Planning of Parking Places on Transportation Infrastructure by Geographic Information Techniques

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Abstract— **Considering the increased number of vehicles every day, parking supplies should meet parking demands on transportation infrastructure. Irregular construction and excessive population growth in urban areas required re-planning and site selection of parking places. In this study, an analysis algorithm was developed to determine location-based parking demand by using Geographic Information System (GIS) techniques. After calculating parking demand and supply balance, the location-allocation techniques of network analysis were implemented to determine the best locations of parking, depending on parking demand. These processing tools were tested for an urban area. As a result, an innovative data processing method was developed to determine the best locations of car parking.**

Keywords-component; parking, transportation planning geographic information systems, network analysis, site selection algorithm

I. INTRODUCTION

Population growth in urban areas and the deficiencies in the implementation plan cause problems in transportation planning. For modeling parking demand, the activities based on human behavior should be determined and then identified at space and time. Due to complex nature of these activities, it is impossible to calculate certain demand and to relate land use functions. Data sets that will be utilized to calculate spatial distribution of demand weights should be available and obtained easily for any residential area. Therefore, It is inevitable to make some assumptions.

An abstraction of the real world is required to model parking demand on GIS environment. In the most basic sense, almost all elements requiring parking demand are expressed in a "structure" having a certain volume. Digital representation of a structure producing parking demand and supply can be defined with point geometry. All these supply and demand locations have to be defined with (x,y) coordinate pairs in a common Projected Coordinate System. A geographic database should manage vector and related tabular data sets to calculate the demand. Then, network analysis and location-allocation techniques help to determine the best location for parking places or car parking.

II. PARKING DEMAND - SUPPLY ANALYSIS

The scope of the parking problem can be examined in two sections as Demand and Supply.

- Demand means parking demand that existing houses and workplaces causes and determined in view of parking behaviour on land use.
- Supply includes all available parking space such as indoor-roadside parking, private parking, and functional parking.

Demand and supply balance can be calculated with network analysis techniques or raster-based map algebra techniques on GIS program. As seen on Figure 1, parking demand weights (blue) and parking supply weights (red) are calculated for each object. These are added algebraically in minimum area or pixel by using GIS presentation techniques.

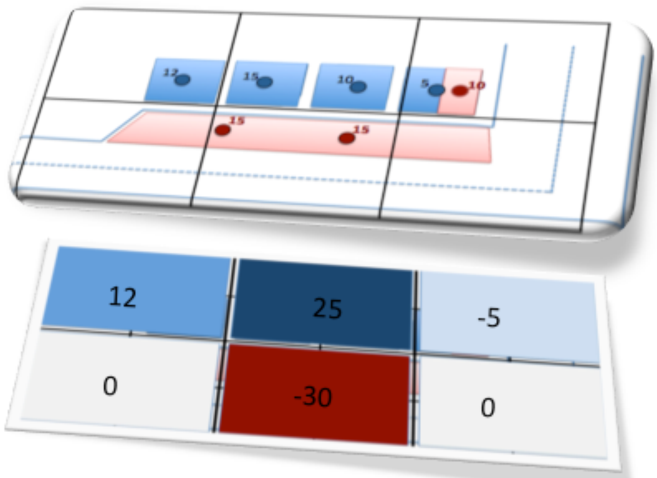


Figure 1. Basic approach for parking demand-supply calculation

The general approach is to calculate fixed demand firstly, then dynamic demand for car parking.

A. Fixed Demand Analysis

Fixed demand concrete and predictable is determined in priority because it is concrete and predictable. It can be calculated with the accumulation of housing (night) and workplace (day) demands;

- If there is a housing, there is parking demand for housing as fixed demand. Time cycle of this demand is generally from 18: 00 evening to 06:00 morning as a daily event.
- If there is a workplace, there is parking demand for workers as fixed demand. Time zone of this demand is from 06:00 morning to 18:00 evening as a daily event.

Housing and workplace parking demands are integrated to determine fixed parking demand. Housing and workplace demands should be considered in complementary time cycles (Figure 2).

B. Dynamic Demand Analysis

Dynamic demand covers daily business and all movements other than fixed demand. People visit workplaces for business, public services, education, shopping, entertainment, sport, and health. It includes continuously changing demands according to time and space. These demands have behaviors at five cycles (Figure 2).

