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CITY CENTRE ENTRY POINTS, STORE LOCATION PATTERNS AND PEDESTRIAN ROUTE CHOICE BEHAVIOUR: A MICROLEVEL SIMULATION MODEL

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Abstract—The aim of this paper is to formulate and test a microlevel simulation model of pedestrian route choice and allocation behaviour within city centres. The model is developed to predict the likely effect of transportation plans and retail planning measures on pedestrian behaviour and hence on the profitability of shopping streets. The model captures the main characteristics of pedestrian behaviour as found so far in empirical studies. The model is tested in the city of Maastricht. The results indicate that the model gives a satisfactory description of pedestrian route choice and allocation behaviour. The paper is concluded by discussing some potential improvements of the model.

1. INTRODUCTION

The viability of retail facilities in city centres has become an increasingly difficult and pervading problem for many municipal governments. Generally, local governments are expected to create the necessary conditions for an optimal distribution of retail facilities over a residential area. Although urban retail planning policies might differ in terms of what they consider to be an optimal distribution, the majority certainly views the city centre of the larger cities in an urban region as the nucleus of the retail system. These city centres should provide the widest range of retail facilities, the most specialized functions and the largest number of shops. City centres have traditionally performed this role, basically due to the accumulated demand for retail facilities in these areas which suffices to meet the threshold requirements of the producers. It hardly needs mentioning that the city centre's centrality with respect to the regional transportation network has been a major determinant of their longstanding eminent position in the hierarchy of shopping centres.

During the last decade, however, the position of many inner-city shopping centres has been considerably weakened as the cumulative result of a series of interrelated fundamental changes in the nature of consumer demands and the methods of business supply. The process of outward migration has caused a reduction in the demand at the central locations while creating a new demand in peripheral locations. The increased demand in peripheral locations gave rise to planned regional shopping centres, superstores and hypermarkets in peripheral and out-of-town locations, a process which was further amplified by changes in the scale economies of business, leading to major changes in locational requirements, i.e. a need for more accessible locations, the availability of lower rents and larger sites in the periphery and a weakening of the linkages with the centrally located wholesaling sector. The consequence of these new peripheral larger-scale developments has been a drainage of the turnover in the inner-city shopping areas.

Many municipal governments and retail planning authorities have attempted to counterbalance this trend by a policy which aims at improving the attractiveness of the inner-city shopping areas. In particular, pedestrianisation of traditional shopping streets, redevelopment of town centre shopping areas, involving new in-town hypermarkets and planned shopping malls, and the improvement of the urban transportation system have been major policy and planning objectives in this respect. Unfortunately, though, such developments will generally not only have an impact on competing shopping centres but also on the existing trading patterns within the city centre itself. It seems that policy makers have paid relatively little attention to such consequences. While the likely effects of retail proposals on consumer behaviour and changes in retail turnover between shopping centres have almost invariably been assessed using rather sophisticated models such as entropy-maximising spatial-interaction models (e.g. [1]) and multinomial logit models (e.g. [2–4]), to the best of the authors' knowledge the effects on traditional trading patterns within the central area have rarely been modelled.

In part this lack of interest into the internal effects of new retailing developments and changes in the urban transportation system might be due to the lack of operational models for predicting and describing the functional and spatial relationships between characteristics of the transportation system, store location patterns and pedestrian route choice and shopping behaviour. The primary aim of the present paper is therefore to develop and test such a model. In particular, a microlevel Monte Carlo simulation model will be outlined. This model is empirically tested on the basis of data on route choice and shopping behaviour of consumers in the city centre of Maastricht. The paper is divided into four sections. The next section provides a summary of a literature study which has been conducted to draw together existing knowledge on pedestrian route choice and shopping behaviour within city centres and which should provide the basis for the formulation of the simulation model. This is followed, in section 3, by a description of the model. Section 4 then presents the main results of an empirical test of the simulation model. The paper is concluded by evaluating the empirical test of the model and discussing some potential improvements of the model.

