tem, fewer iterations will be performed before the optimum solution is reached. It would be advisable to incorporate, let us say, budget constraints to be faced by the planner at each decision point.

6. Both problems analyzed present completely different structures. The first concerns a small network, and the user-optimized rule is used for network equilibration. The second concerns what can be regarded as a medium network, and the equilibration procedure used is the system-optimized rule. The proposed algorithm could be applied in both cases. This illustrates its versatility.

7. As Ochoa-Rosso (4) points out, more research should be devoted to the study of the trade-off between the branch-and-bound and branch-and-backtrack methods. Although the first requires greater computer memory, the second is more time consuming. This needs to be verified.

8. The technique proposed here for capital investment problems should be compared with another optimization procedure such as the Bender method.

ACKNOWLEDGMENT

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**P. A. R. Lago was a graduate student at the Massachusetts Institute of Technology when this research was performed.*

Residential Area Location Preference Surfaces

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Although an understanding of the interaction between land use and transportation is essential to a rational evaluation of urban and regional policy, it is frequently complicated by the introduction of sophisticated mathematical techniques. In an effort to make this interaction more visible to the decision maker, two of the more advanced techniques—multinomial logit analysis and mental maps—are placed in a common framework of analysis and presentation. The strength of a rigorous theoretical background is thus combined with the simplicity of a visual presentation. The theory and development of the technique are outlined, and its use in a case study of the residential location preferences of residents of the inner suburbs of Melbourne, Australia, is described.

An understanding of the ways in which transportation investment, activity placement, and residential location interact is essential to a rational evaluation of urban or regional policy alternatives. Frequently, however, the methods used by planners to examine these interactions are complicated by the introduction of sophisticated mathematical models. Although such models may improve the explanatory power of the planning method, such an improvement is frequently made at the expense of the layman's understanding of the method.

If one wishes to make the interactions clearly visible to the decision maker, who frequently is not aware of the mathematical complexities involved in the modeling process, a clear, concise method for the presentation of results and implications must be devised. This paper attempts to provide such a method and at the same time to use two of the more advanced mathematical techniques in the analysis of location decision: multinomial logit choice modeling and the concept of mental, or cognitive, maps.

The approach, which is shown schematically in Figure 1, has essentially three stages. In this paper, the model is developed in the context of urban residential location. However, the basic model structure, as outlined in Figure 1, could well be applied to problems that involve regional development policies, decentralization, or alternatives of facility location.

THEORY OF CHOICE

A great deal of research in the areas of economics and psychology has been devoted to establishing a general theory of choice. Although many of the results have been conflicting, several general themes permeate all modern theories of choice.

First and foremost is the concept that all choice decisions are probabilistic. This implies that a decision outcome can never be inferred with certainty. All that one can do is to assign a probability to that decision. Second, choice decisions are not made between alternative objects but rather between the alternative sets of characteristics that those objects possess. This idea is expressed in the economic literature in Lancaster's new approach to consumer theory (1) and in the psychological literature in Rosenberg's cognitive summation theory of attitude (2).

Beyond these common principles, however, there are a large variety of methods that link the characteristics of an object with the eventual choice of that object. One basic component of psychological models of choice that is not generally found in economic choice models is the realization that the choice process is composed of three separate but interrelated phases. Such a general choice model, described by Golob and others (3) and Levin (4), is shown in Figure 2.

Economic theories of choice generally do not account for the second phase of the model, i.e., the subjective assessment of the decision maker and the alternatives; rather, they assume, or at least imply, that the choice behavior of a decision maker is directly related to his or her objective socioeconomic characteristics and to the objective physical characteristics of the alternatives. On the other hand, psychological theories of choice not only recognize but also stress the overriding importance of the subjective transformation of the characteristics of both the decision maker and the alternatives.

As important as the recognition of the three phases of the choice process is realization of the links between elements of the three phases. In their discussion of a model structure similar to that shown in Figure 2, Golob and others (3) have highlighted many of the important links. Although they show all of the links in Figure 2 to exist, the relative strength and importance of such links is believed to differ. Golob and others conclude that the most important link is that between the characteristics of the choice alternatives and the perceptions of those alternatives. Thus, the decision maker's subjective impressions of the characteristics of the alternatives are critical in the overall choice process. Although a characteristic may, in reality, be changed, that change will not affect the choice decision unless the perception of the characteristic also changes. Thus, neither minor changes that go unnoticed nor relatively major changes that simply do not come to the attention of the decision maker will affect choice probabilities. On the other hand, choice probabilities can be changed without changing the alternatives if one can instead change the perceptions of those alternatives—for example, by information dissemination, advertising, or propaganda. Thus, an understanding of the choice process as a three-phase process has important consequences for policymaking and modeling.

From a modeling viewpoint, this process requires that, instead of using objective measurements of characteristics in a model, one must first obtain subjective interpretations of such characteristics. In some circumstances, this is inevitable since it is impossible to obtain completely objective measurements of a characteristic (e.g., comfort or convenience in a mode-choice decision); but it also requires that, even when objective measurements such as travel time are obtainable, one must still transform the objective measurement into a subjective impression before using it in a model. For example, is a 20-min trip really regarded as being twice as time consuming and burdensome as a 10-min trip?

