Chapter 2
Uncapacitated and Capacitated Facility Location Problems

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2.1 Introduction

The *uncapacitated facility location problem* (*UFLP*) involves locating an undetermined number of facilities to minimize the sum of the (annualized) fixed setup costs and the variable costs of serving the market demand from these facilities. *UFLP* is also known as the "simple" facility location problem *SFLP*, where both the alternative facility locations and the customer zones are considered discrete points on a plane or a road network. This assumes that the alternative sites have been predetermined and the demand in each customer zone is concentrated at the point representing that region. *UFLP* focuses on the production and distribution of a single commodity over a single time period (e.g., one year that is representative of the firm's long-run demand and cost structure), during which the demand is assumed to be known with certainty. The distinguishing feature of this basic discrete location problem, however, is the decision maker's ability to determine the size of each facility without any budgetary, technological, or physical restrictions. Krarup and Pruzan (1983) provided a comprehensive survey of the early literature on *UFLP*, including its solution properties. By demonstrating the relationships between *UFLP* and the set packing-covering-partitioning problems, they established its **NP**-completeness.

The seminal paper of Erlenkotter (1978), which is reviewed in Sect. 2.2 of this chapter, presents a dual-based algorithm for solving the *UFLP* that remains as one of the most efficient solution techniques for this problem. Prior to Erlenkotter (1978), the best-known approaches for solving the *UFLP* were the branch-and-bound algorithm developed by Efroymson and Ray (1966) and the implicit enumeration technique of Spielberg (1969). Efroymson and Ray (1966) use a compact formulation of *UFLP* to take advantage of the fact that its linear programming relaxation can be solved by inspection. Nonetheless, this linear programming relaxation does not provide tight lower bounds for *UFLP*; Efroymson and Ray's model is therefore

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known as the "weak formulation." Khumawala (1972) developed efficient branching and separation strategies for the branch-and-bound algorithm. Erlenkotter (1978), however, uses the "tight formulation" of *UFLP* that is known to often produce natural integer solutions. This property of the tight formulation was first highlighted by Schrage (1975) and was used effectively by Cornuejols et al. (1977). Here, it is important to credit the work of Bilde and Krarup (1977), which led to the development of a dual-based algorithm for *UFLP* that is quite similar to Erlenkotter's procedure.

In many cases, it is more realistic to incorporate the capacity limitations on the facilities to be established. This version of *UFLP* is called the *capacitated facility location problem* (*CFLP*). Section 2.3 reviews the contribution by Kuehn and Hamburger (1963). Their paper presents one of the earliest models and a heuristic procedure for the *CFLP*. Branch-and-bound procedures for this problem were developed by Akinc and Khumawala (1977) using linear programming relaxation, and by Nauss (1978) through Lagrangean relaxation. The cross-decomposition algorithm of Van Roy (1986) and the Lagrangean-based approach of Beasley (1988) are among the most effective techniques that were subsequently devised for solving the *CFLP*. The basic idea of Van Roy's algorithm is to obtain a *UFLP* structure by dualizing the capacity constraints. This Lagrangean relaxation provides values for the location and allocation variables given a set of multipliers. The location decisions are then used to fix the integer variables and solve the *CFLP* as a transportation problem, obtaining improved multiplier values. It is necessary, however, to solve an appropriately defined linear program at some of the iterations to update the multipliers.

The *UFLP* and *CFLP* constitute the basic discrete facility location formulations, and there is an abundance of papers based on their extensions by relaxing one or more of the underlying assumptions mentioned above. Section 2.4 presents an overview of the prevailing literature. Aikens (1985) presented a survey of the early work on discrete location models for distribution planning. He reviewed 23 models covering a wide range of problems from the single-commodity *UFLP* to the multi-commodity, capacitated, multi-echelon versions. Although the *UFLP* and *CFLP* formulations have been used for tackling a wide range of problems, the most common context for their use has been the production-distribution network (i.e., supply chain) design problem. In a supply chain that comprises suppliers, plants, distribution centers, warehouses and customers, these basic formulations are relevant for making location decisions involving two consecutive echelons. For example, notwithstanding the focus of a majority of the literature on warehouse location, the *UFLP* and *CFLP* formulations are equally relevant for choosing suppliers to satisfy the needs of a firm's plants (Gutierrez and Kouvelis 1995). The next two sections review two classical papers that form the basis of this chapter.