2. A SHORT REVIEW OF PREVIOUS RESEARCH

Before presenting the simulation model, it is relevant to place this study in the broad context of previous research on pedestrian behaviour in town centres. Most research on pedestrian behaviour has been primarily concerned with a description of the relationships between store location pattern, transport termini and pedestrian behaviour. An early example is the study by Johnston and Kissling [5] on establishment use patterns within shopping centres in Christchurch and Melbourne. A major concern of their study was to identify recurring patterns of customer linkages between establishments. Their results suggested a strong sectoral and localized pattern of trip linkages. Using factor analysis and Markov chain analysis they concluded that the distance factor was a major determinant of patterns of within centre establishment choice. Pedestrians tended to patronize a group of neighbouring establishments in that part of the city closest to their homes. It appeared that pedestrian behaviour is closely related to the location of city centre entry points and the location of some magnet stores, which attract most of the trade. The commercial viability of other establishments or perhaps even shopping streets seemed largely to be dependent upon the degree of functional integration of these establishments and streets into the general pattern of pedestrian route choice.

These findings were further substantiated by the results of Bennison and Davies' study of pedestrian movement and the functional use of shopping centres within the city centre of Newcastle upon Tyne [6]. They concluded that in aggregate the movement of shoppers in the central area showed a high degree of organisation. More specifically, they found that the major shopping streets containing the largest magnet stores attract most pedestrian flows. This result emphasizes the importance of a small group of establishments in the organisation of pedestrian movement. In addition, they found that transport terminal points were an important secondary factor in the pattern of pedestrian route choice and shopping behaviour. Again, their results indicated a strong sectoral and localized pattern of pedestrian choice behaviour. Finally, the authors studied the comparative and complementary linkages within and between shopping streets and they identified varying degrees of functional linkages within and between streets. In particular, such linkages appeared to be a function of the varying retail character of the streets. The major shopping streets exhibited strong functional linkages with other streets. Comparative linkages were most important in the sector of durable goods, whereas complementary linkages were especially recorded in the sector of nondurable goods.

These findings suggest that changes in the location pattern of major stores and/or in the location pattern of city-centre entry points might have a considerable impact on the turnover of the shopping streets. The degree of such an impact will likely depend on the position of a street in the network of pedestrian flows. In a subsequent study, Bennison and Davies [7] have actually assessed the impact of a major intervention in the retail structure of the city centre of Newcastle. They found that the opening of the Eldon Square Centre resulted in a substantial decline in trade at neighbouring shops. On the other hand, the impact on more distant streets was almost negligible, suggesting that the degree of impact depends largely upon the strength of the functional relationships between streets and retail sectors. This is further substantiated by the fact that the opening of the new shopping centre has resulted in a new pattern of functional linkages whereby some of the older patterns have changed dramatically, whereas other functional subpatterns have remained relatively stable.

It is evident that the above findings can at least partially be explained in terms of principles of distance- or effort-minimising behaviour. However, some authors have suggested that these patterns of pedestrian movement and shopping behaviour might also reflect consumers' knowledge of the retail opportunities in the city centre and biases in their mental maps. For example, Goodey *et al.* [8] showed that magnet stores predominated respondents' sketch maps of Birmingham city centre. In addition, Meyer [9] demonstrated biases in distance perception within the city centre of Erlangen. Pedestrians tended to underestimate distances of preferred shopping streets, of streets in the direction towards the home and of frequently visited streets. Davies and Bennison [10] also found that a respondent's awareness of shopping streets was heavily influenced by his place of residence, the locations of city-centre entry and trip completion points and the attractivity of the shopping streets.

In summary, the empirical evidence accumulated so far suggests the existence of some regular patterns in pedestrian movement and choice behaviour within inner-city shopping areas. Any model of pedestrian movement within city centres should, in theory at least, be able to reproduce these patterns. In particular, the results of the empirical studies indicate that pedestrian movement within city centres might be envisaged as some type of multipurpose trip, whereby pedestrians patronize a sequence of shops to satisfy their needs. These trips tend to exhibit a strong sectoral and localized pattern which is the result of the tendency that pedestrians are generally engaged in a behaviour which minimizes perceived distance or effort in the act of buying the required set of shopping goods. Major shopping streets and city-centre entry points serve as foci in this trip pattern. The subjective perception and evaluation of street characteristics seems to be more important for pedestrian route choice than their objective counterparts and, finally, the viability of many shopping streets likely depends upon their degree of centrality in the network of pedestrian flows as reflected in the strength of their functional relationships and their relative location within the city centre. Existing models of pedestrian flows, being based on principles of entropy maximalization [11, 12] or on aggregate nonspatial relationships between accumulated demand and land use characteristics [13] are inherently inappropriate to account for these regularities. In the next section, therefore, a simulation model, which is explicitly based on these empirical findings, will be outlined.

