韓國地形空間情報學會論文集 第3卷 第1號 1995年 6月 pp. 91-104

Vector GIS를 이용한 교통 Zone체계 알고리즘 개발 방안에 관한 연구

A Heuristic Algorithm for Designing Traffic Analysis Zone Using Geographic Information System

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要 旨

교통 및 기타 공간계획 과정에 있어서 분석을 위한 공간분할은 필수적이다. 공간 분할에 있어서 두가지의 중요한 변수는 scale과 aggregation이라고 할 수 있는바 이들 2가지의 조합에 따라서 분할된 공간상의 계획결과물은 실로 엄청난 차이를 보일 때도 있다. 본고에서는 이들 공간 zone 분항 및 재구성 체계의 과정 및 결정기법을 살펴 보는데 우선 목적이 있고, 또한 vector형 GIS의 위상관계자료를 이용한 교통 zone 체계의 재설정 방법을 제시해 봄으로써 경직된 교통계획상의 zone체계 구성에의 변화를 창출해 보았다. 시범연구로서는 남한을 132개의 세부 zone 으로 구분한 뒤 사회경제적 지표에 의한 동질적인 zone체계를 구축하여 교통계획에 응용하였으나 애초에 macro 된 세부zone체계를 사용한 나머지 aggregate된 zone이 concave한 문제점 또한 발견되었다.

ABSTRACT

The spatial aggregation of data, in transportation and other planning processes, is an important theoretical consideration because the results of any analysis are not entirely independent of the delineation of zones. Moreover, using a different spatial aggregation may lead to different, and sometimes contradictory conclusions. Two criteria have been considered as important in designing zone systems. They are scale and aggregation. The scale problem arises because of uncertainty about the number of zones needed for a study and the aggregation problem arises because of uncertainty about how the data are to be aggregated to form a given scale problem. In a transportation study, especially in the design of traffic analysis zone(TAZ), the scale problem is directly related to the number dof zones and the aggregation problem involves spatial clustering, meeting the general requirements of forming the zones system such as equal traffic generation, convexity, and the consistency with the political boundary.

In this study, first, the comparative study of delineating spatial units has been given. Second, a FORTRAN-based heuristic algorithm for designing TAZ based on socio-economic data has been developed and applied to the Korean peninsula containing 132 micro parcels. The vector type ARC/INFO GIS topological data mosel has been used to provise the adjacency information between parcels. The results, however, leave some to be desired in order to overcome such problems as non-convexity of the agglomerated TAZ system and/or uneven traffic phenomenon for each TAZ.

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1. Introduction

The spatial aggregation of data, in transportation and other planning processes, is an important theoretical consideration because the results of any analysis are not entirely independent of the delineation of zones. Moreover, using a different spatial aggregation may lead to different, and sometimes contradictory conclusions. This phenomenon is apparent in the typical transportation demand forecasting procedure based on the four step sequential process-trip generation, trip distribution, mode choice, and trip assignment, where it is assumed that all of the trip productions and attractions begin from and end at the centroids of traffic analysis zones.

Two criteria have been considered as important in designing zone systems. They are *scale* and *aggregation*. The scale problem arises because of uncertainty about the number of zones needed for a study and the aggregation problem arises because of uncertainty about how the data are to be aggregated to form a given scale problem (Openshaw, 1977)[10]. In a transportation study, the scale problem is directly related to the number of zones and the aggregation problem involves spatial clustering, meeting the following general requirements (Black, 1981)[3].

1. The zone should contain predominantly one land use.
2. Characteristics of the activities within the zone should be as homogeneous as possible.
3. The zone or spatial cluster should be a compromise between a small zonal area that gives locational precision and a large zonal area that gives a sufficient sample of households or firms to produce statistically reliable traffic estimates.
4. The zone system should be compatible with the boundaries of census enumeration districts.
5. The zone boundaries follow, where possible, major roads, railways, canals, or other physical barriers to movement.

With this general guidelines in mind, the purpose of this paper is both to review the issues and techniques of region building or spatial aggregation thus far, and to develop an alternative method of delineating traffic analysis zones (TAZs) using geographic information system (GIS), reflecting the socioeconomic characteristics of the underlying basic spatial units (BSUs).

2. Nature of Zone Design Problem

The zone-design problem of urban and regional models can be viewed as an aggregation problem. Keane (1975)[7] represents the aggregation problem by a set E, where E is defined as:

$$E = f(S, R, A, F) \tag{2.1}$$

where

E = the aggregation output
S = a finite denumerable non-overlapping set of spatial units
R = a set of criteria
A = a process of aggregation, and
F = a set of aggregation.