MENTAL MAPS

Important as subjective transformation is in the choice process, relatively little work has been performed to indicate the nature of such transformations in the context of mode-choice modeling (4-6). What work has been done has concentrated on the variation in the perception of a single characteristic for a particular alternative (mode). In the context of spatial choice problems, however, the situation is a little different. Here one is concerned more with the variation in the perception of characteristics over an urban or regional area. Fortunately, a well-established body of literature on this subject is available under the concept of "mental maps" (7).

An individual's perception of his or her environment is molded not simply by the physical environment itself but also by the individual's level of knowledge of that environment. Where the level of knowledge is high, then the real environment and the individual's perception of the environment are likely to be similar. But as the level of knowledge decreases so too does the similarity between the real and the perceived environment, and subjective impressions, generalizations, and biases play an increasingly important role in the formulation of the mental image of the environment. Just as a cartographic map can represent the real environment, so too can a mental (or cognitive) map represent the perceived environment.

The study of mental maps has been formalized in the work of Gould and White (7, 8). In a number of studies of various geographic locations, they considered the environment as perceived by the subjects of their ex-

Figure 1. Basic model structure.

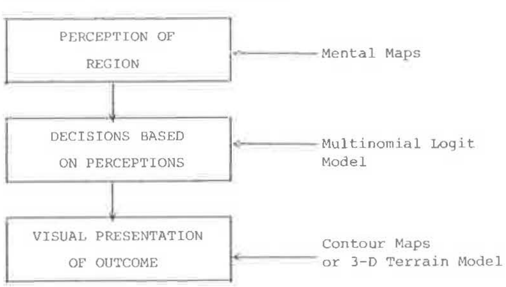
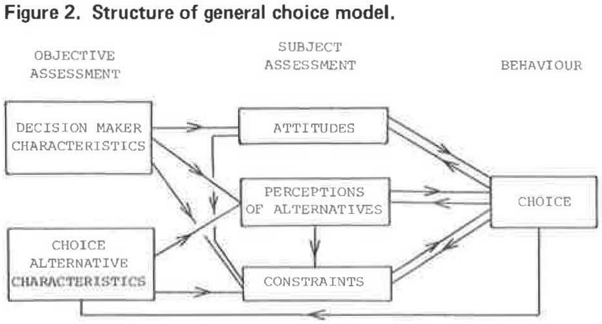


Figure 2. Structure of general choice model.



periments. They considered California school dropouts' impressions of America, British school dropouts' impressions of Britain, a black child's impression of his immediate neighborhood in Boston, and Swedish children's impressions of Sweden, and they found that the mental maps retained by each subject were found to depend basically on the subject's level of knowledge of the area under consideration. The level of knowledge could in turn be expressed in a number of ways. For example, such knowledge may depend on the duration of residence in a certain area, the number of times a place has been visited or traveled through, the proximity of the area under consideration to the place of residence, and the age, education, and background of the respondent.

Previous studies have shown the usefulness of mental maps in describing perceptions of regional areas. Our study differs in three aspects:

1. The study area is a metropolitan urban area. Given the success of the mental-map approach at both the regional and immediate-neighborhood levels, there is no reason to believe that it will not be just as applicable at the intermediate level of an urban area.
2. The charting of mental maps, although of interest in itself, is not the major objective of the study. The mental maps will subsequently be used as input to a modeling process to obtain residential preference ratings.
3. The third point of difference is perhaps the most fundamental. Previous mental-map studies have requested subjects to rate particular geographic locations as, for example, a place to live. It is known, however, that the decision on residential location is not based on a rating of the geographic location per se but on a rating of the various characteristics that describe that location (1). In the light of this recognition that a location is described in terms of its characteristics, it seems reasonable to obtain mental maps of these characteristics in a spatial context as a basic first step to obtaining residential preference indicators.

Obtaining mental maps of area characteristics rather than of geographic areas has several advantages:

1. It enables the respondent to react to specific characteristics rather than to broad classifications such as geographic areas. This feature promises more valid assessment of attitudes and perceptions (4).
2. It enables one to evaluate the contribution of each characteristic to the overall assessment of the area.
3. It gives an indication of the subjects' knowledge of the specific characteristics of an urban area.
4. It enables one to trace the effect of a change in one of the characteristics through to its final effect on residential preference.

A limited attempt to obtain mental maps of characteristics, or categories of characteristics, is described by Gould and White (7) in their discussion of the work of Harris and Scala (9). As will be seen later, our study differs considerably in the way in which the mental maps of characteristics are combined.

Mental maps are traditionally represented as contour maps. They can be represented equally well, however, in the form of a two-dimensional matrix in which the dimensions correspond to the latitude and longitude of the geographic region under consideration and the elements represent respondents' ratings of the geographic area at a particular latitude and longitude. Thus,

$$S = \{S_{ij}\} \quad (1)$$

where S = perceived satisfaction with the geographic region (i.e., a mental map) and S_{ij} = perceived satisfaction with the geographic area at latitude i and longitude j.

