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Spatial–temporal neighbourhood-level house price index

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Abstract

Purpose – The purpose of this study is to develop a spatio-temporal neighbourhood-level house price index (STNL-HPI) incorporating a geographic information system (GIS) functionality that can be used to improve the house price indexation system.

Design/methodology/approach – By using the Malaysian house price index (MHPI) and application of geographically weighted regression (GWR), GIS-based analysis of STNL-HPI through an application called LHPI Viewer v.1.0.0, the stand-alone GIS-statistical application for STNL-HPI was successfully developed in this study.

Findings – The overall results have shown that the modelling and GIS application were able to help users understand the visual variation of house prices across a particular neighbourhood.

Research limitations/implications – This research was only able to acquire data from the federal government over the period 1999 to 2006 because of budget limitations. Data purchase was extremely costly. Because of financial constraints, data with lower levels of accuracy have been obtained from other sources. As a consequence, a major portion of data was mismatched because of the absence of a common parcel identifier, which also affected the comparison of this system to other comparable systems.

Originality/value – Neighbourhood-level HPI is needed for a better understanding of the local housing market.

Keywords Malaysia, Regression, House price index, Neighbourhood, GIS (geographic information systems), Spatial temporal, Geographically weighted regression,

Paper type Research paper

Introduction

Although Malaysian house price index (MHPI) is meant to be a general price indicator, understandably, the heterogeneity of property attributes will naturally result in price differentials across geographic regions and locations. Neighbourhood, which is an important component of location, often displays spatio-temporal price differentials (Archer *et al.*, 1996; Can, 1990, 1996; Can and Megbolugbe, 1997; Quercia *et al.*, 2000). With the notion that the property market is localised in nature, analysing spatio-temporal price differentials in a more restricted locational context is valuable to better understand a particular housing market.

Because of its generality, MHPI is often unsatisfactory when it is used to analyse property prices at the local level. It is not reflective of the local price. For example, it does not

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cater for street-level price differentials when such micro-level price differentials naturally better serve the local market so that people will be able to analyse how prices vary over a small area. Therefore, neighbourhood-level HPI is needed for a better understanding of the local housing market (Schwann, 1998).

The combination of geographic information system (GIS) and property price-related studies have been carried out on various topics by these past researchers: Can and Megbolugbe (1997), Carter *et al.* (1996), Des Rosiers and Theriault (1992), Kauko (2003), Longley *et al.* (1994), McCluskey *et al.* (1997), O'Connor (2001), Orford (1999), Rodriguez *et al.* (1995), Wyatt (1995) and Wyatt and Ralphs (2003). However, incorporation of GIS in the construction of spatial property price index has never been attempted so far. In particular, our study is the first that applies GIS to model, construct and display of the neighbourhood-level HPI for reasons previously mentioned. Nevertheless, the past studies that have been conducted to use surface responses to analyse capital values or prices of properties form the basis for spatial price indexation (Hamid, 2007; LaRose, 1988; McCluskey *et al.*, 1997). The basic principle of this indexation is mapping spatial changes of relative property prices over a geographic space to aid in spatial analyses and decision-making.

The combination of GIS and spatial property price index, in general, is able to provide a better understanding of price changes over a given geographic space, particularly across neighbourhoods. A neighbourhood is the smallest unit of property sub-market and a sub-market really matters (Bourassa *et al.*, 2003; Dale-Johnson, 1982) because it influences the accuracy of property price estimates (Goodman and Thibodeau, 1998, 2003; Hamid, 2006; Watkins, 2001). Most of the GIS packages available in the market are generic and are not naturally designed for a specific purpose. There is a need to develop a domain-specific and easy-to-use application on the existing GIS package to achieve the objective of particular users.

STNL-HPI can provide a better reflection of geographic differences in house price movement at the local level. National level prices have the potential of overestimating or underestimating local prices because they do not fully capture the local market forces or local situations. In China, for example, the national property price index was criticised for understating the severity of the country's property bubble by diluting the large rises in big cities with tamer changes in smaller ones (Anon, 2011).

The existing approach to constructing HPI uses one or a combination of four common methods, namely, central tendency measures (Prasad and Richards, 2006), hedonic regression methods, repeat sales methods (Bailey *et al.*, 1963) and appraisal-based methods (Bourassa *et al.*, 2004). Numerous studies have compared some of these methods of index construction (Crone and Voith, 1992; Hansen, 2006; Mark and Goldberg, 1984; Meese and Wallace, 1997). Several problems have arisen from using the above methods, particularly the inaccuracy of price index prediction because it is an aggregated index. As a result, the constructed HPI may not be reliable especially when it is applied to a local level. This will potentially be misleading to users for decision-making purposes with respect to the local housing market. However, making comparisons of the above methods is not the purpose of this study. Instead, this study focuses on the application of spatial temporal features in constructing a local HPI. In the process, STNL-HPI is preceded by ordinary least squares (OLS) regression for its simpler structure of design matrix compared to other types of regression before the application of geographically weighted regression (GWR). The purpose of including GWR in the analysis is to use it for spatial price indexation which applies spatial interpolation techniques for spatial prediction, namely, kriging. STNL-HPI can provide a better reflection of geographic differences in house price movement at the local level. National level prices have the potential of overestimating or underestimating local prices because they do not fully capture the local market forces or local situations. In China, for example, the national property price index was criticised for understating the severity of the country's property bubble by diluting the large rises in big cities with tamer changes in smaller ones (Anon, 2011). A local study has disclosed that aggregated price index may have underestimated or overestimated disaggregated price indices (Adi Maimun *et al.*, 2012). Since the early 1990s, GIS has shown a rapid development and was being adopted in property-related applications (Hamid *et al.*, 2012). Technological development has bestowed GIS with greater functions and capabilities to suit different user's needs. The application of GIS is able to support real estate activities, functions and decision-making (Castle, 1993, 1998). Studies have also shown that the application of GIS in the study of real estate is able to provide more significant results (Rodriguez *et al.*, 1995). This is because of the nature of GIS that is able to provide spatial analysis and real environment simulation that other tools are lacking.

Malaysian local house price index (MLHPI) published by the National Property Information Centre (NAPIC) is a national level indicator that represents a general profile of house prices in Malaysia. However, as the property market is local in nature, its performance is largely influenced by the neighbourhood's physical, social and economy factors. As price movement is also local in nature, aggregated national and/or regional price movement is insufficient in explaining the micro-market dynamic of housing markets (Schwann, 1998).

Fundamentally, there is relatively less attention given to price movement at the local level compared to price movement at the national level, whereas demand for local market index is increasing because of interest in micro-level price fluctuation. Thus, the absence of LHPI at the local level poses difficulty in the local-level property market research. In addition, spatio-temporal aspect of property price movement is only implicitly and indirectly reflected in the current MHPI. This aspect is yet to be made more explicit and direct for an improved quality of information service delivery. By selecting double-storey terraced houses and taking Johor Bahru as a pilot study area, how could a simple neighbourhood-level spatio-temporal property price indexation be created?

