A STUDY OF URBAN ROAD NETWORK EVALUATION FROM THE VIEWPOINT OF PEDESTRIAN CROSSINGS

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abstract: A new method to evaluate urban road networks from the viewpoint of pedestrian crossings is proposed in this paper. A Location Set Covering model is used to exclude the effect of the location pattern of peoples' destinations. Hypothetical penalty links are introduced into the constraints of the model to express pedestrians' crossings at major road links. A computation is tested in a small city with six alternative plans. It is found that the areal balance or intervals of a major road network is important to harmonize the road network with location of facilities for pedestrian users.

1.INTRODUCTION

Recently the proportion of aged people to the whole population has been rapidly increasing in Japan. The presence of the aged people has become more significant. In this situation, the idea that everyone living in a city, including the aged and the handicapped, has the right to enjoy his or her own safe and comfortable life has become more prominent. The Ministry of Construction has pushed a city development projects scheme to improve social welfare, The Ministry of Public Welfare has started a city development scheme to improve the living environment of aged and handicapped people. While these former schemes have just started city development projects are partly executed in the central areas of cities. However, this trend will increase in the future. Therefore, we should plan an urban road network not only for car traffic but also for pedestrians and/or cyclists.

The urban road network has thus far been designed to serve cars with a high level of traffic services. Larger traffic capacity and route design to guarantee faster movement are desirable conditions for major roads. However, such roads are often dangerous to cross for pedestrians or cyclists. A road with heavy traffic or high speed cars can be regarded as a barrier from the viewpoint of pedestrians. It is considered an important principle for elementary school location that children's paths from their homes to the school do not cross major roads in British city planning(Diamond 1995). It is also desirable for an urban road network design to protect pedestrians from traffic accidents or nuisance.

However, it is not easy to evaluate an urban road network plan from the viewpoint of pedestrian crossings. It does not only depend on road network design but also the location of facilities which are the trip destinations of pedestrians. Strictly speaking, the evaluation of an urban road network plan is that of the product of an urban road network plan itself and a facility location pattern. Suppose several network plans are evaluated with a facility location pattern. The results are only valid under the specific facility location pattern. If the facility location pattern is changed we may have other results from the road network evaluation. That is, the facility location pattern is significant when we evaluate the road network from the viewpoint of pedestrians crossings. Peeters and Thomas(1995) tried to resolve this road network evaluation problem affected by facility location patterns. They introduced a P-median model, one of the basic facility location models, to remove the effect of specific location patterns. In their study the location patterns which causes OD traffic volume is variable corresponding to each different network plan. But it is consistently guaranteed to be optimal in the sense of the P-median model. They analyzed the results of traffic conditions caused by location problems on generated networks systematically and discussed the influence of the shape of the network upon the traffic conditions.

In this paper, we try to evaluate urban road network plans from the viewpoint of pedestrians who visit elderly welfare centers in a small city using the same approach. But our study is different from theirs in the following two points. First, we apply a Location Set Covering (L.S.C.) model instead of their P-median model, because the L.S.C. Model attaches much importance to the equity of facility location than the P-median model. It is considered important in looking at welfare facilities. Second, we do not study car traffic on the roads but rather pedestrians crossing the roads.

2.FACILITIES LOCATION MODEL CONSIDERING THE PEDESTRIANS' MAJOR ROAD CROSSINGS

2.1.Problem

Suppose a city planning authority planning a major road network and elderly welfare centers in a small city. The usual urban road network is composed of a major road network and many minor roads. It is supposed that cars can drive fast along major road links and slow along minor roads and pedestrians walk every road and junction in the city safely apart from major road crossings. It is also supposed that the shape of the original road network is given. A major road network plan is drawn composed of some links selected in the original road network. The other links in the original road network are regarded as minor roads in the plan. We can make several alternative major road network plans by changing the selected links.

Most elderly people usually walk or use bicycles in small cities in Japan because the city area is small and the trip length needed is short. But it is dangerous for old people to cross major roads. Then the city planning authority would want to locate the elderly welfare centers in such a way that people who visit those centers are not impeded by major road crossings. Assume that the authority has a principle about old peoples' major road crossings and it is an important condition for the location problem to address. Since the results of this location problem are influenced by major road network plans we evaluate it by examining those results. The evaluation index is simply defined as the number of centers required to meet the major road crossing constraint because an increase in the number of centers is not desirable for financial reasons.