- First cycle from 06:00 morning to 18:00 evening is the dynamic demand of the workplaces where people go for business and public services.
- Second cycle from 08:00 morning to 24:00 evening is the dynamic demand of the workplaces where people go for social and recreational purposes.
- Third cycle is the dynamic demand of the workplaces where people go all day for purposes like health.
- Periodic cycle represents workplaces where people go at certain time of the month and the week.
- Special time is for exceptional events causing very much parking demands.

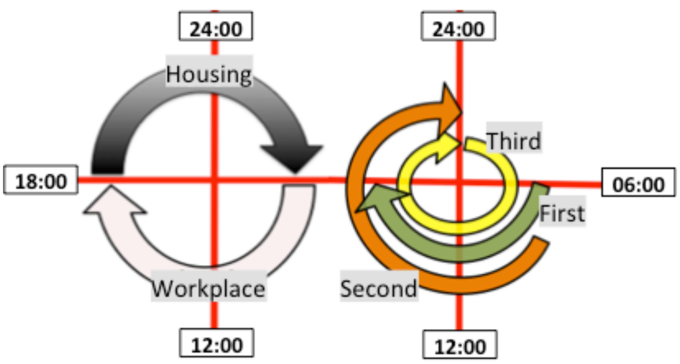


Figure 2. Fixed (left) and Dynamic (right) time cycle

C. Determining Demand and Supply Balance

If a parking supply was linked to a building, demand and supply balance would have been calculated easily for each building. However parking demands can be calculated spatially if the level and quality of available data sets is sufficient.

Parking demand is equal to the sum of fixed demand and dynamic demand for each building. Parking supply is especially situated inside the building or on the roadside. Private parking supply especially meets parking demands in commercial and mixed land use areas.

$\text{Demand}_i = \text{FixedDemand}_i + \text{DynamicDemand}_i - \text{Supply}_j$
Demand_i = the total demand of any building/structure.

To determine demand and supply balance, parking demand subtracts parking supply after removing constraint. This can be calculated by pixel or location-based map algebra techniques of GIS. Then, parking demands can be generalized to district/ neighborhood and traffic zone (TAZ) level if necessary, depending on application needs (Figure 3).

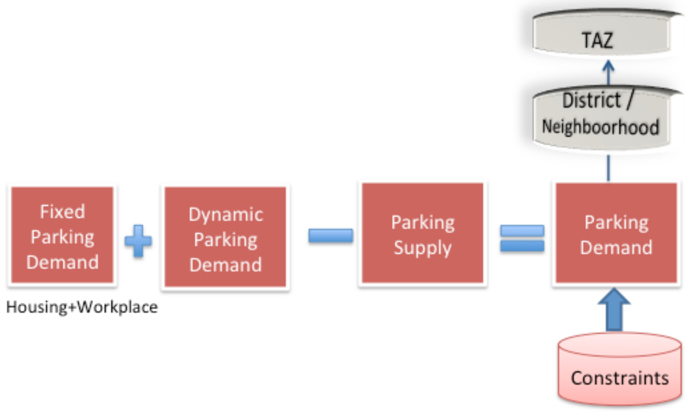


Figure 3. Parking Demand and Supply balance

III. LOCATION-ALLOCATION ANALYSIS FOR SITE SELECTION

Location-allocation models aim to determine optimal locations for facilities based on demand distribution. It minimizes the total weighed distance or time in terms of demand locations and weights.

The models have been developed with GIS technology because it needs network analysis functions. The location allocation problem of this study has three basic components as facility, demand, and network space;

- Facility is chosen and candidate-parking location that will be analyzed to service demand the best in terms of distance and time. The capacity of the facilities can be used for analyzing demand and supply balance or for allocating demand weights.
- Demand is determined as a result of parking demand analysis. Demand locations are identified with demand weights.

- Network space is the base data set on road network to calculate distance or time cost between facilities and demands.

In this study, the p-median model and the coverage models that are the most commonly used methods were chosen for location-allocation analysis.

A. The p-median Model

The p-median model is the first mathematical model and the most studied to minimize the total weighed distance that was aggregated on all of the facility and demand locations. It is expected that demand benefit from the closest facility without considering the capacity of the facilities. The p-median problem searches the locations of p facilities to select the chosen and candidate locations capable of minimizing the weighted distances between the facility and demand locations [1]-[2]. The maximum distance constraint can be determined in the p-median model.