Extending this representation to the present study, in which mental maps of characteristics are being considered, one can use a three-dimensional matrix $\{S_{ijk}\}$ to represent a series of mental maps for the characteristics of the area, where S_{ijk} is the perceived satisfaction with characteristic k at latitude i and longitude j. The manner in which this three-dimensional matrix is collapsed into a two-dimensional preference surface will depend on the choice process assumed to exist in the process of residential location choice.

CHOICE PROCESS MODEL

Recent investigations into choice processes (particularly mode-choice processes) have used the theory of individual utility maximization to derive a choice model known as the multinomial logit model:

$$p(a) = \exp(CU_a)/\sum_{b=1}^{N} \exp(CU_b) \quad (2)$$

where

$p(a)$ = probability of choosing alternative a,
C = sensitivity coefficient,
U_a = utility of alternative a, and
N = number of alternatives.

The utility function U_a is generally assumed to be a linear additive function of the characteristics such that

$$U_a = \sum_{k=1}^{M} I_k \times S_{ak} \quad (3)$$

where

I_k = importance of characteristic k in the choice process,
S_{ak} = level of satisfaction with characteristic k for alternative a, and
M = number of characteristics.

In considering spatial choice problems and recalling the representation of the mental maps of characteristics as a three-dimensional matrix, Equation 3 can be expressed as

$$S_{ij} = U_{ij} = \sum_{k=1}^{M} I_k \times S_{ijk} \quad (4)$$

and subsequently

$$S = \{I_k\} \times \{S_{ijk}\} \quad (5)$$

Equation 5 states that the overall mental map of a region is a weighted sum of the individual mental maps of characteristics for that region. This formulation is a generalization of those of Harris and Scala (9) and McHarg (10) (who used a similar concept for the identification of feasible highway routes). In both of those works, the importance matrix was implicitly assumed to be a unit matrix.

The final step in the development of the area preference surface is to relate the mental map of a region to the probability of choice of subareas within that region. This may be done by combining Equations 2 and 4:

$$p(ij) = \exp(CU_{ij}) / \sum_{b=1}^{m} \sum_{d=1}^{n} \exp(CU_{bd}) \quad (6)$$

where

p(ij) = probability of choosing an area with latitude i and longitude j,
m = all latitudes, and
n = all longitudes.

CASE STUDY

To test the application of the theory described above, a study was conducted to determine the attitudes and preferences of people who had moved into the region that borders on the central city of Melbourne during the period from August through November 1975. The central-city suburbs of Melbourne are, as shown in Figure 3, South Melbourne, Port Melbourne, Melbourne, Fitzroy, Collingwood, Richmond, Prahran, and St. Kilda.

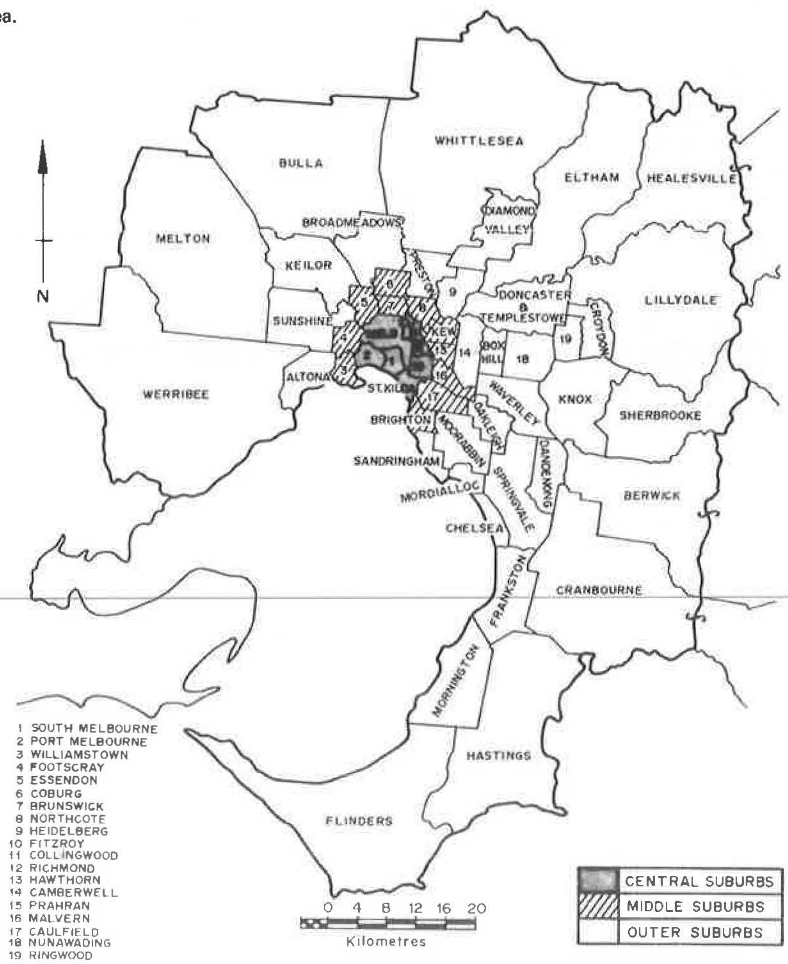
New residents were interviewed as soon as possible after they moved into the study area. This procedure was chosen for two reasons:

1. The respondents had recently made an overt decision to move and so their attitude and actions were likely, at that time, to be closely related.
2. Since all residents in the study had moved at approximately the same time, one could assume that the characteristics describing each area under consideration would be the same for all study respondents.

