A multi-objective model for developing retail location strategies in a DSS environment

12 A Multi-Objective Model for Developing Retail Location Strategies in a DSS Environment

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12.1 Introduction

In developing retail location policies, planners face major uncertainties regarding the questions how the consumer population will develop, where to locate facilities and how consumers and producers will react to new developments. The central aim of spatial decision support system (DSS) is to improve the effectiveness of locational decisions by making data and (analytic) models accessible to decision makers (Densham and Rushton, 1988; Armstrong and Densham, 1990; Densham, 1991). It has been argued on several occasions that recent advances in spatial modelling, information technology and data availability have favoured the cost-benefit ratio of these systems (Bertuglia *et al.* 1994, Birkin *et al.* 1996).

Several applications of DSS or customised GIS in retail planning have been described in the literature. Most systems focus on the feasibility and impact assessment of location plans using spatial interaction or discrete choice models (Roy and Anderson 1988; Borgers and Timmermans 1991; Kohsaka 1993; Birkin *et al.* 1994, 1996; Clarke and Clarke 1995; Arentze *et al.* 1996a). Generating retail plans in the earlier stage of the decision making process has received less attention. Generally, local and regional planners are concerned with developing a vision how the retail system under study should develop to attain a set of planning objectives. Such a vision or plan can serve as a basis for the formulation of location policies.

There exists a vast body of literature on the multiple facility location problem that is potentially relevant for retail planning. The methods developed involve the representation of a location problem in the form of an algebraic location-allocation model and the use of a standard algorithm for solving the model. For an overview of methods and applications see Ghosh and Rushton (1987) and Drezner (1995). Examples of applications in spatial DSS or customised GIS are reported in Armstrong *et al.* (1991), Kohsaka (1993), Densham (1994), Birkin *et al.* (1996) and Arentze *et al.* (1996a). In a former study, we have investigated the use of a knowledge-based system as an alternative approach to supporting retail plan formulation (Arentze *et al.*, 1996b).

The purpose of the present study is to develop a model based on the multiple facility problem literature that should be useful in a DSS for retail planning. To be useful in a DSS the model should meet the following requirements:

a. required data for using the model should be readily available in a standard DSS-database;

b. the model supports an interactive use so that decision makers can participate in the spatial search process;

c. the model can handle the multiple objectives involved in location planning;

d. the model is flexible in the sense that it does not depend on a specific formulation of model components (e.g., the shopping model).

The second and third requirement are particularly important for the acceptance of the system. The importance of an active involvement of decision makers in the spatial search process has been stressed by Malczewski and Ogryczak (1990), Densham (1991) and Armstrong *et al.* (1991). The ability to handle multiple objectives is important for the relevance of model results for real-world problems that are often ill-structured. To develop a model that meets these requirements, this paper is structured as follows. First, section 2 reviews current modelling approaches and clarifies the assumptions and objectives of our approach. The sections that follow describe the specification of the model and a case-study illustrating numerical properties of the model and its application in a DSS. Finally, the last section discusses the major conclusions and possible ways of future research.

12.2 Modelling Approaches

12.2.1 Current Approaches

Since the early sixties, location-allocation models have been widely used to solve multiple facility location problems. These models simultaneously optimise the location of facilities and the allocation of consumers to those facilities. A variety of generic problems has been formulated dependent on assumptions regarding the allocation and location rule. For example, the so-called *p*-median model allocates consumers to the nearest facility and selects the facility locations that minimise aggregate travel.

With regard to the location rule used, it is useful to make a well-known distinction between competitive facility problems and central facility problems. The first problem type is typical for private sector planning. It involves locating a network of facilities in a competitive market environment. In retailing, various location rules have been used for maximising different aspects of network performance. These include market share, profits, accessibility and demand in the catchment area (for a review see Ghosh and McLafferty 1987b; Kohsaka, 1989; Ghosh *et al.*, 1995). The central facility location problem, on the other hand, is relevant for planners who are concerned with finding a balance between consumer's benefit and the cost of supplying facilities. Beaumont (1987) gives an overview of models that can operationalise central place concepts. Leonardi (1981a, b) describes a unifying framework for public facility location models.