3. THE SIMULATION MODEL

Let there be given some network system for a city centre containing a total of N city-centre entry and departure points and L links denoting shopping streets. Let C_n be the total numbers of consumers departing from the nth entry point. Each link l ($l = 1, 2, \ldots, L$) is described by a series of K objective characteristics X_{lk} ($k = 1, 2, \ldots, K$), which represents a set of variables influencing the attractiveness of the lth link. In addition, each link has an associated length d_l. Let P_l denote the total number of pedestrians who pass the lth link. Finally, a route r is defined as consisting of a series of adjacent links through which a consumer passes in the conduct of his shopping.

The problem then is to model the route choice and the destination selection behaviour of the consumers. In the present case, this is accomplished by means of a Monte Carlo simulation model which implies that the behaviour of each individual consumer is simulated by a series of draws of random numbers from successive probability distributions. In particular, the following operations and rules govern the process of pedestrian movement and choice behaviour through the network. First, a number of exogenous quantities are determined. Each consumer is supposed to buy one or more goods. This number of goods is obtained by drawing a random number; that is, the observed relative frequency distribution of number of goods for each city entry point is first transformed into a distribution of accumulated integers, such that the range of integer values for each category corresponds to these relative frequencies and the required number of goods is obtained by drawing a random number within the range of accumulated integers and interpreting the category to which the randomly selected number applies. Let i be the number of goods the consumer is supposed to buy during his shopping trip. In the following step, it is decided in which retail sectors these i goods are bought. Again this is accomplished by randomly drawing i numbers.

The underlying probability distribution is

$$p(g|i) = \sum_{l=1}^{L} B_{li}^{(g)} / \sum_{l=1}^{L} \sum_{g=1}^{G} B_{li}^{(g)}, \quad i = 1, 2, \ldots, I, \qquad (1)$$

where $p(g|i)$ is the probability that a consumer will buy a good of retail sector g, given that he buys a total of i goods, and $B_{li}^{(g)}$ is the observed total number of consumers who buy a good in retail sector g at the lth link of the network given that they buy a total of i goods.

Note that eqn (1) applies to the network as a whole, which implies that the probability of the selection of a particular retail sector is assumed to be independent of the city-centre entry point. Next, the sequence in which these i goods are bought is determined on the basis of the relative frequency distribution of all possible permutations of i goods.

The second phase of the model is concerned with predicting and simulating the links where the different goods are bought. It is assumed that the probability that the first good in the simulated sequence will be bought in a particular shopping street or link equals

$$p_{nl}^{(g)} = \frac{(\sum_{m \in l} F_m^{(g)})^{\alpha} \exp(-\beta \min_{r|n}[\sum_{l' \in r} d_{l'}])}{\sum_{l'=1}^{L} \{(\sum_{m \in l'} F_m^{(g)})^{\alpha} \exp(-\beta \min_{r|n}[\sum_{l' \in r} d_{l'}])\}},$$

$$(n, 1, 2, \ldots, N; l = 1, 2, \ldots, L), \qquad (2)$$

where $p_{nl}^{(g)}$ is the probability that a good in retail sector g will be bought at link l providing that the pedestrian departed from city entry point n, $F_m^{(g)}$ is the total amount of floorspace in retail sector g at destination m ($m = 1, 2, \ldots, M$), $\min_{r|n}[\sum_{l' \in r} d_{l'}]$ is the distance associated with the shortest route from city centre entry point n to link l, and α, β are parameters to be estimated. Equation (2) reflects the empirical finding that pedestrian route choice behaviour is closely related to the location pattern of the shops and city-centre entry points and heavily influenced by distance. It is estimated on empirical data of shopping choice behaviour disaggregated by retail sector.

Having determinated the link where the first good is bought, the model proceeds by simulating the choice of the links of the remaining ($i - 1$) goods, that is, if $i > 1$. Otherwise the model assumes that the consumer returns to the entry point from where he departed. This choice process is simulated on the basis of the following equation:

$$p_{nl}^{(g)} = \frac{(\sum_{m \in l} F_m^{(g)})^{\alpha} \exp(-\beta \min_{r|n}[\sum_{l' \in r} d_{l'}])}{\sum_{l'=1}^{L} \{(\sum_{m \in l'} F_m^{(g)})^{\alpha} \exp(-\beta \min_{r|n}[\sum_{l' \in r} d_{l'}])\}},$$

$$(n, l = 1, 2, \ldots, L). \qquad (3)$$

Equation (3) is identical in form to eqn (2). However, whereas the latter equation is based on the minimum distance between city-centre entry points and shopping streets, the former equation is based on distances between shopping streets. Together, these equations implicitly assume that pedestrians are engaged into a sequential utility-maximizing behaviour rather than into a simultaneously utility-maximizing behaviour.

