance, and contiguity in order to delineate the service area of visiting health-care units. K. Kim *et al*. (2010) developed a spatial optimization model for reconstructing local administrative districts. In modeling they considered homogeneity within districts, equity among districts, and spatial contiguity. Y. Kang and S. Jo (2012) compared three ways to delimitate national basic districts, that is, based on physical features, based on administration boundaries and physical features, and based on automated zoning procedure (AZP) and showed that districts based on physical features are more stable and applicable.

A solution method popularly adopted for solving various districting problems is automated zoning procedure (AZP) introduced by Openshaw (1977). AZP is a heuristic iteratively recombining a large set of geographic areas (basic spatial units) into a smaller set of zones. One reason for utilizing AZP is that it can be easily integrated into GIS environment because of its simplicity. Y. Kang *et al.* (2007), Y. Kang and S. Jang (2008), K. Kim *et al.* (2009), K. Kim *et al.* (2010), and Y. Kang and S. Jo (2012) utilized AZP to solve their optimization problems and implemented it in GIS. S. Lee. (2000) delineated delivery areas of door-to-door services using a module provided by TransCAD. Meanwhile, K. Kim (2011a) aggregated spatial units into districts using AZP according to different objective functions and different levels of scale and evaluated its effect on a spatial interaction model. While the studies so far mentioned focused on districting of multiple zones, M. J. Kim (2011) dealt with land acquisition problem which is an optimization problem delineating a single and contiguous spatial district. She developed a mixed integer programming problem explicitly considering compactness as constraints as well as contiguity and solved the model exactly using Cplex.

3) Routing Problems

Routing problems are spatial optimization problems determining linear path/route or locating linear facilities. The basic and simplest form of routing problems is shortest path problem which is, given a network with costs associated with each of the arcs, to find the shortest path from an origin to a destination. Traveling salesman problem finding the shortest possible route that visits each node exactly once and returns to the origin node and vehicle routing problem designing optimal delivery or collection routes from one or several depots to a number of geographically scattered nodes or customers are the variants or extensions of shortest path problem. Recently, several studies in Korean geography society have utilized these routing problems in order to support linear spatial decision making or spatial planning such as finding evacuation path (Park, I. and Lee, J., 2009), finding transport path of hazardous material (Son, E.-G. and Bae, S.-H., 2010), determining route of waster collecting vehicle (Lee, H.-Y. and Im, E., 2001), and organizing delivery route of visiting health-care services (Kim, K., 2007; Lee, G. *et al.*, 2010).

I. Park and J. Lee (2009) developed a time-dependent optimal shortest path algorithm to support real-time evacuation in indoor space and E.-G. Son and S.-H. Bae (2010) applied *k*-shortest path algorithm, which is to list the paths connecting a given origin-destination pair in a network with minimum total length, to finding the optimal route minimizing impacts by hazardous material transport. H.-Y. Lee and E. Im (2001) applied Mixed Chinese Postman Problem, which is to find the shortest postman tour covering all the roads at least once in the network, therefore, similar to traveling salesman problem, to determining the optimal route of a waste collection vehicle. K. Kim (2007) suggested a sequential location-routing problem combining a location-allocation model to determine visiting locations and vehicle routing problem to find the optimal route of visiting health-care service units. G. Lee *et al.* (2010) introduced an optimization model finding multiple optimal routes for visiting health-care service units. In modeling, they considered management efficiency and health equity.

In order to solve routing problems, I. Park and J.

Lee (2009) utilized the Dijkstra algorithm which can quickly and effectively find optimal solution for shortest path problem. H.-Y. Lee and E. Im (2001) and E. G. Son and S.-H. Bae (2010) used TransCAD which is GIS software specialized into transportation to solve their problems. K. Kim (2007) and G. Lee *et al*. (2010) adopted a heuristic called savings algorithm in order to solve vehicle routing problem.

4. Geosimulation

Geosimulation is used to describe the application of modern micro-level simulation tools such as cellular automata (CA) and agent-based model and simulation (ABMS) to geospatial problems (de Smith *et al*., 2007:390). Research on this topic in Korea kicked into high gear in the late 1990s with GIS revolution. Whereas research related to CA has been extensively performed, ABMS is an inchoate theme.

1) Cellular Automata

CA is a discrete dynamical system. One of popular application fields of CA is urban growth modeling because it is simple to build, flexible to formulate, and capable of generating complex patterns that can emerge from historical evolution trends through the diffusion process. The early research foci were on the integration of CA and GIS and application. S. Park (2001) developed an integrated CA-GIS system in order to enhance dynamic modeling of GIS and S. Park (1997) implemented dynamic spatial models such as innovation diffusion, forest fire, and urban growth simulation models in the integrated CA-GIS system. S. Park *et al*. (2002) designed and constructed a spatio-temporal GIS database for development of urban growth modeling. Y. Kang and S. Park (2000) forecasted urban growth pattern of the Seoul metropolitan area using a CA-based urban growth model. Similarly, J.-J. Jeong *et al*. (2001) applied a CA-based urban growth model to predicting urban growth of Seoul metropolitan area. Recently, I. Park *et al*. (2008) applied a CA model with georeferenced data to simulating fire evacuation in indoor space.