2.2.The Location Set Covering Model

Suppose the city is divided into n residential zones and the population in each zone is given. Subscript i or j denotes a zone in the city. The centroid of the zone represents the position of the zone in the city. Subscript i is usually used for the residential zone and j is usually used for the facility location. The facility location is represented by a centroid too. The distance between zone i and facility location j, d_{ij}, is the length of the shortest path measured along the pedestrian road network between i and j.

The facility location variable is x_j. It is 0-1 integer variable and $x_j=1$ means that a facility is located at zone j and $x_j=0$ means there is no facility at zone j. The planning authority has to choose the maximum allowable distance, S, that may separate a residential centroid i from its nearest facility. Then the original Location Set Covering model is stated as

$$\min Z = \sum_{j=1}^{n} x_j \tag{1}$$

$$\text{s.t.} \quad \sum_{j \in N_i} x_j \geq 1 \qquad i = 1, \cdots, n \tag{2}$$

$$x_j = (0,1) \qquad j = 1, \cdots, n \tag{3}$$

$$N_i : \{ j | d_{ij} \leq S \}. \tag{4}$$

Here, N_i is the set of locations where people in zone i can arrive at a facility within the maximum allowable distance.We call N_i allowable location sets of zone i.

2.3 Major Road Crossing Constraint

It is desirable for pedestrians not to cross any major roads, as the city authority needs a major road network for unimpeded driving to some extent. If they adopt the principle that everyone can visit one of welfare facilities within the maximum allowable distance and without any major road crossing they will have to build too many facilities. Moreover, this principle makes our study useless in the mathematical programming model. Adopted is the principle that the whole city is divided into sections by the major road network and each section needs at least one facility. It means each section is independent in the facility location model and we do not need to solve the whole city problem. But if they adopt the principle to accept more than two crossings it may mean less because the city is small enough so that people can visit most areas of the city within two crossings. Then the principle that one crossing is acceptable but two crossings is prohibited is adopted.

Intersection links are introduced to represent pedestrians crossing major roads. Figure 1 shows the intersection links. Suppose a link is selected as a major road in a major road network plan. The link is represented as a double link where both links serve as pedestrian links. When a pedestrian path crosses a major road link a special intersection link which ties one side to the other in a double link is introduced as shown in Figure 1(a). When a pedestrian path is along a major road and it crosses another major road plural intersection links are introduced as shown in Figure 1(b). These intersection links do not have their length specified by the breadth of the major road crossed because the node of the original road network is located at the center of the road breadth.

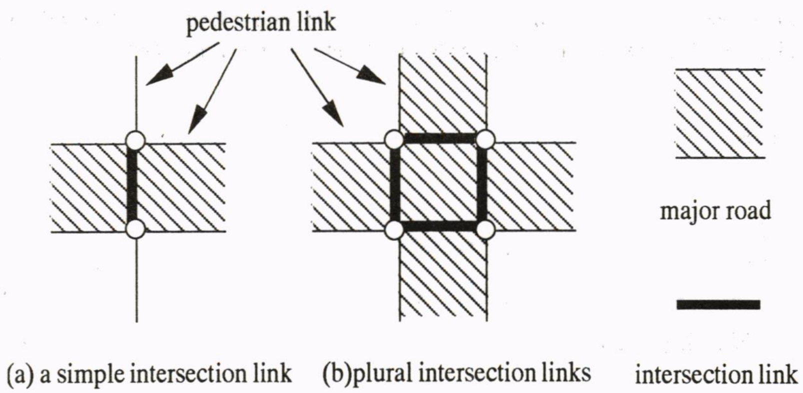

Figure 1. Intersection links

Each intersection has an identical penalty length P. The penalty length is hypothetical and large enough to constrain plural crossings. Then a new pedestrian road network is composed of a set of original pedestrian links in which actual lengths are measured on the original road network and a set of intersection links with a hypothetical penalty length. The shortest path length measured on this new pedestrian road network with penalty intersection links is calculated and it is denoted e_{ij}. Then N_i in equation (4) is changed as following,

$$N_i = \{ j |\ d_{ij} \leq S \text{ and } e_{ij} \leq S + P \}. \tag{5}$$

Therefore, the model to be studied is represented by equation (1), (2), (3) and (5). It minimizes the number of facilities required under the constraint of the maximum allowable distance and at most one major road crossing. If the alterative road plan is not suitable for reducing old peoples' major road crossings then the city government has to build more facilities under the plan.