The study took the form of a home interview questionnaire survey primarily aimed at establishing respondents' perceptions of how well a number of alternate locations would satisfy them with respect to a number of specific factors. The factors considered are given below:

Factor	Key
Closeness to	
Present workplace	Work
Shops	Shops
Public transportation	Transport
Open country	Country
Bay beaches	Beaches
Parks, play areas, golf courses, ovals	Ovals
Entertainment	Entertain
Friends	Friends
Relatives	Relatives
People of same age	Age
People of same social level	Social
People of same nationality	Nationality
Pedestrian safety	Safety
Traffic noise	Noise
Traffic congestion	Congestion
Tidiness of area	Tidiness
How well buildings are maintained	Maintain

Figure 3. Study area.



Factor	Key
How clear the air is	Air
Presence of trees, shrubs, and grass	Trees
Type of housing	Home type
Cost, rent, and value for money	Cost

Respondents were asked to rate, by means of semantic scales, the importance of each of these factors in their choice of residential location. They were also asked, on the basis of each of these factors, to indicate how satisfactory they considered three suburbs: their present suburb plus one each, with which they were familiar, from the middle and outer suburbs.

A total of 261 questionnaires were administered to 244 households. Of these, 122 were renters and 122 were owners of residences. The sample represented 16 percent of renters and 33 percent of owners who moved into the area during the study period.

Mental Maps of Characteristics

Translating theory into practice is usually associated with problems that are resolved by making approximations or assumptions. This study is no exception. It was mentioned earlier that a mental map is a representation of a person's perception of an area. The difficulty in this study was that, as mentioned earlier, not all areas were rated by all respondents. Only three areas (one inner, one middle, and one outer suburban area) were rated by each respondent, and these areas varied from respondent to respondent. Thus, complete individual mental maps did not exist. To obtain the average mental map of new inner-suburb residents, it was necessary to assume that they all perceive the urban area in a similar fashion. Thus, respondent B's perception of a particular area can be substituted for respondent A's perception of that same area when respondent A did not in fact rate the area. The average mental map for all respondents can therefore be obtained by calculating the average rating for each area from those respondents who rated that area and then constructing a composite map of these average ratings. Although this assumption may be severely questioned, it was a necessary step in view of the available data.

Mental maps constructed in this manner are shown in Figures 4 and 5 for two factors considered in the study: closeness to public transportation and closeness to bay beaches. Each map is constructed for the combined group of owners and renters between whom there were no significant differences in ratings.

It can be seen that the mental maps so constructed appear to be reasonably consistent with intuition and knowledge of the Melbourne urban area. The public transportation map shows decreasing satisfaction with increasing distance from the central-city area and from major railway corridors. The bay beaches map, as expected, shows a decreasing satisfaction with increasing distance from bay beaches.

Because of space limitations, it is not possible to include here the mental maps for all factors, but certain general patterns do emerge:

1. A series of concentric rings—Satisfaction with shops, public transportation, and entertainment decreases with increasing distance from the central city, and satisfaction with open country, parks, pedestrian safety, traffic noise, traffic congestion, cost of housing, and cleanliness of the air increases with increasing distance from the central city.
2. An east-west distribution—Generally higher levels of satisfaction were recorded in the eastern than in the western areas for factors such as tidiness of the area, maintenance of buildings, the presence of trees and shrubs, and type of housing.
3. An inland distribution—Satisfaction with bay beaches decreases with distance inland from Port Phillip Bay.

Polynomial Representation of Mental Maps

Although the mental maps, as constructed above, were effective in representing the general distribution of satisfaction with a particular factor, they had three distinct disadvantages. The first disadvantage was the actual distribution of suburbs chosen by respondents. Some suburbs were chosen often for evaluation, whereas other areas did not attract a single response. Thus, the task of interpolating and drawing contour lines in these areas was quite difficult.

Another disadvantage was that the unbalanced distribution of chosen areas also meant that the ratings of some suburbs were obtained from the average of a large number of responses and those of other suburbs were obtained from a single response. If this one response was extreme or atypical, then the resultant mental map showed inconsistencies and discontinuities. Although such discontinuities, or fault lines, are indeed possible (7, p. 191), it was felt that in this study they were more the result of the data than of any underlying intrinsic cause.

A third disadvantage was that, since the mental maps were to be transformed into matrices for use in the modeling process, a simple computer-based process that eliminated the need for tedious hand calculations and contour-map interpolations was desirable.