GIS has been widely used for analysing spatial house pricing but using GIS for spatial property price indexation is yet to be initiated. While HPI is a useful tool for monitoring house price movement, GIS spatial functionality is a value-added element to price index analysis, in that it creates interactivity and user-friendliness. Among other things, GIS permits various ways of data retrieval, query and display for customised analysis. Without overemphasising the need for GIS, the system should naturally be part of the modern property price indexation system in Malaysia. Therefore, how can a GIS-based property price indexation system be developed?

Methodology

A preliminary analysis was performed to understand the concept and methodology of level local house price index (LHPI) construction. Subsequently, a localised version of LHPI will be estimated and constructed using the selected statistical method. This local-based LHPI will be used as the core of GIS application. All of these steps constitute the first milestone of the research. System development life cycle (SDLC) concept was then adopted in the next research milestone. SDLC comprises five stages, namely, preliminary analysis, system analysis, system design, system development and system implementation and evaluation (Eldrandaly, 2007; Ferrari and Onsrud, 1995; George *et al.*, 2004; Kissel *et al.*, 2008; Mbokane, 2005; Rogayah *et al.*, 2009). The main aim of GIS application development is to create an interactive customised user-friendly spatial-based information system that is capable of efficient and effective storage, retrieval, displays, queries, analysis and output generation for customer's end-use.

The third research milestone is to map and analyse the resulting spatial HPI across the selected geographic areas. Prior to the mapping, the modified Laspeyres-based STNL-HPI was calculated using the estimated model. For this purpose, a number of residential neighbourhoods (including the base neighbourhood, e.g. the city area) are selected from where property and sales database [obtained from the Department of Valuation and Property Services (JPPH), Malaysia] is built. This database has an array of spatial information (e.g. property's physical, locational and legal attributes) that can be related to the spatial entity (property parcel) contained in the digital cadastral database obtained from the Department of Survey and Mapping Malaysia (JUPEM). These two sets of databases (cadastral and property information) were merged via a matching process in the GIS environment (ArcGIS 10.0) for further analysis steps. The merged database was used to estimate the spatio-temporal statistical model using IBM, SPSS Statistics software, GIS-embedded OLS and GWR. From the estimated model, STNL-HPI is constructed and mapped. The map shows profiles of HPI across the selected geographic area (Johor Bahru), neighbourhoods (Johor Bahru town, Plentong, Tebrau and Pulai) and years (1999 through 2006). Neighbourhoods with a lower profile indicate lower price-bearing areas and vice versa in comparison to the base area. Comparisons will also be made temporally across a particular neighbourhood during the sample period. The sampling with which the models are estimated will be determined later, depending on data availability. If a large data set can be secured, the Laspeyres-based spatial HPI can be constructed year by year. Otherwise, a cross-sectional time-series sample that comprises geographic areas and period will be used instead.

Literature review

House price index

HPI can be defined as the rate of appreciation or change in market value per unit time of a home. This may be estimated as a combination of observed changes in sale prices of homes of a similar type over a particular period of interest. It serves as a yardstick for gauging the living standard and wealth of households and a nation. Measurements and tracing housing price changes has been increasingly important as rapid increases of housing prices has gained attention from all over the world (Li and Tu, 2011). Residential real estate has gained the attention of investors as an investment vehicle. To trace the changes of housing prices more accurately, there needs to be more accurate and stable indices (Wilhelmsson, 2008, 2009).

LHPI has been the major input for housing and mortgage market investigations and studies. LHPI is expected to provide general price movement of the house prices where these price movements will be interpreted and evaluated by both researchers and business owners to understand the housing market. Use of LHPI in market studies is widely acknowledged. For example, it is used for judging risk in a market, measuring market performance, aiding in property appraisals and valuations (Iversen, 2001). LHPI could also be used in residential property investments such as fixing market benchmarks, developing portfolios and for asset allocation strategies (Wilhelmsson, 2008, 2009). Other than these, LHPI could be a reference for policymakers in formulating policies such as housing and mortgage policies (Can and Megbolugbe, 1997). Iversen (2001) defines LHPI as the rate of appreciation or change in market value per unit time of a home. It may also be estimated as a combination of observed changes in sale prices of homes of a similar type over a particular period of interest.

Compared to other price indices, real estate indices or house price indices has gained relatively less attention until recent years. The construction of HPI is difficult for several reasons and heterogeneous characteristics of housing property is one of the reasons. Variation in housing attributes and quality has exerted difficulties to maintain the constant quality of the index. Property sales are also infrequent. The limited volume of property transactions can result in limited transaction data. This limitation could affect the accuracy of the price index and, thus, representation of the real world. Three main approaches for HPI construction are simple average price index, hedonic price index and repeat sales index (Wilhelmsson, 2008). However, there is not one best method that is free from limitations.

Using the median or average sale prices, and/or simple average price index is the simplest form of LHPI. However, it does not consider the type of house and also it is not very useful for analysing neighbourhood price fluctuation (Case and Shiller, 1987).

Bailey *et al.* (1963) introduced the concept of repeat sales index in real estate whereby transaction prices of the same house over a particular period was compared to the initial transaction price of the house to develop a price index that reflects the changing house prices over the period. This concept assumes that the quality and characteristics of houses do not change between two consecutive transactions. This concept is applied to overcome issues of heterogeneity and changing quality of houses over time.

This indexation approach is subject to criticism. The main defect of this approach is its inability to cover houses that are only transacted once or newly produced (Nagaraja *et al.*, 2010, 2011). This has mainly resulted from the pre-requisite of input data that a house needs to have more than one transaction over a period. This requirement has constrained the market to use transaction evidence. As a result, the index produced is unable to represent the housing market as a whole.

This approach is also handicapped by its inability to incorporate time effect on the house quality such as depreciation, impact of maintenance and vintage effects (Li and Tu, 2011). As the quality of houses is assumed to be constant over time, the effect of time is neglected in the index composition, whereas, time effect is affecting house prices. Utility of houses is often linked to physical obsolescence; maintenance activity however is the counter for physical obsolescence. Meanwhile, as technology and the standard of living are becoming advanced, new house model fits for contemporary demand, while old houses may experience economical and utility obsolescence. As the house price is expected to drop because of aforementioned obsolescence, contradictive house price appreciation resulted by inflation is influencing the house price as well. This approach is said to be handicapped in capturing the magnitude of interactions of these effects.

Hedonic HPI (HHPI) is another approach for HPI construction. Every house is different. It is important that HPI takes account of these quality differences. Hedonic methods which express house prices as a function of a vector of characteristics (such as number of bedrooms and bathrooms, land area and location) are particularly useful for this purpose (Hill, 2011). Accordingly, HHPIs are computed from estimated hedonic pricing models (Rambaldi and Rao, 2011).