3.COMPUTATION RESULTS

3.1 Study Area

The model is computed for a road network in the central area of Saijo City with a population of 60 thousand. Figure 2 shows a simple picture of the study area. It is between two rivers, one in the east and the other in the west. There is a coastal industrial area outside of the northern border of the study area. The study area confronts steep mountains at the southern border. There are two regional highways in the area. One is an Industrial Highway located in the northern part of the area. The other is Route 11 of the Japanese national highway system located in the southern part of the area. These regional highways are included in every alternative major road network plan examined in the computation examples.

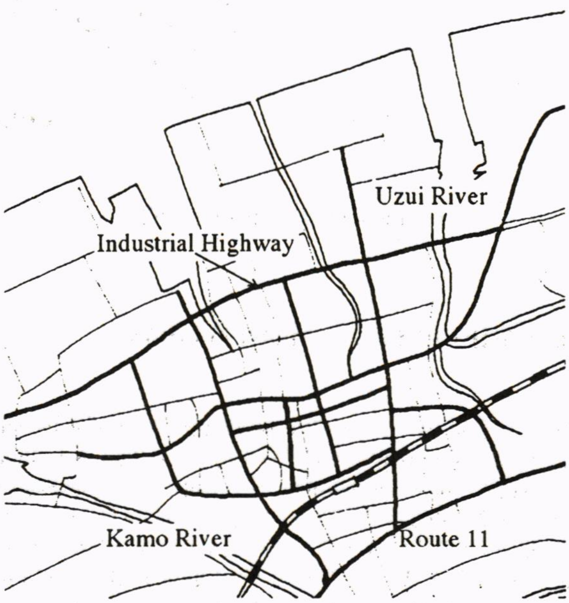

Figure 2. Study area

The study area is divided into 58 zones. The position of centroid is set at the center of a densely inhabited tract in each zone. The centroid can be the location of a facility allocated in the plan. People of more than 65 years old in a zone in 1993 are regarded as pedestrians who visit elderly welfare centers in this study. Figure 3 shows the original road network. Here, the two regional highways are shown beforehand with a double link. The penalty value of each hypothetical intersection link is determined to be 10,000m. This is large enough for the constraint because the size of the study area is at most 6 km in an east-west direction or north-south direction.