The solution to these three problems was to replace the hand-drawn mental maps shown in Figures 4 and 5 with polynomial surfaces fitted to the data in the mental maps. The idea is similar to the terrain-smoothing methods used in highway location studies such as GCARS (11). The basic objective of the method is to replace the observed mental map by a polynomial equation in terms of i and j (the coordinates of latitude and longitude within the urban area). This technique has several advantages:

1. It makes interpolation at any point in the urban area very simple by merely requiring the substitution of the i and j coordinates in the polynomial equation.
2. The surface-fitting process automatically gives more weight to suburbs that receive a large number of respondent evaluations and less weight to single-response (possibly extreme rating) suburbs.
3. Expressing mental maps in polynomial form makes it possible to combine different mental maps in simple algebraic steps.

One decision that had to be made was the order of the polynomial to be used. In the GCARS terrain-modeling exercise, little difference was found between polynomials of order six and higher-order polynomials. To determine the order of polynomial to be used in this study, four measures of effectiveness were considered: changes in the residuals, in the correlation coefficient, and in the F-ratio and visual observation of changes in the predicted surface as the order of the polynomial increases. In Figures 6 and 7, variations in the F-ratio and the correlation coefficient are shown for two factors—closeness to public transportation and closeness to bay beaches. It can be seen that, as the order of the polynomial increases, the degree of fit increases but at a decreasing rate and that, as in the GCARS study, increasing the order of the polynomial to more than six does not improve the analysis substantially. A sixth-order polynomial was therefore used to mathematically describe the mental maps.

The best-fit sixth-order polynomial surfaces for the mental maps of closeness to public transportation and closeness to bay beaches are shown in Figures 8 and 9. The basic features of the original mental maps are retained. The mental map for the bay beaches factor (Figure 8) shows the same inland distribution; the map for the public transportation factor (Figure 9) shows the predominant radial distribution with the influence of rail lines, especially for the Dandenong corridor to the Southeast. These maps exhibit much more regular contour variations and none of the isolated peaks and depressions shown in Figures 4 and 5.

PERCEIVED UTILITY SURFACE

To obtain the perceived utility surface of an area, it is necessary to multiply the matrix of mental maps obtained in the previous section by the matrix of importances as shown in Equation 5. The importance of each characteristic in the location choice decision is shown in Figure 10. As stated earlier, these ratings were obtained from the respondents in the study by means of semantic differential scales. The values shown in Figure 10 are average importances for all respondents and do not allow for individual differences.

To obtain a perceived utility surface on the same scale as the previous mental maps, Equation 5 was modified slightly to give

$$S = (I_k / \sum_{k=1}^{M} I_k) \times \{S_{ijk}\} \qquad (7)$$

Thus, instead of obtaining a weighted sum of the satisfactions, one obtains a weighted average. Although this procedure contravenes theoretical evidence (12), it should make no difference in this situation since the sets of characteristics for all alternatives are the same size. It does have the advantage of making the mental

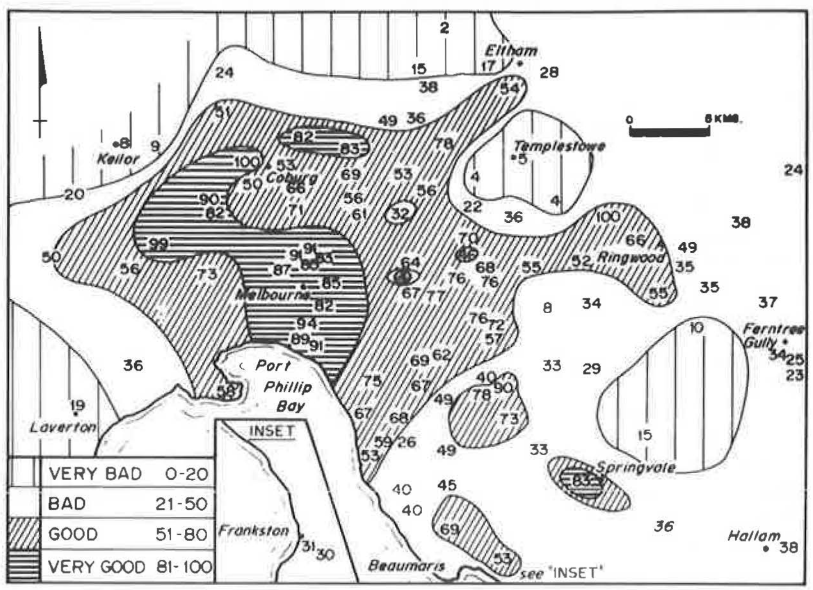


Figure 4. Mental map of satisfaction with closeness to public transportation.

