Systems analysis of the transformation of South African cities

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This study derives from the observation that since the advent of democracy most cities in South Africa have undergone some form of transformation. Through the journey of trying to determine causes and mechanisms through which city transformation come into being, I realized the importance of group work through seeking assistance of other people. This led me to value the importance of group approach in research.

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Abstract

The need to quantify and model transformations that have taken place in the cities of South Africa is one of the grand challenges linked to country's transition to Democracy. Given the complexities associated with different stages of city transformation, it is imperative that models used to unpack processes of city transformation are novel. In this study it emerged that statistical methods alone are not adequate to fully present, in a comprehensible way, all facets of drivers of city transformation. As a result, statistical methods have been combined with mathematical and system dynamics models. Results revealed that city transformations derive from a number of triggers. Underlining these are income, migration and houses. The empirical data collected through questionnaire survey that was later incorporated into mathematical models demonstrated that income is a primary driver that fuels city migration. System Dynamic Models demonstrated that the availability of houses or accommodation serve as constraints that keep the city population within the limits of the carrying capacity of a city. In addition it was further confirmed, through mathematical models that income has varying effects on the attractiveness of cities. This was found to be linked to the shape of the distribution of income in the city. A normally distributed income with a peak in the middle results in a city being more attractive than an evenly distributed income that peaks either at very low or high income levels. This observation brought forth a need to test heterogeneity when analyzing city transformation using income as an index. Mathematical Models that incorporated heterogeneity demonstrated the usefulness of systems analysis in unpacking the mechanism of city transformation, a component of city management that requires serious consideration for planning, budgeting and provision of limited resources like houses in the cities. Success of methods used in this study led to a conclusion that these can be enhanced through other techniques like agent based models. With this call, improvements on this study that can be attained through these techniques are recommended. This will enrich the understanding of the transformation and dynamics of cities under different conditions than those that exist in South Africa.

Key Words: Systems analysis, Mathematical modelling, System dynamics, City transformation, City heterogeneity

CHAPTER 1

STUDY OVERVIEW

1.1 Introduction

The purpose of this thesis is to provide a systems modelling platform that can be used to define the influence of factors that have led to the transformation of cities in South Africa. Transformation is defined as intended or unintended changes that have taken place in the cities of South Africa, post Democracy (Harris, Todero and Watson, 1997; Chakravorty, 2000). Changes that have taken place represent a significant shift in the look of the cities that warranted investigations conducted in this thesis (Donaldson and Marais, 2002; Landman, 2002). These are possibly due to various causes or triggers. They represent the unintended consequences of South Africa's migration to Democracy. Specifically they demonstrate the unintended effects of the removal of the pre democracy policies used to manage urban influx and to sustain the attractiveness of cities in South Africa.

Changes that have taken place include i) a shift in population structure and composition, ii) infrastructure decay, especially in the city centres, iii) the emergence of new forms of lifestyles, which indicate cultural transformation and emerging diversity iv) several forms of small businesses and economic activities that have emerged and v) the loss of attractiveness in city centres (Gnad, Bǻhr and Jǘrgens, 2002; Schensul, 2009). These are attributable to different triggers that are linked to economic attributes such as income (Cameron, 2000; Williams, 2000; Schensul, 2009).

The study sought to bring forth a new paradigm of analysing changes that are taking place in the cities of South Africa through systems thinking and modelling. Systems thinking being a way of thinking that focuses on relationships that exist between the parts of the system (Caulfield and Maj, 2001). It thus provides a holistic view of reality (Forrester, 1968; Jackson, 2003).

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The primary aim of applying this technique was to identify factors that have triggered the transformation of cities in South Africa and to explain the mechanisms through which this have come into being. The secondary aim was to generate systems models that can amplify mechanism of city transformation thus demonstrating the dynamic nature of cities (Inouye and Oda, 1981; Batty, 2008). As can be observed, the greater portion of people who have migrated to cities in South Africa, come from rural and surrounding areas (townships), with some from other African and Asian countries (Dewar, 1992; Southall, 1988; Tomlison, 1994; Wall, 1994; Baker, 1996; Ruel, Haddad and Garrett, 1999; Donaldson and van Der Merwe, 2000; Schensul, 2009).

This indicates a new link that has developed between cities, its surrounding areas, other parts of the world and rural areas. It illustrates that rural areas and other parts of the world (especially Africa) now serve as sources of city populations in South Africa, whose contribution to overall populations of the cities need to be studied to propose strategies for retaining city attractiveness in the face of heightened wave of influx. Most of the characters that have emerged in South African cities did not exist prior to 1994, the year in which South Africa attained its Democracy.

Regarding the extent of city transformations in South Africa, one of the characteristics that has become obvious is the demographic shift and the rate of population growth (Gillian, 2002; Du Plessis, 2003; South African Cities network, 2012). This represents a breakaway from the previous demographic composition and trends of population growth (Klasen, 2000; Rogerson, 2006). It has affected the cultural and social dimensions of city life (Barham and Boucher, 1998) by creating direct and indirect clashes between local and foreign cultures. It has also caused cities to lose their attractiveness due to degradation, decay and overpopulation.

Several authors (Tacoli *et al*. 2003; Nakosteen and Zimmer, 1980; Chu, 1998; Benson and O'Reilly, 2009) have documented the scale and magnitude of city transformations across the World (Chandhurry, 1980; Inouye and Oda, 1981; Amin, 1986; CUS 1990; Lei, 2001, www.demographia.com, accessed November 2014). The dimension of the nature of the transformation of South African cities has also obtained some attention (Gerson, 1981; Bhorat, 2004; Keller, 2004; Meth and Dias, 2004; Simelane, 2012). This study sought to supplement any existing information on the transformation of cities in the World by highlighting the role of income, housing and population growth in transforming cities and how these have brought characteristics that are emerging in South African cities (Simelane, 2012).

The study employed systems thinking and modelling as a platform for analysis. It considered that under urban management policies implemented prior to 1994, which were restrictive, cities in South Africa functioned as closed system and were reserved for a small proportion of country's population (Smith, 2001). Under normal conditions, cities play an important role in the development of social structures (Todaro, 1997). As cities grow, certain patterns of social organisation emerge that match the orientation of the population growth and transformation (Batty, 2008). In this process land becomes central to social, cultural, diversity, population growth and economic activities that emerge (Park, Greenberg, Marsh, Baro and Mjahed, 2003). It is thus important that when assessing city transformation, attention be given to the way life organizes itself around the available land (Batty, 2008). This gives insight into mechanisms of city transformation (Spiegel, Watson and Wilkinson, 1996; Smit, 1998; Cattaneo, 2008).

In assessing city transformation there are many methods one can choose from (Batty, 2008). These range from simple descriptions of geographical distribution of residential, industrial, commercial, institutional, recreational and other uses (i.e. geospatial analysis), to complex statistical and mathematical models (Batty, 2008). In this study, a combination of mathematical, systems theory and system dynamics models were used. The aim was to demonstrate that a city is composed of a number of components whose collective performance can be expressed through different characters that can be represented through the transformation of a city (Batty, 2008).

By their origin, systems models have mathematical inclination (Inouye and Oda, 1981; Aitkin, Anderson, Francis and Hinde, 1989). These range from differential equations, linear algebra to complex number theories (Choopojcharoen and Magzari, 2012). Developing models that explicitly combine systems models with mathematical models or equations does not only strengthen their competence but enhances their magnifying powers. This has been emphasized by Choopojcharoen and Magzari (2012) who investigated the centrality of mathematics in system dynamics models.

A system is a collection of parts that collaborate to accomplish a particular objective (Jackson, 1993; Pruyt, 2006; Jackson, 2010). In its everyday application the word implies a collection of components that interact with one another in a non-trivial way to accomplish a particular goal (Meadows, 2008). For urban systems, the ultimate goals can be articulated through development policies and plans, intended to benefit the broader city community (Forrester, 1969). The outcomes, however, may end in circumstances different from those intended (Bennett, Cumming, Peterson, 2005). For example, people may move to a city with the aim of pursuing goals that may result in different types of diseconomies or the escalation of endemic problems, which ultimately may lead to unintended or evil consequences like the transformation of a city. Under such situations, problems emerge that prove difficult to reverse or solve within a short span of time either due to negative feedback linkages or time delays (Lane, 2001).

In South Africa, the transition to Democracy represents a positive and socially accepted event that seem to be associated with a number of unintended consequences, with the transformation of cities being one of them (Landman, 2002). This has increased curiosity as to why South African cities have been negatively affected by this event. There exist a number of explanations. The first being that prior to 1994, most people were restricted from settling permanently in the cities through policies like Group Areas Act and others that were restrictive (Beinart, 1980). When these were removed, more people aspired to migrate to the cities with intentions of maximising chances of generating higher income (Ellis, 2000; Axelsson and Westerlund, 1998; Gugler, 2002). This represented a moment of sudden transformation of cities in South Africa (Borjas, 1987; Potts 2000; Silveira, Espindola and Penna, 2005).

The phenomenon of the transformation of cities is also observed in other parts of Africa (Ayeni, 1979; State of Africa Cities Report, 2012 and 2014; African Development Bank, 2014; www.demographia.com, accessed 22 November 2014). As such, comparisons, in this study, were made to five selected other African cities. These are Windhoek (Namibia), Harare (Zimbabwe), Nairobi (Kenya), Lusaka (Zambia), and Kinshasa (Democratic Republic of Congo). The literature shows that, when countries where these cities are located attained independence, new patterns of city transformation emerged (Berry, 1988; Benenson, Omer and Hatna, 2002; Miller, Hunt and Abraham, 2004). What the literature shows is that as people take up residence in the cities, a number of unintended activity systems, norms and networks emerge with particular characteristics being acquired by the cities (Wegener, Mackett and Simmonds, 1991; Landman, 2002; Veldhuisen, Timmermans and Kapoen, 2005).