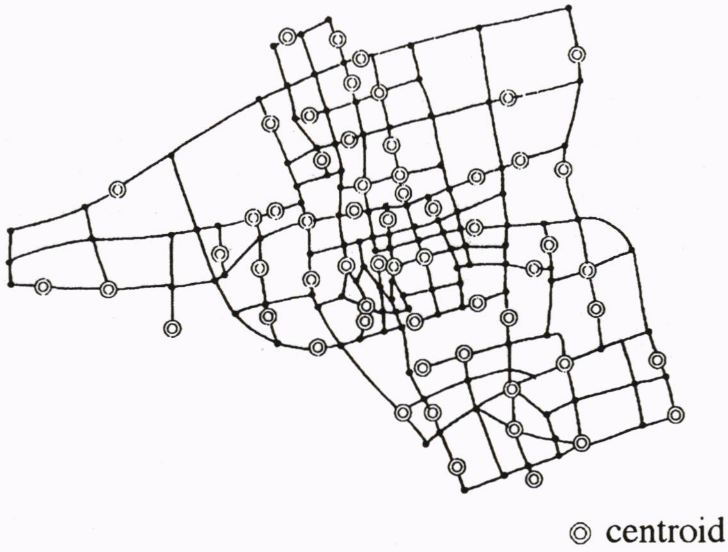

Figure 3. Original road network

3.2 Basic Characteristics of L.S.C. Model Solution

The L.S.C. model is a kind of a parametric programming model because the value of S should be given before solving the problem. We can solve the L.S.C model for successive values of S and investigate how the number of facilities is influenced by the maximum distance S. Normally, as S value is chosen every 100 meters in our study. The number of facilities, Z, and the maximum distance, S, tradeoff curve so obtained on the original road network is shown in Figure 4. Each point in the figure is the solution of problem with equation(1), (2), (3), and (5). The curve exhibits an increase in the number of facilities as the maximum distance is reduced. It is seen that the required number of facilities remains the same for large S values. For instance, for distances between 1,500 meters and 1,800 meters three facilities are required. Reducing the maximum distance within this interval has no effect on the number of facilities although the spatial pattern of facilities may be altered to meet the tighter distance requirement. Each of the points circled on the graph is adopted to evaluate the alternative major road network plan because all solutions to the right of these points on the flat portion of the curve are dominated by the left-most point(Revelle 1987).

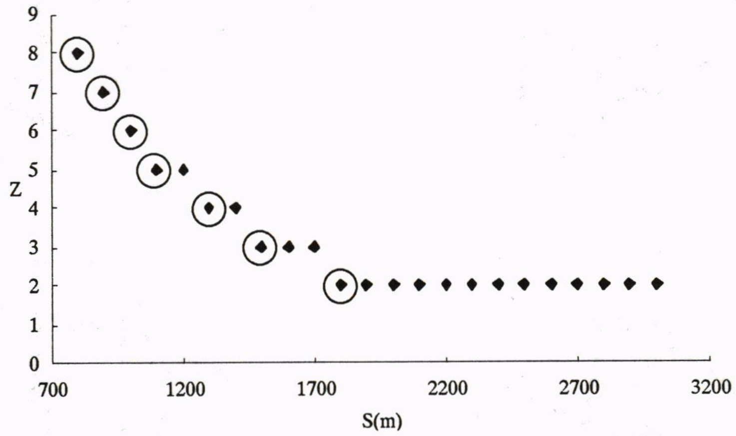

Figure 4. Z(number of facilities) as a function of S(maximum distance)

3.3 Alternative Major Road Network Plan

Figure 5 shows six alternative major road network plans. The two regional highways are common for all alternatives. Five alternatives except Plan 6 have two major roads in a north-south direction and one major road in an east-west direction between the two regional highways. The length of major road network links for each plan is 12,720m(Plan 1), 13,430m(Plan 2), 13,670m(Plan 3), 13,400m(Plan 4), and 13,000m(Plan 5) respectively. Roughly speaking, they are equivalent. On the contrary, Plan 6 has a denser major road network than the other plans. The length of major road links is 20,240m. It is about 50% higher than the average length of the other five plans.

3.4 Solution of the L.S.C. Model

The L.S.C. model for alternative major road network plans is solved under given maximum distances from 800m to 1,800m. Table 1 shows the number of facilities Z obtained by solving the L.S.C. model for a given alternative major road network plan and a given maximum distance S. Here, the numbers in Plan 0 column represent the solution of the L.S.C. model on the original pedestrian road network, that is the solutions under the constraint of $N_i : \{ j \mid d_{ij} \leq S \}$. While other problems for Plan 1, 2, 3, 4, 5 and 6 are solved under N_i represented by equation (5). The numbers in the "distant" row represent the solutions of the L.S.C. model under only crossing major road constraints, that is

Figure 5. Six alternative major road network plans

$N_i: \{ j | e_{ij} < 2P \}$. Here, there is no constraint about d_{ij}. But, that the condition e_{ij} should be less than 2P means that the maximum distance of d_{ij} should be less than 10km considering the constraint of at most one major road crossing. Moreover, this maximum distance 10km substantially means infinity because the maximum path length without penalty in the study area is less than 8 km.