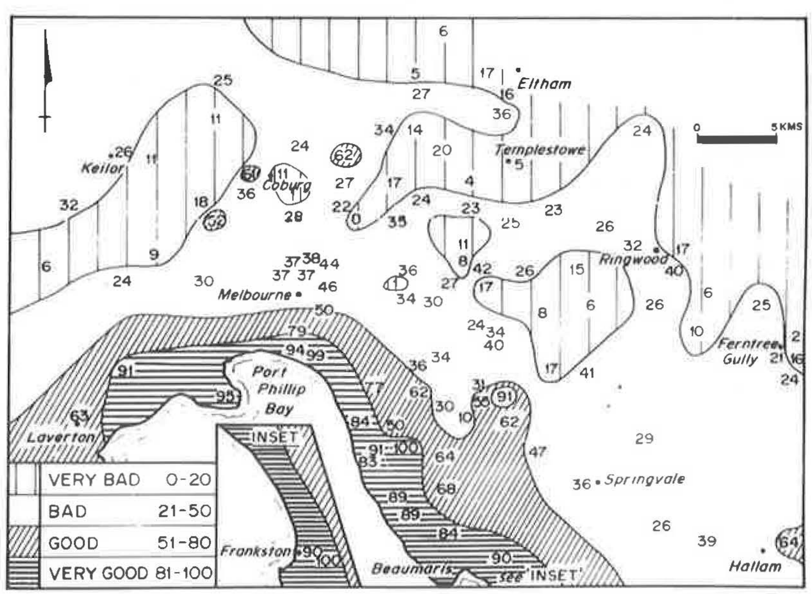


Figure 5. Mental map of satisfaction with closeness to bay beaches.

maps and utility surface easily comparable. The resultant utility surface is shown in Figure 11 (the utility values shown are on a 1:100 scale, where 1 represents completely unsatisfactory and 100 represents completely satisfactory).

The most desirable locations, according to respondents in the survey, are the inner suburbs and the Eltham area. This reflects the fact that many of the respondents were either students or young professional people who were probably aware of and in sympathy with the environmental advantages of a semirural area like Eltham but who for practical reasons lived close to work or the university in the inner-city area. The most undesirable areas were the northwestern suburbs and the vicinity around the industrial Springvale and Dandenong areas in the Southeast. Beyond Springvale, desirability improved as one reached areas like Frankston and Hallam.

AREA PREFERENCE SURFACE

Although Figure 11 gives a good indication of how the urban area of Melbourne is perceived by the type of person included in the survey, it does not indicate how such people would react to this perception in a choice situation. To convert the utility surface into an area preference (or choice) surface, one must apply Equation 6. The preference surface that results from using values of c = 0.1 is shown in Figure 12. The elements of this preference surface matrix represent the relative probabilities that a particular combination of latitude and longitude will be selected in a choice decision. Since the area of each location is constant, the elements also represent the potential residential density of survey respondents at that point.

The contour lines in Figure 12 show the percentage chance (or preference) of people locating in that area of Melbourne. Clearly, the most attractive areas are around the central city, Eltham and east of Hallam. The least attractive areas are in the Northwest and at Springvale and Dandenong.

To illustrate the effect of the sensitivity coefficient c, a new area preference surface was constructed by using c = 0.2. The resulting map is shown in Figure 13. As might be expected, when the sensitivity coefficient increases, the sensitivity of people to differences in the utility gained from living in each area increases. In terms of the actual preference surface, the peaks become higher and the troughs lower. The shape of the surface is more evident in the three-dimensional perspective drawing shown in Figure 14.

Obviously, the choice of the sensitivity coefficient

Figure 6. Change in correlation coefficient with increasing order of polynomial.

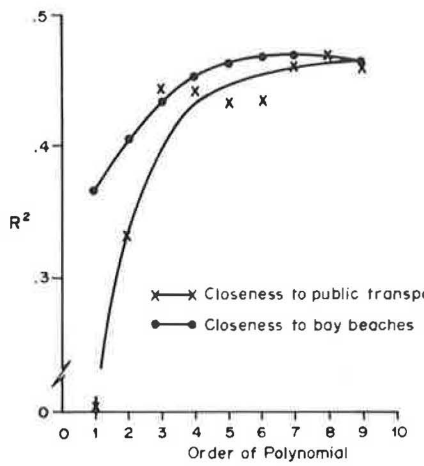


Figure 7. Change in F-ratio with increasing order of polynomial.

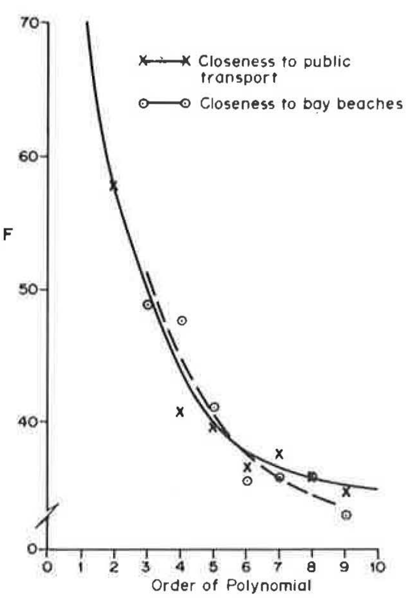


Figure 8. Polynomial surface mental map of satisfaction with closeness to bay beaches.