The concept of systems approach was adopted to emphasize that various elements of a city are inter-related as system components and not as random, apparently discrete, or isolated entities (Sayer, 1976; Cavaleri and Obloj, 1993; Maani and Cavana, 2000; Lane, 2001a; Batty, 2008). It is for this reason that cities are referred to as complex adaptive systems (Batty, 2008). In describing patterns of transformation that have emerged in the cities of South Africa, the study applied an approach that is not purely positivist or deterministic (Sayer, 1976). It tried to open a new avenue by using a humanistic-informed approach (Lane, 2001a). The study involved residents of the studied areas in articulating their views about city experiences, needs and what drove them to migrate to cities (Lane, 2001b). Reasons provided reflects what can be regarded as indirect drivers of city transformation (Lane, 2001b).

As Sayer (1976 and 2000) and other humanistic-aligned urban system dynamics architects observed (Forrester 1958 and 1961; Jackson 2000, Lane, 2001 a and b; Pruyt, 2006), a better projection of city dynamics can be achieved through integrating interpretations and meanings of the affected agents (Lane, 2001b). This represents a bottom up approach of constructing and conceptualising the root cause of an observed problem. Once this is done the intricacy of the system is captured and presented in an understandable way. These help to frame the dynamic hypothesis of a model that can later be developed to examine the root cause of the problem.

Such examination can be enhanced by applying four basic perspectives of system analysis. These are dynamic thinking (represented through graphs that capture the event over time), causal thinking (which can be done through causal loops), stock and flow thinking (through stock accumulations) and thinking endogenously by viewing the system as a cause. These provide insight and improve actions taken such that intervention measures intended to solve the problem derive from the core of the system behaviour (Sayer, 1976).

1.2 Relevance of the study

Human development through city life and urbanization is a popular mode of modern day adaptation process (Walker, Holling, Carpenter and Kinzig, 2004; Lucas, 2006). With independence in Africa, the theme that dominated development thinking emphasized modernization of economies through urbanisation and industrialisation. This emphasized that the development route to pursue post-independence is urbanization and industrialization. These emerged as twin pillars of development thinking in Africa.

As a response, city life gained prominence and migrants started to vacate rural areas to pursue better opportunities in urban areas, where industrial activities are high. When it strikes that employment opportunities in urban areas are also limited, people resorted to informal sector as a coping mechanism. This explains why cities in Africa are abuzz with informal traders. It demonstrates that if cities cannot offer income generating opportunities for its population, certain character traits emerge that are linked to income. It also shows that with low levels of industrial activities in most African cities, the informal economic sector serves as an alternative source of income. This is probably one of the drivers behind the look of many cities in Africa.

It has been widely documented (Beauchemin and Bocquier, 2004; de Haas, 2010) that in cities where large portions of incomes are derived from informal sources, overpopulated areas are used as residences. This is apparently due to shortages of houses or inability to afford decent accommodation. This illustrates existence of direct correlation between accommodation, income and its sources. It demonstrates the hierarchy through which people organise themselves around their income.

The relevancy of this study, in systems thinking and analysis is to demonstrate social constructionism, i.e. to establish how various factors influence the emergence of certain features of the system, which in this case is the loss of attractiveness by the cities of South Africa. The study focussed on the concept of emergence in an open system i.e. how, through interlinked relationships, processes, at one level generate qualitatively new characteristics at other levels that generate the overall characteristics (Checkland, 1981). This concept was adopted to stress the mechanisms through which components of the system in a lower or initial level interact to produce characteristics at another level that can express themselves through system transformation, which in this study is the transformation of cities.

The study considered that negative feedbacks linked to urban influx by migrants in South Africa has a direct effect on the current look of cities. To reduce the negative impacts of this, proper planning techniques are required. Modelling is one of the alternative ways through which approaches for city management policies and strategies can be developed.

1.3 Problem Statement

It can be argued that any good policy intended to sustain attractiveness of a city may be associated with unintended outcomes. These can be expressed in various ways. For South Africa, changes that have emerged in the cities post democracy represent unintended outcomes of two sets of policies used to manage flow of people in and out of the cities.

While Apartheid era policies were inherently restrictive, it can be contended that under these policies cities maintained highest levels of attractiveness. Under those implemented since the dawn of Democracy, most cities have acquired new features. This has raised questions as to:-

- What population profile can best describe changes that have taken place in South African cities? This question is addressed in Chapter five and seven.
- What types of triggers had influenced the transformation of South African cities? This question is addressed in Chapter six, seven and eight.
- Is it possible to develop system models that can assist in developing strategies for predicting population growth dynamics in the cities of South Africa? This question is addressed in Chapters six, seven and eight.

The key objective of this study is to provide satisfying answers to these questions.

1.4 Limitations of the Study

In addressing questions formulated, data collected did not include all characteristics of the chosen city system. The study focussed on those considered to be relevant to the scope of the study. A further consideration was that one of the important recognitions, when analysing city transformations, is that city populations are composed of migrants. As such, migration and urbanisation were considered to be an interlinked process that is dynamic. The application of the term migrants as used in the study excluded forced migration (i.e. those that leave their areas of origin because of conflict, war or environmental hazards such as floods). This is because none of these type of migration have taken place in the country under study.

In developing a better view of how each city differs from the other and how cities differ in response to influencing factors, observing mechanisms through which migrants adapt in a city was regarded as an important indicator that could mirrors heterogeneity among the cities. While it is acknowledged that South Africa is part of Africa, in this study, for the purpose of comparison (only), cities that were located outside the boundaries of South Africa are referred to as other African cities and those within the boundaries of South Africa are referred to as South African cities.

1.5 Discussion

Modelling can be essential for both long and short term forecasting of city dynamics, including management of limited resources in the city (Espíndola *et al*., 2006). This stems from consideration that the relationship between a city and its environment defines how influencing processes can emerge and change over time (White and Engelen, 1994; Allen, 1997; White and Engelen, 2004; Herold, Couclelis and Clarke, 2005). Change a city experience can be positive or negative. Understanding mechanisms through which these lead to the transformation of a city is critical. This is to forecast effects of developmental policies and plans that can be implemented to promote successful management of city system and its complexities. Cities represent a branch of complex system that has high aggregation of agents (people) where access to resources is determined by income. A combination of factors that constitute this subdivision of the complex system is being rigorously explored to explore cities as complex adaptive systems.

Complex systems involve numerous interacting agents whose aggregate behaviours are non-linear. Immersing this definition to social systems, the character of non-linearity command that computer modelling be used to demonstrate the non-linear behaviour in social systems (Mitchell, 1994; Capra, 2003; Freeman, 1988). This acknowledges that social systems are naturally dynamic and its actors (i.e. human beings as agents) are heterogeneous and operate at large scales that perpetuate complexity (Klovdahl, 1989; Benenson and Omer, 2006). It is for this reason that social systems are classified as multi-loop nonlinear feedback systems (Forrester, 1971).

In real life social systems do not only comprise living human beings, but include nontangible elements such as language, consciousness, and culture (Capra, 2003; Jackson, 2004). The main feature of these is communication, which recursively produce networks through which the emergence of processes like migration are shaped as people communicate opportunities available in the cities and decide through conscious choice to migrate to the city (Proctor, 1953; Wasserman and Fraust, 1994). This demonstrates that in complex systems each connection (network) creates meaning, which gives rise to a particular process, through which the entire network evolves (Capra, 2003).

To represent this connection, feedback loops are used to signify self-producing features (Freeman, 1988). Feedback loop diagrams are tools used to present the basic structure of a complex system. This is a bottom-up method that attempt to amplify even subtle structures of the system. It models the basic conditions of the system and captures all possible behaviour patterns a system can produce (Klovdahl, 1981; Hage and Harary, 1983). The central gravity of using these techniques is to illustrate how elements in the system interact with one another, which is mostly through 'feedback' mechanisms and relationships (Wolfe, 1978).

Such relationships are defined through causal loops that depict intricate connections between structures of the system. These can be negative, positive or stock-and-flow connections. In such relationships, a change in one variable either positive or negative, influence other variables (in a system) over time (often including delays), which in turn affect the original variable. Representing these relationships is the means to capture the behaviour and develop an understanding of complex systems (Axtell, Epstein and Cohen, 1996).

The purpose of this study is to use systems methods to define the influence of selected factors presumed to have driven the transformation of cities in South Africa. While government policies like urban renewal, rapid bus transit system and inner city revival, represent quick attempts of reversing characteristics that have emerged in the cities of South Africa (African National Congress, 1994; Republic of South Africa 1995; Department of Housing, 1997; Gauteng Provincial Government, 1997), there is still a need to provide an understanding of the nature and mechanisms through which cities in South Africa have acquired new characteristics and the sudden loss of attractiveness.

A consideration that systems approach can produce better perspectives of policy input and city management options is the motive behind the use of systems thinking in this study. The study considered the important role of models in providing policy alternatives. With failures in most policies, there is a growing switch towards the use of models to generate alternative options. Efforts have thus been increased to develop models that are precise, measurable and accurate (Batty, 2008).

CHAPTER 2

STUDY CONTEXT AND DESCRIPTION OF PRIMARY STUDY AREAS

2.1 Introduction

Chapter one provides the rationale of the study. It outlines the purpose and key questions the study should answer. This chapter gives an overview of the context of the study. It provides a historical description of the possible drivers of city transformation in South Africa.