Suppose that the basic spatial units in our regional system are n areas. In the zone design problem, each basic spatial unit is combined to form k zones, where $1 \leq k \leq n$. The total possible number of different aggregations, F, will depend on the contiguity constraints that are imposed upon the way in which areas may be grouped together. We now define the $n \times n$ matrix, Δ, as follows. Let the typical element of Δ, δ_{ij}, be $\delta_{ij} = 1$ if areas i and j may be combined to form a region or part of a region, and $\delta_{ij} = 0$ otherwise. There are two extreme forms for Δ:

1. $\delta_{ij} = 1$, if $i \neq j$; $\delta_{ij} = 0$ otherwise. This is a totally unconstrained situation in which each area may, if we wish, be grouped with any other area

2. $\delta_{ij} = 1$, if $j = i-1 , i+1$; $\delta_{ij} = 0$ otherwise.. This is a maximally constrained situation in which the areas form a chain, and each area can only be grouped with its physically contiguous neighbors.

The solution to the combinatorial problem of placing n areas into k regions under no constraint (Δ assuming form 1) is equal to $S(n , k)$, where $S(n , k)$ is defined as:

$$S(n, k) = \frac{1}{k!} \sum_{i=0}^{k} (-1)^i \binom{k}{i} (k-i)^n, \quad (2.2)$$

and is called the Sterling number of the second kind. Table 2.1 shows some of the Sterling numbers for different n and k. To illustrate the use of Equation 2, let $n = 4$, and $k = 3$. Then:

$$\begin{aligned} S(4,3) &= \frac{1}{3!} \sum_{i=0}^{3} (-1)^i \binom{3}{i} (3-i)^4 \\ &= \frac{1}{3!} \left[\binom{3}{0}(3)^4 - \binom{3}{1}(2)^4 + \binom{3}{2}(1)^4 - \binom{3}{3}(0)^4 \right] \\ &= 6 \end{aligned}$$

Table 2.1 Sterling Numbers of the Second Kind, S(n, k).

n	k									
	1	2	3	4	5	6	7	8	9	10
1	1									
2	1	1								
3	1	3	1							
4	1	7	6	1						
5	1	15	25	10	1					
6	1	31	90	65	15	1				
7	1	63	301	350	140	21	1			
8	1	127	966	1701	1050	266	28	1		
9	1	255	3025	7770	6951	2646	462	36	1	
10	1	511	9330	34105	42525	22527	5880	780	45	1

There are six different ways of aggregating 4 areas into 3 regions. From Table 2.1 we see that there are a total of fifteen (1 + 7 + 6 + 1) different ways in which we can regionalize the 4 areas into 1, 2, 3, or 4 regions. Figure 2.1 shows how different spatial arrangements of basic spatial units would produce a different number of aggregations (Cliff and Haggett, 1970)[4] according to the number of zones to be produced. At the same time, Table 3.1 shows alternative aggregations with given n and k.

Table2.2 Aggregation up to Four Basic Spatial Units

n	k	Number of BSUs in Each Zone	Alternative Aggregations
1	1	1	1
2	2	1, 1	1, 2
	1	2	12
3	3	1, 1, 1	1, 2 ,3
	2	2, 1	12, 3 ; 13, 2 ; 23, 1
	1	3	123
4	4	1, 1, 1, 1	1, 2, 3, 4
	3	2, 1, 1	12,3,4:24,1,3:34,1,2:13,2,4:14,2,3:23,1,4
	2	3, 1	123,4; 124,3; 134,2; 234,1
		2, 2	12,34:13,24:14,23
	1	4	1234

As is common in combinatorial problems, however, the number of possible solutions increases explosively with the size of the problem. The Sterling's numbers of the second kind presented here are particularly useful for estimating the upper bound on the number of aggregations for large problems.

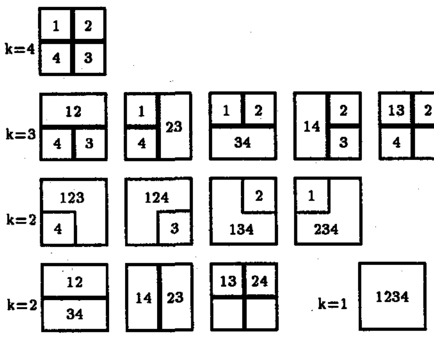

Figure 2.1 Aggregations of Four Areas with Minimal Contiguity Constraint

3 Zone Aggregation Method: A Review

3.1 Heuristic Approach

As a classic example of the heuristic approach, Ward (1963)[12] developed a procedure that describes for forming hierarchical groups of mutually exclusive subsets on the basis of their similarity with respect to specified characteristics. Given k subsets, Ward's procedure permits their reduction to $(k - 1)$ mutually exclusive subsets by considering the union of all possible $k(k - 1)/2$ pairs that can be formed and accepting the union with which an optimal value of the objective function is associated (Ward, 1963)[12]. The brief procedure behaves as follows and for further information on this algorithm, see Ward (1963)[12].