2.2 Erlenkotter 1978: A Dual-Based Procedure for the UFLP

Let *I* denote the set of *m* alternative facility locations, indexed by *i*, and *J* denote the set of *n* customer zones, indexed by *j*. The *UFLP* has two sets of decision variables:

x_{ij}:   the fraction of customer zone j's demand satisfied by the facility at i, and
y_i: binary variables that assume a value of 1, if a facility is to be established at location i, and 0 otherwise.

Note that the demand data pertaining to each customer zone j is implicit in the definition of the facility-customer allocation variables x_{ij}. The cost data is represented by the following notation:

f_i: the (annualized) fixed cost of establishing a facility at location i, and
c_{ij}:   the total capacity, production and distribution cost for supplying all of customer zone j's demand by the facility at i.

The variable costs c_{ij} are assumed to be linear functions of the quantities produced and shipped at each facility, thus ignoring any possible economies of scale in the variable costs. Erlenkotter (1978) presents the following formulation of *UFLP*:

$$\text{Max} \sum_i \sum_j c_{ij} x_{ij} + \sum_i f_i y_i \qquad (2.1)$$

$$\text{s.t.} \sum_i x_{ij} = 1 \quad \text{for all } j \qquad (2.2)$$

$$x_{ij} \le y_i \quad \text{for all } i, j \qquad (2.3)$$

$$x_{ij} \ge 0, \quad y_i \in \{0, 1\} \quad \text{for all } i, j.$$

The objective function (2.1) represents the total fixed and variable costs, whereas constraints (2.2) ensure that the demand at each customer zone is satisfied. Constraints (2.3) guarantee that customer demand can be produced and shipped only from the locations where a facility is established, i.e., if $y_i = 1$, and in such a case, the firm incurs the associated fixed costs. The weak formulation of *UFLP* uses a more compact formulation of these constraints by aggregating the constraints (2.3) into a single constraint for each facility location i:

$$\sum_j x_{ij} \le n y_i \quad \text{for all } i.$$

In developing the solution approach, Erlenkotter (1978) utilizes a condensed dual formulation to the linear programming relaxation of *UFLP*. To this end, let v_j and w_{ij} represent the dual variables associated with constraints (2.2) and (2.3), respectively. By relaxing y_i as non-negative variables, the dual problem can be formulated as follows:

$$\text{Max} \sum_j v_j \qquad (2.4)$$

$$\text{s.t.} \sum_j w_{ij} \le f_i \quad \text{for all } i \qquad (2.5)$$

$$v_j - w_{ij} \le c_{ij} \quad \text{for all } i, j \tag{2.6}$$

$$w_{ij} \ge 0 \quad \text{for all } i, j$$

Note that the w_{ij} variables are not part of the dual objective, and hence can be safely fixed at the minimum levels permitted by the values of v_j. Erlenkotter assumes that $w_{ij} = \max\{0, v_j - c_{ij}\}$ and develops the condensed dual formulation below that has a single set of decision variables:

$$\text{Max } \sum_j v_j$$

$$\text{s.t. } \sum_j \max\{0, v_j - c_{ij}\} \le f_i \quad \text{for all } i \tag{2.7}$$

The *dual ascent procedure* that constitutes the core of Erlenkotter's algorithm aims at increasing the values of v_j so as to maximize their sum. The idea is to use a quick and simple heuristic for solving the condensed dual rather than searching for an exact solution. To this end, the heuristic starts by setting the v_j values to the smallest c_{ij} for each customer zone j. At each iteration of the dual ascent procedure, the customer zones are processed one by one and the v_j value at each zone is raised to the next higher c_{ij} value, unless such an increase is constrained by (2.7). When the inequality (2.7) becomes binding during this process, the v_j value is increased to the highest level allowed by the constraint. The heuristic terminates when no further increase is possible for the v_j values.

To illustrate the dual ascent procedure, consider a *UFLP* instance with eight customer zones and five alternative facility sites, which was also used by Erlenkotter. Table 2.1 depicts the variable costs c_{ij} and fixed costs f_i for this problem instance. At the initialization, the v_j values are set at the lowest c_{ij} value at each column in Table 2.1. As a result, s_i, the slack of constraint (2.7), is equal to the fixed cost f_i at each location. The initialization step is denoted as *Iteration 0* in Tables 2.2 and 2.3, which depict the progress of the v_j and s_i values during the course of the algorithm.