Table 1. The Number of facilities Z

S(m)	alternative major road network plan						
	1	2	3	4	5	6	0
800	8	9	8	8	9	10	8
900	7	8	7	7	8	8	7
1000	7	7	6	6	6	8	6
1100	6	7	6	5	6	7	5
1200	6	6	6	5	6	7	5
1300	6	5	5	5	5	7	4
1400	5	5	4	4	4	7	4
1500	5	5	4	3	4	6	3
1600	3	5	4	3	4	6	3
1700	3	4	3	3	4	6	3
1800	3	3	3	3	3	5	2
distant	3	3	3	3	2*	4*	2

Comparing the number of facilities which are required under the same maximum distance S in Plan 4 column is consistently fewest of the six alternative plans. But we cannot properly order the rank of Plans 1, 2, 3 and 5 because the numbers are superior for some S values but inferior for other S values. Plan 6 is the worst among the six alternatives. However, we may not conclude that Plan 4 is definitely best. If the city decides that the maximum distance should be 1,300m then the number of facilities required is identical for Plan 2, 3, 4, and 5. Therefore, Plan 4 is favorable when the city is not sure about determining the maximum distance for facilities. On the contrary, it is clear that Plan 6 is the worst among the six alternatives because it has a dense major road network. We have to build more facilities to cover the study area without more than two major road crossings for users when this major road network plan is adopted.

Figure 6 shows the location of facilities and zones covered by each facility for the five major road network alternatives (Plan 1~5) in the case of 1,500m maximum distance. Black triangle marks show the location of facilities and dotted lines the boundary of an area covered by each facility. Here, each zone is judged to be covered by the nearest facility. The number of facilities required is 5, 5, 4, 3, and 4 for Plan 1, 2, 3, 4, and 5 respectively. The shapes and sizes of the areas surrounded by the major road network in Plan 4 look more balanced than those of other plans. Roughly speaking, the L.S.C. Model is a kind of puzzle that tells at most how many pieces of area each with a facility within the maximum distance, do we need to satisfy the entire study area compactly. It seems that a well regulated major road network enables us to envelop the whole study area with fewer pieces.