At the outset, the algorithm is initiated by assigning each data point to a single group, of which it is the only member. Then that particular pair of groups whose aggregation produces the least increase in the value of the objective function is formed into one group. Now this process of aggregation by local optimization proceeds until only one group remains. At each stage of the algorithm, the number of groups contained in the problem is always one less than at the preceding stage. Moreover, at each stage, the new solution is directly derived from the immediately preceding solution. This means that any particular grouping of data points, once established, can never be disaggregated at some stage in the remainder of the solution process. One thing to note is that there is never any guarantee that the objective function associated with the groupings on any iteration is the fully optimal (minimal) solution (Scott,1971)[11].

Batty developed a spatial entropy function and applied an entropy maximizing approach for generating 20 zones out of 130 zones based on Ward's algorithm. In his method between-set entropy is maximized at each level of the hierarchy by computing the measure for every possible aggregation of single spatial units to their spatially adjacent sets. In this way, he tried to overcome the problem of the Ward algorithm. A new algorithm by Batty is designed to minimize the within-set entropy at any particular level of aggregation so that the solution can be optimal at that hierarchy. The algorithm operates by attempting to improve a basic feasible solution in a trial-and-error fashion. First, the within-set entropy of the basic feasible solution is calculated and the contribution of each zone to this entropy is ranked. Then, a search is initiated to discover the greatest difference in entropies between any two zones; if these two zones are contiguous and if the zone with the largest entropy belongs to a set of two or more zones, then a new set is formed by combining these two. If this combination is impossible, then the search continues to discover the next highest difference in entropies and so on (Batty, 1974)[2].

He argued that the revised Ward algorithm is considerably more efficient than the cluster analysis in producing a near optimal solution. However ,whether contiguity constraints are used or not, it is likely that a zoning system produced by the aggregation procedures will not produce irregularly shaped, straggling zones which are of limited value in the development of zoning system. This problem has led to the recognition of the *compactness constraint* to be taken into account during the grouping procedure.

3.2 Statistical Approach

Cluster analysis which encompasses many diverse techniques for discovering structure within complex bodies of data can be used as a way of extracting zones out of a set of basic spatial units. It is the most commonly used term for techniques which seek to separate data into constituent groups by a series of identification or classification processes. Its techniques may be classified into the following types (Everitt, 1974)[5] :

hierarchical technique -in which the classes themselves are classified into groups, the process being repeated at different levels to form a tree.

optimization-partitioning technique -in which the clusters are formed by optimization of a clustering criterion. The classes are mutually exclusive, thus forming a partition of the set of entities.

density or mode-seeking technique -in which clusters. are formed by searching for regions containing a relatively dense concentration of entities.

clumping techniques -in which the classes or clumps can overlap.

All of these techniques have been frequently used in many disciplines like life science (botany), medical science (pathology), social science (psychologyj, and natural science (earth science). However, the results of cluster analysis do not guarantee that the spatial units grouped together on the basis of their similarities during the aggregation will form contiguous zones in space. But in a spatial problem like transportation zone delineation, contiguity is needed for an area to serve as a proper traffic zone.

3.3 Combined Approach

Masser, Batey and Brown (1975)[8] summarize some of the main grouping procedures and give examples of their application based on the main types of zone-definition criteria that mainly minimize the spatial variation. They presented five-stage operational procedures and applied that to Wirral, UK. Their procedure is as follows:

1. The number of zones is required.
2. A basic feasible solution for this number of zones is obtained with respect to the intrinsic variables.
3. The basic feasible solution is progressively evaluated and revised to take account of intrazonal trip variables and the lower-priority dominant-flow characteristics and secondary variables.

4 TAZ Design Principles and Issues

4.1 TAZ Design Principles

As alluded in the introduction, the sequential process of defining a traffic analysis zone scheme prior to trip generation is very fragile since a slight change in the zoning scheme impacts the results of the four-step modeling process. In practice, however, zone design procedures are mainly based on considerations of convenience and the existence of readily available data rather than on the criteria mentioned above. Furthermore, in most transportation studies, the choice of zones and the results have seldom been investigated, even when the data are sufficient .