In the present context, we focus on the latter type of models. The majority of these models use the nearest-centre rule for allocating users to facilities. These models do not provide an adequate representation of retail location problems. In retail systems, consumers determine which facilities to patronise and, hereby, they make a trade-off between the attractiveness of facilities and travel distance. Two lines of research are potentially relevant for the present study. The first tradition has focused on making basic models more realistic by replacing the nearest-centre rule by a spatial interaction or choice model that can account for these trade-offs. Examples of this approach can be found in Hodgson (1978) and Beaumont (1987). Ghosh and McLafferty (1987a) used an allocation rule that accounts for multipurpose shopping. This rule assumes that consumers minimise a cost function and may, therefore, be criticised for not taking into account facility attractiveness.

Another tradition has focused on extending spatial interaction models to consider facility locations simultaneously. A number of approaches deserve attention. The models developed by Coelho and Wilson (1976) and Leonardi (1978) simultaneously optimise the location and size of facility centres based on maximising consumer surplus and a measure of accessibility (log-accessibility), respectively. Both models are formulated in the form of a mathematical program such that they can be solved using available non-linear programming methods. Furthermore, it is shown that in the optimum consumers are allocated to facility centres in accordance to a production constrained interaction model.

A closely related family of models is concerned with the dynamics of retail systems given assumptions of consumer and producer behaviour. Harris and Wilson (1978) introduced a retail equilibrium model that has invoked a large number of follow-up studies. The model is derived by solving the centre attractiveness term in a production constrained interaction model for which the costs of supplying facilities balances revenues. The costs-revenues balancing condition reflects equilibrium if producers maximise profits and there is enough competition between producers. The model describes a non-linear system in which producers and consumers react on each others actions. Follow-up studies have focused on numerical properties and extensions of this model (e.g., Beaumont *et al.* 1981; Clarke and Wilson 1983; Lombardo and Rabino 1989; Wilson 1990).

The above mentioned interaction-based location models appear to be equivalent. Leonardi (1978) shows that maximisation of consumer surplus, maximisation of log-accessibility and balancing of costs and revenues give the same solutions. Roy and Johansson (1984) interpret these solutions as Nash equilibria in a two-player game involving producers and consumers both pursuing their own interests. They suggest an extension to a three-player game by including the planning authority as an additional player. In their model, the role of the planner consists of formulating macro-location policies for allocating floor space across locations. The behaviour of producers and consumers is represented by entropy maximisation. The aim of the planner is to ensure overall efficiency and equity of consumer' and producer' benefits in the retail system. The efficiency criterion is a compromise between the interests of the three groups involved. The criterion is given by a weighted sum of factors related to transaction profits (retailers), travel costs (consumers) and operating and capital costs of the required public infrastructure (public interests). The equity criterion, on the other hand, is given by multiple objective functions related to equity in profits (retailers) and accessibility (consumers). Roy and Johansson suggest a satisficing approach to solve the multiple objective function problem.

12.2.2. Assumptions of our approach

Our approach combines elements of the approaches reviewed above motivated by the criteria a DSS-model should meet outlined in the introduction section. Following Roy and Johansson, we consider consumers, producers and planners as the three groups involved. We suggest that they have the following roles:

1. consumers decide on the allocation of expenditure across centres and pay for the services and travelling;
2. producers (developers and retailers) take facility investment decisions and pay for the investment and operating costs of supplying facilities;
3. planners decide on the potential location and available land for retail facilities and pay for the required public infrastructure costs (e.g., the road network and parking facilities).

We emphasise that the assumed role of the planner is somewhat more modest than previous approaches have assumed (e.g., Roy and Johansson's model). We assume that planners can create conditions for establishing facilities by designating shopping locations and providing public infrastructure. Whether or not opportunities offered are utilised eventually depends on producers' decisions. Implied by this assumption is that centre size is the outcome of interaction between consumers and producers rather than the decision of planners. To make effective location decisions, planners must, however, anticipate on centre size. The practical consequence of this assumption is that the location model should be based on realistic assumptions on consumer and producer behaviour. We further assume that the planning objective is to balance the interests of all the groups involved. In global terms, these include opportunities of consumers, opportunities of producers and public investments costs and externalities (Van der Heijden, 1986; Oppewal 1995). It follows that planning decision support requires a multiple objective analysis.