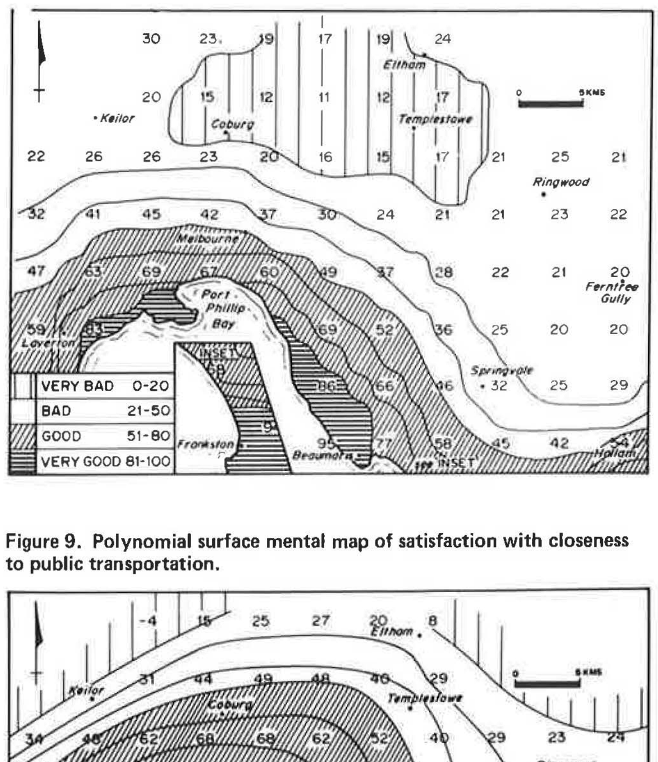
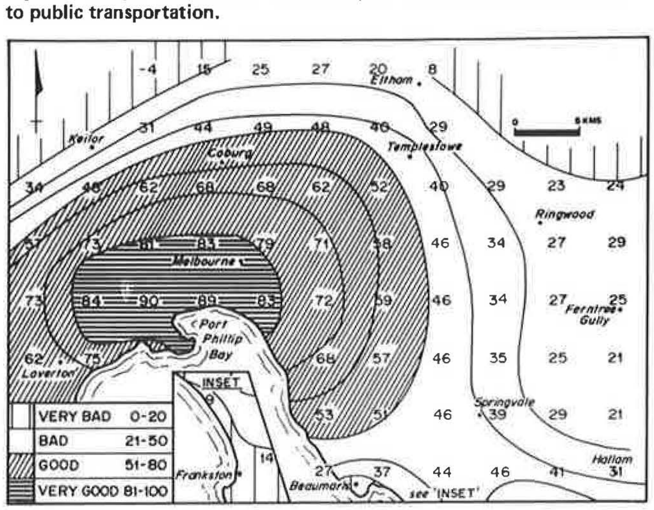


Figure 9. Polynomial surface mental map of satisfaction with closeness to public transportation.



has a great impact on the actual distribution of choice that results from a perceived utility surface. No attempt has been made in this paper to estimate this sensitivity coefficient. One possible technique would be to match the density distribution obtained from the model with an observed density distribution for the population in question (e.g., young married couples and professional couples with no children). Adjustment of the coefficient to achieve maximum agreement of the density distributions may result in a valid estimate of the sensitivity coefficient. Further research on this problem is needed.

USE OF THE MODEL

The model outlined in this paper has several uses:

1. The model can be used to estimate the area preferences of a particular group in a community. This group may be defined on the basis of socioeconomic classification or by current residential location. Such information would be most useful in migration studies such as those performed by Maher (13) and could also be collected on a regional basis to assist in the planning and prediction of the impact of the development of growth centers (14).
2. Since areas are described in terms of their characteristics, individual mental maps can be constructed to help isolate the perceptions and misperceptions of individual factors. Such information would be most useful in a marketing campaign to help promote particular locations.
3. Since each characteristic is considered individually, changes in each characteristic that may result from a change in the physical environment (e.g., an improved transportation system or a new regional center) can be traced through the model to assess their impact on the overall area preference surface.
4. Finally, and most important, since the output of the model is in visual form as a contour map (Figure 13), a perspective drawing (Figure 14), or a model of physical terrain, the uses of the model can be communicated to the decision maker with maximum effectiveness. No knowledge of the mathematics and equa-

Figure 10. Importance of factors in choice of residential location.

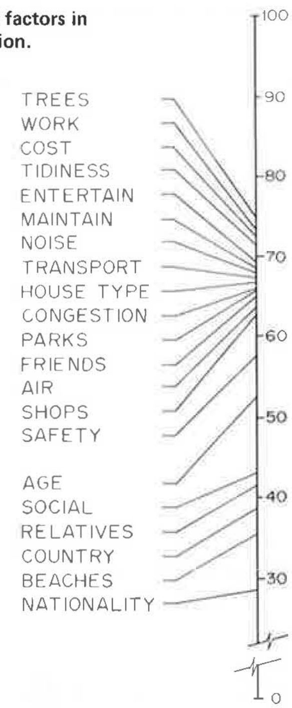


Figure 11. Perceived utility surface where U = ΣI x S/ΣI.

