○ ACCESSIBILITY ANALYSIS FOR HOUSING DEVELOPMENT IN SINGAPORE WITH GIS AND MULTI-CRITERIA ANALYSIS METHODS

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This paper presents a study on accessibility analysis for public housing development in Choa Chu Kang/Bukit Panjang area, Singapore, using geographical information systems (GIS) and multi-criteria analysis methods. GIS is used to measure accessibility to different types of facilities and amenities, while a multi-criteria method is employed to weight buyers' preferences about the importance of each type of accessibility and to derive the overall attractiveness of each location for housing development in terms of these multiple types of accessibility. The results could be used to assist the housing planning and development authorities to prioritise sites where public housing should be developed in the study area.

1. INTRODUCTION

With a population density of 5,900 persons per square kilometre, Singapore is known to be one of the most densely populated countries in the world. Given the extreme shortage of land and a growing population, planning assumes paramount importance. In particular, housing planning has been given increasing consideration. Recently, more than 90% of Singaporean households own their own homes, a significantly higher proportion compared to 50 to 60% home ownership in most developed countries (Tan 1999). According to the Singapore Census 2000 (SDS, 2001), 88% of households in Singapore are now living in public housing developed by the Housing and Development Board (HDB), a statutory board of the Ministry of National Development. Public housing in Singapore is not generally considered as a sign of poverty or lower standards of living as compared to public housing in other countries. Most of the residents in public housing are owners rather than tenants. While public housing development in Singapore was spurred by the critical housing shortage, it provided opportunities for the state to re-engineer the society, aiming at creating ethnically mixed neighbourhoods and supporting the development of community relations (Ling and Shaw 2004). The HDB public housing is compactly concentrated in 26 HDB housing estates, also called HDB Towns (Figure 1). Since its incorporation in 1960, HDB has planned and developed low cost public housing and related facilities. It has not only shaped Singapore's housing infrastructure but also Singapore's landscape with its increasingly higher-rise, higher density public housing.

Figure 1 HDB Towns

The success of HDB in solving the problem of housing shortage in the early days has been widely recognized. However, growing affluence in Singaporean society means that people now want more spacious homes. Improvements in health care mean people will live longer, and therefore more housing overall is needed for the growing population. The trends towards nuclear families and more people living alone also mean that more homes are needed. Before Year 2000, HDB housing supply had always fallen short of demand. However, HDB is now facing an increasing challenge in managing the supply and demand issue. At the end of 2001, the public was informed of the oversupply of 17,500 new HDB flats in new towns with an estimated worth of \$4.4 billion. As of January 2003, the over supply stood at 12,000 new HDB flats in new towns such as Punggol, Sengkang and Jurong West (Ibrahim and Ying 2003). This over supply had various implications. Some analysts attributed it to economic slowdown which resulted in a shift of demand away from new flats towards resale flats, combined with a dip in demand among upgraders. The depressed prices in the resale property market made the pricing of new flats less competitive, turning buyers to resale flats where they could select locations according to their preference. The other implication may be a fundamental shift in buyers' preferences due to the higher aspirations of the population (Wong and Yap 2004). Whichever the reason, it is acknowledged that the stagnation of sales in new HDB flats is caused by both external and internal factors.

The biggest internal factor noted concerns the accessibility of the new estates. Although HDB makes concerted effort to integrate transport and land-use, the timing of the integration poses a major issue. For instance, it was reported that the MRT (Mass Rapid Transit) line was not even developed when the first Sengkang New Town residents moved in. Amenities such as childcare

centres and clinics were also lacking (Yeo 1998). Jurong West New Town faced the same problem where residents complained about the lack of amenities like convenience stores in the neighbourhood. This led to only seven units being purchased in a block of 96 flats at the time of a recent study (Yeo 2002).

Whatever the cause for dwindling demand in these new housing estates, the reality is that these unsold HDB flats cause the government to incur economic opportunity costs. Hence, there is a need to optimise resources in order to avert the problem of over supply in the future. To achieve this, it has been suggested that the Singapore HDB planners should consider geographical factors, such as accessibility to amenities and services, that may influence buyers' preferences and incorporate these into their future planning for housing development so that the nature of the demand and the proposed supply can be more closely harmonised.