Malaysia house price index

MHPI was introduced by the Valuation and Property Service Department in 1993 (VPSD, 1993). A sharp rise in property asset inflation during 1995, fuelled by easy credit, low borrowing interest rates and increasing wealth per capita, has given rise to the need for MLHPI to trace and monitor house price movement. As a result, MHPI monitors the overall movement of house prices in Malaysia and officially came into force in 1997. It was initially prepared and published by the National Institute of Valuation (INSPEN) and was later taken over by NAPIC. MLHPI is a hedonic model-based price index where the databank of property transactions and stamp duty valuation is utilised for the multiple regression analysis. MHPI is a Paasche price index where it is weighted at the model house of comparison year. The index is covering the housing market of the whole of Malaysia with more than 60 sub-indices of the national and state house prices. MLHPI provides index information at the national and neighbourhood levels, but not at the local level. However, the construction of a price index still needs the input of the data from which MHPI is constructed. Housing markets are complex and characterised by the existence of segmented and sub-markets at different levels. House price movement is also proven to be different across a geographic area with different changing rates in different neighbourhoods (McMillen, 2003). LHPI reflects a measurement of house price movement aggregated from these segmented and sub-market price fluctuations. To understand price movement at a micro level, a measurement of local price movement is necessary. Therefore, LHPI that serves as the yardstick for house price movement is required to be built for the local market to gauge market price fluctuations at the local level.

Local house price index (LHPI)

Housing markets are complex and characterised by the existence of segmented and sub-markets at different levels. House price movement is also proven to be different across a geographic area with different changing rates in different neighbourhoods (McMillen, 2003). LHPI reflects a measurement of house price movement aggregated from these segmented and sub-market price fluctuations. To understand price movement at a micro level, measurements of local price movement is necessary. Therefore, LHPI that serves as the yardstick for house price movement is required to be built for the local market to gauge market price fluctuations at the local level. While tremendous effort has been made for aggregate LHPI, local-based LHPI has received relatively less attention (Schwann, 1998).

Local LHPI can be constructed in various ways. Both repeat sales and a hedonic approach could be applied for local LHPI construction with necessary modifications. Can and Megbolugbe (1997) pointed out that a hedonic approach is more suitable for cross-sectional quality adjusted price indexing. They also demonstrated a hedonic price index that is capable of comparing price movement among neighbourhoods by integrating locational factors in the multiple regression equation. Different hedonic price functions is necessary to reflect different house price functions of the neighbourhood (Straszheim, 1974), while Michaels and Smith (1990) stated that single hedonic price equation is inadequate to describe the large housing market aptly.

Spatial analysis via geographical information system

GIS as an information technology envisioned by researchers in the late 1950s to early 1960s was originated from the development of computer graphics, computer assisted cartography and automated mapping techniques. Pursuant to computerised database applications, researchers envisioned a combination of geographical data and numerical data as a new approach to database development. Broadly, GIS is a set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough and McDonnell, 1998). It can also be defined as a computer-based system that provides four sets of capabilities to handle geo-referenced data, namely, data capture preparation, data management including storage and maintenance, data manipulation and analysis and data presentation (Huisman and de By, 2009). Another definition views GIS as computer technology that combines geographic data (locations of man-made and natural features on earth's surface) and other types of information (names, classifications, addresses, etc.) to generate visual maps and reports (O'Looney, 2000). The global leader in GIS software developer, Environmental Science Research Institute (ESRI) defines GIS as a system designed to capture, store, manipulate, analyse, manage and present all types of geographically represented data. In the simplest terms, GIS is the merging of cartography, statistical analysis and database technology.

From these definitions, GIS mainly comprises three elements. First, GIS is an information system and database method. However, it is different from other types of information technology because of its specialisation of spatial elements where GIS uses geo-references as the primary means of storing and accessing information. Second, GIS integrates technology, developed with the ability to handle spatial statistics, to analyse aerial photographs or draft thematic maps. Third, GIS is a process rather than a combination of software and hardware. The management of data and use of its function should reflect the method that the information should be used for specialised purposes. In short, it should be a tool that helps in decision-making.

GIS software packages are mostly generic in nature; they are not designed for measurement of linkages identified by urban economic theory (Clapp and Rodriguez, 1998). To serve particular purposes, researchers have developed various customised GIS applications. These applications have been further accelerated by programming languages such as Microsoft's Visual Basic (Thrall, 1998). Among specialised GIS applications developed were the ones used for the purpose of valuation and property management (Stylianidis *et al.*, 2008; Suriatini and Taher, 1998; Wyatt, 1997), rating assessment (Ibrahim *et al.*, 2001) and land management (Joerin and Musy, 2000). A simple Web-based GIS application for online-listing of property was also created (Teh, 2011).

It is well known that property value represents the value of a combination of attributes such as physical build-up, socio-economic factors and legal rights (Wyatt, 1997). Neighbourhood, environment and accessibility are all the locational attributes affecting the value of real estate. However, location is the main factor affecting property value (Goodall, 1972). The maxim "location, location, location" has implied that location is the most significant attribute for real estate (Barnett and Okoruwa, 1993). Thus, location is possibly the most important consideration in any real estate decision-making.

The emphasis on location in real estate without ignoring other attributes is perfectly matched with the ability of GIS to handle and integrate spatial data and attribute data. Besides matching of GIS and real estate, GIS applications for real estate have become important for three reasons (Roulac, 1994, 1998; Roulac *et al.*, 1990). First is the information explosion. Since the early 1980s, the era of informative began with liberalisation of data and information. Data and information became more readily available and accessible by the public. Advancements of information infrastructure of both the public and private sectors have enabled information guided decision-making to be implemented by individuals and organisations. Second is the technological innovation. The revolution for affordable and user-friendly computers was also initiated in the early 1980s. IBM Personal Computer and Apple Macintosh made efforts to provide cheaper but better capable computing measures. Computer applications became readily available. Computing has been widely applied across the public and private sectors for better organisational performance. Third is the structural change within the real estate industry. Real estate players have become more data-oriented nowadays than in the past. Institutional background and information favouring of the real estate player has rendered them to be more favouring on number and data backed decisions instead of acumen-based judgment.

Geographical information system application development

Analysis of system development was performed to identify the basic GIS functionality for STNL-HPI application. Functional requirements for STNL-HPI such as display and input selection were specifically investigated. Database construction needed for STNL-HPI was also determined at the early stage of system application design. The STNL-HPI process was also reviewed to identify the steps and actions required for the STNL-LHPI construction.

SDLC is a standard procedure in any GIS application development. It has five interrelated stages. System design is conducted at the third stage in this study. This stage covers database design, which consists of conceptual design, logical design and physical design. Data items are collected from respective departments (JUPEM, NAPIC and JPPH). At the same time, user-interface design is also initiated in the third stage.

The fourth stage of the study is focussed on system development. Completed system design will be translated into application through coding and programming. Database and interface will also be integrated at this stage. The final stage of this study is system deployment and evaluation. Integration of database and interface is the deliverable of a particular system implementation. The process of integration of database and interfacing marks the completion system application. Evaluation stage is conducted by carrying out a trial among the targeted users. Feedback from the users is then analysed as system evaluation.