The chapter offers an analysis of the past and new urban management policies and their effects on features that have emerged in the cities of South Africa. The need for developing models that can capture this and enhance the understanding of the overall changes that have taken place in the cities of South Africa has been emphasized. These are essential for providing short and long term assessment of the transformation trends observed as taking place in the cities of South Africa.

As a developing country, South Africa is prone to constant urban transformation. This could happen through various ways including the decay of city centres (Crush and Frayne, 2007; Crush 2008). Understanding mechanisms through which this will happen is imperative for the development of intervention measures that can halt the deterioration of cities (Becker and Morrison, 1995), and improve the management of associated effects.

Key among aspects of city transformation that require attention is the provision of houses whose demand always exceeds supply and this leads to dire consequences. If housing demand is not met, it increases informal settlements, which ultimately triggers the deterioration of the whole city. In instances like these city authorities respond by implementing quick solutions like providing low cost houses. This has been found to be disastrous in cities like New York. It exacerbates the deterioration of cities through attraction of low income earners.

Models that highlight these undesirable relationships between policy and effects are necessary. Such models can improve the management of cities, especially among the developing economies (Bigsten, 1992). In South Africa, due to a failure to predict effects of rapid urbanisation and the extension of access to electricity to under serviced areas in and around cities, electricity shortages have emerged as one of the unintended consequences of government's policies that sought to extend services to previously underserviced areas (Todaro, 1969; Goldstein, 1983).

The negative feedback of this policy has been the inability to sustain the delivery of services in these areas, which has led to widespread protests. Despite negative feedbacks, urbanisation seem to have some positive derivatives like the creation of market opportunities. This in turn creates demand for goods and services. These are reflected through small businesses that emerge as part of a transforming city. This explains why for instance, informal trading always emerge as one of the early features of a deteriorating city (Beker and Morrison, 1995). This study intends to provide a magnified view of these relationships and mechanisms.

Comparisons between rural and urban areas have been done, in various disciplines, for the purposes of reducing rural migration (Jenkins, 1999). Among these disciplines, rural lifestyle is labelled as representing backwardness or lack of sophistication. To demonstrate that people in rural areas are able to catch up, they then migrate to urban areas. Researchers are now trying to provide insights of the effects of linkages between rural areas and cities (Simelane, 2011). The general consensus is that there should be a fair balance when drawing comparison between rural and urban life. This has turned out to be one of the focuses of urban dynamics, especially in Africa (Becker and Morrison, 1995), where much of the population increase in the cities result from rural-urban migration.

On assessing the effects of rural-urban relationship on cities, economic disparities between rural and urban areas are the main driver behind people migrating from rural to urban areas (Todaro, 1976a; Herzog, Schlottmann and Boehm, 1993; Baker, 1996). This migration takes place in the form of people vacating less economically active (rural) areas, and moving to economically active (urban) areas (Nakosteen and Zimmer, 1980; Tacoli *et al*., 2003). This form of migration, is different from forced migration, which results from either war, environmental degradation (such as droughts) or political conflicts. Rural-urban migration referred to in this study is the one that is purely driven by economic incentives provided by urban areas. The focus of this study is limited to what can be referred to as voluntary migration.

While movement of people from rural to urban areas, in search of economic prosperity represents a search for population equilibrium between rural and urban areas, it also widens the economic gap between rural and urban areas as resourceful, skilled, and educated people leave the rural areas (Cliffe, 1977). For urban areas, this migration widens the economic gap between rural and urban areas. It introduces a number of consequential effects such as the increase in population densities and the subsequent demand for limited resources (Klasen, 2000). These effects, because of untimely delays, trigger secondary challenges. Mechanisms through which this happens are explained in dedicated chapters of the thesis.

2.2 Historical overview of rural-urban migration in South Africa

While rural-urban migration takes place in Africa as a whole (Chandhurry, 1980; Tacoli *et al*., 2003), the history of rural-urban migration in South Africa is unique, in that it has a history of political influence.

After the discovery of diamonds, gold and other precious metals, the demand for labour in urban areas of South Africa became insatiable (Wilson, 1972; Mayer, 1980; Lucas, 1985). Labour demand became the sole determinant of the relationship between rural and urban areas, as rural areas were seen to be sources of labour (Wilson, 1972; Beinart, 1980). To trigger the migration of Black labour from rural areas, policies that deliberately reduced economic activities in rural areas were devised and implemented (Beinart, 1980). These policies were aimed at influencing the migration of unskilled Black labourers from rural to urban areas to seek employment, especially in the mining sector.

First to implement these policies was Cecil John Rhodes who, through the Glen Grey Act of 1894, encouraged Black migration and urbanisation by initiating the division between rural and urban Blacks. Later, similar initiatives were initiated by the Smit Committee of 1942, the Social and Economic Planning Council of 1946 and the Fagan commission which defined a system of migrant labour practice that could only be maintained if Blacks were allowed to settle permanently in the urban areas.

This system was rejected in 1948, when the National Party came to power on ideological grounds that permanent residence in cities was an exclusive right reserved for Whites (Posel, 1991). Through this, influx control measures were introduced, prohibiting non-whites from residing permanently in city centres. This anchored the creation of squatter camps and informal settlements around major cities of South Africa (Cross, Mngadi and Mbhele; 1998), and imprinted a character that is still a common sight around most cities of South Africa (Smith, 2001).

Through influx control, Black migrants were expected to take one-year employment contracts with their employers, which allowed them only a few weeks at home (i.e. areas of their origin). A circular pattern of migration was created, where men would be away from home most of the time to take contract work in urban areas, with women left behind to look after children (Posel, 2001a). This type of migration reduced rural productivity and fuelled rural-urban migration (Posel, 2001b).

With the 1994 transformation to democracy, restrictive policies were removed, intensifying rural-urban migration, with settlements in cities by the number of Blacks increasing exponentially. The obvious effect of this has been the development of new features in the city centres. The most affected cities are Pretoria (Sunnyside-Arcadia area), Johannesburg (Hillbrow-Yeoville area), Port Elizabeth (Central area), Durban (Durban Central Business District) and Cape Town (Central Business District). The key concern is that people are continuously abandoning rural areas in favour of city centres and there are no signs that this could slow down soon.

This represents an emerging urban system that requires analysis and interpretation. It is interesting to note that people who have settled in the city centres of South Africa do not only come from within the borders of South Africa but from other parts of Africa as well. This means that the city centres of South Africa have been transformed into a microcosm of emerging African cultures and lifestyles that might truly represent Africa at large.

In improving the understanding of the processes taking place in the cities of South Africa, a broader picture of the linkage between political, economic and social transformations needs to be created, through modelling and simulation (Benenson, 1999; Portugali, Benenson and Omer 1994; Gilbert, 1995; Gerson, 1981).

2.3 Emerging trends of urban transformation in South Africa

In urban areas of former self-governing territories, a range of patterns have emerged, especially in secondary towns, such as Lusikisiki (in the Eastern Cape), Klerksdorp (in the North West) and former homeland capitals of Mahikeng-Mmabatho (in the North West) and Ulundi (KwaZulu Natal), while local economies have attracted increasing settlements (Bencivenga and Smith, 1999). In places where previous income streams have diminished, as in the surrounds of former capitals such as LebowaKgomo, Bisho, Qwaqwa and Umtata, the pace of transformation seems to be slower (Bencivenga and Smith, 1999).

In both cases, the relationship between the defined urban areas and the surrounding rural areas is a key question for development and urbanisation (Bencivenga and Smith, 1999). Within urban areas, which have long established local government structures, a different set of urban transformation trends are emerging. Words expressing the nature of transformation are suburbanisation, peripheralisation and densification (Bencivenga and Smith, 1999).

While there has long been an influential process of residential suburbanisation, what is relatively new is the market related decentralisation of shops and specialised services, and even of productive activity (Bencivenga and Smith, 1999). To some extent, changes that have taken place are a consequence of the increasing types of service provision and the larger scale of contracting taking place in the hands of the public and private sector entities (Bencivenga and Smith, 1999).

In smaller towns, there has been an emerging process of peripheralisation of economic activities, in which more commercial and service activity takes place from new buildings and converted houses outside the established commercial centres

(Bencivenga and Smith, 1999). What constitutes valuable and desirable residential space has also undergone major transformation (Bencivenga and Smith, 1999).

These changes have reached their peak in larger towns and cities, which has had grave implications, at least in some cases, for the future of the cities in South Africa (Bencivenga and Smith 1999). Two different, but in many respects similar examples, are those of Durban and Johannesburg (Bencivenga and Smith, 1999). In both, there has been an extreme flight of sophisticated services to suburban localities, sometimes to newer concentrations but also to dispersed locations (Bencivenga and Smith, 1999). The consequences for city centre economies have been profound, as large amounts of vacant space have opened up in most buildings that were previously used as offices and these have since been converted into residential properties (Bencivenga and Smith, 1999).

The building of freeways and roads has made many suburban areas attractive for business and residential purposes and this has seen an increase in the development of new forms of mixed residential areas that are built adjacent to shopping centres (Bencivenga and Smith, 1999).

In some cases, suburbanisation takes place within a single local authority's area of jurisdiction, as a result of the demarcation of new local governments (Bencivenga and Smith, 1999). This is, however, not always the case. In the urban areas that remain divided into multiple jurisdictions, whether as local councils within metropolitan areas or as multiple local councils or even multiple metropolitan areas, there is still the perennial question of the location of appropriate outer boundaries for urban local government areas (Bencivenga and Smith, 1999). In the former cases, the weaker metropolitan councils are unable to redistribute income from suburbanising local council areas to others; and the stronger ones find it costly to do so. In the latter case, it is only Gauteng province that is growing, while suburbanising urban economies are divided across 'metropolitan' lines (Bencivenga and Smith, 1999).