Ibrahim and Ying (2003) conducted a study on public housing choices in Singapore. The findings from their research suggest that people generally preferred new HDB flats that were added into mature estates, as new residents could enjoy the dual benefits of new flats in good condition and an established network of amenities and public transportation. Conversely, a main reason for the lack of interest for new flats in new estates is the lack of amenities and transportation infrastructure. To resolve this mismatch, and improve prospects for more rapid uptake of new property, we suggest that the Singapore HDB should pay more attention to the facilities and amenities accessible to these new housing estates. In other words, the accessibility to existing facilities and amenities should be an important criterion when planning and developing future HDB flats and housing estates.

Liu and Zhu (2004) developed an integrated GIS approach to accessibility analysis and a GIS tool called Accessibility Analyst which incorporates a number of accessibility measures for accessibility analysis. This paper integrates their GIS approach with multi-criteria analysis (MCA) for assessing accessibility of potential housing development sites to existing facilities and amenities from a buyer's perspective. Here, MCA provides a systematic approach that can make explicit the value judgments of home buyers about how important each facet of accessibility (e.g. access to public transport, as opposed to shops) is in determining their overall preference for choosing to buy an HDB flat in one area, compared to another. An application is presented in which measures of accessibility are computed in Accessibility Analyst; the relative importance of each of these measures, from a buyer's perspective, is then elicited by a questionnaire survey of local residents. An MCA technique called SMARTER is then used to weight each measure of accessibility according to their relative importance and to determine the overall desirability of locations for new HDB development within the Choa Chu Kang – Bukit Panjang region of Singapore.

2. ACCESSIBILITY ANALYSIS AND HOUSING PLANNING

Accessibility is concerned with the opportunity that an individual at a given location possesses to participate in a particular activity or set of activities. Basically accessibility represents the ease with which activities may be reached from a given location by means of a particular transportation system (Zhu and Liu 2004). It is usually measured in terms of travel distance, time or cost. The less time and money spent in travel, the more activities that can be reached in a given amount of time and the greater the accessibility.

Accessibility analysis has a wide range of applications, particularly in housing and service planning. Soles (2003) used accessibility as a measure to assess housing need in North Saskatchewan, Canada. He put emphasis on accessibility to transportation and community facilities. Lee and McNally (2002) explored the concept of accessibility in the context of access to health-care services based on a case study in Portland, Oregon. Guy (1983) assessed accessibility to shopping opportunities from both the supply and demand side perspectives. Halden et al (2002) used accessibility as a criterion to measure the level of service provision in the rural areas of Scotland. They examined the travel-time and analysed the patterns of accessibility to urban centres, shopping opportunities and to regional health care facilities. Their study resulted in a policy review by the Scottish Executive to re-prioritise service provision, including public transport, employment, health and social care, education and leisure facilities, amongst other services. These studies illustrate how measures of accessibility can be used as criteria by which to evaluate locations and re-prioritise the supply of services. However, some studies have evaluated the overall accessibility of a site according to only a small number of opportunities. In the context of housing development, a location may have good access to some opportunities (e.g. shopping centres) but not to others (e.g. schools). Potential home buyers need to consider a wider range of individual opportunities to weigh these up and to trade-off the relative benefit of having access to different facilities, when forming an overall impression of the desirability of a given location for house purchase. MCA provides a framework for undertaking such an analysis.

3. A MULTI-CRITERIA FRAMEWORK FOR ACCESSIBILITY ANALYSIS

MCA includes techniques for evaluating options or alternatives on individual, often conflicting criteria, and for combining the separate evaluations into one overall evaluation. An overall evaluation is achieved by establishing preferences between options with reference to a set of defined criteria. The degree of fulfillment of the multiple criteria of each alternative is then assessed. Usually, no single criteria will determine the most desirable alternatives; rather the most desirable alternatives will be found from a combination of different measures, varying in weight between them. MCA allows each of the criteria to be weighted according to their relative importance. The overall scores for the alternatives are computed based on the equation below:

$$\text{score} = \sum_{j=1}^k w_i * s_{ij} \quad (\text{Equation 1})$$

where k is the number of criteria

j represents the alternative j under consideration

w_i is the weight representing the relative importance of criterion i

s_{ij} is the score representing the relative attainment of alternative j on criterion i

If we consider each potential site for housing development as an alternative and accessibility to individual opportunities as criteria, and if the weighted priorities w_i for the different accessibility criteria can be derived from public opinions, we may calculate the overall desirability score

for each potential site using Equation 1. Public opinions can be obtained from questionnaire surveys. Accessibility Analyst developed by Liu and Zhu (2004) can be used to measure accessibility to different types of facilities and amenities. Figure 2 outlines our approach to accessibility analysis for housing development that integrates multi-criteria analysis and GIS.