12.3 Model Specification

The proposed location model consists of two components. The first component describes the equilibrium state of the retail system with respect to the behaviour of consumers and producers. This component differs from the equilibrium model developed by Harris and Wilson (1978) on minor points related to the specification of the shopping model. However, in contrast to the work of Harris and Wilson, the model is a component of a broader model representing the location problem from the planner's point of view. The second component defines this location problem in terms of a set of objective functions. This section describes these two components in turn and, next, considers procedures for solving the location problem.

12.3.1 The Equilibrium model

The retail system is disaggregated into G branch sectors, such as for example convenience goods, semi-durable goods and durable goods. To reduce the complexity of the problem, location and size decisions are considered one branch sector at a time. In the following, we consider a certain branch sector, g, of the system, but for simplicity of presentation we will leave out the g-subscripts of the model variables.

The study area is subdivided into a set of residential zones $i \in I$ with retail demand $\{E_i\}$. Retail facilities are supplied at a set of shopping locations $j \in J$ with centre size $\{W_j\}$. Consumer choice behaviour is represented by an array $\{p_{ij}\}$ indicating the probability of a consumer in zone i selecting shopping destination j. A discrete choice model or production constrained spatial interaction model (or any other allocation model) is used to predict these probabilities based on centre size W_j, optionally one or more centre attributes X_{sj} and travel time or distance C_{ij}. For example, a discrete choice model of the multinomial logit (MNL) type can be written in general form as:

$$p_{ij} = \begin{cases} \dfrac{\exp(V_{ij})}{\sum_K \exp(V_{ij})}, & if\ W_j > 0 \quad j,k \in J_i \\ 0 & , otherwise \end{cases} \tag{12.1}$$

where:

$$V_{ij} = \alpha W_j + \Sigma_s \beta_s X_{sj} + \theta C_{ij} \tag{12.2}$$

p_{ij} probability of a consumer in i selecting centre j;
$J_i \subseteq J$ a location-specific choice set;
X_{sj} value of the j-th centre on the s-th attribute;
α weight of centre size (referred to as the scale parameter);
β_s weight of the s-th attribute;
θ distance decay parameter;
C_{ij} travel time or distance from the i-th zone to the j-th centre.

The size variable W_j is a fixed component of the model and can be taken as a measure of the choice range of products offered by the centre. The additional attributes, s, are optional and should be chosen in such a way that W_j can be manipulated independent of these attributes. The choice set J_i is location-specific and is usually defined as the set of centres reachable within a given travel time or distance (Borgers and Timmermans, 1991).

An estimate of centre revenues (sales) is then simply given by:

$$D_j = \sum_i p_{ij} E_i \quad \forall j \in \boldsymbol{J} \tag{12.3}$$

where:

D_j estimated sales (revenues) of centre j;
E_i amount of retail expenditure in zone i.

It should be noted that by using a constant for the expenditure term, E_i, this equation does not account for demand elasticity with respect to available supply. In an useful extension of the model, E_i is modelled as a function of the W_j's, possibly in the way described by Ghosh and Mclafferty (1987b). Furthermore, this equation assumes that the study area is closed in the sense that incoming expenditure and outgoing expenditure flows are zero. In reality, however, these flows are nonzero and depend on the available supply in the study area W_j.

Following much work in dynamic retail models, we assume that the costs of supplying facilities is given by $p_j W_j$, where p_j is a location-specific constant denoting the average cost per unit size. These costs include rent price, average wage and overhead for stores at location j. In particular, due to rent price these costs will vary across locations. Transaction profits are a proportion of revenues given by aD_j, whereby $0 < a < 1$. Now, we define $k_j = p_j/a$ to indicate the breakeven revenue per unit size.

Centre size W_j is the outcome of investment decisions of individual producers. However, the possible range of W_j is restricted by a given minimum W^{min} and a given location-specific maximum W_j^{max}. The minimum reflects the minimum scale of a centre required for an economically feasible exploitation. The maximum, on the other hand, is defined by the available land for retail activities designated by the planner. The value $W_j = 0$ indicates the absence of retail facilities at the possible shopping location j.