Development of GIS application from zero is often difficult. A leading developer of GIS software, ESRI, has proposed an approach for GIS application development through the use of ArcGIS Engine. ArcGIS Engine is a collection of GIS components and developer resources designed to build customised and domain-specified GIS applications (ESRI Environmental Science Research Institute, 2004). ArcGIS Engine has two main components. First is the ArcGIS Engine Software Developer Kit that is designed for developer's application to build custom GIS applications and to embed GIS logic in the new application. Second is the ArcGIS Engine Runtime which acts as a platform for the end-user's machine to run applications that contain several other components. These are:

- base services (ArcObject that is the core for almost all GIS applications including feature geometry and display);
- data access (geo-database that includes spatial data and attribute data);
- map presentation (created and displayed with ArcObject's symbology, labelling, and thematic mapping);
- developer's components (high-level user interface that controls and helps in application development); and
- extensions (functions of ArcGIS Engine Runtime that can be deployed with existing standard functions or with additional advanced function extensions).

Application system developers can access a set of controls that allow for the use of ArcGIS Engine properties, events and methods. Applications can be built ranging from simple GIS applications that only display maps to sophisticated applications with high-level control functions. ArcGIS Engine is an object-based application which is formed by the component's library of ArcObjects. GIS application development (based on ArcGIS Engine) requires adequate knowledge of the different libraries that compose ArcGIS Engine (ESRI Environmental Science Research Institute, 2004).

ArcObject library is the logical collection of ArcObject Components ranging from individual geometry objects to aggregate logical collections of functionality. In the implementation of ArcGIS Engine, developers have to choose their preferred API to develop interface and logical functions that control the ArcObjects. Developers could also build and extend the functionality of ArcGIS Engine while providing graphical user interface through Engine Control. Engine Control is available in ActiveX Controls, .Net Windows control and Visual JavaBeans.

Conceptual design

Conceptual design was the first aspect of database design whereby the relationships between the data used have to be identified. Conceptual scheme using entity relationship (ER diagram) was used to outline the relationships between data. The schematic diagram has included all entities of the database with clear relationship indications between the entities to provide a better understanding and reference in the later stage. The uniqueness of this database lies in the information for house prices over the period and LHPI over years. These two items were not recorded in static figures but were generated using the query function (Figure 1).

Index modelling

There are numerous methods of constructing property price index, and they have been extensively discussed in the literature. Discussing these methods is not the main purpose of this study. Notwithstanding this, the most contemporary methods are founded on spatial and temporal dimensions of property values. Among the methods having these features are spatial temporal auto-regression and flexible neighbourhood-time models. A short discussion follows.

Local design

Logical design was the second stage in the database design whereby the conceptual design was translated into the model of a specified system. Relational database model was adopted in this application. The attributed data were stored together with spatial object in the spatial data, i.e. the map. The map was prepared prior to the application development. Map and attributed data were joined using ArcObject embedded in the application.

Physical design

The selection of database structure or data storage method was the main scope in the physical design stage. As the proposed GIS software was stand-alone, processing speed and

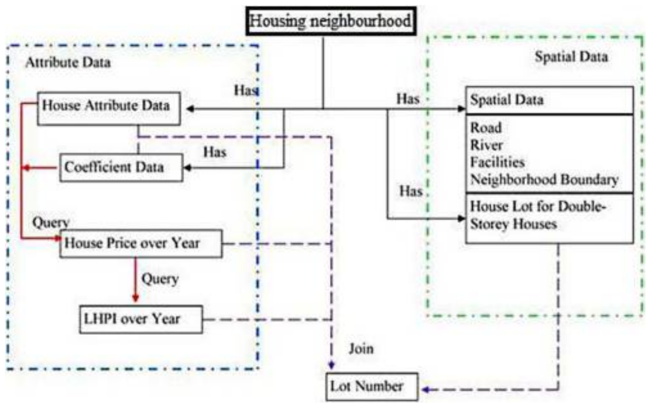

Figure 1.
Conceptual design of database

storage capacity are generally acceptable with current technology. Stability and reliability are more important for the software. The major considerations in physical design were providing a smooth operating function of the application software and stable and good linkages between spatial and attributed data while allowing for changes in attributed data.

Spatial–temporal autoregression model

The spatial temporal features improve accuracy through the following modelling structure (Pace *et al.*, 1998, 2000):

$$Y = X\beta + \varepsilon \tag{2-2}$$

$$\varepsilon = W\varepsilon + \mu \tag{2-3}$$

$$W = \varnothing_s S + \varnothing_T T + \varnothing_{ST} ST + \varnothing_{TS} TS \tag{2-4}$$

$$\varnothing = [\varnothing_{S'} \ \varnothing_{T'} \varnothing_{ST'} \varnothing_{TS}] \tag{2-6}$$

$$\mu \sim N\left(0, \sigma^2 I\right)$$

The general specification is given as follows:

$$Y = Z\varnothing + X\beta_2 + TX\beta_z + SX\beta_z + STX\beta_4 + TSX\beta_5 + \varnothing_s SY + \varnothing_T TY + \varnothing_{STY} STY + \varnothing_{TSY} TSY + \mu \tag{2-7}$$

where:

N = normality assumption;
Y = n × 1 vector of house prices;
Z = n × k matrix of observations unassociated with spatial, temporal or spatio-temporal lags;
X = n × k matrix of house attributes and n by p2 matrix of house attributes associated with spatial, temporal or spatio-temporal lags;
β = regression parameters in which are k by 1 vectors of parameters associated with spatial, temporal or spatio-temporal lagged variables;
μ = vector of white noise error term;
ε = auto-correlated error;
W = spatio-temporal weight matrix;
S = spatial weight matrix;
T = temporal weight matrix;
$\varnothing$ = auto-regressive parameter;
$[\varnothing_{S'} \varnothing_{T'} \ \varnothing_{ST'} \varnothing_{TS}]$ = set of scalar auto-regressive parameters;
$\varnothing_S$ = spatial dependence parameter;
$\varnothing_T$ = temporal dependence parameter; and
$\varnothing_{ST}$ and $\varnothing_{TS}$ = spatio-temporal compound dependence parameters.

This STPI model uses Pace *et al.*'s (1998, 2000) filtering method. First, all observations are temporally ordered according to the year of transaction whereby the earliest transaction (year) is ordered in the first column of the dataset while the latest is in the last column. The subject property is influenced by previous transacted neighbouring properties. Zeros on the diagonal of W prevent self-predictions among the observations. Each row in W is summed to 1. Therefore, W acts as a linear filter of the model (Davidson and MacKinnon, 1993). Matrix W is partitioned into spatial and temporal weight matrices. The spatial weight matrix, S represents the spatial relationship between previous observations. In the temporal weight matrix, T represents the temporal relationship between previous observations. In the S and T weight matrices, weighted by only auto-regressive parameters, act as space and time lag operators, respectively. These lag operators are not appropriate for frequently occurring data, but also for infrequently occurring data, which is one of the real estate's data characteristics. The calculations for S and T weight matrices are simplified, as only previous observations are considered. Thus, the general specification of matrix W is written in equation (2-4) which contains spatial and temporal filtering. ST and TS matrices allow for the model of the spatio-temporal effects. The form of filter in equations (2-4) and (2-5) is substituted into equation (2-2). This generalises the model into a linear regression model which is then used to estimate the hedonic and auto-regressive parameters. Equation (2-7) shows the STPI model includes lagged dependent and lagged independent variables as explanatory variables in the model specification. This is in contrast to the traditional hedonic model in equation (2-2), which does not include any form of lag as one of its variables.