Figure 2 A multi-criteria framework to accessibility analysis

This framework involves first identifying major opportunities (facilities and amenities) to which accessibility will be measured for all possible locations considered for new housing development, and then obtaining public opinions for prioritising the relative importance of each accessibility criterion. The identification of the opportunities themselves and the relative importance placed upon the accessibility to them can be both obtained through questionnaire surveys. Next, accessibility to individual opportunities is assessed using GIS. The results of the accessibility assessment are translated into GIS data layers. Each data layer is assigned a weight derived using a multi-criteria analysis technique based on the preference data acquired from the survey. These data layers are then synthesised into one data layer by applying Equation 1. This will result in the overall accessibility of each potential location for housing development. In the following sections, we apply this framework to analyse accessibility to facilities and hence compute the desirability for areas of new housing development in Choa Chu Kang – Bukit Panjang, based on an evaluation of the overall accessibility of these areas to multiple opportunities.

4. CASE STUDY

The study area is located in the Northwest region in Singapore (Figure 3). It covers a total area of about 1160 ha. with residential development being the largest land use activity. There existed more than 500 HDB residential buildings in this region at the time when the study was conducted. It has a comprehensive transport network which includes the MRT, the light rail transit (LRT) and the bus network. The study area is tessellated into 265 5-hectare hexagons to facilitate the accessibility analysis. The reasons for the use of hexagonal tessellation have two folds: (1) the distance from each hexagon to all its neighbors is the same, thus it is easy to calculate inter-zonal distances which is required for accessibility analysis; (2) it can be used to present the outcome of the accessibility analysis as an almost continuous surface without the need of interpolation, therefore, reflecting gradual changes in accessibility across the study area. 5-hectare is small enough to show the almost continuous variations of accessibility across the region. Indeed each hexagon is seen as a potential HDB housing development area.

Figure 3 Choa Chu Kang – Bukit Panjang region of Singapore

4.1. IDENTIFICATION AND PRIORITISATION OF HOUSING ACCESSIBILITY CRITERIA

Questionnaire surveys were conducted in local shopping centres in November 2003 and February 2004. The questions on the questionnaire asked respondents to identify opportunities that are relevant and important to the public and to determine the relative importance of accessibility to these identified opportunities. A total of 500 local residents with different ethnic backgrounds were interviewed. The responses were then summarized. This resulted in a list of eight opportunities that the respondents were most concerned and an rank order of these opportunities according to how important accessibility to each opportunity was to them. Table 1 shows the summary. Accessibility to each opportunity was rated using a 5 point Likert scale, 1 represents ‘not important’ and 5 represents ‘very important’ based on their opinion when considering a housing location. The second column in Table 1 lists the average scores. These scores determine the rank order of the housing accessibility criteria, which is listed in the 3rd column of the table.

Criteria	Mean Score	Ranking
Accessibility to public transport	4.94	1
Accessibility to shopping centres	4.92	1
Accessibility to health care services	4.34	2
Accessibility to banks	3.55	3
Accessibility to schools	3.23	4
Accessibility to community centres	2.98	5
Accessibility to post offices	2.75	5
Accessibility to parks	2.12	6

Table 1 Mean scores and rank order of the housing accessibility criteria

The SMARTER weighting method in Decision Analyst (http://www.coastal.crc.org.au/mca/decision_analyst.html) (Zhu et al 2001) was then used to derive the weights of the housing accessibility criteria based on their rank order of importance listed in the 3rd column of Table 1. SMARTER is an approximate method for multi-attribute utility measurement based on an elicitation procedure for weights (Edwards and Barron, 1994). It estimates the set of weights based on the rank order of a set of criteria using the centroid method. The centroid method assigns weights as follows.

Assume W_1 is the weight of the most important criterion, W_2 is the weight of the second most important criterion, and so on. For n criteria:

$$\begin{aligned} W_1 &= (1 + 1/2 + 1/3 + \dots + 1/n) / n \\ W_2 &= (0 + 1/2 + 1/3 + \dots + 1/n) / n \\ &\dots \\ W_n &= (0 + 0 + 0 + \dots + 1/n) / n \end{aligned}$$

Generally, if $W_1 > W_2 > \dots > W_n$, then the weight of the i th criterion is:

$$W_i = (1/n) \sum_{j=i}^n (1/j) \quad (\text{Equation 2})$$

Figure 4 shows the weights of the housing accessibility criteria derived from Equation 2 based on their rank order of importance. These weights represent priorities of accessibility to each identified opportunity in housing development.