Following Harris and Wilson's equilibrium model, we assume that the collective behaviour of producers can be described as minimising the imbalance between costs and revenues. That is, investments continue as long as revenues exceeds costs and available land (W_j^{max}) allows further growth. Vice versa, de-investments (closure of stores) continue as long as costs exceeds revenues. If the minimum size W^{min} is reached, then facilities are not feasible at the location under concern and W_j drops to zero. Therefore, in equilibrium the following conditions hold:

$$W_j = \begin{cases} \dfrac{D_j}{k_j} \; if \; k_{jW}^{\min} \le D_j \le k_j W_j^{\max} \\ W_j^{\max} \; if \; D_j > k_j W_j^{\max} \quad \forall j \in \boldsymbol{J} \\ 0 \; if \; D_j > k_j W_j^{\min} \end{cases} \tag{12.4}$$

where:

k_j breakeven revenue per size unit;
W^{min} minimum scale required for a viable centre;

W_j^{max} metrage of the area available for retail facilities at location j.

Hence, for any centre: costs and revenues are in balance (12.4a), centre size has reached the maximum (12.4b) or facilities are not feasible (12.4c). If 'normal' profits are included in k_j, these conditions imply that retail activities do not generate more than normal profits unless the maximum size constrains further growth (4b).

The system defined by equations 12.1-12.4 is non-linear with respect to the W_j's. A required change in W_j to bring size in balance with revenues D_j affects the relative attractiveness of j and therefore causes a change not only in D_j but also in all D_k's, $k \neq j$. Equilibrium values of W_j's are therefore interdependent. The non-linear behaviour of a costs-revenues balancing condition in a spatial interaction model of the Huff-type has been extensively studied in the context of Harris and Wilson's model. A review of the findings can be found in Lombardo and Rabino (1989). The finding that is presently relevant indicates that within a reasonable range of the scale parameter of the interaction model ($0 < \alpha \leq 1$) there exists a positive ($W_j > 0$), unique and globally stable equilibrium solution (Rijk and Vorst, 1983). This finding cannot be readily applied to the present model. The minimum size constraint may prohibit nonzero solutions particularly when a relatively high minimum level is used. Furthermore, a system based on a MNL-formulation of the shopping model may have different properties in this respect. At present it is important to establish that a solution for W_j in equations 12.1-12.4 is unique and stable for reasonable values of the scale parameter.

An iterative procedure is commonly used for computing equilibrium points in systems like the one defined by equation 12.1-12.4. Bertuglia and Leonardi (1980) describe heuristic algorithms for solving this type of problems. The computed array of equilibrium values $\{ W_j \}$ is taken to represent the equilibrium state of the retail system with respect to consumer and producer behaviour. Obviously, the validity of this model depends on the validity of the shopping model and the balancing mechanism. The first assumes utility (or entropy) maximising shopping behaviour. The latter assumes profit-maximising behaviour of producers and a competitive retail market structure. With respect to the latter, Roy (1995) suggests that the competitive market assumption may be reasonable for low-order good retail markets (e.g., convenience goods), but that an oligopolistic model is needed to describe market equilibrium in higher-order good sectors. Therefore, a useful extension of the equilibrium model allows different market equilibrium conditions dependent on the retail sector under concern. A more general discussion on market structures and urban modelling can be found in Anas (1990).

12.3.2 Planning Objectives

Given the uniqueness of the solution of equations 12.1-12.4 for W_j, planners cannot exercise any influence on the equilibrium retail structure $\{ W_j \}$, once shopping location J and size $\{ W_j^{max} \}$ decisions have been made. Or, if planners do have the power to decide on $\{ W_j \}$, these decisions are completely restricted by the consumer and producer imposed conditions 1-4. In both perspectives, only the set $\boldsymbol{J}$ and array $\{ W_j^{max} \}$ are subject to planning. We assume that the available land $\{ W_j^{max} \}$ is given by higher level plans. Therefore, the only decision variable left for retail planners is the set of possible shopping locations ***J***. We emphasize that for any ***J*** the equilibrium model makes sure that demand matches supply for all centres included. Given the minimum size constraint W^{min}, the matching constraint implies that in equilibrium not necessarily all locations in a given ***J*** locate a facility (i.e., possibly $W_j = 0$).