Garber and Hoel (1988)[6], though, proposed more fine-tuned traffic analysis zone design criteria than those of Black's as follows.

1. Socio-economic characteristics should be homogeneous.
2. Intrazonal trips should be minimized.
3. Physical, historical, and political boundaries should be utilized where possible.
4. Zones should not be created within other zones (i.e., no "doughnuts").
5. The zone system should generate and attract approximately equal trips and/or contain approximately equal population, households, or area per zone.
6. Zones should be defined by census tract boundaries where possible.

4.2 General Issues: Zone and Network Compatibility

The establishment of zones and a traffic assignment network should basically be developed in accordance with the objectives of the assignment since too coarse a network with comparatively large number of zones will lead to the overestimation of link traffic volume whereas a too detailed network with a small number of zones will lead to underestimation. For region-wide planning level assignments, a coarser network and larger zones are typically needed than when a more detailed study is being made of a specific transportation corridor. Within this context, however, there is still considerable agreement on the premise that within practical limits of accuracy and reliability, the smaller the zones and the more detailed a transportation network established for a particular assignment objective, the better the results will be.

This, however, must be tempered by cost considerations and other pertinent factors. The greater the number of zones and the greater network detail required, the higher the cost of making an assignment will be. Regional assignments for the development of an overall transportation plan requires assignments to high level facilities (i.e., highways, freeways, and major arterials). Assignments made for detailed design purposes required as high an accuracy as possible in relatively small parts of an urban area. Small area studies, such as a CBD, require assignments to all levels of a facility. As a general rule, the network and zones should be established to allow the achievement of accuracy to commen surate with the objectives of the traffic assignment to be made. In addition to the effects on assignment results, the selection of zones and the network are dependent upon non-assignment considerations, such as, the availability of data, either forecasted or collected, to some level of area detail (FHWA, 1973)[1].

4.3 Design Issues Associated with GIS

In using GIS with the transportation planning model, especially in the context of the TAZ generation, the GIS can be a spatial processor, equipped with spatial algorithms, to extract a set of traffic zones, satisfying the rules listed above.

This operation requires an integration of several data layers, such as population, land-use, and other geographic barriers like streams.

To perform this spatial processing, a raster- or grid-based GIS is generally better suited because raster-based GISs facilitate database design and the analysis of multiple polygon overlays (O'Neil, 1991)[9]. However, vector-based GISs are much more appropriate for doing the rest of the transportation demand modeling. Therefore, a GIS with raster-to-vector conversion capabilities may be required to effectively integrate transportation planning models with GIS in the context of traffic analysis zone delineation.

Another problem, even after using GIS for extracting spatial block groups, is that the extracted zones satisfying the above zone delineation criteria are not always spatially contiguous. Therefore given the scale setting a method of spatial aggregation should be sought that produces both spatially contignous and homogeneous block groups, so that the automated development of the traffic analysis zone scheme is always warranted in the integration.

5 TAZ Design Using Topological Adjacency and Clustering

In this article, two approaches for delineating traffic analysis zones have been proposed. One is using classification and statistical clustering methods to extract spatially homogeneous blocks (Figure 5.1), the other is using a modified clustering procedure that ensures both homogeneity and contiguity (Figure 5.2). In both approaches, the topological data structure of polygon (basic spatial unit)coverage has been used to assure the contiguity of zones derived by clustering methods.

5.1 Zone Aggregation Procedure I

The first method uses a hierarchical cluster analysis by a statistical package called SPSS, based on socia-economic data As shown in Figure 5.1, this method starts with the database update. With this update and locational data (x, y coordinates of the centroid of each parcel), the cluster analysis produces a set of homoeneous blocks. The topology, now, comes into play to provide a contiguity information, giving a scheme of TAZs.