The power of contemporary South African suburbanisation has raised questions about demarcations. An aspect of suburbanisation or decentralisation of work that deserves mention is a parallel process of densification (Bencivenga and Smith, 1999). While some of the most dramatic transformations in urban environments are in new developments towards the outer urban areas, much increased intensity of activity has also characterised many older, lower density city areas (Bencivenga and Smith, 1999). Land for settlement has been subdivided, vacant land has been developed and new uses have appeared in formerly residential neighbourhoods (Bencivenga and Smith, 1999). New residential developments have been at much higher densities over the past years and it is expected that these processes of transformation will continue and accelerate (Bencivenga and Smith, 1999).

Another process that has affected cities is peripheralisation (Bencivenga and Smith, 1999). This derives from the fact that the abolition of apartheid controls was accompanied by the increase of less formal settlements in many places: for example, evicted farm workers who previously sought bases in reserves increasingly appear to have found residences in smaller towns (Bencivenga and Smith, 1999). In most cases the new places of residence are in site and service areas, or more informal places, located further from town centres than the former townships. This peripheralisation tends to be common in almost all South African cities and overlaps with changes in the rural-urban relationships, to which reference has been made (Bencivenga and Smith, 1999).

2.4 The unintended consequences: emerging housing problems

Since the transition to Democracy, low-cost housing provision has been a strategy for the government with which to address historical inequalities, poor municipal service provision and rapid urban migration. In the early stages of democracy, former president Nelson Mandela spearheaded an offensive strategy that succeeded in winning broad-based domestic support for poverty eradication, through the Reconstruction and Development Programme (RDP). Through this programme, known as ‘RDP’, the South African government committed itself to eliminate informal settlements, especially in urban areas by ensuring that communities, who cannot afford houses, are assisted through government subsidy.

According to the Social Housing Foundation (2009), the Department of Housing has to date produced not more than 2.4 million houses. However, even with this achievement, the housing backlog still stands at 2.2 million and the annual production of houses is at a mere 272 000 units per annum. Notably, the inability of the government to catch up with the backlog in the programme of providing houses indicates the extent of challenges linked to urbanisation and migration in South Africa.

Key challenges, identified by the Department of Housing, include access to land for housing development, access to housing finance, sub-standard building constructions, corruption and the exponential increase of building costs due to the increased demand for building materials (South Africa yearbook, 2011/2012).

According to Goebel (2007) additional challenges that hamper the success of the programme include:

- The perception (or fact) that the low-cost housing programme has continued to place poor and low-income Blacks in under-serviced townships on urban peripheries, far from jobs and services;
- Low quality houses and infrastructure that rapidly deteriorate and require maintenance;
- The dynamics of poverty being inadequately dealt with by the dominant model of free-hold tenure, as several poor people (e.g. temporary workers and women) would be better served by rental accommodation;
- People seem to prefer larger houses - the main RDP housing model for the Department of Housing is 30m^2.

In addition to these, the following challenges were highlighted by the minister of housing (Ms Lindiwe Sisulu):

- Lack of a complete public land asset register, which means the three spheres of government do not know how much land is available for housing,
- Massive areas of municipal commonage in some provinces are tied up in land claims,
- Parastatals, such as Transnet, are sitting on vast tracts of land that can't be transferred to the housing department due to legal complications.

As a consequence of the above challenges, in particular, transport costs and proximity to income generating activities, people are selling or renting out their subsidised houses and are moving back to informal settlements closer to economic activities (Bencivenga and Smith, 1999). What this means is that, although most urban migration seems to take place from rural areas, internal urban migration is also on the rise in South Africa (Percival and Homer-Dixon, 1998). The question is whether it is possible to create a balance between rural and urban areas.

This review confirms a rapid socio-economic transformation in the cities of South Africa that is linked to the achievement of democracy (Aron and Kingdon, 2007). At present, little is documented about this transformation and the future negative impacts of this shift, as there are no reliable tools to demonstrate it. Predictions about future socio-economic transformation of South African cities are needed. For these analyses, dynamic models that predict population growth, as developed in this study, could be beneficial.

2.5 Socio-economic outlook of urban South Africa under the emerging system

The most important challenge facing South Africa, years after the transition to democracy, is that of breaking the grip of poverty (Bhorat, 2004). Economic and political analysts agree that approximately 40 percent of South Africans are living in poverty, with the poorest 15 percent being in a desperate struggle to survive (Meth and Dias, 2004; van Der Berg *et al*., 2005). This means that approximately 18 million out of 55 million people have not experienced the benefits of democracy, which poses a challenge among South Africans to work together towards the economic and social prosperity of all citizens (van Der Berg, 2001).

In the 1998 parliamentary debate on reconciliation and nation-building, former president Thabo Mbeki warned that South Africa comprises two ‘nations’ divided by poverty (van Der Berg, 2001). The issue re-emerged in 2003, when the South African Human Rights Commission released a report critical of the government’s performance regarding socio-economic rights, following the publication of a number of studies, which concluded that poverty levels in South Africa had remained constant or worsened since the advent of democracy (van Der Berg, 2001).

Bhorat (2004) has noted that in 1999, there were an estimated 26.3 million people in South Africa aged between 15 and 65; this cohort of the population can be considered as potentially, economically active in any given country. Taking this into consideration and applying the expanded definition of unemployment, South Africa's rate of unemployment was at 36 percent (Bhorat, 2004). This was far higher for Black females (52 percent) than any other group. Comparing employment data from 1996 and 1999, the rate of unemployment increased from 34 percent to 36 percent (Bhorat, 2004). Furthermore, while the actual number of people employed during this time grew from 9.1 million to 10.0 million (an increase of 14 percent), the number of unemployed people also grew (Bhorat, 2004).

According to Bhorat (2004), in 1999 some 22 percent of South African households reported going hungry due to a lack of money to buy food. Measured by household income, 83 percent of households in the bottom fifth have no people in employment (Bhorat, 2004). Also, 38 percent of Black households in 1999 contained no employed people, up from 32 percent in 1996 (Bhorat, 2004). The intensity of poverty has been found to be to be spatial, i.e. just less than half of the South African population live in rural areas. However, a disproportionate 72 percent of South Africa's poor live in rural areas. There also appears to be a gender bias, i.e. the poverty rate among female-headed households is double that of male-headed households (Bhorat, 2004). As Mbeki noted (in his parliamentary debate in 1998), poverty has a stark racial dimension, 61 percent of Blacks were poor in 1996 compared to just one percent of Whites.

Notably, social transfers are also inadequate, 60 percent of the poor, or 11 million people, are without social security transfers (Bhorat, 2004). Uptake of existing measures is also poor, 85 percent of state old age pension are utilized and just 20 percent of child support grants are utilized (Bhorat, 2004). The average uptake across all social grants stands at 43 percent (Bhorat, 2004). A 2002 enquiry noted that the existing social security system 'has the capacity to close 36.6 percent of the poverty gap' if all benefits were distributed to those entitled to them (Bhorat, 2004). But even with a full uptake, there would still be some five million people living in poor households (Bhorat, 2004).

On a limited scale, it is significant that South Africa's political transformation resulted in an upturn in rural incomes (Mabin, 1990). Black rural pensioners now earn the same as Whites, representing an increase in disposable income for the elderly, who constitute a large portion of the rural population (Bryceson, 2002a).

Current data suggests that at least 15 percent of all households suffer from chronic as opposed to transitory poverty i.e. they remain in poverty when measured over time (Bhorat, 2004). In general, poverty is one of the prominent concerns for South Africa. Again, while the problems are complex and not easy to solve, population dynamic models can help in at least providing data on how and where resources need to be channelled.

2.6 Drivers of urbanization in South Africa

One of the most imperative strategic issues facing South African cities today is urban growth (Percival and Homer-Dixon, 1998). On average, the population of South African cities has grown much faster than the national population since the 1970's, especially since the end of apartheid; on average an annual population rate of approximately 4.4 percent between 1991 and 2001 (Boraine, Crankshaw, Engelbrecht, Gotz, Mbanga, Narsoo and Parnell, 2005).

In trying to interpret how this has happened, it is relatively difficult to differentiate the effects of 'push' factors, such as the reduction in agricultural production, unequal access to land and high population densities in rural areas, and 'pull' factors, such as the removal of restrictive laws, the rapid construction of rented backyard shacks in townships and the increasing transformation of land outside urban areas for residential development.

Percival and Homer-Dixon (1998) have made three generalisations:

- The majority of those moving into urban settlements are rural migrants,
- the same processes of resource capture and ecological marginalisation that occurred during Apartheid are occurring in urban informal settlements and
- the combination of resource capture and environmental challenges forces greater urban-urban migration.

In assessing the extent of transformation that has taken place in South African urban areas, the following dimensions of drivers of change have been identified:

- **The initial trigger**: In South Africa, the 1994 democratic dispensation opened up South African society for free movement. This led to a number of developments in cities. Influx of the population to urban centres and the choice of city centres as a destination. Lack of employment opportunities for migrants in urban centres resulted in the use of the informal sector as a coping mechanism for addressing the basic needs for income, food and shelter. The low income resulted in the development of overcrowding in the informal sector.
- **Emergence of problems**: With the inability of a city's carrying capacity to cope with the population increase, sanitation and environmental problems have emerged, while access to schools and other amenities needed for social development has become limited. This creates confrontation between residents and new comers. If this takes place between South Africans and non-South Africans it reflects an emergence of xenophobia.
- **City centre residents** develop a city's culture, consisting of religious, entertainment, cultural and other activities, to support their situation. The phenomenon of positive feedback develops to reinforce the emerging trends of adaptation characterised by a number of similar interlinkages that reflect urban development in the city centre. This represents a complete cycle of transformation of a city.

