Layout Planning Study for Off-road Park Facilities Based on Complex System Theory

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***Abstract*—Urban off-road park facilities layout planning is an important component of the parking system planning and an integrated system engineering issue with multi-index and multi-constraint. This paper includes the study of the organizational mechanisms of parking facilities layout form and analysis of all factors that impact the public parking facilities layout. In this paper, the author established the simplified model of multi-objective optimization of the parking facilities site considering the highest social benefit of their layout. The Intelligent Ant Colony Optimization Algorithm is introduced to solve the model.**

Keywords-Ant Colony Optimization Algorithm; Complex System Theory; layout planning; parking facilities; self-organization

I. INTRODUCTION

Urban parking facilities layout planning (UPFLP) is a crucial component of parking planning. With its own distinct characteristics, it has intimate connection with Dynamic Traffic Planning. Based on the overall object of urban parking planning and behavioral decision of parkers, as an integrated system engineering issue with multi-index and multi-constraint, UPFLP takes the Urban Parking System as research object, refers to the satisfaction of the parking service indicator as research purpose, uses limited local resource as constraint condition, and depends on the guidance of executive department[1]. Within the restricted urban area, how to properly handle the relationships between urban system, traffic system and parking system; how to reasonably dispose parking facilities; how to improve the service level of parking facilities to the extreme; and how to satisfy the need of urban sustainable development, all above-mentioned matters are major research issues.

II. ORGANIZATIONAL MECHANISMS FOR PARKING FACILITIES LAYOUT

There are many multi-objective and multi-layered forces for changing urban parking facilities layout status. However, it's an ordered whole from the global view. Accordingly, the internal forces of urban parking facilities layout is regarded as a whole in this paper.

For the self-organization development of urban traffic, as the materialization and result of urban traffic development, parking facilities layout has the characteristics and conditions of dissipative structure self-organization[2]. Although many very complex factors involved in the development of parking facilities layout form, its features have hidden order and the laws of their own. From a certain level, parking facilities layout form is a macro-embodiment for material manifestation of the individual parking system (individuals, businesses, government units, etc.). In the absence of planning control, with their own requirements, individuals act to maximize the effectiveness of their pursuit, such as parking user choose applicable parking lot according to travel terminal, traffic condition, parking costs, etc. At the same time, parking supplier should build parking lot according to market demand, land costs, return on investment and so on.

As individual actions are independent, individuals pick over places following the rule of distance attenuation along the direction of diminishing resources and the descending direction of comparative advantage. With the influence of the surrounding land development, they could get parking facilities layout forms that are certain reasonable, while considering the interaction between these factors (choosing sites, project scale, service objects, styles and forms) and present urban & traffic environment. Thus， in a sense, the development of parking facilities layout form is self-organization, and the inner mechanism is the comprehensive self-organization effect formed by the interaction among these subsystems.

As the people's initiative will inevitably shape the external organizations of parking facilities layout and intervene the development of it, urban parking facilities planning, the direct outside means of organization and human intervention, is the "specific" interference of the parking facilities development. With the development of the cities, when the old layout of parking facilities gradually can not meet the city's traffic functional requirements, the planners can create a new form of external conditions and environment through the dominant control of the layout and intensifying efforts of induced control. The optimization of different aspects of the urban parking facilities layout will ultimately lead to the generation of a more orderly structure with less detours and reduce unnecessary losses. As a result, the development of parking facilities layout is also other-organization.

The alternate and complex role of self-organization and other-organization in the layout of parking facilities accordingly create the organizational mechanisms of parking facilities layout. The overall organization mechanism of

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parking facilities layout form is the development process of self-organization and other-organization with the support and limitations of the external and internal environment. The layout of parking facilities has the features of both self-organizing and other-organization. Natural growth and development of self-organization and man-made conscious planning control jointly form the development process of urban parking systems.

III. INFLUENCE FACTORS OF PARKING FACILITIES LAYOUT

For specialized parking place， its site selection and space determination are both restricted to its unit condition. As the ancillary facility of main building, accessorial parking place is subject to the main building for its site selection and layout. A public parking place has the broadest customers and the most important influence factors. So that its site selection and layout are determined by many factors, such as: the distribution and scale of the existing parks, optimization of parking facilities layout, balance between supply and demand, economic & social benefits and so forth. The layout planning for off-road park facilities is mainly discussed and explored in this paper.