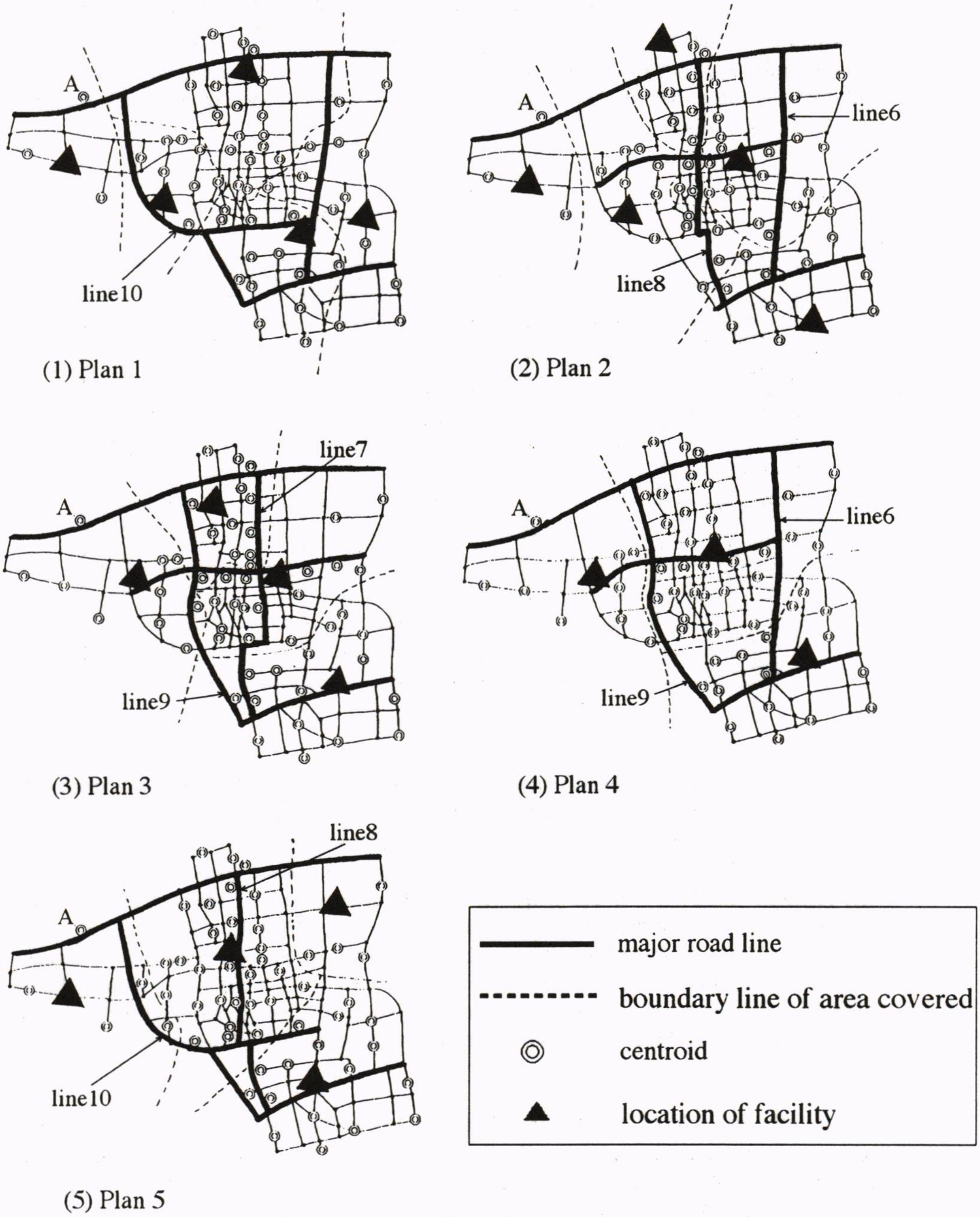

Figure 6. The location of facilities and zones covered by each facility

In Figure 6(1) there is a facility outside of major road line 10. It is needed for centroid A. Because if there is no facility outside people living at centroid A have to visit a facility inside of line 10 and it forces them to cross two major road links. At the same time, it is seen that two facilities are closely located in the southeast area. They are needed because of a smaller area surrounded by major road links in the southern area. In Figure 6(2) the number of facilities required is larger by two than that of Plan 4. The north-south line 8 seems to be located too close to the central area of the city and the interval between line 6 and 8 looks shorter. Then it seems that the line 8 is an effective barrier to people who visit facilities. The same situation as Plan 2 is seen in Figure 6(3). The north-south line 7 looks to be located too close to the central city area and the interval between line 7 and 9 looks shorter. Therefore, more facilities are required than that of Plan 4. In Figure 6(5) there is a facility outside of major road line 10 the same as Plan 1. Thus, three facilities are required in the northern part of the study area in Plan 5 while only two are needed in Plan 4. It is concluded that line 10 which appears in Plan 1, 5, and 6 is not useful and major road lines with shorter intervals located in the central area as seen in Plan 2 and 3 are barriers.

4.CONCLUDING REMARKS

In this paper a new method to evaluate an urban road network from the viewpoint of pedestrian crossings is proposed. So far many road network evaluation studies using accessibility measures have been done for specified destinations. However, the locations of those destinations may change in the future. Thus, the accessibility value may change while the road network itself does not change. Therefore, if we try to evaluate the road network excluding the effect of the destination location pattern a more general concept of trip destination patterns is needed. Location Set Covering model which attaches importance to equity is introduced into our study since we are interested in older peoples' trips to their welfare facilities. We also propose a way to express pedestrian crossings of major road links and introduce this as a constraint in the L.S.C. model. A new pedestrian road network with hypothetical penalty links is developed in this paper.

A computation is tested in a small city with a population of sixty thousand with six alternative major road network plans. It is natural that a dense road network plan needs more facilities to meet the pedestrian crossing constraint. One of the six alternative plans is evaluated best because the number of facilities required is always less than that of other plans over a wide range of maximum distances. Two reasons are suggested. One is that the shapes and sizes of the areas surrounded by the major road network in this plan look more balanced. Another is that there is no north-south major road line in the central city area. The second reason has been popular among city planners, but the first reason has not. It is considered that the introduction of the L.S.C. model produces this result. It seems that areal balance or intervals of the major road network is important to harmonize the road network with facility location where users are pedestrians.

There is some work to do in the near future. First of all, the pedestrian crossing constraint should be improved. The condition that at most one crossing is allowed does not always seem proper. We have to develop a better way to express the danger to pedestrians at major road crossings. Second, it may be better to examine other types of facility location models. The L.S.C. model sometimes seems strict and over sensitive because its objective function is too simple and the constraints greatly affect the solution.

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