The bolded entries in Table 2.2 indicate the v_j values blocked by (2.7) from further increase. Note that in iteration 1, all v_j values are raised to the next higher c_{ij} value (under column j in Table 2.1), except v_8. We would normally raise v_8 from 120

Table 2.1 Cost data for the illustrative example

i/j	Variable cost								Fixed cost
	1	2	3	4	5	6	7	8	
1	120	180	100	–	60	–	180	–	100
2	210	–	150	240	55	210	110	165	70
3	180	190	110	195	50	–	–	195	60
4	210	190	150	180	65	120	160	120	110
5	170	150	110	150	70	195	200	–	80

Table 2.2 The values of the dual variables v_j

Iter/v_j	1	2	3	4	5	6	7	8
0	120	150	100	150	50	120	110	120
1	170	180	110	180	55	195	160	**155**
2	180	190	**110**	**180**	60	**195**	**160**	155
3	**180**	**190**	110	180	**65**	195	160	155

to 165, but this would violate (2.7). Therefore, the value of v_8 is raised to 155 reducing the dual slack s_4 to zero, as indicated in Table 2.3 under *Iteration 1*.

At *Iteration 2*, the dual variables for customer zones 3, 4, 6 and 7 are blocked, and the heuristic terminates after *Iteration 3* when no further increase is possible. Table 2.3 indicates that the dual constraints for locations 4 and 5 are binding at the end of the dual ascent procedure.

It is helpful to analyze the complementary slackness conditions for the condensed dual and the linear programming relaxation at this point. The bolded terms in (8) and (9) indicate the optimal values of the primal and dual decision variables.

$$y_i \left[f_i - \sum_j \max\{0, v_j - c_{ij}\} \right] = 0 \quad \text{for all } i \tag{2.8}$$

$$[y_i - x_{ij}] \max\{0, v_j - c_{ij}\} = 0 \quad \text{for all } i, j \tag{2.9}$$

The dual ascent produces a feasible solution v_j with at least one binding constraint (2.7). For each associated location i, the slack of the dual constraint is zero, and using (2.8) it is possible to set $y_i = 1$. Examining (2.9) for these open facilities, we hope that there is only one facility i with $c_{ij} \le v_j$ for all j, because in this case it is possible to set $x_{ij} = y_i = 1$ and obtain a primal integer solution that satisfies both complementary slackness conditions. It is likely, however, that the dual ascent procedure terminates with a solution where, among open facilities, there is more than one facility i with $c_{ij} \le v_j$ for some j. This would violate (2.9), since each customer zone must be served from the lowest-cost open facility. Therefore it is possible to set $x_{ij} = y_j = 1$ for only the smallest value of c_{ij}, and the primal integer solution is not optimal.

In the illustrative example, customer zones 1, 2, 3, and 4 are served from facility 5 and zones 5, 6, 7, and 8 are served from facility 4. A comparison of the v_j values at *Iteration 3* of Table 2.2 with the c_{ij} values in Table 2.1 reveals that there are no

Table 2.3 The values of the slack of (2.7)

s_i/iter	0	1	2	3
1	100	40	20	15
2	70	20	15	10
3	60	55	50	45
4	110	0	0	0
5	80	20	0	0

complementary slackness violations and the solution produced by the dual ascent procedure is optimal. Consider another instance with fixed costs $f_i = (200, 200, 200, 400, 300)$ and the same variable costs. At the termination of the dual ascent procedure, $s_2 = s_5 = 0$ and $v_6 = 285$ (the other v_j values are irrelevant here). Given that $c_{26} = 210$ and $c_{56} = 195$ (see Table 2.1), there is more than one c_{ij} with a smaller value than v_j, and hence (2.9) would be violated.

To close the duality gap in such cases, Erlenkotter first uses a *dual adjustment procedure*, and if this does not suffice, he resorts to a simple branch-and-bound. The dual adjustment procedure focuses on a customer zone j for which (2.9) is violated. Reducing the value of v_j can create slack for some of the binding dual constraints (2.7), which in turn can be used for increasing the value of other dual variables. As a result, the dual solution can be improved. Even if the dual solution remains the same, the associated primal integer solution would be altered because a different set of dual constraints would be binding after the adjustment. Continuing the above illustrative example, the value of v_6 is reduced to 210 in the adjustment procedure, creating slacks for three of the dual constraints (2.7) that are then used for improving the dual solution. The dual adjustment procedure processes each customer zone j associated with a complementary slackness violation and terminates when no further improvement to the dual solution is possible. If the duality gap persists, a standard branch-and-bound is utilized to identify the optimal solution. The solutions generated by the dual ascent and dual adjustment procedures serve as bounds during this final phase of the algorithm.