Again, the simulation process proceeds by drawing random numbers. Each potential link received a range of accumulated integer numbers proportional to eqns (2) and (3) respectively and a link is assumed to be chosen if a randomly selected number falls within its range of integer numbers.

The results of the second phase of the simulation model is that a pedestrian's city-centre entry point and the links where he buys a number of goods are known. In the third stage the model simulates the route choice behaviour of a pedestrian given this information on the location of the entry point and the links. It is assumed that the point of completion of his trip is the same as his point of entry. Dynamic programming techniques can be used to simulate route choice. More specifically, it is assumed that route choice is subjectively based as is indicated by the results of the empirical studies. If x_{lk} denotes the subjective perception or evaluation of a shopping street's attributes, it is assumed that these subjective quantities are systematically related to the objective characteristics of the shopping streets; that is,

$$x_{lk} = f_k(X_{lk}), \quad k = 1, 2, \ldots, K. \qquad (4)$$

The form of the functional relationships (f_k) is assumed to depend upon the kind of characteristic in question. Given these equations, the subjective utility for each link can be obtained by a suitable combination of these subjective values:

$$U(l) = h(x_{lk}), \quad k = 1, 2, \ldots, K, \tag{5}$$

where $U(l)$ denotes the subjective utility of link l, and h is some algebraic function for combining the separate subjective values across attributes. Likewise, the utility of a route equals

$$U(r) = h'(U(l); d_r), \quad l \in r, \tag{6}$$

where h' is some algebraic function, and d_r is the total (subjective) distance associated with route r. It is assumed that a pedestrian will choose that route which maximizes his subjective utility. Hence

$$p(r|R) = \begin{cases} 1, & \text{if } U(r) = \max_r(U(r)), \quad r \in R, \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Consequently, a pedestrian passes through link l if $l \in r$.

The route choice problem can be solved in terms of the well-known generalized stagecoach problem of dynamic programming, which is applied in a series of successive steps, given two consecutive destinations in the simulated sequence of i destinations.

This whole simulation process is repeated for each consumer at each entry point in a series of replications, such that the total number of replications for each city-centre entry point equals C_n. In addition, the following quantities are calculated:

$$P_l = \sum_{s=1}^{C'} \sigma_s, \tag{8}$$

$$S_l^{(g)} = \sum_{s=1}^{C'} \phi_{ls}^{(g)}, \tag{9}$$

where

$$\sigma_s = \begin{cases} 1, & \text{if } p(r|R) = 1 \wedge l \in \mathrm{r} \text{ at simulation } s, \\ 0, & \text{otherwise,} \end{cases}$$

and

$$\phi_{ls}^{(g)} = \begin{cases} 1, & \text{if at simulation } s \text{ a good in} \\ & \text{retail sector } g \text{ is bought at link } l, \\ 0, & \text{otherwise,} \end{cases}$$

$$C' = \sum_{n=1}^{N} C_n,$$

$S_l^{(g)}$ is the total number of goods in sector g bought at link l.

For practical planning purpose additional quantities can easily be computed in a straightforward manner. For example,

$$T_l^{(g)} = S_l^{(g)} E^{(g)}, \tag{10}$$

$$V_l^{(g)} = T_l^{(g)} / \sum_{m \in l} F_m^{(g)}, \tag{11}$$

where $T_l^{(g)}$ is the turnover in retail sector g at link or shopping street l, $E^{(g)}$ is the average per capita expenditure in retail sector g, and $V_l^{(g)}$ is the turnover-to-floorspace ratio in retail sector g in shopping street l. Such quantities might prove useful in assessing the impact of alternative retail and transport policies on the viability of shopping streets within a city centre.

4. AN EMPIRICAL TEST OF THE MODEL

The model outlined in the previous section was tested using data pertaining to the city centre of Maastricht. The city centre of Maastricht constitutes an interesting case in that it has a relatively complex structure which allows several possible routes. For this city centre, a network involving 88 links and 6 entry points was constructed.