For example, a parking facility must not far from demand locations with maximum distance constraints (d_{max}=250m) to identify a different subset of facilities in each demand [3]. It can be specified below;

$$Minimize\ Z \quad \sum_{i \in I} \sum_{j \in J} a_i d_{ij} x_{ij}$$

Given the following constraints;

- A facility has to be allotted with a separate demand site: $x_{ij} \le x_{jj}$ for all (i, j)
- An open facility must be allotted a demand: $\sum_{j \in J} x_{ij} \quad 1$ for all i
- Only the p facilities are to be located: $\sum_{j \in J} x_{jj} \quad p$ for all j
- The sum of them equals the number of facilities to be located.

Z = objective function;
i = all the demand locations on the network;
j = all the candidate facility locations on the network;
a_i = the number of demands at the demand location i;
d_{ij} = the distance on the network, from candidate facility j to demand i;
p = the number of facilities that needs to be located;
d_{max} =maximum distance constraint

The total demand from a separate demand location is given as:
X_{ij} = (0,1) for all (i,j) is allotted to only one facility, where:
$(d_{ij} \le d_{max}) \Rightarrow 1$ and $(d_{ij} > d_{max}) \Rightarrow 0$

B. The Coverage Models

The Minimum Facilities model minimizes the number of facilities that cover all demands within a distance constraint or travel time. It differed from other models because trying to determine minimum number of facilities. It is similar to the Maximum Coverage Model in terms of allocating demand points.

The Maximum Coverage Model maximizes coverage for the number of demand points within a distance constraint or travel time. It differs from the minimum facilities model in terms of facility selection because it does not minimize the number of facilities. This model aims to cover the largest area of demand points.

The Maximum Attendance Model aims to maximize attendance of the demands within a distance constraint or travel time. It especially allocates facilities that are close to the majority of demands [4]-[5].

IV. CASE STUDY

This study uses GIS techniques to plan parking places. Map algebra techniques analyze demand and supply balance of parking places. Then, location-allocation techniques were used on road network dataset to determine the best locations of parking places.

Firstly, required data sets were defined for these GIS applications. Base datasets explained below were collected for a test area of Istanbul;

- Building with the number of sub-units, function type, working cycle, and locations,
- Road network data set,
- Available parking supply with capacity and candidate parking places,
- The survey about examining parking and car use behaviors for Istanbul Transportation,
- Demographic data such as population density, car ownership, and employment at neighborhood level.

A. Calculating Parking Demands

Housing parking demand depends on the number of housing and the ratio of car ownership. So housing parking demand of each building is calculated by algebraic multiplying the number of residences and the rate of car ownership.

Workplace parking demand depends on the number of workplaces and the behaviors of car use. The number of employees at neighborhood level is distributed to the buildings spatially according to the number of workplaces and workplace volumes. So the number of employees was determined for each building. Workplace parking demand of each building was calculated by algebraic multiplying the number of employees and the ratio of car use of employees obtained from the survey.

Housing and workplace parking demands that should be in complementary time cycles are integrated to determine fixed parking demand. For this, land use zones can be used to calculate fixed parking demand in terms of residential, commercial, and mixed-use areas. Figure 4 shows parking demand weights for example locations of study area.

For dynamic parking demand, each building was defined with 5-function type and 5-cycle type. The weight of each building that is defined with a function type can be calculated according to the ratio workplace weight to total workplace weight in a neighborhood. To calculate the number of car visits, the weight of each building is multiplied with car visits of a neighborhood according to function type. It is supposed that the number of car visits defines dynamic demand for each building.

By taking data quality and content into account, 50mx50m pixel size was determined for calculating parking demand. That is why fixed parking demand (Figure 4.c) was added to dynamic parking demand (Figure 4.d) and subtracted parking supply with GIS based algebraic calculation.