Erlenkotter solved *UFLPs* of up to 100 alternative facility sites and 100 customer zones, including the classical problem instances provided Kuehn and Hamburger (1963). In all but two of the instances, there was no duality gap at the end of the dual ascent and adjustment procedures and hence branch-and-bound was not necessary. Among the largest problem instances, two required branching and 21 nodal solutions were evaluated for the most challenging *UFLP*. Perhaps more importantly, the solution from the dual ascent procedure was within 1% of the optimal objective value in all reported instances. The quality of the lower bounds obtained from the condensed dual formulation, coupled with the ease of constructing primal integer solutions from a dual solution, underlies the efficiency of Erlenkotter's algorithm.

2.3 Kuehn and Hamburger (1963): A Heuristic Program for Locating Warehouses

Kuehn and Hamburger's classical paper presents, perhaps, the earliest heuristic solution approach for discrete facility location and describes in detail a set of twelve problem instances. Focusing on warehouse location, they highlight the potential advantages of these facilities due to (1) economies of scale in transportation costs between factories and warehouses, (2) economies of scope from combining products

from different factories into a single shipment in serving customer demand, and (3) improved delivery times by increased proximity to customer locations. In determining the locations for a set of capacitated warehouses, Kuehn and Hamburger trade off these potential cost savings associated with the new facilities with the costs of establishing and operating them.

They state the following three principles concerning the proposed heuristic:

1. most geographical regions are not promising sites for a regional warehouse, as locations with promise will be at or near concentrations of demand,
2. near optimum warehousing systems can be developed by locating warehouses one at a time, adding at each stage of the analysis that warehouse which produces the greatest cost savings for the entire system; and
3. only a small subset of all possible warehouse locations needs to be evaluated in detail at each stage of the analysis to determine the next warehouse site to be added.

In essence, Kuehn and Hamburger assume that the set of M alternative facility sites is a subset of the set of demand locations. They adopt a myopic approach as the basis of their heuristic, and confine the detailed evaluation at each iteration of the heuristic to a small subset of N location alternatives that they call the "buffer" (where $N<M$). The heuristic comprises a constructive phase ("the main program") and an improvement phase ("the bump and shift routine").

At the beginning of the constructive phase the buffer is initialized with the N sites, where serving the local demand with a local warehouse results in the highest cost savings. Then the N sites in the buffer are assessed one by one in terms of the system-wide cost savings that can be attained by opening a warehouse. The site that brings in the highest cost savings to the distribution network is assigned a warehouse, while the sites that do not offer any cost savings are eliminated from further consideration. The algorithm cycles between re-constructing the buffer from the remaining sites and the detailed evaluation step until all the sites are either eliminated or assigned a warehouse. The resulting solution is evaluated in the improvement phase to determine whether it is possible to attain cost savings by closing any of the open warehouses and/or by shifting each warehouse to another alternative site within its service region.

Kuehn and Hamburger propose 12 problem instances comprising combinations of three sets of factory locations and four levels of warehouse setup costs. The sample problems involve a single commodity and the transportation costs are assumed to be proportional to the railroad distances. The set of customer zones comprise 50 large cities across the United States, and 24 of these are also identified as alternative warehouse locations. The computational experiments were carried out with a buffer of 5 facilities. The Kuehn and Hamburger problem instances are available through the OR-Library at http://people.brunel.ac.uk/~mastjjb/jeb/info. html (developed and maintained by J. Beasley). These problems still constitute benchmark instances for comparing computational efficiencies of different algorithms for *UFLP* and *CFLP*.

2.4   Major Works that Followed

The classical *UFLP* and *CFLP* models have been extended in a number of ways by relaxing one or more of their underlying assumptions mentioned in Sect. 2.1. Here we provide an overview of the major works that extend the classical formulations by increasing the number of products, the number of facility echelons, and the number of time periods included in the model, as well as by more realistic representation of problem parameters through incorporation of possible scale and scope economies and uncertainties.