We assume as given the set ***K*** containing all locations, $k \in \boldsymbol{K}$, considered as optional for inclusion in ***J***. In many cases, these will include existing shopping locations and new locations where centres can be built. We suggest that planners try to balance the interests of consumers, producers and the community in general (public). Then, the planning problem can be formulated as finding $\boldsymbol{J} \subseteq \boldsymbol{K}$ optimising or satisficing multiple objective functions $Z_q(\{ W_j \mid j \in \boldsymbol{J} \})$ related to interests of the different groups. The following objective functions may represent the planning problem.

Related to consumers:

•maximisation of aggregate utility for the consumer population:

$$\sum_{i \in I} \left(P_i \ \ln \sum_{j \in Ji} \exp(V_{ij}) \right) \tag{12.5}$$

•maximisation of minimum utility for the consumer population:

$$\min_{i \in I} \left(\ln \sum_{j \in Ji} \exp(V_{ij}) \right) \tag{12.6}$$

Related to producers:

•maximisation of total amount of viable floor space:

$$\sum_{j \in Ji} W_j \tag{12.7}$$

Related to the community in general:

•minimisation of aggregate shopping travel:

$$\sum_{i \in I} \left(P_i \ \ln \sum_{j \in Ji} (p_{ij} C_{ij}) \right) \tag{12.8}$$

•minimisation of retail infrastructure costs:

$$\sum_{j \in Ji} Z_j \qquad (12.9)$$

where:

P_i consumer population size in zone i;
Z_j costs of public infrastructure for retail activities at j.

and other elements are defined as above. Criterion 12.5 is a measure of the utility consumers derive from available facilities. Ben Akiva (1978) developed this measure based on assumptions of multinomial logit choice models. Maximisation of this measure tends to result in a few large centres near high population concentrations. In contrast, the next objective 12.6 tends to result in a larger set of (smaller) centres which are more evenly spread across the area. By maximizing the minimum utility across zones this objective reduces differences in shopping opportunities between locations. Criterion 12.7 favours locations with relatively low capital and operating costs (i.e., k_j) and favourable growth possibilities (large W_j^{max} compared to attracted demand D_j). Criterion 12.8 favours solutions that reduce aggregate travel so that these solutions have positive value for improving environmental quality and reducing traffic congestion. The last criterion 12.9 gives preference to locations where public infrastructure costs are low, for example, because infrastructure can be shared with other activities.

Objectives 12.5-12.9 are constrained only by the requirement that $\boldsymbol{J} \subseteq \boldsymbol{K}$. Generally, it is useful to impose as an additional constraint that some of the elements of $\boldsymbol{J}$ are fixed, i.e. must recur in any solution. Typically, planners may want to fix those existing centres that are not considered candidates for closure (or relocation). If $\boldsymbol{F} \subseteq \boldsymbol{K}$ is the set of fixed locations, then the more restrictive constraint can be written as $\boldsymbol{F} \subseteq \boldsymbol{J} \subseteq \boldsymbol{K}$. Finally, we emphasise that a solution for $\boldsymbol{J}$ indicates *potential* locations for retail activities. The equilibrium model determines which of these locations will be effective and will contribute to the performance of $\boldsymbol{J}$ in terms of the objective functions. In this sense, the equilibrium model constrains the extend to which solutions are effective.

12.3.3 An Iterative Multi-Objective Analysis

Malczewski and Ogryczak (1990, 1995, 1996) formulate a useful interactive approach for handling multiple objectives in central facility location problems. Their approach is based on a reference-point method, which, in contrast to goal-programming techniques, guarantees efficient (Pareto-optimal) solutions and does not require the specification of weights. In this approach, a solution to the problem emerges through interaction between the decision maker and the model (i.e., computer system). In global terms, the decision maker sets an aspiration level and a reservation level for each objective and the model generates efficient (Pareto-optimal) solutions. In an iterative process, the decision maker adjusts aspiration and reservation levels until a satisficing solution is obtained (for details, see the above mentioned studies).