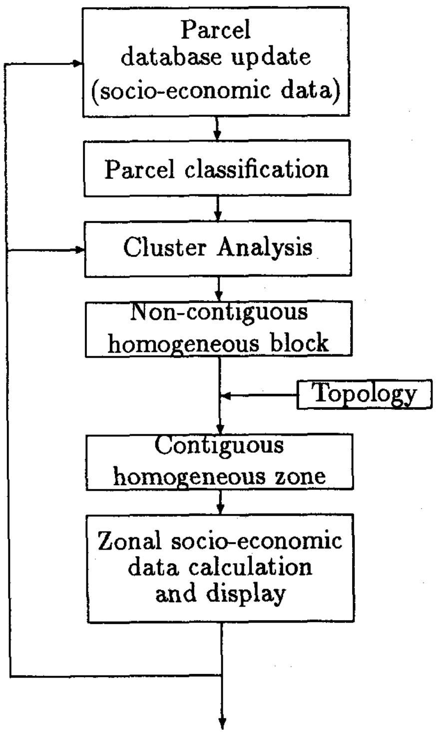

Figure 5.1 Zone Aggregation Procedure Ⅰ: Cluster Analysis

This method, however, may violate the fifth rule proposed by Garber and Hoel (1988)[6] in the sense that the size of zones will vary so much that the amount of trip generated and/or attracted will be much different amount zones. But, it is simple to change the current traffic zone scheme, and it can provide a basic zoning structure for a transportation planner to polish the derived zoning scheme in such a way that it can meet some criteria proposed by Garber and Hoel.

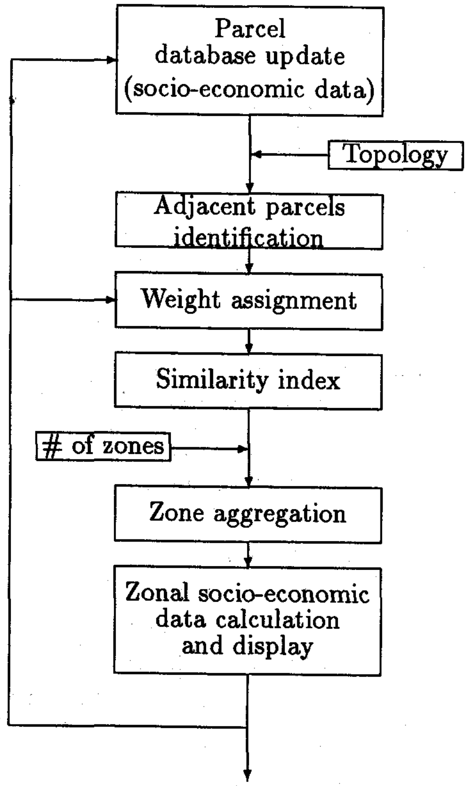

Figure 5.2 Zone Aggregation Procedure II : A Modified Cluster Analysis based on Similarity Index and Weights

5.2 Zone Aggregation Procedure II

As shown in Figure 5.2, the second approach assigns weights to socio-economic variables such as population, employment, car ownership, and political boundaries. The main thrusts of this approach are two fold. One is to overcome a weak point of the current hierarchical cluster analysis. That is, the cluster analysis implemented in commercial packages (SPSS or SASj generally do not employ a weighting scheme to put more emphasis on certain variable(s) during cluster analysis. The other is to guarantee roughly the same amount of trips generated or attracted for each zone.

In both aggregation methods I and II, the number of zones(κ) should be decided exogenously, so that parcels will be allocated to k contiguo?s clusters, which will eventually serve TAZs. However, this approach is more likely to produce balanced trip amounts (in fact, balanced socio-economic data). To implement the process, a statistic called the *siin.zlarity indez* was proposed. And the mathematical structure of the distance measure for this approach is as follows:

$$S_{ij} = \sqrt{\sum_n w_n (p_{in} - p_{jn})^2}$$

where,

S_{ij} = similarity index between parcel i and j,

w_n = weight of n-th attribute data of a parcel,

p_{in} = Z score of n-th attribute data of parcel i,

that is, $\frac{x_{in} - \bar{x}_n}{s_n}$, and

p_{jn} = Z score of n-th attribute data of parcel j.

The outline of the second aggregation method is as shown in Figure 5.3. It starts with GIS (database building and topology construction), works with FORTRAN routines (calculating similarity index and regrouping parcels), and finishes with

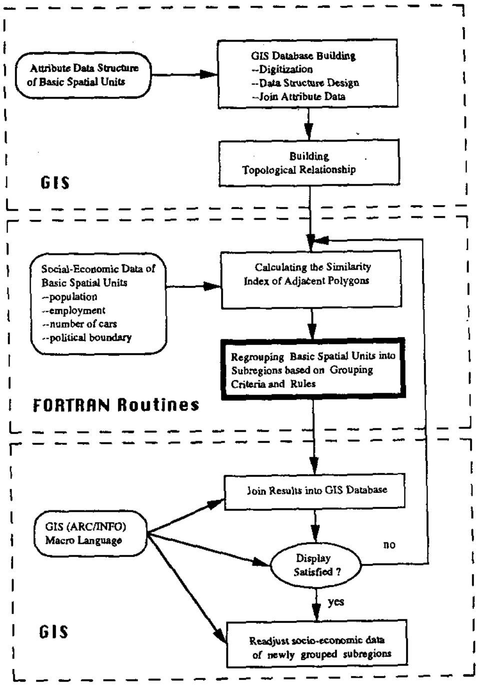

Figure 5.3 Schemastic Procedure of Zone Aggregation Procedure II: A GIS-based Heuristical Approach