2.7 Description of primary study areas

2.7.1 Johannesburg

Johannesburg is the largest city in South Africa. It serves as the capital of Gauteng province, which is the wealthiest province in the country. The city is one of the largest metropolitan areas in South Africa and one of the forty largest metropolitan areas in the world (www.en.wikipeadia.org, accessed March 2013). Its land area is estimated to be 1,645 square kilometres (van As, 2012). The city encompasses the popular township of Soweto (www.en.wikipeadia.org accessed, March 2013) and the surrounding areas of historical significance such as Apartheid Museum, Hector Peterson Square, Lilies farm and many others.

The population of the city is estimated to be around six million (Van As, 2012; www.demographia.com, accessed November 2014). According to 2001 South African National Census, the population was estimated to be around 3,225,812 people (STATS SA 2010). The current estimate of population size reflects a significant growth. By 2030 Johannesburg's population will exceed eight million. The demographic composition is such that Africans (Blacks) account for 73 percent of the total population, followed by Whites at 16 percent, Coloureds at six percent and Asians at four percent (www.en.wikipeadia.org, accessed March 2013, STATS SA, 2010).

Thirty two percent of the residents of Johannesburg speak Nguni languages (i.e. IsiZulu, IsiXhosa and IsiNdebele), 24% speak Sotho, 18% speak English, 7% speak Afrikaans and 6% speak Tshivenda (STATS SA, 2010). With the increased arrival of migrants from other parts of Africa, the numbers of other African languages like Shona, KiSwahili and Yoruba can be heard on the streets of the city.

2.7.2 Durban

Durban is the third most populous city in South Africa. It is the largest city in the province of KwaZulu-Natal, and is recognised as one of the busiest port cities in Africa (Schensul, 2009).

Its land area is 2292 square kilometres. The city is comparatively larger than most cities in South Africa. It encompasses the townships of Umlazi, Kwamashu, Inanda, Chatsworth and others (www.en.wikipeadia.org. accessed in March 2013). Due to its warm subtropical climate and beaches, the city is a popular centre for both local and international tourists.

It has an estimated population of 3.5 million (Schensul, 2009; van AS, 2012, Demographia, 2015). Of this, the metropolitan area of Durban has an estimated population of 2147000 people (Smit, 1998). The demographic composition is such that the majority of the population are Africans (71%), followed by Indians (19%), Whites (8%) and Coloureds (8%) (Ethekwini Municipality, 2011). Sixty three percent of Durban's residents speak isiZulu, 29.6 percent English, 3.4 percent isiXhosa, 1.44

percent Afrikaans, 0.7 percent Sotho, 0.2 percent isiNdebele and 0.1 percent Northern Sotho (STATS SA, 2010).

2.7.3 Port Elizabeth

Port Elizabeth is situated in the Eastern Cape Province. The city was founded as a town in 1820 to house British settlers, as a way of strengthening the border region between the Cape Colony and the Xhosa (www.en.wikipeadia.org, accessed March 2013). It now forms part of the Nelson Mandela Metropolitan Municipality. Its population is estimated to be 1.3 million (Demographia, 2015), making it the fifth largest city in terms of population size (Nelson Mandela Bay Municipality, 2013).

The economic and industrial activities of the Nelson Mandela Bay Municipality (www.property24.com, accessed March 2014) where the city is located, are automobile industries, with factories for companies such as General Motors, Volkswagen, Ford and Continental Tyres (www.property24.com, accessed March 2014). The city's seaport is the most crucial ore loading facility in the southern hemisphere. It mostly serves the mining industry in southern South Africa (www.property24.com, accessed March 2014). A recently constructed Industrial Development Zone is intended to cater for increasing industrial demand in the region (Nelson Mandela Bay Municipality, 2013; www.property24.com, accessed March 2014).

The demographic composition is such that 57.3 percent of the residents speak IsiXhosa as their mother language, while Afrikaans is the mother tongue to 29.7 percent of city residents, with English at 12.1 percent (Nelson Mandela Bay Municipality, 2013).

2.7.4 Pretoria

Pretoria is located in Gauteng Province. It is contained within the Tshwane Metropolitan Municipality. The city is frequently referred to as "Tshwane". It is one of the country’s capitals. It serves as the executive and *de facto* national capital (www.touristlink.com, accessed June 2014).

With 687.54 km^2 of land, the city is one of the largest municipalities and the third largest in the world in terms of land mass. The whole city has an estimated population of 2 345 908 (www.demographia.com accessed November 2014). Some publications estimate the population of the city to be around 2.950 million (Van As, 2012). Even since the end of Apartheid, Pretoria is the only city with a white majority, albeit with an ever increasing black middle-class.

In the nearby townships of Soshanguve, Mamelodi and Atteridgeville, Africans make up close to all of the population. The demographic composition is such that the main language spoken in Pretoria is Afrikaans (STATS SA, 2010), with sePedi, seSotho, seTswana, XiTsonga, IsiZulu and English also widely spoken (STATS, 2010).

2.7.5 Cape Town

Cape Town is the second most populous city in South Africa. It is the provincial capital, as well as the legislative capital of South Africa, where the National Parliament and many government offices are located. The city is famous for its harbour, as well as its natural setting in the Cape floral kingdom. It is one of the most popular South African destinations for tourism.

With a land area of 2 455 square kilometres, the city of Cape Town is larger than that of Johannesburg and other cities in South Africa. Its population size is estimated to be around 3 813 million (Demographia, 2015). Its composition is such that Coloureds account for 48.13 percent of the population, followed by Black Africans at 31 percent, Whites at 18.75 percent and Asians at 1.43 percent.

28.7 percent speak Xhosa at home, 27.9 percent speak English, 0.7 percent speak Sotho, 0.3 percent speak Zulu, 0.1 percent speak Tswana and 0.7 percent of the population speak a non-official language at home (STATS SA, 2010; www.en.wikipeadia.org accessed March 2013).

Figure 2.1. Map of South Africa showing geographical location of studied cities.

2.8 Discussion

This overview outlines the evolution of the South African city system in the face of policies that imposed restrictions on human movement between rural and urban areas. These were influx control and the Group Areas Act, to mention the two that shaped the look of cities in South Africa. It highlights how these policies influenced the development of cities in South Africa. Policies which have since replaced these, as of 1994 have transformed the cities from being closed to an open system. This has led to the emergence of new characteristics. It has also fuelled urban migration, which has subsequently triggered population growth.

The overview reflects that although cities seem to share similar characteristics and are likely to be influenced by the same set of parameters, they get transformed at different rates. This displays existence of heterogeneity among the cities. Thus determining different rates and levels of transformation in the cities is vital for future planning and management of urban space, especially in developing countries like South Africa. Of critical note is that populations of the cities grow at different rates (www.demographia.com, accessed November 2014). This is apparently due to influencing factors, which might include attractiveness, income as well as direct relationships that exists between these factors.

At current trends of population growth, it is estimated that not less than 3.2 billion people are already living in the cities (Gilbert, 1992; www.demographia.com, accessed November 2014). This will double by 2030 (May, Carter and Posel, 1995; www.demographia.com, accessed November 2014). The expected effects include heightened strain on cities to accommodate growing populations and provide essential services like housing. This brought to the fore a sad reality that cities will struggle to provide high quality of life for their residents (Park, Greenberg, Nell, Marsh, Baro and Mjahed, 2003; www.demographia.com, Accessed November 2014).

This might be true for most cities in Africa that are struggling to cope with rapid urbanisation and population growth and are unable to provide their citizens with reasonable quality of life (www.demographia.com, accessed November 2014). As noted by Gilbert (1994), instead of bringing high health, economic dynamisms and environmental standards, city life in Africa is accompanied by stagnation, negligible health gains, lax environmental standards and social instability.

These features are observably on the rise in the cities of South Africa. This reflects that new perspectives of understanding the driving forces behind the trends of transformation of cities are needed. These cannot be provided without appropriate models. The main concern is that inaccurate planning normally leads to the implementation of wrong policies. Implementing wrong policies escalates problems. This can be reflected through irreversible urban decay. There is thus a need to devise appropriate models that can be used for proper planning and management of cities in Africa.

The essential fact is that political transformation in South Africa and programmes of recruiting unskilled migrants from rural areas served as a basis for wrong policies that have fuelled urban migration, which have shaped the social system of cities in South Africa. This cannot be reversed (Dosi, Marengo, Bassanini and Valente, 1999). This has created uncertainty about the success of any intervention measure or policy (Silveira *et al*., 2005). Studying and analysing processes of transformation through systems thinking is thus relevant to propose better planning approaches for cities that find themselves entrapped in similar situations like South Africa (Preston-Whyte and Rogerson, 1991; Becker and Morrison, 1995). This could improve the provision of limited resources such as houses (Chant, 1998) that tend to be quickly affected by population growth.

In conclusion it can be stressed that approaches that seek to unpack all aspects of urban dynamics are needed. This should be supported by innovative methods (Bencivenga and Smith, 1999; Smit, 1998; Tacoli, 2002). It is for this reason that models presented in this thesis aim to contribute to the enhancement of urban planning and management by developing applicable methods of simulation. While it is obvious that political transformation in South Africa is the main trigger for urban change, it can be hinted that any transformation (either negative or positive) that takes place in a city has a direct bearing on its attractiveness. What can be deduced from South Africa's experience is that policies implemented to rectify social exclusion in cities have generated unintended consequences and events that are reflected through the rapid transformation of cities. To gain a better understanding of how the future outlook of cities is going to be in South Africa will take a long time, especially as most changes are still at transit levels.