Construction of spatial–temporal neighbourhood-level

This research proposes that the construction of spatial–temporal neighbourhood-level house price index be performed by area and neighbourhood to ensure inter-area and inter-neighbourhood price index comparisons. Besides, the price index is based on unit price and per square metre price. Further, the index comprises three price variants, namely, long-term price (eight years, in this case), annual price and quarterly price. In this context, however, the amount of data readily available for analysis is the vital factor determining a good property index series to be developed. In the case of Syed *et al.* (2008), as many as 170,000 individual property transactions in ten Australian cities were used to construct flexible neighbourhood-time property index. In this case, only 4,819 parcels (20 per cent) could be successfully matched with the digital cadastral database sourced from JUPEM. This could have been caused by various problems such as different parcel identification systems used by the data custodians (JUPEM, JPPH, NAPIC) and changes in parcel information that have not been updated. Consequently, none of the property parcels transacted beyond 2006 could be mapped. Because of this limitation, highly accurate street-level price index construction was not possible; resulting in having to resort to constructing what is called "simple STNL-HPI". The simple STNL-HPI is constructed in the following ways:

- Long-term index (TL_INDEX_BLSN, TL_INDEX_SQM).

To construct this index, select the index areas, in this case: Johor Bahru Town, Plentong, Tebrau and Pulai. Then, take Johor Bahru Town as a "control" area. The rationale for selecting it as a control area is because it is an area with the busiest commercial activities. Next, take mean of house prices for Johor Bahru Town for the eight-year period (1999 to 2006):

$$\overline{P}_{JB} = \sum_{i=1,t=1}^{n,T} P_{iJB}/N \rightarrow 100 \quad (3\text{-}1)$$

Then, take the mean of house prices for other areas:

$$I_{TLj} = \frac{100}{\overline{P}_{JB}} x\overline{P}_j \quad (3\text{-}2)$$

where $\overline{P}_{JB}$ is the mean house price for Johor Bahru Town, and $\overline{P}_j$ is the mean house price for area j. Thus, the means of house prices for other areas, namely, Plentong, Tebrau and Pulai, are compared to the mean house prices of Johor Bahru Town:

- Annual index (TA_INDEX_BLSN, TA_INDEX_SQM).

This index is constructed in the following steps. First, select the index areas: Johor Bahru Town, Plentong, Tebrau and Pulai. Then, take Johor Bahru Town and the year 1999 as a "control" spatio temporal group for the reason previously mentioned:

$$\overline{P}_{JB-1999} = \sum_{i=1,t=1}^{n,T} P_{iJB}/N \rightarrow 100 \quad (3\text{-}3)$$

where $\overline{P}_{JB-1999}$ is the mean house price for Johor Bahru Town in 1999, and P_j is the house price of individual properties in Johor Bahru Town in 1999 where t = 1,. . .T = 12 months. Next, take the mean of HPI for other areas and the rest of the annual periods from 2000 to 2006:

$$I_{TAj} = \frac{100}{\overline{P}_{JB-1999}} \cdot P_{t,j} \quad (3\text{-}4)$$

where $\overline{P}_{JB-1999}$ is the mean house price for Johor Bahru Town in 1999, and $P_{t,j}$ is the house price of individual properties in year t and area j. Thus, the means of house prices for other areas (i.e. Plentong, Tebrau and Pulai) and in other years (2000 to 2006) are compared to the mean house prices of Johor Bahru Town in 1999.

Construction of STNL-HPI map

Two series of maps are developed using ArcScene prior to the development of GIS application (Table I). These maps are HPI map and house price map that are later displayed and loaded in the GIS application. Three series of maps that are created are house price map, LHPI map, and geographical index (GI) map. House price map is displaying the prices of housing units using an extrusion function to create 3D columns for each parcel or lot. Also, house price inverse distance weightage (IDW) interpolation and house price contours are constructed. Meanwhile, the LHPI 3D column map is showing the value of each house. Finally, the GI map is using the lowest house price in the neighbourhood as a base to create an index to show the variation of house prices within the neighbourhood.

Database design and development

Database is essential for the GIS software where it affects the accuracy of analysis results and output. Design and construction of the database fulfils the objectives of this study. The

Table I.
Malaysian HPI

	Sub-indices/Composition
National index	Malaysian HPI Malaysian terrace HPI Malaysian semi-detached HPI Malaysian high-rise unit price index
State index	13 states and two federal territories of Malaysia (one index for each state) Kuala Lumpur, Selangor, Johor and Penang have sub-indices according to housing types, i.e. terrace, semi-detached, detached and high-rise housing units. Other states have three sub-indices based on terrace, semi-detached and detached houses
Neighbourhood index	Klang Valley HPI Penang Island HPI Johor Bahru HPI Seremban–Sepang HPI Ipoh–Kinta HPI

Source: VSPD (1993)

data used as the input for LHPI construction were divided into spatial data and attributed data. The spatial data were formed by mapping housing neighbourhoods with attributes of double-storey terraced houses used as input for LHPI construction. The database was also designed with the necessary analysis to enable users to carry out investigations regarding the LHPI. The characteristics and development of LHPI have remarkable influence on the database design. The LHPI model adopted in this study was developed using GWR. One of the unique characteristics in this model is that the coefficient for regression variables is not static but changing across space. Thus, to predict house values using the regression function, coefficient at the location has to be identified. It is implied that the coefficient has to be captured and stored.

Data collection

Spatial data. Spatial data comprise the location map of the Johor Bahru City Council's planning blocks. The map was provided by the Council in the form of a digital cadastral map. It comprises layers of information such as roads, rivers and neighbourhood boundaries. The digital cadastral map obtained shows land parcels in the study area but it did not specify the double-storey terraced houses. Matching the cadastral map with Johor Bahru City Council's housing list helped identify all double-storey terraced houses in the neighbourhoods. To construct STNL-HPI, a sample of 4,968 transacted double-storey terraced houses in Johor Bahru was mapped in the form of points.

Attribute data. Attribute data were divided into housing attribute data and coefficient data. Housing data were obtained from Johor Bahru City Council in the form of a housing information list. These attributes were also the variables used in the GWR analysis. The coefficient data have to be extracted manually from the GWR outputs. In the GWR analysis, the coefficients were produced in the form of raster layer which showed the changing coefficients across space. These coefficients have to be extracted for each of the double-storey terraced houses in the study area.