An immediate generalization of *UFLP* is the *multi-commodity* facility location problem that relaxes the single product assumption. Although Neebe and Khumawala (1981) and Karkazis and Boffey (1981) offered alternative formulations for this problem, both papers assumed that each facility deals with a single product. Klincewicz and Luss (1987) was the first paper that studied a multi-commodity facility location model without any restrictions on the number of products at each facility.

Another important extension involves increasing the number of echelons incorporated in the problem formulation. One of the earliest *multi-echelon* formulations is by Kaufman et al. (1977), which determined the locations of a set of facilities and a set of warehouses simultaneously. Tcha and Lee (1984) presented a model that could represent an arbitrary number of echelons. Both of these papers ignored the cost implications of possible interactions among the facilities at different echelons. Generalizing Erlenkotter's dual-based method, Gao and Robinson (1992) proposed an efficient dual-based branch-and-bound algorithm for the two-level facility location problem. Barros and Labbe (1994) presented a profit maximization version of the same problem and developed a branch-and-bound procedure based on Lagrangean relaxation as well as various heuristics.

Perhaps the most influential paper following the sketchy *CFLP* formulation in (the Appendix of) Kuehn and Hamburger (1963) was the contribution by Geoffrion and Graves (1974). Their model aimed at minimizing the total cost of transportation and warehousing over a distribution network comprising three echelons; factories, distribution centers (*DC*s), and customers. Given the existing plant and customer locations, Geoffrion and Graves (1974) devised a Benders decomposition approach for determining the optimal number and locations of the distribution centers to be established. They assumed a single-sourcing policy that requires serving each customer from a single *DC*. Their model contained both lower and upper bounds on *DC* throughput, which enabled modeling piecewise linear concave operation costs for the distribution centers. The differentiating feature of Geoffrion and Graves (1974) from earlier multi-echelon models was the way they modeled the flow variables. In earlier work, the flows between each pair of consecutive echelons were represented by a different set of decision variables, which required the use of flow conservation constraints at each facility. In contrast, Geoffrion and Graves (1974) used a single set of variables to represent the flows from the factories through the *DC*s to the customer zones. Although this leads to a considerable increase in the number of

decision variables, the resulting model is a tighter formulation of the problem that enables the development of efficient algorithms. Moon (1989) extended the model and solution procedure in order to incorporate possible economies of scale in *DC* throughput costs. To this end, he used general concave cost functions to represent the *DC* throughput costs. Pirkul and Jayaraman (1996) provided another extension that enables facility location decisions at both the *DC* and the plant echelons. However, they imposed limits on the number of *DC*s and plants that could be opened and relaxed the lower bound used by Geoffrion and Graves (1974) on *DC* throughput levels. In a subsequent paper, Jayaraman and Pirkul (2001) also incorporated supplier selection in a multi-commodity problem setting. Both papers used Lagrangean relaxation as a solution framework. Recently, Elhedhli and Goffin (2005) highlighted the efficiency of interior point techniques in solving multi-echelon formulations.

A number of researchers focused on relaxing the single period assumption of the *UFLP* and *CFLP*, and developed models and solutions for the *dynamic* facility location problem. The objective was to determine the spatial distribution of the facilities at each time period so as to minimize the total discounted costs for meeting the customer demand over time. The earliest work on this problem is by Van Roy and Erlenkotter (1982), who extended the dual-based algorithm of Erlenkotter to handle multiple time periods. Lim and Kim (1999) and Canel et al. (2001) proposed alternative methods for solving the problem with capacity restrictions at the facilities. Recently, Melo et al. (2005) presented a dynamic and multi-commodity formulation as an extension of the *CFLP* and investigated the possible use of the model as a framework for strategic supply chain planning.

Another stream of research to extend the classical *UFLP* and *CFLP* formulations focuses on improving the realism of the *cost representations* in these models. These efforts are motivated by the possible economies of scale and scope in the fixed and variable costs, as well as the potential cost implications of the interactions between a plant's location and the other structural decisions including capacity acquisition and technology selection. Soland (1974) is one of the earliest attempts to develop an extension of the *UFLP* that incorporates scale economies by representing the fixed facility costs as a concave function of facility size. Holmberg (1994) and Holmberg and Ling (1997) extended the *CFLP* by formulating the capacity acquisition costs as arbitrary piecewise linear functions. Verter and Dincer (1995) proposed a model where the capacity costs are assumed to be general concave functions of the capacity acquired at each facility. Erlenkotter's dual based algorithm is utilized as a subroutine during the progressive piecewise linear under-estimation technique developed in this paper. Dasci and Verter (2001) and Verter and Dasci (2002) provide extensions to a multi-product setting, where the firm is enabled to select among product-dedicated and flexible technology alternatives. At each alternative facility location, the technology options present different forms of scale and scope economies. More recently, a number of authors studied the integration of inventory control and logistics decisions with facility location. Shen (2005) used concave functions to represent economies of scale in the costs pertaining to the firm's inventories, whereas Snyder et al. (2007) and Sourirajan et al. (2007) presented facility location models that also considered the logistics costs.