CHAPTER 3

LITERATURE REVIEW

3.1 Introduction

Transformation of cities have been viewed through different lenses (Forrester, 1969; Hemson, 2003; Maharaj and Mpungose, 1994; Maloutas, 2007; Murry, 2004; Swanson, 1976; Robinson, 2006). The contribution of different authors on city transformation and dynamics is exhibited through huge literature on the subject, whose point of convergence is Jay Forrester's Urban Dynamics. This shows that popular literature on city transformation constantly make reference to Jay Forrester's Urban Dynamics (Forrester, 1969) and use it as a source of departure.

Prior to Forrester's Urban Dynamics, most authors relied on traditional theories that attribute urban transformation to rural urban migration (Checkland, 1978). They considered economic disparities between rural and urban areas as the main driver behind rural-urban migration (Becker and Morrison, 1995). These represent a set of intellectual genealogy on city transformation that has been successfully challenged through new methods and ideas generated using computational analysis.

With advances in computational analysis, system modellers have become more creative and have gone beyond traditional theories that attribute city transformation to single set of causes (Algarten, Posamentier and Moresh, 1983). They have started to query the influence of combined factors that are likely to drive city transformation. The result of this is the increase in systems analysis literature, new ideas and development of systems methods that employ multifaceted approaches. This has broadened the scope of analysing urban transformation as new models and novel ideas are being developed that come from different angles of analysis like geospatial, social, demographic, networks and complexity analyses.

The idea of migration being a driver of city transformation derives from equilibrium theories that linked rural migration to urban systems. One of such theories is that of Revenstein (1889). This theory emphasizes that:

- people migrate from areas of low income economic opportunities to areas of high opportunities,
- the choice of destination is regulated by distance, meaning that people first move to nearby towns and then to large cities,
- each stream of movement tends to dominate urban areas, suggesting that urban residents are less migratory than the rural residents, and
- movement accelerates with the improvement of transportation, communication and the expansion of trade and industry.

In addition, Everett S. Lee's (1966) theoretical framework provides an outline for interpreting processes and effects of human movement between rural and urban areas. According to Everett (1966), every case of migration involves an origin, a destination and the intervening set of factors.

Everett categorised factors that influence people's perception into 'pluses', 'zeros' and 'minuses', with zeros representing competing forces, which are more or less evenly balanced. A broad range of migration studies reflects this theory. One of the obvious shortcomings is that it contributes very little to the interpretation of movement and the associated effects on the cities, and has a high degree of generality. On application it is, however, difficult to determine which "plus" factors and which "minus" factors, at both origin and destination, are quantitatively the most important to different groups and different classes of people. No insight is provided into trade-offs between "dependent" and "independent" variables and minimal practical policy guidance on city transformation is offered.

An attractive theory worth considering, was developed by Arthur Lewis (1954 and 1955), and later modified into a model by Ranis and Fei (1961). Arthur Lewis' theory stresses that the heart of urban development and transformation lies in the gradual shift of the economy's centre of gravity from agriculture to industry. This happens through labour reallocation between agricultural and industrial sectors. The theory holds that unlimited supplies of labour are available to the modern sector (i.e. industrialised economy) at a fixed wage, slightly higher than the average income, in the traditional agricultural sector (i.e. rural economy). It stresses that people move to urban areas with the purpose of occupying surplus vacant jobs.

This theory, unfortunately, makes three assumptions that are at variance with the realities of human movement, especially in the developing world. It assumes that the rate of employment creation in urban areas is proportional to the rate of urban capital accumulation. The faster the rate of capital accumulation, the higher the growth rate of modern sector development and the rate of creation of new jobs will be. It suggests that, if surplus capitalists' profits are reinvested in more sophisticated labour-saving capital equipment rather than duplicating the existing capital, all extra income and the output could be distributed to the new owners of the capital, while the income levels of the masses of workers remain largely unchanged.

The theory further assumes that "surplus" labour exists in rural areas, while there are full employment opportunities in urban areas. This is in contradiction to the reality of the current relationship between urban and rural areas (Simelane, 2012). Despite this, there are recognisable exemptions to this theory. The assumption that urban surplus labour exists is more valid than the Lewis' assumption of general surplus labour.

The third assumption, which is at variance with the reality, is the notion of the continued existence of constant real urban wages, to the point where the supply of rural surplus labour is exhausted. In developing countries, one of the striking features of the urban labour market and wage determination is the tendency for wages to rise substantially over time, relative to rural income.

With these concerns, Lewis' theory appears inaccurate and less attractive for adoption and use to interpret the current dynamics of urban transformation. This is largely due to following realities:

- the rate of population and labour force growth tends to, in most cases, be larger than expected, and
- the difference between rural and urban incomes is always much greater than Lewis's assumptions, owing partly to various factors, including inherited income differentials.

Without exhausting all theories and traditional models on rural-urban relationship, an alternative view of rural urban relationship is embedded in Harris-Todaro model (Todaro,1969). This model emphasizes that prospective migrants maximise their expected income. The model differs from other models in that its central gravity is expected income.

Basic features of the model include considerations that:

- Migration is stimulated primarily by rational, economic consideration of relative benefits and costs, mostly financial;
- The decision to move depends on 'expected' rather than 'actual' urban-rural wage differentials and the probability of successfully obtaining employment in the urban, modern sector;
- The probability of obtaining urban employment is inversely related to the urban unemployment rate;
- Rates in excess of urban employment opportunities are not only possible but also rational and probable in the face of continued positive urban-rural expected income differentials,
- High rates of urban unemployment could be the inevitable outcome of the imbalance of economic opportunities between urban and rural areas.

This model provides the basis for analysing the effects of income on the population of cities. It traces the process of urban migration in two stages. The first stage is that of the migrant's arrival in an urban area, where he either remains unemployed for some time or obtains employment in the traditional sector, while searching for a job in the modern sector. The second stage is when the migrant succeeds in obtaining employment in the modern sector, which carries higher earnings considered to be enough to offset low traditional sector earnings.

The Harris-Todaro model specifies that migrants act rationally, as long as the present value of urban income during their lifespan exceeds the present value of rural income and costs of relocation. The weakness of the Harris-Todaro model is the assumption that potential migrants are homogeneous in respect of skills and attitudes and have complete information for working out the probability of finding a job in the urban sector (Harris and Todaro, 1970).

What this shows, is that each model has its own limits (Checkland, 1981), which calls for a look at how models are developed (Forrester, 1968), rather than critiquing their purposes and what they seek to achieve (Jackson, 1991). Siviera, Espindola and Penna (2005), in analysing the effects of the key parameters in the Harris-Todaro model, used agent-based computational analysis. They defined rural-urban migration as part of the industrialisation process. In their analysis, they consider rural-urban migration as a discrete choice problem, which allows the formalisation of migration process (Siviera, Espindola and Penna, 2005). Through this approach, it emerged that aggregate regularity, which indicates decentralised migration decisions, can lead to an emergence of equilibrium macrostates.

Having a macrostate, with a predominantly rural population and the expected urban wage higher than the rural wage, provokes transitional, rural-urban, migratory dynamics with a continuous growth of urban share. Silviera *et al* (2005) demonstrate that, during this process, the reduction of the rural share takes place together with the per capita income increase of the economy. Such an inverse relation has been broadly discussed in economic statistics (Harris and Todaro, 1970; Jackson and Keys, 1984).

As could be derived from this review each theory has its shortcomings (Eberlein, 1989; Winch, 1993). It can however, be specified that there ae three prominent categories of theories that define the rural urban link and its effects on urban transformation in context more cohesive was. These are:

- neoclassical economic theory,
- segmented labour theory and
- World systems theory.

These form basis for consideration, when developing models for analysing urban-rural relationship and its associated effects on cities. From this review, it appears that there has been constant evolution in the analysis and interpretation of urban transformations. One of the prominent framework that had emerged, which has also dominated the literature is that cities are complex adaptive systems. This has entrenched systems theory and thinking in the domain and genealogy of urban analysis (Brent and Kruger, 2009).

3.2 Evolution of systems thinking

The period 1950 to 1980 represents a significant era in the application of systems thinking to various World problems. This field of knowledge emerged when systems practitioners brought together various systems ideas and techniques and employed them to provide answers to real world problems. First attempt to devise systems methodologies as a means for tackling real-world problems began during the Second World War. It was at this time that fields such as Operational Research, Systems Analysis and Systems Engineering emerged. These were later referred to as Hard Systems Thinking (Checkland, 1981). Hard Systems Thinking represented a breakthrough in the application of systems thinking to world problems (Checkland, 1981).

Despite its advancement in application to different world problems, considerable amount of criticism also emerged. This was related to the inabilities of hard systems to handle complexity and to cope with plurality. It meant that Hard Systems alone were unable to handle multiple perceptions of reality. Because of this shortcoming, this study adopted a multifaceted approach, which integrated systems thinking, system dynamics and mathematical modelling. This sought to represent a break away from the traditional norm of using single method when analysing urban dynamics. It intends to contribute to the advancement of the application of systems thinking.

The field of systems thinking would not have been so advanced in application should it not be the contribution of Ludwig von Bertalanffy (1968), who pioneered the concept of general systems theory. The theory stipulates that a consequence of the existence of general system properties is the appearance of structural similarities in different fields. Von Bertalanffy's assertion is that a general theory of systems would be a useful tool for providing models that can be used in, and transferred to, different fields (Checkland, 1981).