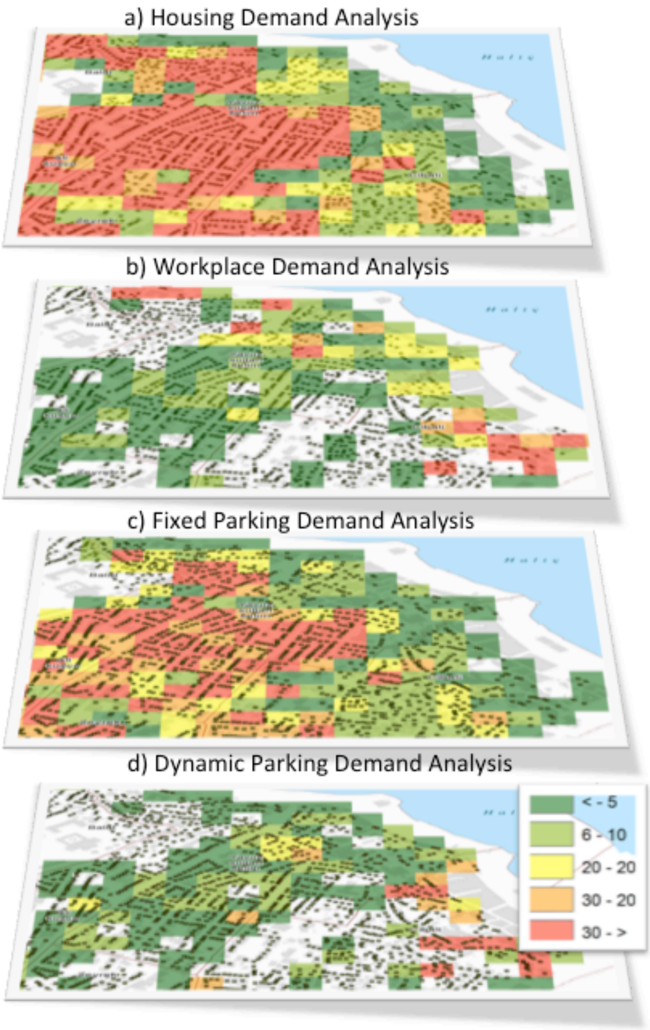


Figure 4. Parking Demand Analysis

B. Site Selection

Pixel-based parking demand was eliminated and converted to point geometry with demand weight. Parking demands and requied/candidate parking data sets were used with road network data sets for parking site selection.

As a location-allocation algorithm, the maximum attendance model was implemented firstly with 250m-distance constraint (Figure 5). Demand points were allocated for required parking facilities as regards their capacity. Then, the p-median or the minimum facilities models were implemented, remaining demand points were allocated for candidate facilities. Beside, other location-allocation methods were also used depending on parking policy.

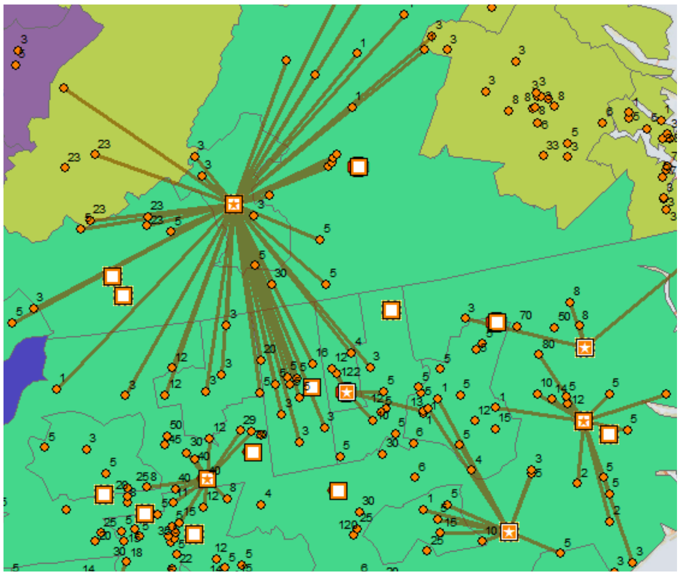


Figure 5. Allocation of required parking facilities depending on the capacity

Figure 6 gives location-allocation analysis of a neighbourhood. Parking demands were allocated for required (green P) and selected (red P) parking facilities, not including unselected (blue P) facilities. After this allocation, possible parking places were determined and remaining demand pixels/locations were calculated with demand weights.

V. RESULTS

Parking demand-supply analysis and location-allocation analysis were combined and tested for a case area of Istanbul Metropolitan Municipality in this study. Analysis algorithm was revised depending on this case study. Thus, by using geographic information techniques, an automated approach for parking site selection was developed to support planning in urban areas.

To support urbanization, this approach should be implemented in developing cities. However parking demand analysis can be developed with more qualified data sets because this model was developed based on available data sets. Data sets about parking supply and demand should be updated in database realtime.

Transportation has become main issue in urban areas more crowded. This study will contribute significantly to the transportation planning and management for decision makers. Using geographic information technologies has importance as a decision support technology. This kind of techniques should be implemented in transportation main plan or parking master plan projects.