An important stream of efforts to extend the classical *UFLP* and *CFLP* models involves the incorporation of *uncertainties* in the problem parameters. This is particularly relevant for global manufacturing firms that diversify their operations and facilities across many countries. Globalization has many potential advantages: access to cheap labor, raw material, and other production factors; presence at regional markets, and access to locally available technological resources and know-how. The resulting production-distribution networks are, however, increasingly exposed to price, exchange rate, and demand uncertainties in the international domain. The earliest efforts to incorporate exchange rate uncertainty in the *UFLP* are by Hodder and Jucker (1985) and Hodder and Dincer (1986). They used scenario-based approaches in modeling a risk-averse decision maker's structural choices. To this end, the expected profit is penalized by a term that corresponds to the constant portion of profit variability. Gutierrez and Kouvelis (1995) also used a scenario-based approach to find robust solutions under all possible scenario realizations. Canel and Khumawala (2001) and Kouvelis et al. (2004) studied the inclusion of subsidies and tariffs in international facility location models. Despite the popularity of the scenario-based approach in modeling the various types of uncertainties in the international domain, the prevailing papers show that the proliferation of the set of possible scenarios as a function of the problem size remains the major challenge from both academic and practical perspectives.

This section is an overview of the major works that followed the two classical papers reviewed in the preceding sections. The reader is referred to the recent reviews by Goetschalckx et al. (2002), Klose and Drexl (2005), Meixell and Gargeya (2005), Snyder (2006), Sahin and Sural (2007), and Shen (2007) for more exhaustive and comprehensive accounts of the state of the art in discrete facility location.

2.5 Potential Future Research Directions

In line with the classical *UFLP* and *CFLP* formulations, an overwhelming majority of the proposed extensions aim at minimizing the total fixed and variable costs relevant to the location problem under consideration. Using the categorization in Fisher (1997), these models are certainly suitable for designing efficient supply chains with functional products. The cost minimization objective, however, does not seem to be appropriate in the context of responsive supply chains that typically deal with innovative products. Note that many of the reported practical applications of discrete facility location models are associated with plant closure decisions, resulting in improved efficiency but mostly ignoring the possible ramifications concerning customer response. According to Ferdows (1997), the access to skills and knowledge and the proximity to markets are at least as important as the access to low-cost production factors in the firms' plant location decisions. Among the list of factors provided in Ferdows (1997), improving customer service, preemption of potential competitors, learning from supply chain partners, and attraction of a skilled workforce are typically not incorporated in the prevailing discrete facility location

models. It is necessary to improve the location modeling paradigms in order to better represent all the factors deemed important by firms in current practice. The need to improve the realism of the objective functions utilized in location models is also highlighted in Avella et al. (1999), summarizing the personal views of 20 young location researchers.

There is a need for increased empirical research in order to develop a better understanding of the factors that impact the facility location decisions of manufacturing and service firms and their decision making processes. Based on the location decisions of foreign-owned manufacturing plants in the United States in the 1990s, three factors seem to be most significant: the presence of a skilled workforce; the existence of a manufacturing base comprising suppliers, competitors and relevant industries, and the quality of transportation infrastructure. Interestingly, some of the past research reported rather conflicting empirical findings. For example, based on a survey of 73 plant managers, Brush et al. (1999) identified proximity to markets as the most significant location determinant, and concluded that subsidies and free trade zones are among the least important factors. Other authors, however, have pointed out that firms have been quite sensitive to subsidies, free trade zones, taxes and labor costs in making their location decisions (Coughlin and Segev 2000; Head et al. 1994). This calls for more empirical research and is perhaps due to the differences between the strategic priorities of the industries represented in the sample populations. If this observation can be confirmed through empirical studies, the development of industry-specific models rather than locating "generic" facilities would arise as a fruitful avenue for future research in location science.

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