Another contributor, that warrant recognition for his contribution in the advancement of the application of systems thinking is West Churchman (1994) who was an active member of the network of zealots that came together to found the Operations Research (OR). He applied OR techniques during the Second World War as a statistician at the Frankford Arsenal in Philadelphia, where he developed methods for testing small arms ammunition and detonators. After the war he became a professor of engineering administration at Case Institute of Technology. He co-authored with R. Akoff and E. Arnoff "Introduction to Operations Research", one of the first textbooks on OR. He quickly built Management Science, both in size and reputation.

Latest applications of systems thinking to different fields was pioneered by James G. Miller (1916-2002), who initiated the use of the term "*behavioral science*" and incorporated it into the living systems theory. Having served on the faculty at Harvard, in 1948 he accepted the position of Chairman of the Department of Psychology at the University of Chicago, which he held until 1955.

This was extended by Herbert A. Simon (1916-2002) who was among the founding fathers of several of today's significant scientific domains, including artificial intelligence, information processing, decision-making, problem-solving, attention economics, organization theory, complex systems, and computer simulation of scientific discovery. He coined the terms bounded rationality and satisficing, and was the first to analyze the architecture of complexity and to propose a preferential attachment mechanism to explain power law distributions.

A review of selected articles published in System Dynamics Review (1986-2014), a journal dedicated to publishing work on system dynamics, reflects that present day applications of systems thinking (in the form of system dynamics) had been largely influenced by Jay W. Forrester's work. Jay Forrester's ambition in developing system dynamics was to extend a range of applied systems thinking to more strategic problems (Jackson, 2003). Through his popular work on Urban Dynamics, he introduced a new perspective in interpreting urban problems through linking together engineering and social sciences.

Urban Dynamics theory views the city as a complex social and economic system formed by the interactions of individual efforts to achieve personal goals (Jackson, 2003). Forrester (1969) made insights to the understanding of the important urban mechanisms, which cause the urban dynamics. One of such mechanisms is "*Urban attractiveness*". Urban attractiveness is premised on observation that when one area is slightly more attractive than the other, the population begins to move in the direction towards the more attractive area and this creates disequilibrium. The effect of attractiveness on urban change is presented in Chapter six.

Other contributors in the field include Peter Senge and Khalid Saeed both of Massachusetts Institute of Technology. Peter through his publication "*the Fifth Discipline*" popularized System Dynamics and extended its application to different fields. To immerse the application of System Dynamics into different fields in South Africa and Africa, South African System Dynamics Chapter has been established. This came as a response to the growing need for a combined effort in dealing with complex, real-world challenges in Africa (Musango *et al.,* 2016). The objectives of the Chapter are to:

- Promote understanding and awareness of system dynamics as a problem solving approach to many of the Africa-based problems;
- Identify, develop, extend and disseminate knowledge contributing to the understanding of feedback systems in South Africa and the rest of Africa;
- Promote the development of the field of System Dynamics and the free interchange of learning, research and scholarship in all related fields in South Africa and the rest of Africa;
- Encourage and develop educational programmes in the feedback behavior of systems in South Africa and the rest of Africa.

An in-depth review of the application of system dynamics in various areas, especially in southern Africa has been conducted by Musango *et al.,* 2016. The assessment has shown that the total number of publications on system dynamics in Southern Africa have increased greatly over the period 2003 to 2014. The highest number of publications was produced in the 2013 and 2014. This suggest an uptake in interest in the field of system dynamics in Southern Africa as well as increased understanding and application of the various uses and techniques involved in systems thinking and system dynamics (Musango, *et al.,* 2016).

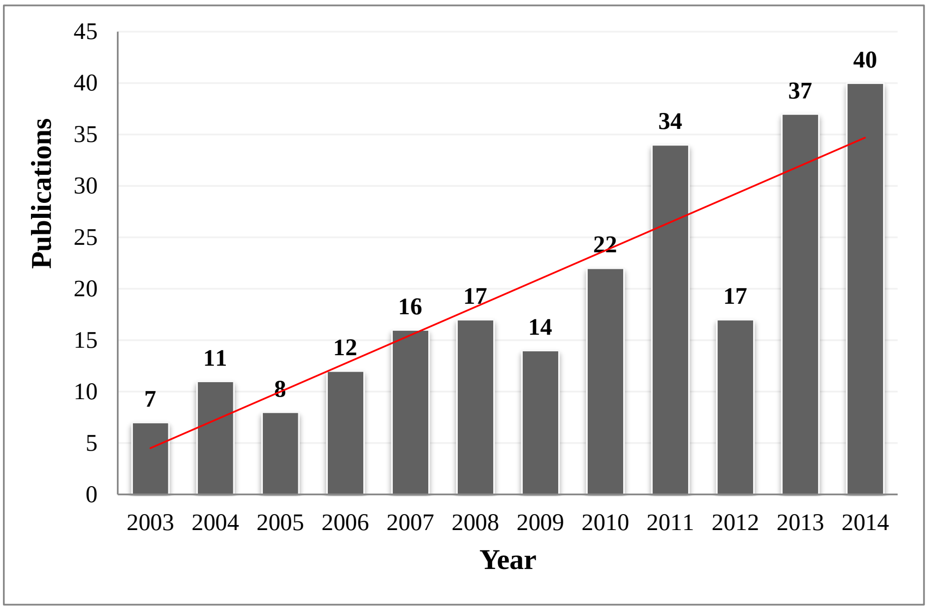

Figure 3.1. Total number of publications on System Dynamics in Southern Africa, 2003 -2014 (source Musango, *et al.,* 2016)

The review further revealed that South Africa dominates in the number of publications produced that utilises systems thinking and system dynamics as a decision making tool.

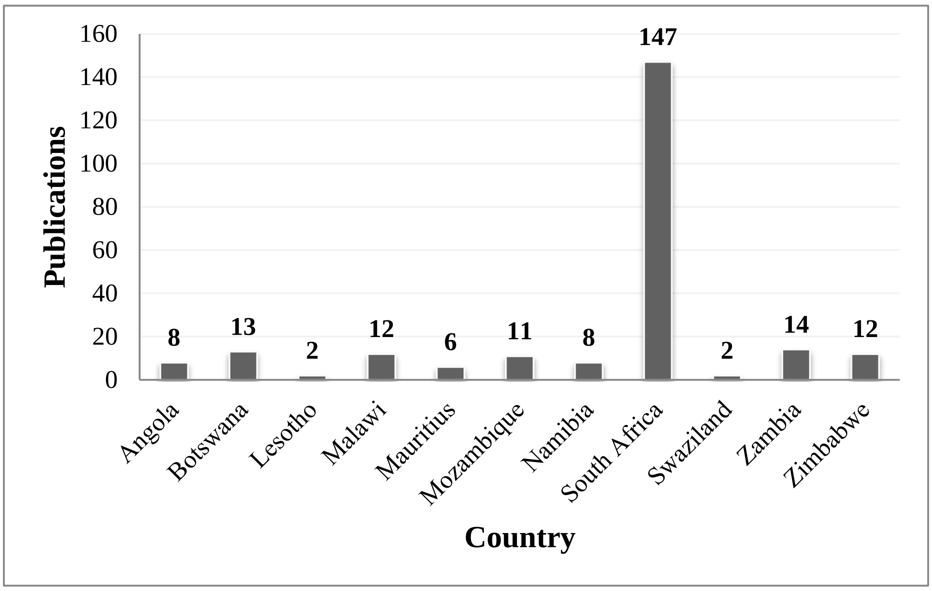

Figure 3.2. Total number of publications on System Dynamics by country for the period 2003 – 2014 (Source Musango, *et al.,* 2016)

According to Musango, *et al.,* 2016 systems thinking and system dynamics has mainly been used within the fields of Environment (which yields 81 instances); Resource management (which yields 63 instances); and Public Policy (which yields 54 instances). Other areas that have used or referred to system dynamics include Security and Stakeholder Engagement, both with one instances respectively.

These indicates that the application of systems thinking and analysis in urban studies is still at an embryonic stage, especially in Africa. This study intends to contribute by extending the application of system dynamics and systems thinking in urban studies using experiences of South Africa.

3.3 Applications of systems thinking and systems Dynamics in urban studies

The application of systems thinking and system dynamics in urban planning over the past thirty years has increased significantly. When applying systems thinking in urban planning there seems to be distinctly two traditions that are followed. One tradition started when General System Theory and Cybernetics were applied to the softer social sciences in the 1950s by Ludwig von Bertalanffy (1969) (in biology) and Norbert Weiner (1948) (in engineering). This began in biology in the 1920s. It was gradually introduced in engineering in the 1950s and spread to the management and social sciences, particularly sociology and political science (Allen, 1982). It was part of a wave of change in the social sciences. The focus then was on the ways in which elements, comprising the system interacted with one another through structures that embodied feedbacks, keeping the system sustainable within bounded limits (Allen, 1998).

The application in urban planning began around 1960 (Andersson, Rasmussen and White, 2002). Its focus was on transportation planning (Batty, 2010; Brail, 2008). Models developed had a large degree of disaggregation and represented the spatial distribution of economic activity as a result of various transportation development plans (Barredo, Kasanko, McCormick and Lavalle, 2003). These models were later extended to include land use concerns and eventually became known as “Land Use Transportation Models” (Alonso, 1964). Both researchers and city planners have used them to study zoning policies and transportation development plans (Batty, 1974).

The economic activities of such models was semi exogenous. That is, an economic development growth trend was overlaid onto the model. It was the distribution of economic activity rather than the dynamic of economic activity that were of interest (Batty, 1976). In general, these models used an input-output design, or social accounting matrix (Batty, 1976). Most of them were too general, and the scale of the system was usually limited (Park, Kim, Lee, Han and Choi, 2013).