Figure 4 Derived weights of the housing accessibility criteria

4.2. ACCESSIBILITY ANALYSIS

Accessibility analysis was performed using Accessibility Analyst to analyse the level of accessibility by public transport (bus and LRT) to all instances of each of the eight defined types of opportunities. We used the modified potential model offered in Accessibility Analyst to measure accessibility, which is expressed as below. The potential accessibility for an origin in hexagon i P_i is calculated as

$$P_i = \frac{\sum_j (M_j / c_{ij}^{\alpha-1})}{\sum_k (M_k / c_{ik}^{\alpha})} \quad (\text{Equation 3})$$

where M_j and M_k are the relative attractiveness of destinations j and k ; c_{ij} and c_{ik} are the travel time between origin i and destination j , and between origin i and destination k , and α is the time decay parameter. The modified potential model was developed by Geertman and van Eck (1995), which allows comparison of different measures of potential accessibility, and evaluates potential for all locations in terms of weighted average travel time to all destinations. The result is in the same unit as C_{ij} .

In our analysis, the centroids of the hexagon zones served as origins, and 165 opportunities (there are 63 bus stops, 14 LRT stations, 1 MRT station, 15 schools, 11 shopping centres, 47 clinics, 5 banks, 2 post offices, 2 community centres, and 5 parks) as destinations. Attractiveness of each destination is measured respectively as the number of establishments in each shopping centre, number of students in each school, number of doctors in each clinic, number of counters in each bank, etc. α is set as 1.0. Travel time from each hexagon centroid to an opportunity (e.g. a school) is calculated along the LRT network and bus routes, using the *Network Time Matrix* function of Accessibility Analyst. The *Network Time Matrix* function calculates travel time between hexagon centroids and opportunities based on three parts of distance: (a) the distance from the hexagon centroid to the nearest LRT station or bus stop, called *OB*, for travel by walking; (b) the shortest network distance by LRT or bus from *OB* to the LRT station or bus stop nearest to the opportunity, called *DA*; and (c) the distance from *DA* to the opportunity for travel by walking. This function is based on the physical distance and the average travelling speed of a particular travel mode (LRT, bus or walking) for each part of distance. For the detailed algorithm of the three-part distance calculation, please refer to Liu and Zhu (2004).

Eight accessibility surfaces or maps for the eight individual opportunities were created using the potential model discussed above. Figures 5 and 6 show two of them, which are the potential accessibilities computed to shopping centres and health care services respectively. The accessibility values are all standardized using the following equation:

$$S_i = \frac{X_{\max} - X_i}{X_{\max} - X_{\min}} * 100 \quad (\text{Equation 4})$$

where S_i is the standardised accessibility value for hexagon i which ranges from 0 to 100, X_i is the accessibility value of hexagon i generated from the modified potential model, $X_{\max}$ is the

maximum accessibility value, and X_{min} is the minimum accessibility value. The purpose of standardisation is to transform the accessibility values calculated by the potential model to a common 0-100 scale for all accessibility surfaces. Locations with high potential accessibility receive high values and vice versa.

Figure 5 Accessibility to shopping centres

Figure 6 Accessibility to health care services

To obtain an overall assessment of the compound accessibility of each location, all the eight accessibility surfaces or maps were combined into one by using the weighted overlay technique in GIS. The relative weighting of each individual accessibility map was derived from the

SMARTER technique of the public opinion data obtained from the questionnaire survey as discussed in Section 4.1. The overall accessibility value of hexagon j is calculated using Equation 1. Here w_i is the weight of the opportunity i derived using SMARTER in Decision Analyst, and s_{ij} is the value of the accessibility to opportunity i of hexagon j which is the standardised accessibility value for each zone in the i th map calculated using Accessibility Analyst using Equations 3 and 4. After applying the weighted overlay technique of GIS, the result is a new map data layer showing the overall accessibility values as shown in Figure 7. In this map, better accessibility is visually represented by the darker hues and poorer accessibility by lighter hues. Overall accessibility is generally greater along the central belt from the east to west of the area and gradually diminishes as the distance from this belt increases. As the overall accessibility diminishes, the computed suitability for housing development also decreases. The areas with the poorest overall accessibility to public facilities and amenities are located at the southern and south-eastern tips of the study area and these are considered the most unsuitable locations for housing development, based on the presently built infrastructure.