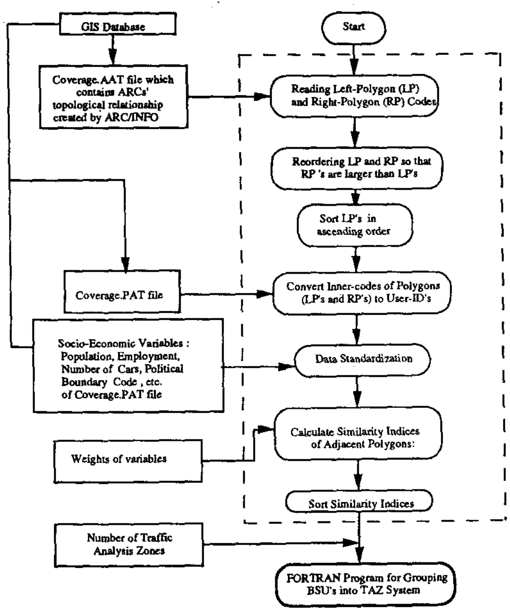

Figure 5.4 Similarity Index Calculation for Adjustment Polygons (Parcels)

GIS (display and readjust socio-economic data[1]). The bold-faced rectangle in the second box in Figure 5.3 can be elaborated as shown in Figure 5.4. Here, the topological adjacency information from coverage. AAT file (ARC/INFO convention representing the arc-attribute table) is read and sorted to identify any two contiguous parcels (basic spatial unit: BSU). Then similarity indices between the adjacent BSUs (i and j) are calculated using the formula S_{ij} with the standardized socio-economic variables (sometimes called as a *Z-score* as shown in Figure 5.2) and the user-specified weights. The calculated similarity indices are then sorted and fed into the detailed flow of grouped BSUs into the TAZ system along with the value of the number of TAZs.

The last stage of the aggregation method II is depicted in Figure 5.5, where the reasonable size of each TAZ is generated based on the value of the TAZ specified by the user and the sorted similarity indices as presented in Table 5.1. The upper and lower bounds in deciding the ultimate number of zones should be specified at the same time. For example, when the user specifies 14 TAZs, each TAZ should roughly contain 9 or 10 parcels ($\frac{132}{14} = 9.xx$), which is the reasonable size (k_r). However, the current FORTRAN routine does not always guarantee the grouping of this reasonable number of parcels since it may violate the homogeneity, which is also specified implicitly by the users. So, the acceptable size of a TAZ (k_a) may be $k_r - \theta < k_a < k_r + \theta$, where θ is a heuristic deviation implicitly decided by the user. If θ is 3, and the k_r is 14, the k_a is between 11 and 17.

The role of GIS, in both procedure I and II, is two-fold. One is providing topological relationship among parcels (basic spatial units as polygons), and the other is performing the role of database integrator. That is, once the zone delineation is complete, GIS will generate a revised shrunken data matrix ($k \times p$, where p is number of attributes per basic spatial unit) from the original $n \times p$ matrix.

Table 5.1 Sample Sorted Similarity Indices of Adjacent BSUs

L-Poly	R-Poly	S_{ij}
117	123	.00080
93	98	.00088
110	117	.00097
8	12	.00148
67	68	.00152
105	110	.00177
.	.	.
.	.	.
6	7	8.17380
6	11	8.27438
1	6	8.29570

Table 5.2 Generated 14 TAZs and Relationship with BSUs
(κ: newly delineated TAZ numbers)

κ	Grouped BSUs
1	12 117 123 110 105 116 124 121 106 122 125 129 130
2	11 93 98 104 103 101 29 25 94 32 92 97
3	7 8 12 16 34 18 33 39
4	7 67 68 66 69 65 73 76
5	10 91 96 90 36 95 99 35 37 100 28
6	8 86 70 114 115 88 87 78 89
7	10 20 21 19 23 24 26 27 31 30 22
8	10 14 15 11 7 17 48 47 38 56 10
9	7 62 63 60 72 71 74 64
10	9 84 85 83 82 81 80 77 79 75
11	9 41 42 57 40 55 59 52 58 61
12	13 112 118 119 111 108 102 126 107 127 120 113 109 132
13	9 49 51 45 43 44 46 50 53 54
14	8 1 2 3 5 4 9 13 6

1 This role of GIS can be said as a database integrator, providing an efficient data preparation for a readjusted TAZ scheme.