12.3.4 A Possible Solution Algorithm

The reference-point method discussed above can be used to solve the multiple objective problem, provided that there is a solution procedure for solving each of the objective functions 12.5-12.9 separately. The objective functions incorporate the equilibrium model 12.1-12.4, in the sense that to evaluate a solution for ***J***, the equilibrium values of the W_j's must be known. A straightforward method of solving each single-objective function involves embedding an algorithm for calculating equilibrium values of W_j in an algorithm for optimising the number and location of centres. Informally, a procedure for solving an objective function, q, can be described in terms of the following steps:

a. set the number of centres N to a reasonable minimum
b. initialise N elements in a solution for ***J*** and make sure that $\boldsymbol{F} \subseteq \boldsymbol{J} \subseteq \boldsymbol{K}$
c. define starting values $W_j^{(0)}$ such that:

$$W_j^{(0)} = W_j, \qquad \text{if } j \in F$$
$$W_j^{(0)} = \tfrac{1}{2}\,(W^{min} + W_j^{max}), \qquad \text{else}$$

d. solve the equilibrium model (eq. 12.1-12.4) given starting values $\{ W_j^{(0)} \}$
e. calculate the objective function value of the equilibrium: $Z_q\,(\{ W_j^{(t)} \})$
f. set ***J*** to the next solution satisfyng $\boldsymbol{F} \subseteq \boldsymbol{J} \subseteq \boldsymbol{K}$ and repeat from step 3
g. increase N
h. repeat from step 2 until N exceeds a reasonable maximum
i. return the best solution

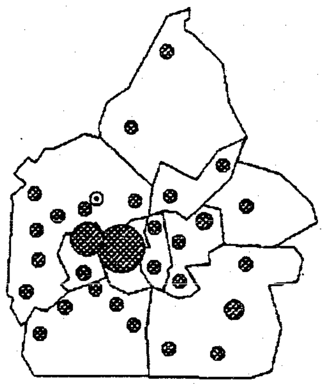
This algorithm optimises locations for each possible number of centres. To reduce required computer time, the number of centres is varied within a reasonable minimum and maximum defined by the planner. For generating new solutions for a given number of centres (step 6) a complete enumeration or a heuristic method can be used. The heuristic vertex substitution method developed by Teitz and Bart (1968) searches solution spaces in an efficient way and frequently converges to the optimum solution (Rosing *et al.*, 1979). To solve the equilibrium model for each solution (step 4) the iterative method mentioned earlier can be used, provided that suitable starting values $W_j^{(0)}$ are chosen (step 3). Starting values must be larger than zero, because the balancing mechanism operates only on centres with positive size. To facilitate rapid convergence and to ensure suitable starting positions, the size of new centres is set halfway between the minimum and maximum value and the size of existing centres is set to the existing size.

12.4 Illustration

The central component of the location model described in the former section is the equilibrium system based on the costs-revenues balancing mechanism. The behaviour of such systems has been extensively studied in the past, as noted before. However, no attention has been paid to the dynamic behaviour of MNL-based shopping models. This section describes a case-study conducted to investigate some numerical properties of this type of model. Furthermore, the case serves to demonstrate the application of the equilibrium model in a DSS-environment. To this end, we have implemented the equilibrium model in the retail planning DSS that we developed in earlier studies (Arentze *et al.* 1996a, 1996c, 1996d).

The case concerns convenience good facilities in Maastricht - a middle-sized city in the Netherlands with approximately 117.000 inhabitants. Figure 12.1 shows the spatial pattern of facilities in the situation that existed in the early nineties. Typically, convenience good facilities are supplied in a relatively dense set of small neighbourhood centres. In addition, convenience good facilities are present two larger centres with an above-local service area. The most centrally located one is the major shopping centre. As in many other larger cities in the Netherlands, the increase in scale of retail facilities that occurred over the last decade has threatened the viability of the small neighbourhood centres. To test its face validity and use in a DSS, we used the model to find a new equilibrium state of the retail system when a larger minimum scale (W^{min}) is imposed on the existing centres.

The study area was subdivided into ten residential zones, for which estimates of retail demand, E_i, were available. With respect to the supply side, table 12.1 shows



centre size

- 10 000 m²

- < 3 500 m²

Fig. 12.1. Spatial Pattern of Convenience Good Facilities in the Present State

Table 12.1. Data and Solutions of a MNL-based Equilibrium Model in the Maastricht case. Minimum centre size is 750 sq.m. and the scale parameter (α) is 0.00022 (solution 1), 0.00027 (solution 2) and 0.00032 (solution 3).