Research interest has gradually shifted toward extracting spatial relation or transition rules and developing more sophisticated models. S. Cho and S. Park (2004) proposed a method to extract spatial relation rules using GIS and Knowledge Discovery methods in order to improve CA-based spatial modeling. S. H. Lee *et al*. (2004) determined an appropriate neighborhood and a transition rule of CA based on analyzing the historical data of Gimhae. J.-M. Yun and S. H. Lee (2006) utlized a Fuzzy-AHP and CA model in order to more exactly predict urban growth patterns; Fuzzy for minimizing data loss, AHP(Analytic Hierarchy Process) for determining relative weight of factors, and CA for simulating urban growth patterns. J.-J. Jeong and H.-T. Kim (2008) predicted urban growth pattern of the Seoul metropolitan area using the concept of allometry and a CA-urban growth model. D. Cho (2008) developed a CA-based landuse change model considering global and local components of development density and demonstrated that it is possible to realistically simulate urban landuse change. Meanwhile, J.-M. Yun and J.-W. Park (2008) automated from assigning weights to simulating CA in order to reduce complexity and repeatability of urban growth modeling.

2) Agent-based Model and Simulation

ABMS is a computational model for simulating the actions and interactions of autonomous agents. Research on ABMS in Korean geography society is in the beginning stage. T.-H. Moon (2009) developed a multi-agent housing market model and simulation system for analyzing the influence of changing housing market. S. Cho *et al*. (2011) addressed ABMS as a methodology of ecosystem research and built a model to investigate the relation between the retreat of polar glacier and the extinction of polar bears.

5. Concluding Remarks

This paper aimed at providing an adequate and comprehensive review of what has been done in South Korea in the field of geospatial analysis and modeling. This review focused on spatial data analysis and spatial statistics, spatial optimization, and geosimulation among various aspects of geospatial analysis and modeling. It is recognized that geospatial analysis and modeling in South Korea got through the initial stage during the 1990s when computer and analytical cartography and GIS were introduced, moved to the growth stage during the first decade of the 21st century when there was a surge of relevant researches, and now is heading for its maturity stage, even though the phases vary among different subfields or topics.

In spatial data analysis and spatial statistics, various topics have been addressed for each of the four sub-categories, spatial point pattern data analysis, areal data analysis, geostatistical data analysis, and spatial interaction data analysis. In spatial point pattern data analysis, some works were the applications of the standard techniques of exploring and modeling spatial point patterns; others were about devising new tools to detect hot spots in spatial point patterns. The most prominent sub-category in terms of the publication amount was areal data analysis which is classified into visualizing areal data, measuring and exploring spatial autocorrelation, and spatial regression. While most of the works were simple applications of textbook techniques (thematic mapping techniques, univariate ESDA, and regression-based spatial modeling), some methodological advances have been made particularly for bivariate spatial dependence and heterogeneity. Geostatistical data analysis has been preoccupied by the applications of various types of kriging to create statistical surfaces. In spatial interaction data analysis, a mixture of simple applications of preexisting techniques and some creative methodological experiments was observed in various subjects such as statistical modeling, spatial autocorrelation analysis, spatial accessibility analysis, and functional regionalization.

In spatial optimization, modeling and applications related to facility location problems, districting problems, and routing problems have been mostly researched. At the beginning, many researches had focused on applying standard models to examples of Korea. Recent researches began to deal with building models and developing algorithms beyond simple applications. In facility location problems, coverage-based models like location set covering problem and location allocation-models such as *p*-median and *p*-center problems were utilized to locate private as well as public facilities. Most of research solved their problems with commercial GIS and optimization software. Recently, several studies solved their problems with heuristic algorithms. Districting problems applied to various planning and decision making situations such as delineating commercial or public service areas, and delimiting statistical, administrative or national basic districts. Automated zoning procedure was widely adopted as a solution technique for districting problems. Routing problems used to find evacuation or transport paths, or determine route for providing public services.

In geosimulation, while most of research has focused on cellular automata, studies on agent-based model and simulation are in beginning stage. The early research foci were on the integration of cellular automata and GIS and application. Recently, research interest has gradually shifted toward extracting spatial relation or transition rules and developing more sophisticated models.

In conclusion, geospatial analysis and modeling has a bright future in South Korea. In this regard, we'd like to mention two things. First, there is a rapidly growing pool of scholars who have a strong commitment to the field. They are either those who are trained in South Korea by the first generation in the field or those who are in-comers who obtained their Ph.D. degrees in the field in other countries, particularly the U.S. and U.K. Second, Korean scholars outside the country have made a great input to the field in South Korea. This has been done in many ways: their publications and other academic activities have fostered the growing interest in the field; they have provided young Korean scholars with opportunities to get funded when they study abroad; and they have made direct and indirect contributions to the restructuring of geography towards geospatial science in South Korea. The time that geospatial analysis and modeling in South Korea enters its maturity stage will come sooner than many people might think it will.

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