On the whole, the distribution and scale of parking source is the determinant factor for urban parking facilities layout. Specific influence factors are shown as follows[3]:

1) Average walking distance: the average distance between parking place and destination. Obviously, for the parkers, it's the shorter the better.

2) Land development fee: including land occupancy charge, construction cost, operating expenses etc.

3) The accessibility: the difficulty degree for the parkers to arrive at the parking place, and road resistance is used to describe it.

4) The traffic condition of surrounding roads: parking facilities layout is closely related to the traffic condition of linked roads.

5) The compatibility of site selection: in the tenure of use, the parking place must be compatible with traffic &urban planning of other regions.

Site selection is the most important aspect for parking facilities layout planning, which is a complex system optimization problem that concerns many other factors (the distribution of berth number, the regions' exploring degree, the quantitative restriction of usable parking places and so on). Consequently, based on the self-organization of parking facilities layout, this paper aims at achieving maximal efficacy of parking system individuals (mainly park users and facilities' suppliers). And this goal is realized mainly by analyzing the characteristics of park users' action and site selection, creating the simplified site selection model of off-road park facilities' multi-objective optimization, and introducing Ant Colony Optimization Algorithm into the model solution to get the satisfactory parking facilities site.

IV. THE SIMPLIFIED SITE SELECTION MODEL OF OFF-ROAD PARK FACILITIES' MULTI-OBJECTIVE OPTIMIZATION

Parking facilities layout is the homodromous compound of parking system's self-organization & other-organization. When its other-organization is in process, parking system's self-organization must be considered in order to minimize the cost and maximize the efficacy of park users and facilities' suppliers. The benefit of park users manifests in the aspects of the length of walking distance, the convenience of parking, parking price and so on; while the benefit of facilities' suppliers concerns with the following items: the cost of construction, operating cost, its degree of attraction, its utilization rate and so forth. From the angle of park user F_1 and facilities' supplier F_2, create the object function for the optimization of parking site selection as follows:

$$\begin{cases} Min(Z) = \min(F_1, F_2)^T \\ F_1 = \sum_{j=1}^{m}\sum_{i=1}^{n}\left\{ a_{ij}\cdot d_j \cdot d_{ij} + \frac{a_{ij}\cdot d_j}{d_{ij}}\left[1+0.15(\frac{V}{C})^{4.0}\right] + a_{ij}\cdot d_j \cdot \beta_i \right\} \\ F_2 = \sum_{j=1}^{m}\sum_{i=1}^{n}\left[a_{ij}\cdot d_j (B_i\lambda_k + E_k)\right] \end{cases} \tag{1}$$

subject to

$$\begin{cases} d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \\ \gamma_{ij} = \frac{1}{d_{ij}}\left[1+0.15(\frac{V}{C})^{4.0}\right] \\ f = \sum_{i=1}^{m}\beta_i \\ F_2 = \sum_{i=1}^{m}(B_i\lambda_k + E_k) \\ N_{\min} \le n \le N_{\max} \end{cases} \tag{2}$$

In these formulas:

m——the number of required parking site;

n——the number of park facilities;

$X_i=(x_i,y_i)$ ——position coordinate for park facility i;

$X_j=(x_j,y_j)$——position coordinate for parking demand site j;

a_{ij}——a two-value symbol expressing whether park facility i services for parking demand site j. If it does, a_{ij}=1; otherwise, a_{ij}=0;

$d_{ij}(t_{ij})$——the walking distance (time) between park facility i and parking demand site j;

γ_{ij}——the resistance between road section ij and demand point;

V/C——the ratio between flow rate and volume for road section ij;

β_{ij}——the coefficient for parking fees;

B_i——the unit cost of land at parking site *i*;

E_k——the unit cost of the berth in type *k* parking site;

λ_k——the coefficient for land area occupied by the berth in type *k* parking site

V. MODEL SOLUTION WITH ANT COLONY OPTIMIZATION ALGORITHM

Ant Colony Optimization Algorithm (ACOA) makes use of the transferring information between ant colonies in the foraging process to optimize the solution. As a new type of simulating-evolving algorithms, ACOA owns excellent ability of global optimization and distributed computation, which provides new train of thought for complex and massive planning computation accordingly[4].