REFERENCES

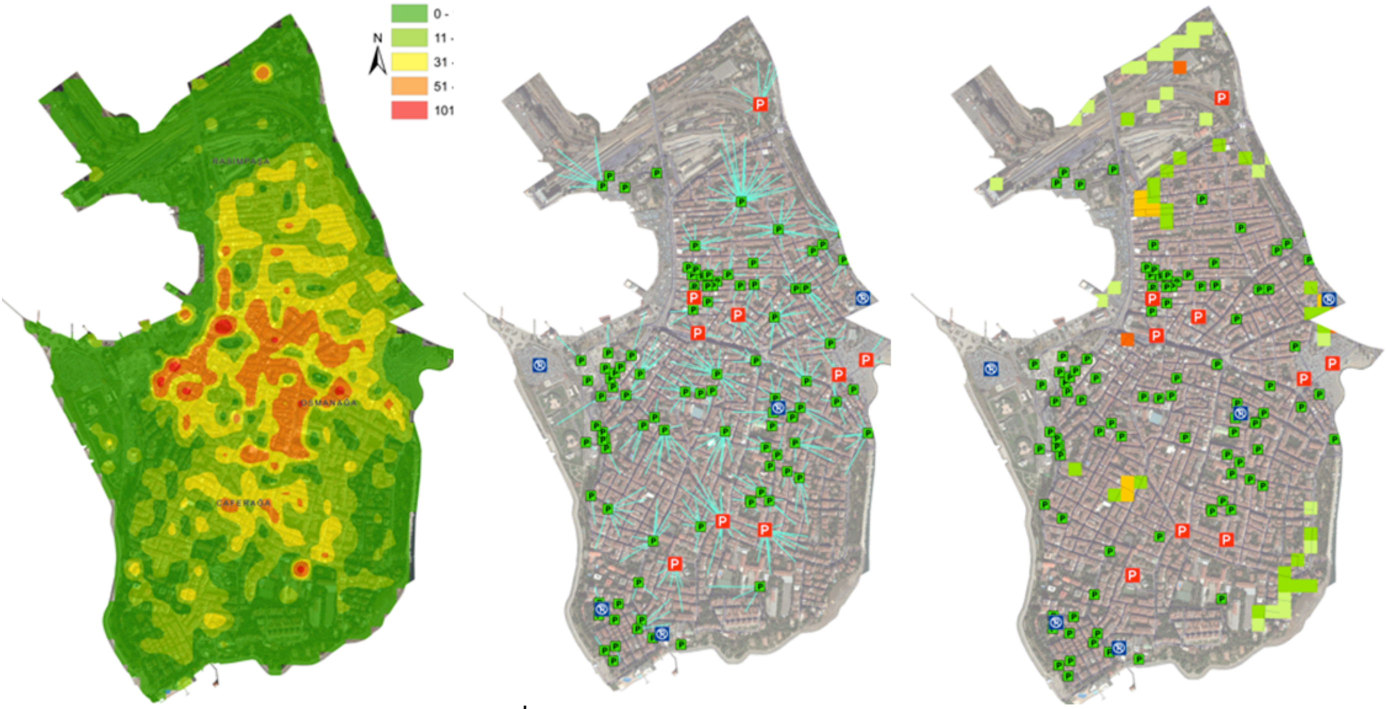
[1] S. Arifin, “Location Allocation Problem Using Genetic Algorithm And Simulated Annealing: A Case Study Based On School in Enschede”, M.Sc. thesis, University of Twente, Twente, the Netherlands, 2011.

[2] R. Church, P. Sorensen, “Integrating Normative Location Models into GIS: problems and prospects with the p-median model”, National Center for Geographic Information and Analysis, Technical Report, USA, 1994.

[3] M.B. Teitz and P. Bart, “Heuristic Methods for Estimating the Generalised Vertex Median of a Weighted Graph", Journal of the Operational Research Society of America 16, (5), pp 955-961, 1968.

[4] S.M. Algharib, “Distance and Coverage: An Assessment of Location-Allocation Models for Fire Stations in Kuwait City”, PhD thesis, Kent State University, Kuwait, 2011.

[5] I.O. Alshwesh, “GIS-Based Interaction of Location Allocation Models With Areal Interpolation Techniques”, Ph.D. thesis, The University of Leicester, England, 2014.



Parking Demand Analysis Location-Allocation Analysis Parking places and remaining demand

Figure 6. Parking site selection and remaining demand calculation