Results and analysis

The index viewer was designed to enable users to investigate LHPI in both map and numerical form. The first layer's menu bar comprises file, price index and house price sub-menus. The second layer's menu bar comprises map view and tables and graph sub-menus.

The map view provides the user option of whether to investigate LHPI in map or table and graph form. The LHPI can be presented in time-series' index and geographical index. In this context, to enrich the user's experience, neighbourhood-level maps of house prices can be prepared as well. To investigate neighbourhood's price movement visually, users can choose a view either in the form of price index or house price. In this study, the focus was only to analyse price index; thus, house price was not given attention.

Price index map can be displayed by state, district, region, neighbourhood and type of value base (square metre). As the data set used in this study was relatively small to enable a complete local-level price indexation, only a few housing neighbourhoods in Johor Bahru can be included and only a generalised neighbourhood-level HPI can be computed. Another option for model and specification is based on ArcGIS's built-in module of GWR that can be invoked through the database and REPORTS component in index viewer. Therefore, the STNL-HPI model has to be displayed in map form to show the characteristics of GWR. In the map view, transacted lots are displayed in point form. Users may investigate the lot's GWR results using the Identify Too. One of the characteristic of GWR analysis is that it will produce non-static coefficients for each variable (coefficients for each variable are varying across the geographical area). To display the coefficients that vary from place to place, these coefficients are displayed in raster form where varying coefficients are displayed in varying colours.

If the user does not prefer the display of GWR model in map view, they can choose an alternative display form in specification. In the specification window, GWR model is presented in econometric form. To illustrate the spatial characteristics of GWR, the GWR is summarised into five phases, namely, minimum, lower quartile, mean, higher quartile and maximum. In addition, an econometric equation is also prepared for user's reading.

Database and report

Data for construction of the STNL-HPI is stored in the database of index viewer. For users who intend to navigate this data, they can browse through the database. On the other hand, one can also investigate house prices and STNL-HPI for particular housing units in the database. To suit the different needs of users, the database is developed in two forms, spatial database and relational database.

Spatial database

Spatial database is designed in spatial map. The map consists of different layers that link to different data sets of the relational database (Table II). Users can navigate it as a map and

Series map	Name	3D column representation	Formula	Other features
Time series index	House price map	Price per square feet	Price per square feet = house price/land area	House price IDW interpolation Houser price contour Base map
	LHPI map	Local house price index	LHPI= price of compare year/price of base year	LHPI IDW interpolation LHPI contour Base map
Geographical index	Geographical index map	Geographical index	GI = compare unit/base	House price IDW interpolation House price contour Base map

Table II.
Map series and respective components

also search for required information on the map. Two major highlights in the spatial database are the Identify and Search functions. These two functions are developed from ArcObject in ArcGIS Engine and embedded in the MTB. For using the identify function, users only need to click on Identify Tool in the MTB. The application will convert the mouse tool into Identify Tool. Then, users can click on the object that is intended to be investigated. A pop-up window will be launched to show the details of the object. For objects that overlap in several layers, the user is given the option to view data stored in the respective layers.

Relational database

The relational database is presented in table form and is directly linked to the Microsoft Access database. This window form is prepared for users who prefer to investigate data in table form instead of map form. The relational database is designed with four-tab pages where each tab page is linked to respective datasets in the Microsoft Access Database. This database is also equipped with a search function. In using the search function, users can choose to search the information within specified fields from the combo box function. If the field to be searched is not selected, the search will default to search in the ID field. However, the search function is deemed to be less flexible because users are required to key-in keywords that exactly match with the data to perform the search function successfully. This is because of the nature of the database that is stored as double. The system cannot perform searches for similar value if data are stored in double storage unless the data are converted into string. However, if data are converted to string, house price and LHPI cannot be derived from query and only can be presented in a static manner.

STNL-HPI mapping and modelling

The STNL-HPI mapping was created in several stages. The first stage was to create map features, followed by interpolation for STNL-HPI and house price and creation of 3D columns. Then, maps were produced for STNL-HPI such as house price map and geographical index map. Figure 2 shows the created base map of the study area containing essential features such as area boundaries (four polygons representing Bandar, Plentong, Tebrau and Pulai), roads, rivers, housing lots (not shown here) and housing neighbourhoods (222 polygons representing 222 housing estates). These data were extracted from JUPEM's digital cadastral map provided by the Johor Bahru City Council showing a sample of 4,819 transacted double-storey terraced houses in Johor Bahru.

Index construction using GWR

To enable an overall perspective of spatial variation in house prices across neighbourhoods, generalisation of STNL-HPI is necessary particularly for spatial comparison purposes. Based on the four model specifications a choice was made to determine the best model for the construction of STNL-HPI for the study area based on the results shown in Table III.

The selected property attributes have managed to explain variations in HPI modestly (adjusted R^2 ranged from 0.65 to 0.68) using the total price function. However, this variation was poorly explained by the attributes in question using per square price function. This indicates modelling shortcomings whereby other relevant property attributes have not been included in the specification. After some consideration, Model 4A has been chosen in furthering steps for spatial prediction of HPI.

Figures 3 and 4 show quarterly and annual GWR-predicted STNL-HPI, kriged over the study area during 1999-2006 period. With the creation of STNL-HPI, spatial comparison of HPI can be made temporally and spatially at neighbourhood and street levels. For example, the maps show a generally higher price index profile in the western region (mainly region of

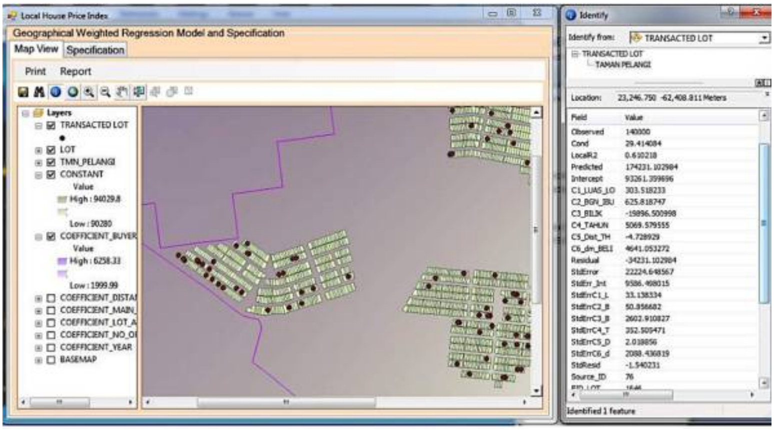

Figure 2.
Display of GWR model in map view

Table III.
Map layers in spatial database

	Map layer	Linking with relational data set	Content
1	Coefficient_Data	Coefficient_Data	Coefficient for each variable derived from GWR analysis
2	Attribute_Data	Attribute_Data	House attributes for input as independent variables in GWR analysis
3	House_Price	House_Price	House price for each unit from 2000 to 2012 derived from query
4	House_Price_Index	Local HPI	Price index for each unit from 2000 to 2012 derived from query