When a parker is choosing among public park facilities, every parking demand site is assumed as an ant colony; every candidate of park facility can be assumed as a food source. Based on the assumption above, choosing park facilities site is in fact the combinatorial optimization of multi ant colony and multi food source. Generally, park planning is the process of determining proper site among many candidates, which needs to reasonably choose part of park facilities to satisfy the parking requirements in different regions. In this paper, this problem (layout optimization) is analyzed by simulating the multistage behaviors of ant colonies.

According to the created model, object function consists of two parts: F_1 and F_2. F_1 is the cost of park users and can be obtained by synthetically calculating the walking distance after parking, the accessibility of park facilities and parking fees; while F_2 is the cost of park facilities' suppliers and includes land development fee, operating cost and so on. Therefore, the model solution can minimize the object function consisted of both F_1 and F_2. The procedures of this algorithm can be shown as follows:

1) Initialization:

To partition the planning region, and then calculate the requisite quantity of each region d_j by utilizing the relationship between the traveling flow rate of distributing site *D* and parking rate to confirm the position coordinate for parking demand site $X_j=(x_j,y_j)$; after that, to survey the roads' traffic volume per rush hour, to calculate the traffic capacity and *V/C* for every road;

2) Filter the candidate sites:

For each subarea unit, considering the land restriction, surveying the possible candidate sites of parking facilities layout needs to combine room distributing of parking remand, impedance degree of facilities and remand, constructing cost and operating cost. So that the model can get the practicable site position coordinate for park facility *i* $X_i=(x_i,y_i)$;

3) Calculate the possible solution sets:

Choose parking demand site X_j to calculate the distance d_{ij} between this site and X_i and set up possible solution sets;

4) Calculate amount of information in the route from X_j to X_i:

$$\tau_{ij}(t)=\begin{cases}1, d_{ij}\le r\\ 0, d_{ij}>r\end{cases} \tag{3}$$

r is the service radii of parking facilities, that is 300m.

5) Calculate transition probability from X_j to X_i:

$$p_{ij}(t)=\frac{\tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t)}{\sum_{s\in S}\tau_{is}^{\alpha}(t)\eta_{is}^{\beta}(t)} \tag{4}$$

In this formula, $S=\{X_s|d_{is}«r,s=1,2,\cdots,j,j+1,\cdots,N\}$.

All the conditions' transformation needs to take every demand site as the origin, and all amount of parking requirements should be assigned to the corresponding candidate site;

6) Check the volume limit:

$N_{min}\le n\le N_{max}$, assume the volume limit is [50,300], and then judge whether $50<p_{ij}(t)<300$ is tenable. If $p_{ij}(t)<50$, it should be deleted from the candidate sites; if $p_{ij}(t)>300$, then return to ② to assign again;

7) Calculate objective function value z(t):

If $z(t)>(z-1)$, that is the optimal solution. If $z(t)<z(t-1)$, assume the maximum acceptable error is ε, then repeat the iterative computation according to procedure steps above if the error is larger than ε, otherwise stop searching if the error is smaller than ε.

VI. DESCRIPTION OF ALGORITHM EXAMPLES

Take the downtown of Huangshi as the research example, set up the coordinate system[5]. The road network, distribution of parking demand sites, parking demand quantity and facilities candidate sites in the downtown of Huangshi is shown in the Figure below.

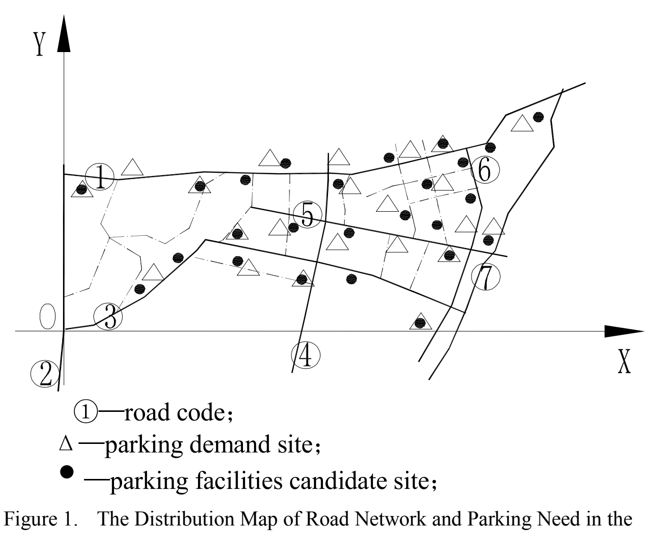

Figure 1. The Distribution Map of Road Network and Parking Need in the Downtown of Huangshi

The roads' V/C rates are shown in Table I; the position coordinates for parking demand sites are displayed in Table

II; and the position coordinates for parking facilities candidate sites are shown in Table III.