Present State		Solution (1)		Solution (2)		Solution (3)	
W_j (sq.m.)	D_j/k_jW_j	Δwj (sq.m.)	D_j/k_jW_j	ΔW_j (sq.m.)	D_j/k_jW_j	ΔW_j (sq.m.)	D_j/k_jW_j
12398	0.91	-1076	1.00	2602	1.09	2602	1.13
1962	0.83	-372	1.01	-412	1.01	-994	1.03
3136	0.63	-1093	1.00	-1258	1.01	-2051	1.01
229	1.25	-229	-	-229	-	-229	-
1905	0.51	-498	1.00	-909	1.00	-1905	-
351	1.08	-351	-	-351	-	-351	-
575	0.55	-575	-	-575	-	-575	-
1685	0.50	-540	1.00	-888	1.01	-1685	-
8710	1.08	-5889	1.00	-6232	1.01	6290	1.22
3755	0.56	-908	1.00	-1348	1.00	-3755	-
1061	1.33	1581	1.00	1308	1.01	-1061	-
932	1.44	1461	1.01	1192	1.00	-932	-
1084	1.27	1316	1.01	1092	1.01	-1084	-
1961	0.62	-332	1.01	-447	1.02	-1961	-
716	1.63	1447	1.01	1241	1.01	-716	-
1671	0.57	-424	1.00	-642	1.01	-1671	-
638	0.82	112	1.00	-638	-	-638	-
931	1.34	581	0.99	355	1.01	-113	0.99
1088	0.86	-59	0.97	-215	0.98	-1088	-
4490	0.80	-1259	0.99	-1454	1.01	-2855	1.00
3051	1.27	854	1.00	677	1.00	-1819	1.01
1500	1.19	455	0.99	258	0.99	-448	0.99
725	1.56	653	1.00	635	1.01	176	1.01
532	1.31	428	1.02	-532	-	-532	-
306	1.75	-306	-	-306	-	-306	-
2142	0.55	-938	0.99	-998	1.01	-1392	1.01
742	1.94	922	0.99	602	0.98	-742	-
1987	1.57	1887	0.99	1400	1.00	-1987	-
5074	1.24	1118	1.00	1590	1.00	9926	1.11

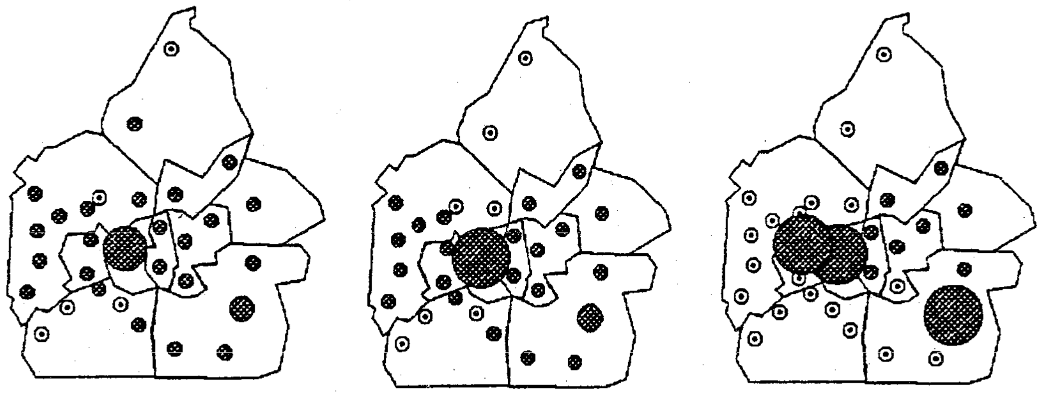


Fig.12.2. Graphical Display of Model Solutions 1-3.

the centre size, W_j, data that were used. The breakeven revenue per size unit, k_j, was set to a relatively low value (6 500 Dutch guilders) for the neighbourhood centres and a relatively high value (7 500 Dutch guilders) for the two larger above-local centres, to reflect differences in rent price. Travel time data, C_{ij}, were based on travel times reported by respondents in a consumer survey. Consumer choice behaviour was described by a MNL-model that included as explanatory variables floor space size in the convenience good sector (W_j), floor space size in the comparison good sector (say X_{1j}) and travel time (C_{ij}). Model parameters were estimated based on a survey of consumers residing in the area.