Most of the data used to calibrate the model was collected using on-street interviews. These interviews were in the form of a structured questionnaire. Only pedestrians who were leaving the city centre were asked to complete the questionnaire. The data collected in the interview consisted of the entry point in the city centre, the route taken on the pedestrian trips and the destinations associated with it, and the goods bought at these destinations.

The route taken was marked by the respondent on a map of the city centre of Maastricht. The respondents also indicated on this map the locations where they had shopped and which goods they had bought at these locations. These goods were classified into five classes: groceries, clothing, department stores, markets and other. The respondents also indicated whether or not they shopped regularly at these locations. The sample consisted of 426 respondents. The model was calibrated on the basis of those respondents who shopped regularly at one of their destinations; that is, the responses of 345 respondents were used to calibrate the simulation model. The distribution of these respondents over the six entry points is provided in Table 1. This table clearly illustrates that the respondents are equally distributed over the entry points.

The first step in the calibration process involved the calibration of the submodel, which predicts the probability that a destination (link) will be chosen [eqns (2) and (3)]. A gradient search technique was employed to find the parameter values, the objective function being the squared differences between the observed and the predicted choice probabilities. The model was calibrated for each sector of goods separately. The following equations were obtained (Table 2). Table 2 also gives the goodness-of-fit of the model. Specifically, it provides the value of Pearson's product–moment cor-

Table 1. Distribution of respondents over the entry-points

Entrypoint	Number	Percentage
1	68	19.7
2	59	17.1
3	60	17.4
4	60	17.4
5	52	15.1
6	46	15.3
Total	345	100.0

Table 2. Results of the distribution submodel

Sector of good	Parameters α	Parameters β	Correlation coefficient inter-actions	Correlation coefficient dest. totals
I	1.214	0.027	.730	.890
II	1.172	0.034	.756	.928
III	1.732	0.006	.999	.999
IV	1.648	0.162	.997	.999
V	1.047	0.021	.405	.620

relation coefficient both on the basis of the destination totals and on the basis of the interactions.

Table 2 clearly illustrates that the goodness-of-fit of the submodel for product classes, one, two, three and four is satisfactory. Pearson's product–moment correlation coefficient ranges from .730 to .999 for the interactions and from .890 to .999 for the destination totals. The results for product class five are, however, less convincing. In part, this disappointing result might be due to the small sample size for this product sector in connection with the wide supply within the sector. As a result of these factors the average number of respondents buying a product within this sector in a link is small. Moreover, the measurement of the available floor space in the various links might be inconsistent with the behaviour of the sample respondents. And, finally, given the wide range of products falling into this sector, pedestrians' behaviour itself might be too heterogeneous to obtain good results.

Once this submodel has been estimated, the simulation model can be run. Each run involves the following steps. First, the total number of stops is determined by drawing at random from the relative frequency distribution of the total number of nonimpulse stops for each entry point. Next, the type of goods as well as the sequence in which these types of goods are simulated by drawing randomly from the respective relative frequency distributions. The locations or links where these goods will be bought are then predicted by drawing aselect numbers from the distribution, provided by eqns (2) and (3). The steps are repeated for each entry point until the total number of simulated pedestrian trips equals the total number of observed pedestrian trips for each entry point. To get a stable outcome, a total of 100 of such simulation runs were performed.

The predictive validity of the simulation model was tested on the basis of the following quantities:

1. the goodness-of-fit of pedestrian flows between the links of the network for each type of good;
2. the goodness-of-fit of the arrivals in the links of the network for each type of good;
3. the goodness-of-fit of the departures from the links of the network for each type of good;
4. the goodness-of-fit of the total pedestrian flows between the links of the network;
5. the goodness-of-fit of the total number of arrivals in the links of the network;
6. the goodness-of-fit of the total number of departures from the links of the network;
7. the goodness-of-fit of the demand in the links of the network for each type of good;
8. the goodness-of-fit of the total demand in the links of the network;
9. the goodness-of-fit of the total demand for each type of good.

Although several measures were calculated to quantify the goodness-of-fit of the model, only Pearson's product–moment correlation coefficient is reported here. In general, though, the results were consistent across the several goodness-of-fit measures.