TABLE I. THE ROADS' V/C RATES

Road Code	①	②	③	④	⑤	⑥	⑦
V/C	0.75	0.67	0.61	0.49	0.52	0.58	0.72

TABLE II. THE POSITION COORDINATES FOR PARKING DEMAND SITES AND DEMAND AMOUNT

Code	Position Coordinate	Demand Amount
1	(675，66)	80
2	(256，644)	40
3	(337，225)	50
4	(512，579)	60
5	(652，389)	80
6	(693，243)	70
7	(774，683)	50
8	(813，410)	60
9	(894，206)	60
10	(1033，687)	80
11	(1076，572)	80
12	(1026,347)	60
13	(1215,500)	120
14	(1250,339)	40
15	(1299,713)	80
16	(1424,750)	100
17	(1424,588)	60
18	(1448,303)	80
19	(1338,32)	80
20	(1514,420)	40
21	(1613,414)	50
22	(1720,821)	80

TABLE III. THE POSITION COORDINATES FOR PARKING FACILITIES CANDIDATE SITES

Code	Position Coordinates	Code	Position Coordinates
1	(675，66)	14	(1222,694)
2	(285，167)	15	(1215,500)
3	(435，292)	16	(1424,750)
4	(512，579)	17	(1402,425)
5	(653，280)	18	(1448,303)
6	(682，605)	19	(1338,32)
7	(774，683)	20	(1500,675)
8	(833，671)	21	(1528,531
9	(813，410)	22	(1595,363)
10	(894，206)	23	(1602,735)
11	(1031，589)	24	(1364,588)
12	(1081,208)	25	(1783,857)
13	(1072,393)		

Use Matlab software to program the Ant Colony Optimization Algorithm and get the results as follows (Table IV):

TABLE IV. COMPUTATION RESULTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	**80**	**22**																				
3			**50**	**5**	**20**	**23**																
4		**18**		**55**	**19**		**4**															
8							**37**	**17**		**37**	**7**											
9					**24**	**26**	**5**	**48**	**8**		**7**	**9**										
10					**17**	**31**		**6**	**45**			**9**										
11							**4**	**9**		**43**	**68**	**6**	**22**									
13									**7**		**10**	**70**	**26**	**24**								
15											**8**	**6**	**72**	**10**	**27**	**6**	**18**			**18**		
16															**53**	**54**	**16**					**20**
18														**6**			**26**	**72**	**12**	**32**	**16**	
19																		**8**	**108**		**4**	

The distribution of all facilities and parking demands is shown in Figure 2:

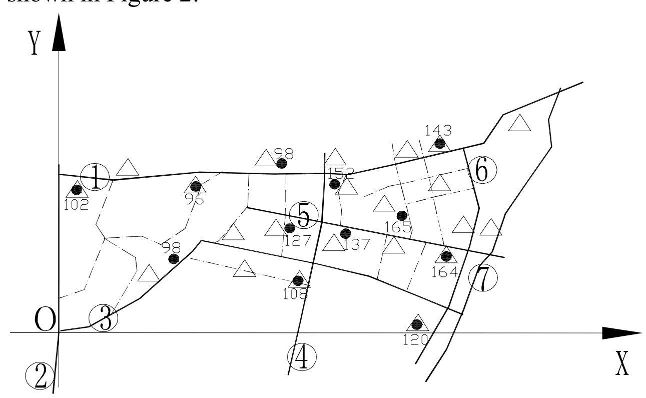

Figure 2. The Distribution of All Facilities and Parking Demands

VII. CONCLUSION

As the other-organization of parking facilities' morphology, the layout planning for park facilities owns the self-organization characteristics too. Therefore, in the process of planning, those traits should be considered properly to maximize the utility of parkers and parking facilities' suppliers, to minimize the overall cost. The reasonable parking facilities layout morphology will be formed through the repetitive interactions and self-adjustments among the individuals in parking system. Therefore, it is obvious that the layout planning for park facilities is an issue concerning complex nonlinear system optimization. As a new type of algorithms, Ant Colony Optimization has great application value in random search guiding and global optimization, which provides new methods for complex large scale site choosing-planning computation.

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