Equilibrium points were calculated for various values of the scale parameter, α, of the shopping model, using an iterative method. The minimum size W^{min} was (arbitrarily) set to 750 square meter. All maximum values, W_j^{max}, were set to the same arbitrarily large value (15 000 sq.m.), so that in effect the growth of all centres was unconstrained. In all cases convergence was reached within 8-10 iterations. The results are shown numerically in table 12.1 and graphically in figure 12.2. The solutions 1-3 are ordered based on increasing values of the scale parameter. Not surprisingly, this series is characterised by an increasing degree of concentration of retail facilities. Solution three represents the upper extreme case. In this solution three centres have reached the maximum size (15 000 square meter) at the expense of the smaller centres. In general, the solutions 1-3 seem to indicate that the floor space distribution pattern is relatively insensitive for variation in the scale parameter up to a certain point.

Beyond that point (solution 3), centres with a large starting size value tend to grow strongly at the expense of smaller competing centres, giving rise to highly unequal distributions of floor space across locations. More systematic computer experiments are needed to verify these statements and investigate other ones.

Given appropriate values of model parameters, the equilibrium points can provide useful information for plan decision making. A model solution shows the equilibrium state of the retail system under given starting conditions. Users can vary these starting conditions to evaluate the implications for the equilibrium. In this way, the impact of various assumptions regarding population and economic (per capita expenditure) developments can be investigated. Of particular interest are those starting conditions that can be controlled by planners in real-world situations. For example, the quality of the retail environment influences the competitive strength of centres and may be used by planners as an instrument to support weak centres. If the model is sensitive to such qualitative aspects of centres, then planners can use the model interactively to determine whether such supportive actions are likely to be effective for a particular centre.

12.5 Conclusions and Discussion

This paper described a multi-objective optimisation model for use in a DSS for retail planning. As a distinguishing characteristic of our approach, a retail equilibrium model is embedded in objective functions for evaluating retail plans. A retail plan specifies the possible locations and available space for developing retail activities. The equilibrium model then generates the equilibrium state of the retail system with respect to consumer and producer behaviour. Thus, the equilibrium model makes sure that the solutions generated are consistent not only with the goals of planners (as in most location-allocation models), but also with the behaviour of consumers (as in interaction-based location models) and the behaviour of producers (as in dynamic retail models). In that sense, the model is consistent with micro-economic theory. A case-study demonstrated some of the numerical properties of a MNL-based equilibrium model and the use of such models in a DSS.

This approach seems to have advantages particularly in an interactive DSS-environment. There are, however, also some potential problems that ask for further research. First, the computing time needed to solve the optimisation model may prohibit a highly interactive use. Efficient solution algorithms need to be developed. Second, it should be noted that the predictive validity of the shopping model is critical, as prediction errors may propagate in unknown ways across iterations. Therefore, in applications it is important to assess the sensitivity of the model for reasonable variations in parameter values. Furthermore, the shopping model should be extended to relax unrealistic assumptions, such as demand inelasticity and single-purpose shopping trips. Third, the balancing mechanism used in the present model may produce unrealistic equilibrium points in the case of market structures characterised by oligopolistic or monopolistic competition. This property is a potential limitation only if the equilibrium model is used for prediction. Alternatively, model outcomes can be taken to indicate the state of the retail system that planners can attain through negotiation with producers. In the latter case, the balancing condition is appropriate as it complies with conditions for optimal service provision (in terms of consumer satisfaction).

Besides the latter normative use, the retail equilibrium model is potentially useful for analysing impacts of decision scenario's for longer time horizons than would be possible based on a shopping model alone. A promising line of future research focuses on a model type in which equilibrium conditions are replaced by empirically estimated models of retailer's reactive behaviour. A framework for such models is developed in Van der Heijden (1986) and elaborated in Oppewal (1995). Then, successive steps in model solutions can be interpreted as describing retail development trajectories in time. Within limited time horizons the trajectories may give reliable information that planners can use to formulate actions in a time frame to guide developments.

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