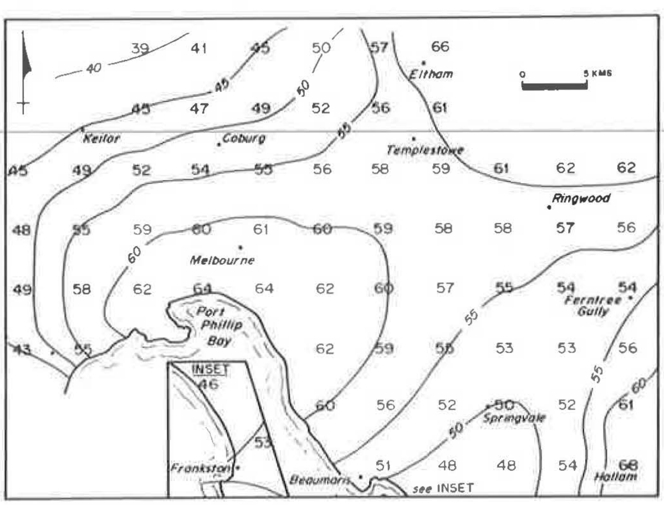


Figure 12. Area preference surface where c = 0.1.

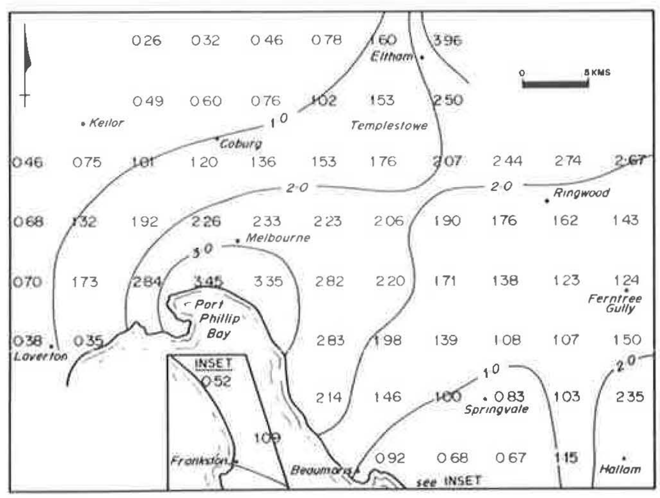


Figure 13. Area preference surface where c = 0.2.

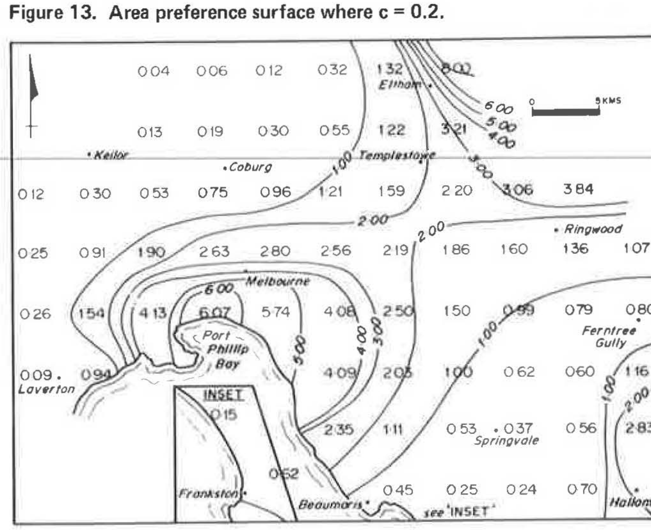
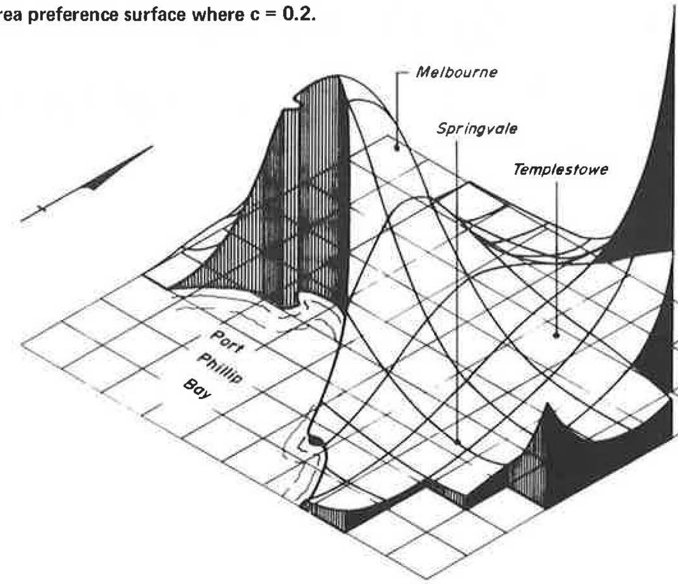


Figure 14. Three-dimensional view of area preference surface where c = 0.2.



tions is necessary for the decision maker to appreciate the effect of his or her policy decisions. In this regard, the model is ideally suited to use with an interactive computer graphics display.

CONCLUSION

By combining the feature of multidimensional mental maps with multinomial logit choice theory, the technique described in this paper makes it possible to present results in an easy-to-understand, visual manner. Such a technique should ensure maximum comprehension of the effect of transportation or land-use policies on the choice of residential location.

The model is demonstrated by using data collected from a survey of new residents of the inner suburbs of Melbourne. It is shown to produce in study respondents a logical and consistent perceptual view of Melbourne. Further research is needed on the choice of a sensitivity coefficient for use in the model.

The model is believed to be particularly useful in bridging the gap between the planner, the technologist, and the decision maker in the land-use and transportation planning task.

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