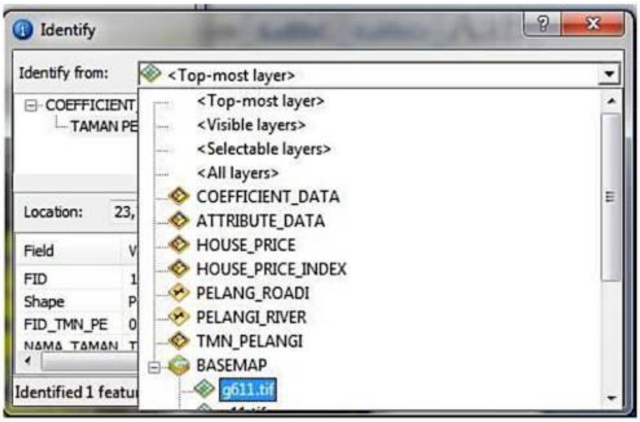

Figure 3.
Selection of layers in the identify function

Tebrau) compared to the southeastern region (region of Plentong). Small patches to the west of intersection between Jalan Kempas Baru and Pasir Gudang Highway, to the south of intersection between Jalan Tun Razak and Jalan Datin Halimah and triangular intersection between Jalan Tun Abdul Razak, Jalan Abu Bakar, and Jalan Tebrau have shown the highest per square metre price index. To determine the reliability of the resulting STNL-HPI,

Figure 4.
Use of identify in the spatial database

a simple heuristic evaluation method has been adopted by comparing the index figures of individual property parcels and the kriged STNL-HPI.

Dynamic testing

Dynamic Testing was conducted after static testing was completed. At this stage, test group users were invited to run the system application and to evaluate it accordingly. As many as 20 university students majoring in real estate were invited to test the application. An evaluation form was used as an instrument to capture their personal ratings of the application.

Table IV shows the summary of application evaluation results obtained from the users. Overall, the application has scored between average and good for each of the criterion (3.778-4.06). Among the three criterions, Simple and Easy to use has the lowest

Component	Assessment	Minimum	Maximum	Mean
Index viewer	Usefulness	2.00	5.00	4.03
	Simple and easy to use	3.00	5.00	3.83
	Clearly an understandable information display			
	Mapping display of house price and LHPI across the neighbourhood	3.00	5.00	3.93
	Display of house price and LHPI in table and graph	3.00	5.00	3.85
Model and specification	Usefulness	2.00	5.00	3.98
	Simple and easy to use	2.00	5.00	3.55
	Clearly an understandable information display			
	Shows the specifications of the index model clearly	300	5.00	4.25
Database and report	Usefulness	3.00	5.00	4.38
Database	Simple and easy to use	2.00	5.00	3.80
	Clearly an understandable information display			
	Displays the spatial data clearly	2.00	5.00	3.77
	Displays the attribute data clearly	3.00	5.00	3.95
	Investigate and query of required data	3.00	5.00	3.85
Report	Usefulness	3.00	5.00	4.05
	Simple and easy to use	3.00	5.00	4.12
	Clearly an understandable information display			
	Reporting for attribute and coefficient	3.00	5.00	4.23
	Reporting for house price and LHPI	3.00	5.00	4.25

Table IV.
Descriptive analysis of scoring obtained from users' evaluation

overall score which only 3.778. Model and Specification component has also recorded the lowest scoring among all components, which was only 3.55. In contrast to the second criterion, the application has scored highest in the third criterion, namely, clear and understandable information display. Again, Model and Specification component made its unique position as highest scorer within this field. The application has scored moderately in the first criterion. It is remarkable that Index Viewer is deemed to be most useful in helping users to understand house price movement in the neighbourhood.

Suggestions and recommendations from test group users were analysed qualitatively. These were important in explaining evaluation scoring of each component. Feedback from users are then summarised and categorised according to respective components of the application. Table V tabulates the individual user's feedback on selected respondents.

User's feedback

Dynamic testing was conducted after static testing was completed. At this stage, test group users were invited to run the system application and to evaluate it accordingly. As many as 124 participants from real estate companies as well as government agencies that relate to the housing sector were invited to test the application. An evaluation form was used as an instrument to capture their personal ratings of the application. The main criterion of selection was that the respondents were potential users of this system to have a direct view of the system.

Generally, users have provided positive feedback on the system application. They have commented that some of the components such as 3D Mapping of Index Viewer and Model and Specification of GWR as "good". However, not all feedback was complimentary; some comments have highlighted the weaknesses of the system application. These weaknesses in the application have generally resulted from the shortcomings and technical limitations in the application programming. Apart from strengths and weaknesses, users have also provided comments for improvement of the system application. These comments were useful for further improvements of the system application.

Table V. Selected individual users' feedback

No.	Comment and suggestion
1.	Good
2.	The 3D mapping is good
3.	Unable to search and identify the 3D map
4.	Good. Saves time and effort to process the data for mapping process
5.	Unable to understand GQR concept
6.	There is room for improvement for application design
7.	Database query is difficult to use because have to key in specified keywords
8.	Navigation on the map is unsmooth
9.	Useful for understanding house price movement in the neighbourhood
10.	Maybe supplementary function such as help and user guide should be provided with the application
11.	The 3D mapping is attractive
12.	The 3D map is complicated at first look. But it is quite OK after knowing how to operate it
13.	Database should be integrated with 3D mapping so that investigation for information will not be so cumbersome
14.	The report will be better if users are given an option to select required information, which element to be reported

Weakness of application – not user-friendly

The application has scored lowest for the "simple and easy to use" criterion which was only 3.78. This may be caused by respondents who have minimal or no experience in GIS use. This has rendered the application to be perceived as rigid and less flexible to use. Besides that, as 3D mapping and database were not integrated in this application, users often face difficulties in identifying information for particular objects in the map. Among all components, the application is weakest in displaying the model and specification of the LHPI (score 3.55). Comments from the candidates indicate that some of them did not understand the concept of GWR. This could be a reason for giving a low score in the assessment. Feedback analysis also showed that users were less satisfied with the database system. This was mainly attributed to lack of integration between mapping display and the database. Even though the database was quite comprehensive, most of the information needed by users in both spatial map and relational database, however, was not integrated with 3D mapping display. Users had to run additional windows and work to identify particular information. Some of the users suggested improving the user-friendly application by providing supplementary help functions and a user manual. Help functions and user manual for the application could assist users to understand the concept and master the application more easily.

Strength of the application – clear display of required information

The application has the highest overall score of 4.06 for clear display of information. Among all components, the Model and Specification had the highest ranking where users felt easy in understanding the model and specification. This is because the testing candidates were university students who are equipped with knowledge of price function while the application displayed the price function in the form of econometric in the model and specification window. Another reason for the high scoring of this criterion is the background of application developers and testers. As both testers and developers have the same background as university students, the requirement for information to be displayed could be well fulfilled by the developer.