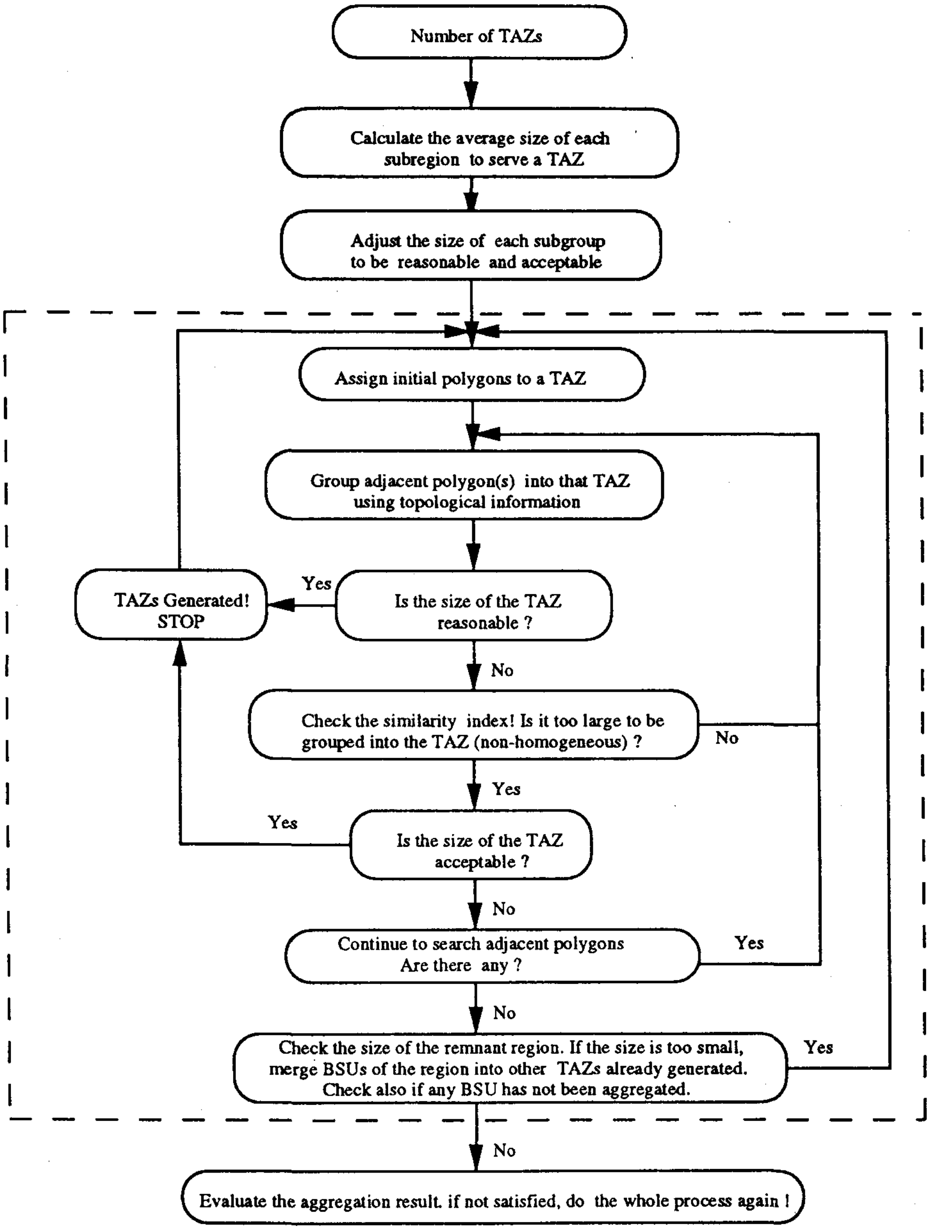

Figure 5.5 Detailed Flow of Producing Roughly the Same Amount of Trip Generation

Figure 5.6 132 Traffic Zones Serving Basic Spatial Units

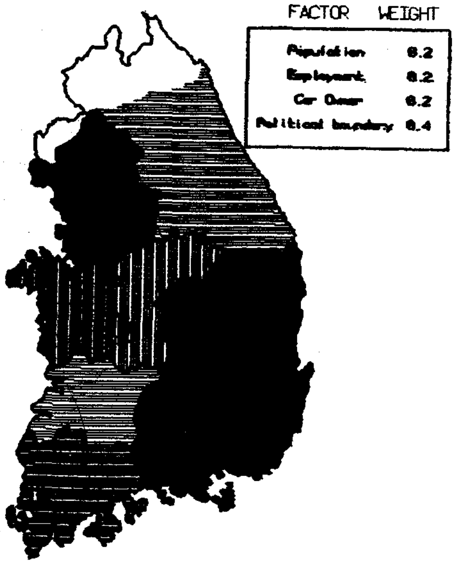

Figure 5.7 Traffic Analysis Zone Generation (8 Zones)