Table 3 provides the results for the first three quantities. It clearly shows that in general the predictive validity of the simulation model in terms of predicting the pedestrian flows between the links of the network and the arrivals in and departures from the links of the network for each type of good is satisfactory. In particular, the goodness-of-fit for department stores and markets is very good, but the goodness-of-fit for clothing and groceries is still quite satisfactory. Only for the category "other" is the correspondence between the observed and the predicted pedestrian flows relatively weak, but this is not surprising given the results of the calibration of the submodel for this category. Table 3 also illustrates that after, say, 20 simulation runs the results tend to stabilize. Hence, only 20 runs would suffice to predict pedestrian movement within the network.

Table 3. Predictive validity of the Monte Carlo simultation model in terms of Pearson's product–moment correlation coefficient for each type of good

Number of runs	I F	I A	I D	II F	II A	II D	III F	III A	III D	IV F	IV A	IV D	V F	V A	V D
1	.377	.808	.967	.593	.915	.960	.977	.999	.977	.979	.999	.983	.146	.449	.929
10	.696	.901	.988	.736	.941	.982	.990	.999	.990	.989	.999	.993	.319	.619	.983
20	.722	.903	.988	.752	.939	.983	.991	.999	.992	.988	.999	.992	.362	.648	.983
30	.711	.902	.986	.755	.940	.985	.991	.999	.991	.989	.999	.994	.371	.658	.984
40	.714	.902	.986	.756	.941	.985	.991	.999	.992	.990	.999	.994	.382	.651	.985
50	.716	.903	.984	.758	.942	.987	.991	.999	.992	.990	.999	.994	.390	.653	.985
60	.717	.904	.985	.756	.941	.986	.991	.999	.992	.991	.999	.994	.388	.647	.985
70	.721	.903	.986	.759	.942	.987	.991	.999	.992	.990	.999	.994	.383	.646	.985
80	.720	.903	.986	.757	.941	.988	.991	.999	.992	.990	.999	.994	.387	.641	.985
90	.722	.903	.986	.759	.942	.988	.991	.999	.992	.991	.999	.994	.395	.640	.986
100	.722	.903	.986	.759	.942	.988	.991	.999	.992	.991	.999	.994	.393	.639	.986

F = flows, A = arrivals, D = departures.

Table 4. Predictive validity of the Monte Carlo simulation model in terms of Pearson's product–moment correlation coefficient for total pedestrian flows

Number of runs	Flows	Arrivals	Departures
1	.889	.984	.984
10	.937	.992	.992
20	.941	.992	.992
30	.941	.992	.992
40	.941	.992	.992
50	.941	.992	.992
60	.941	.992	.992
70	.941	.992	.992
80	.941	.992	.992
90	.941	.992	.992
100	.942	.992	.992

Table 3 provides the results for each type of goods. However, since the various types of goods are not equally important, still other quantities for expressing the goodness-of-fit of the model are based on the total number of pedestrian flows. The results of such an analysis are given in Table 4, which clearly illustrates that the correspondence between the observed and the predicted total pedestrian flows, arrivals and departures is high. Pearson's product–moment correlation coefficient for the pedestrian flows between the various links of the network is .941 after 20 simulation runs, while the coefficient even equals .992 after 20 runs for the arrivals and departures.

Finally, the goodness-of-fit of the simulation model was tested by calculating Pearson's product–moment correlation for the observed and predicted "type of good" × "link" (5 × 88) demand matrix. The results are given in Table 5. Again, Table 5 indicates that the predictive validity of the model is satisfactory. Already after 10 simulation runs the coefficient is equal to .984 on the basis of the cells of this matrix; that is, the demand in the various links of the network for each type of good. The prediction of the total demand in the various links is also good, as indicated by the value of .989 after 10 simulation runs. As would be expected, the simulation model exactly predicts the total demand for the types of goods.

The next step in the analysis involved the estimation of the submodel which predicts route choice behaviour of pedestrians, given their destination choice. It was assumed that route choice was primarily influenced by the distance separations between alternative links. Hence, it was assumed that

$$U(r) = h'(d_r).$$

Since not all factors influencing the route choice process will be captured in this way, the additional assumption was made that a pedestrian's utility for a route consists of a deterministic part, $\bar{U}(r)$, and an error term ϵ_r. These two parts were assumed to be independent and additive, yielding

$$U(r) = \bar{U}(r) + \epsilon_r.$$

If pedestrian choice behaviour is assumed to be the result of a utility-maximizing process, it follows that the choice probabilities can be obtained by specifying distributional assumptions regarding the error terms. If a double-exponentional distribution is assumed, a tractable closed-form expression, known as the multinomial logit model, results. It can be expressed as