The 3D mapping display has received complimentary feedback from the users. It has the highest score of 4.06 in the first criterion. It shows that the 3D mapping display of house price and LHPI is useful in helping users understand price movement in the neighbourhood. Map display of LHPI is able to visualise the variance in house price movement within the neighbourhood. The LHPI is represented by 3D columns for each house lot where the column height represents the value of LHPI. The presentation of 3D columns in different colours could further highlight the differences in LHPI value for every lot. Apart from the index display, house price map is prepared to enrich the user's experience and to enable users to identify differences of house prices between houses. However, in terms of performance, the component did receive negative responses from the users such as slow and unsmooth loading because of heavy 3D elements. Besides that, users experienced rough map navigation.

Usefulness of system application

The users acknowledged that the application was useful in displaying LHPI and helped to identify the house price variation across neighbourhoods. The high score of index viewer (4.06), in terms of usefulness, has reflected user's affirmation on its contribution in helping them understand the house price variance and movement. Besides that, other components have also scored around 3.9. This has indicated that the components are enhancing the user's understanding of micro-level house market performance.

GWR has varying coefficients across the space which shows that house attributes also have varying values across space. The effect of space towards house price has been depicted in the GWR model. Meanwhile, the application is also said to have a comprehensive database. The database has recorded every element that contributes to the houses price based on the GWR. Users can retrieve information such as house attributes, coefficient, yearly house prices and LHPI in the database. Concluding from the user's evidence, the application is deemed to be useful for users in understanding the house price movement and variance at the local level.

Data improvement

As mentioned in the previous section, the poor explanation of variation in property prices was caused by modelling shortcomings whereby many relevant property attributes were not included in the model specification. The absence of such data has impaired their inclusion in the model. Therefore, inclusion of more detailed property data such as building age (year built), architectural design, renovation, number of bathrooms, general building conditions and accessibility should be part of future improvements in NAPIC's valuation database.

A successful STNL-HPI system depends very much on data compatibility. Because of data limitation, STNL-HPI has yet to achieve better accuracy. Apart from being costly, data inconsistency has contributed to problems in developing a good STNL-LHPI system. More numbers of matching property parcels and sales transaction data were not achieved because of these problems.

As an initial solution, data providers (especially NAPIC and JUPEM) could adopt a consistent national data format. For example, a unique national parcel identifier system (UNPIS) could be devised and adopted by both data custodians so that automatic data analysing and matching can be performed as instantly as possible. In this case, the cadastral data produced by JUPEM could be used as the basis for all other spatial data by introducing UNPIS instead of particular institution's own preferences.

NAPIC is the government organisation that collects and provides real estate market data in Malaysia. Providing STNL-HPI is an added-value component of the existing MHPI. The index could be published in the form of mapping or subscription of a Web-based application. The existence of LHPI enhances people's understanding of the local real estate market situations and performance.

Feedback provided by the respondents in the application testing shows that there were user expectations towards construction of LPHI where users could freely choose their own index model and specification. This option was not included in this study. Thus, future study could focus on the development of alternative STNL-HPI modelling and application. The shortcomings identified in this study could be used for future studies.

The STNL-HPI GIS-statistical application proposed in this study could be further improved by focussing on other application options such as Web-based, Cloud or Smartphone applications. Further, these applications could be more widely used by the public, as well as be updated.

Application improvement

A dedicated GIS-based STNL-LHPI system is proposed to be enhanced from the current capabilities to be part of a computerised MHPI. The improvements are as follows:

- Improving the 3D map navigation functions by programming the mouse control with additional functions such as "zoom" and "select" without depending on the Map Tool Bar too much.

- Integrating the 3D map and database by linking an Access database and the 3D spatial map. Besides, programming the 3D map with "identify" and "search" functions is needed so that users do not need to perform data searches separately. User's evaluation and feedback has provided input for the application design. It was discovered that the users demand more interactive GIS applications. For example, in this study, the 3D mapping and database components were not integrated, whereas users often expect more interactive mapping where they can directly retrieve information from the map.
- Improve the database search system by providing more flexible "search" functions like those of Google where no exact keyword is required to perform search functions.
- Provide a user guide and help function in explaining the application's components to help users understand more of the LHPI and applications as well.
- Provide options for users to select items to be included in the report.

Summary

This study has focussed on GIS-statistical method in the construction of STNL-HPI. In particular, GWR was applied in modelling HPI using sales transaction data. Stand-alone GIS application was then developed using ArcGIS Object with minimal object-based programming requirements to generate visual displays of price index information across selected neighbourhoods. Neighbourhood-level HPI (STNL-HPI) was presented in both map and numerical forms to enhance the user's understanding of house price movement in a particular neighbourhood. Time-series and geographical-indexes were computed to present the STNL-HPI in map form. With these two-index series, users could understand house price variation and movement across time and space within a limited geographic span. Application of the 3D graphic, in particular, was able to further illustrate the variation of STNL-HPI across time and geographic space while enhancing user's visualisation of the phenomenon under study. Besides map display, GIS-statistical-based STNL-HPI has provided some information on house attributes, coefficients for the attributes, index model and specification for the selected type of properties, i.e. double-storey terraced houses. To enable users with minimal GIS skills to apply the technique, all data processing and mapping efforts have been carried out before embedding-in the GIS application. Users can enjoy the benefits of GIS and mapping visualisation without much processing and analysis work in GIS. The GIS application was also designed with only the necessary functions so that users would not be confused with too many analysis options and would be able to master the application within a short time.

The results have shown that GWR was able to provide accurate predictions of house prices at the neighbourhood level. It recognises the spatial dependence of real estate values and accounts for the varying house attributes and marginal prices of attributes across space. Besides that, GIS can enhance the user's understanding of value patterns through map visualisation. In combination, GIS-statistical-based LHPI construction is able to help users better understand spatio-temporal house price variation or movement across a given neighbourhood. Valuers can use the outputs for valuation investigation where they can make spatial deductions of property values and their associated spatial factors across a given neighbourhood. Besides that, the system could also be used by local authorities for rating purposes.

This study was aimed at developing a stand-alone GIS-statistical application of STNL-HPI. To achieve the main aim of the study, two objectives were specified, namely, the development of a stand-alone GIS-statistical application that customises STNL-HPI outputs and testing and evaluation of the proposed system application. A stand-alone GIS-statistical application for STNL-HPI was successfully developed in this study. Testing and evaluation of the GIS-statistical application was conducted among test group users, namely, real estate students, who fulfilled the requirements as test candidates. Respondents' evaluations and feedback was analysed to identify the strengths and weaknesses of the application. The overall results have shown that the modelling and GIS application were able to help users understand the visual variation of house prices across a particular neighbourhood. They also appreciated the usefulness of the application especially to understand the dynamics of the property market in the local context. Notwithstanding this, some shortcomings of the application were identified in terms of methodology and functionality, and further improvements have been suggested.

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