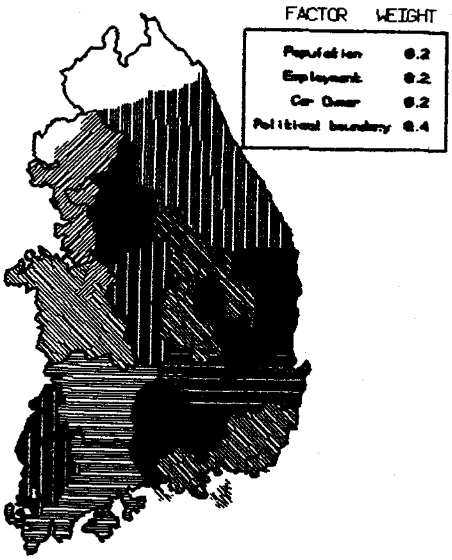

Figure 5.8 Traffic Analysis Zone Generation (13 Zones)

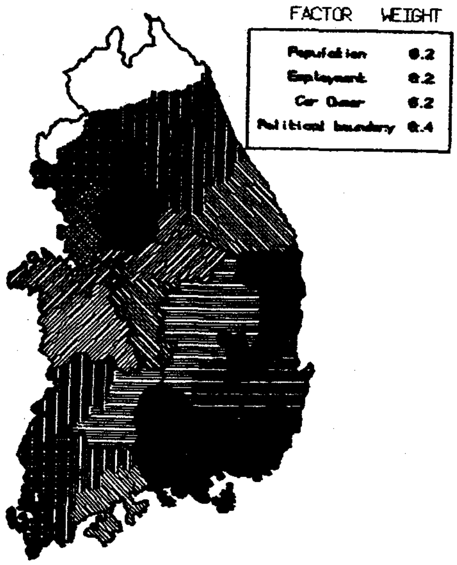

Figure 5.9 Traffic Analysis Zone Generation (19 Zones)

Both conceptual methods have been implemented within PC platform. Figure 5.6 shows the county political boundary which has served as a typical traffic analysis zone scheme in national transportation planning projects in Korea. This zoning system is composed of basic spatial units to be aggregated. Figure 5.7, Figure 5.8, and Figure 5.9 show the results of traffic zone delineations according to different numbers of zones (8 zones, 13 zones, and 19 zones), with given weights 0.2, 0.2, 0.2, and 0.4 for population, employment, car ownership, and political boundaries specified by users respectively.

6. Conclusion and Future Research Agenda

The GIS-assisted TAZ design approach introduced in this article may produce a more flexible TAZ system with considering several socio-economic characteristics simultaneously. However, it has been shown that the flexible and automatic generation of TAZs may not satisfy all of the guidelines prescribed by Garber and Hoel. In spite of that, the TAZ design approach here can be a good alternative method for transportation planners by allowing the feedback mechanism of incorporating the results of traffic assignment into the repeated TAZ design for establishing the appropriate zone-network compatibility. During this process, the method can overcome the inherent static nature of the conventional fixed TAZ system in the transportation planning process.

The main drawback of two approaches, however, is the problem of unequal size of the delineated zone system, which may lead to an inappropriate estimation of travel demand. This is cause by the logic of aggregating spatial units into zones. That is, the procedure is bottom-up, where searching and combining spatial units begins from the maximum homogeneity between two contiguous units. At the same time, the agglomeration procedure does not adopt the concept of the geographic centers of the agglomerated zones. The centers should be constructed based on statistical principle that guarantees the maximum differences between zones and maximum similarities within zones during aggregation.

In the future research, it is desired that the compactness criterion be considered at the same time to avoid the concavity of any TAZ . The measurement of compactness of shape will be a function of perimeter and diameter. Such being the case, the topological distance among polygons may be used to determine the center ofeach delineated zone, so that the zone aggregation may be allowed in such a fashion of from top to bottom. The purpose of implementing this procedure is to achieve maximum interzonal difference rather than maximum intrazonal homogeneity.

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