Figure 7 Overall accessibility

5. CONCLUSIONS

This paper has presented a GIS-based multi-criteria analysis approach to assess different measures of accessibility and hence identify areas most favourable to purchasers of new housing. It applies SMARTER to incorporate buyers' opinions as weights into an evaluation of multiple measures of accessibility, used to determine the overall attractiveness of an area for house purchase. The approach proposed here allows planners and housing developers to examine accessibility requirements from a buyer's perspective so that demand and supply issues can be better managed. The case study has illustrated a method to identify suitable locations for housing development that have good accessibility to facilities and amenities which cater to the preference of potential home buyers. However, the study covers only one spatial aspect affecting the desirability of an area

for housing development, i.e. locational accessibility of potential housing development sites. It has not addressed other aspects such as housing prices, which are as important, if not more important in affecting a purchaser's decision making. In addition, this study only analysed the accessibilities to the facilities and amenities in the local area. It did not consider the impact of services outside the study area on the accessibilities. Further work is required to analyse how far desirability based on measures of accessibility alone can realistically capture the pattern of demand for new housing in these areas, and to assess how the services outside the study area may affect the overall accessibility of the areas for housing development.

The paper focuses on the analysis of accessibility to the existing facilities and amenities, which does not take into account the new infrastructure to be introduced. However, by incorporating the locational information for the infrastructure planned to be constructed in the future, the methodology proposed in the study can be used to help planners evaluate the desirability of the potential sites for housing development according to accessibility to both existing and future facilities and amenities.

REFERENCES

- Edwards, W; Barron, F.H. 1994. "SMARTS and SMARTER: improved simple methods for multiattribute utility measurement". *Organizational Behavior and Human Decision Processes* 60: 306–325.
- Geertman, S.C.M; van Eck, J.R.R. 1995. "GIS and models of accessibility potential: an application in planning". *International Journal of Geographical Information Systems* 9: 67–80.
- Guy, C.M. 1983. "The assessment of access to local shopping opportunities: a comparison of accessibility measures". *Environment and Planning B: Planning and Design* 10: 219–238.
- Halden, D.; Farrington, J.; Copus, A. 2002. *Rural Accessibility*. Internet. Accessed November 5, 2003. Available from: <http://www.scotland.gov.uk/cru/kd01/blue/ruac-03.asp>.
- Ibrahim, M.F.; Ying, W.S. 2003. "Public housing choices in Singapore: planning implications". *Proceedings of 39th International Planning Congress, International Society of City and Regional Planners*. Singapore.
- Lee, M.S.; McNally, M.G. 2002. *Measuring Physical Accessibility with Space-Time Prisms in a GIS: A Case Study of Access to Health-Care Facilities*. Internet. Accessed November 11, 2003. Available from: <http://repositories.cdlib.org/itsirvine/casa/UCI-ITS-AS-WP-02-8>.
- Ling, O.G.; Shaw, B.J. 2004. *Beyond the Port City: Development and Identity in 21st Century Singapore*. Singapore: Pearson Prentice Hall.
- Liu, S; Zhu, X. 2004. "An integrated GIS approach to accessibility analysis". *Transactions in GIS* 8: 45–62.
- Singapore Department of Statistics (SDS). 2001. *Singapore Population*. Singapore: SDS.
- Soles, K. 2003. *Affordable, Accessible Housing Needs Assessment at the North Saskatchewan Independent Living Centre*. Internet. Accessed January 12, 2004. Formerly available from <<http://www.usask.ca/cuisr/Publications/Publications/SolesFINAL.pdf>>.
- Tan, S. 1999. *Home. Work. Play*. Singapore: Urban Redevelopment Authority.
- Wong, T.C.; Yap, Adriel L.H. 2004. *Four Decades of Transformation: Land Use in Singapore, 1960–2000*. Singapore: Eastern University Press.

- Yeo, A. 2002. "7 homes in a block of 96 flats". The Straits Times. 30.04.2002.
- Yeo, G. 1998. "Transport woes for first Sengkang residents". The Straits Times. 19.10.1998.
- Zhu, X; Liu, S. 2004. "Analysis of the Impact of the MRT system on accessibility in Singapore using an integrated GIS tool". *Journal of Transport Geography* 12: 89–101.
- Zhu, X.; Walker, D.; Mayocchi, C. 2001. "Integrating Multi-Criteria Modelling and GIS for Sugarcane Land Allocation", *Proceedings of MODSIM 2001 – International Congress on Modelling and Simulation*. 10–13 December, 2001. Canberra.

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