$$p(r|R) = \frac{\exp(\beta d_r)}{\sum_{r' \in R} \exp(\beta d_{r'})}.$$

The parameter of this submodel was estimated by maximum likelihood procedures on the basis of the observed route choices of the pedestrians. The estimated parameter value was −0.04, its standard error 0.005 and the model correctly predicted 52.4% of the observed routes, which is a satisfactory result if the large number of routes is realized. Once this submodel was estimated, it was used to simulate pedestrian's route choice behaviour. This phase of the simulation process involved identifying choice sets, estimating the utility associated with each route and then predicting the route a pedestrian will choose. It was assumed that a pedestrian will choose the route that maximizes his utility. The identification of the routes within a choice set required special attention since the enumeration of all possible routes would require too much computing time. Hence, it was decided to limit a pedestrian's choice set by implementing the following rules.

- The length of a route will not be more than 2.5 times the length of the shortest route; 91.2% of the observed routes in the survey satisfy this condition.
- A route has a maximum of 13 links. This rule applied

Table 5. Predictive validity of the Monte Carlo simulation model in terms of Pearson's product–moment correlation coefficient on the basis of demand

Number of runs	Demand in links for each type of good	Demand for each type of good	Demand for links
1	.973	.997	.978
10	.984	1.000	.989
20	.985	1.000	.989
30	.985	1.000	.989
40	.985	1.000	.989
50	.985	1.000	.989
60	.985	1.000	.989
70	.985	1.000	.989
80	.985	1.000	.989
90	.985	1.000	.989
100	.985	1.000	.989

Table 6. Some goodness-of-fit measures for the submodel of pedestrian route choice

Measure	Value
Coefficient of correlation	0.902
Robinson's agreement measure	0.942
Root mean square	29.879
Standard deviation of residuals	30.039
Theil's inequity coefficient	0.112
Mean absolute difference	17.788
Standardized information index	0.367

to 94.7% of the observed routes. If a destination cannot be reached within 13 links, this rule was relaxed by calculating the minimum required number of links.

- If a pedestrian has two sequential stops in the same street, he is supposed not to have left the street. This rule applied to 94.0% of the cases in the survey.
- A route consists of mutually exclusive links. This rule was satisfied by 86.8% of the observations.
- If the total number of routes included in a pedestrian's choice set, given the above rules, is greater than 50, the 50 shortest routes were identified, and these 50 routes then constitute a pedestrian's choice set.

Given these rules, a variant of the stagecoach algorithm of dynamic programming was used to simulate the route choice of pedestrians within the city centre of Maastricht. The submodel was tested by calculating some goodness-of-fit measures, which quantify the degree of correspondence between the observed and predicted number of pedestrians in all shopping streets within the city centre.

The results are given in Table 6. Table 6 clearly shows that the fit is satisfactory. Pearson's product–moment correlation is 0.902, which implies that the submodels account for 81% of the variance in the number of pedestrians in the shopping streets. The value of Robinson's agreement measure suggests that the predictions are also sufficient linearly related to the observations. Finally, Table 6 demonstrates that the root mean square, the standard deviation of residuals and the mean absolute difference are quite acceptable, given the sample size and the total number of links in the network.

5. SUMMARY AND CONCLUSIONS

The main thrust of the present paper has been to develop and test a Monte Carlo simulation model to predict the destination and route choice behaviour of pedestrians within city centres. Such a model could be used to predict the likely impacts of changes in locational patterns of shops and the location of city centre entry points on pedestrian behaviour and thus on the viability of shopping streets. A literature search suggested that pedestrian destination and route choice is strongly sectoral and that the functional relationships between shops play an important role in this respect. The model, developed in this study, attempts to incorporate these elements and others such as the sequence in which goods are bought into a modelling framework and it is in this very respect that it differs from existing models. A general framework for modelling pedestrian choice behaviour was outlined and an operational model was tested.

The findings of the empirical analysis generally support the model. The correspondence between the predicted and the observed quantities is satisfactory. Nevertheless, the operational model only constitutes one approach for predicting pedestrian destination and route choice. The various submodels could be made more complex, alternative functional relationships could be tested and additional independent variables could be incorporated into the submodels. In addition, the simulation model could be disaggregated according to the number of stops. The effect of such extensions on the model's predictive validity warrants, however, further research. The authors hope to report on such developments in future publications.

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