The second tradition entails the applications of physical analogies to social and city systems, particularly ideas about gravitation and potential, which were incorporated into urban planning in the mid-19th century under the banner of 'social physics'. Softer approaches in sociology and political science provided support for the idea of cities as organizational systems while the notion of cybernetics as the basis for management, policy and control of cities was adopted as an important analogy in their planning (Chadwick, 1971; McLoughlin, 1969).

In these applications main ideas defined cities as sets of elements or components that are tied together through sets of interactions. The archetypal structure was fashioned around land use activities with economic and functional linkages between them, represented initially in terms of physical movement. The idea of feedbacks, which is the dynamic that holds a general system together, was largely represented in terms of the volume and pattern of interactions. The prime imperative was to determine how improving interactions between components can be made more efficient while also meeting goals that promote social and spatial equity. Income and housing were considered to be of central importance.

As could be deduced this assessment the application of systems thinking in urban studies was motivated by different intentions that have physics and biological foundations. In this study the primary intention is to bring a new paradigm of assessing the transformation of cities through interpretation of social dynamics. As South Africa is part of Africa, observations were extended to other African cities. Although no direct comparisons can be drawn between cities across countries in the continent, developing a broader view of the transformation trends of cities in general is desirable so as to design programmes that can enhance the management and administration of cities at continental level.

3.4 Discussion

A detailed post-Apartheid assessment of urban transformation in South Africa is provided by Schensul and Heller (2010). According to Schensul and Heller (2010), post-apartheid cities represent an important test case for South Africa's spatial dimensions of social inequality that is shaping its transformation. What Schensul and Heller (2010), reveals about urban transformation is that in the past there has been much emphasis on politically motivated social transformation of cities.

This is also reflected in most literature (Harrison et al., 2003). In these publications debates revolve around structural views that link globalization to the polarization and fragmentation of cities (Sassen, 1998). Some of these views have been successfully challenged through emerging publications that query the globalization–polarization opinions and argue that changes in cities are more complex than once thought, as cities represent complex adaptive system (Marcuse and Van Kempen, 2000; Maloutas, 2007; Crankshaw, 2008).

In line with most existing views on city dynamics, this study focussed on two perspectives of complex system analysis, namely the descriptive and predictive assessments. With regard to descriptive perspectives, Forrester (1971) emphasizes that a system is composed of a number of interlinked sub-systems that can easily be altered through human's desire to adapt to his environment. In examining this relationship, the study analysed changes that have taken place in South Africa as representing the transformation process in cities (Chan and Li, 1999; Lei, 2001; Garcia, 2004). The emphasis is on determining triggers of city transformation and the associated characteristics that have emerged. Factors incorporated into models used are regarded as obvious drivers of city transformation.

As noted by authors such as Nakosteem and Zimmer (1980); Pissarides and McMaster (1990) and others, any form of city transformation can lead to:

- a disequilibrium in the growth of the population,

- loss of attractiveness through environmental contamination ,
- inadequate resource supply such as housing and social services and
- psychological stress resulting from competition for resources such as job opportunities, educational facilities and other limited resources (Goldstein, 1983).

These are the root causes of the emergence of the undesirable features in city system (Espíndola, *et al*., 2006).

Other factors considered are challenges likely to be faced by urban migrants once they enter city system and are unable to generate income (as one of the basic needs) in the city (Todaro, 1986). As most of them come from rural areas, they find it difficult to be absorbed by available employment opportunities in the city. This contribute directly to the surplus of skills that do not match available opportunities (Herzog, Schlottman and Boehm, 1993; Ruel, Haddad and Garret, 1999). The final effect of this is the contribution to an emergence of features like urban unemployment, poverty and crime (Nakosteem and Zimmer, 1980; Goldstein, 1983; Chaudhuri, 2000).

As could be derived from this assessment, there is still a need to increase the relevance of systems thinking and modelling in urban studies, especially in Africa (Espíndola, *et al*., 2006). It is the intention of this study to contribute towards bridging this gap. The study seek to generate information that can be used to improve beneficial linkages between rural and urban areas in South Africa (Ruel, Haddad & Garrett, 1999).

Various literature that present cities as complex adaptive system reflect that changes that take place in the cities derive from a number of factors. The underlying factor being the unpredictability of the behaviour of the cities as complex adaptive systems. The larger portion of existing literature emphasise that this might be due to a nature of complex adaptive systems, which are composed of many interacting components. These are adaptive, meaning that they change over time (are dynamical) and are thus difficult to predict as they are modular i.e. they are susceptible to interactions within the element of the system. This might illustrate the underlying complex mechanisms through which cities get transformed.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

Chapter three provides a review of the literature that guided the conceptualisation of the problem statement of the study. In conceptualising the problem statement, and developing questions for the study, a non-experimental, quantitative and inferential approaches were used to collect and analyse primary data. This multi-pronged approach was combined with systems thinking and analysis (Forrester, Mass and Ryan, 1973). The intention was to consolidate observations and make accurate inferences that are supported by systems thinking.

Data was collected using questionnaires (its description analysis is provided in Chapter five). This method allowed for quicker and efficient collection of primary data. It is widely used in both natural and social sciences (Simelane, Kerley and Knight, 2006; Mendenhall, Beaver and Beaver, 2002).

Surveys were conducted in Pretoria, Johannesburg, Durban, Port Elizabeth, and Cape Town. During each survey, the following set of data was collected:

- information about the origin of the person interviewed,
- income level of respondents,
- reasons for moving into the city centre,
- willingness of respondents to go back to their areas of origin,
- the challenges experienced by residing in the city centre,
- different types of food city centre residents can afford,
- whether a person was living in a family, commune or singly in their place of residence and
- whether a person was renting or owned the property where they lived.

To increase the understanding of the extent of the transformation of cities in other parts of Africa, additional data was obtained from Kinshasa (DRC), Lusaka (Zambia), Harare (Zimbabwe), Nairobi (Kenya) and Windhoek (Namibia). These cities were chosen based on consideration that they are in countries that obtained democracy earlier than South Africa.

The survey did not cover all socio-economic variables of urban systems. It focussed mainly on those considered to be relevant for the study and models developed. In each city, a maximum of 200 and a minimum of 100 participants were set to be reasonable sample to interview, with targeted ages of respondents ranging between 20 and 50 years. These were regarded as economically active individuals who either aspire to establish themselves (20–35 years) in the city or have already established (36–59 years) themselves in the cities where they live.

The sample was sub-divided into six sub-samples or groups as follows: Group I (20-25 years, regarded as entry level group), Group II (26-30 years, early established group), Group III (31-40 years, established group), Group IV (41-50 years, group approaching retirement) and Group V (51 years and above, advanced group closer to retirement). This grouping made it easy to assess responses provided by different age groups that could possibly be due to disparities among age groups, like income, accumulated assets and education levels.

Interviews took place during an informal encounter with the respondents. They were based on informal discussions that were guided by the questionnaire. Interviewers were recruited from local areas where surveys took place. Within each city (in South Africa), the study focused on areas considered to have been adversely affected by transformation of the city. In South Africa, these were Central in Port Elizabeth, Yeoville and Hillbrow in Johannesburg, Sunnyside and Arcadia in Pretoria and Central Business Districts (CBDs) of Durban and Cape Town. CBD being defined as the area that falls within the 3 km radius of the place where high economic activities are taking place. The defining characteristic for a participant to be involved in the survey was his or her likelihood to be from a rural area or have rural experience. In South Africa not all populations or races live or have lived in rural areas. Populations with less experience of rural life or likelihood to have lived in rural areas were thus exempted from participating in the study.

For other African cities interviews were conducted around open market places, where city residents trade their goods and conduct businesses. Before interview take place, potential respondents were asked if she/he is the resident of the city. Interviews were only held with those who indicated that they were residents of the city. This ensured that only those who are directly affected by the transformation of a city or have the experience of city life participate.

Additional information such as total numbers of people residing in each city, as well as other information considered to be essential to supplement primary data, were obtained from reports and records published by institutions such as Statistics South Africa (South Africa) and Statistics Bureaus of other African cities.

Both the primary (collected through questionnaires) and secondary data (obtained from records and data bases) provided variables that were incorporated into models.

Overall, the methodological process entailed:

- exploratory investigation, which consisted of a literature review (Chapter three) and information gathering through questionnaires (analysis and results presented in Chapter five),
- conceptual model building, which entailed identifying variables and determining systems methodology (Chapters six, seven and eight),
- model calibration and testing, which involved running computer simulations with the acquired variables (Chapters six, seven and eight) and,
- observing the model behaviour so as to extract confirmatory evidence of real world situations (Chapters six, seven and eight).

The inclusion of systems thinking and modelling as part of the methods used sought to primarily address questions four and five of the study. Description of how each question was addressed is provided in the dedicated chapters that address each of the formulated questions.

4.2 Data type and analysis

Two sets of data (i.e nominal and numerical) was collected. These were captured, stored and processed using Microsoft Excel®.

Descriptive and inferential statistical analyses were performed on Sigma Stat®. Sigma Stat® was combined with Microsoft Excel's capabilities of analysing data and presenting the analyses pictorially by means of tables and graphs. Descriptive statistics was used to describe the sample and give summaries of information about the sample. Inferential statistics was used to make inferences or generalisations about the broader population.

4.2.1 Descriptive analysis

This included determining means, median, standard deviations, frequencies, measures of central location and measures of dispersion from primary data. This provided summaries of samples. It presented quantitative descriptions of data in a pictorial form.

4.2.1.1 Frequency distributions

Observed frequencies were determined and used to establish the proportional representation of the population samples. The expected frequencies were then compared to observed frequencies, using Chi-Square (χ^2). This analysis determines the numbers (percentages) of a response occurrence. Frequency analysis is a good way to start statistical analysis of data.

4.2.1.2 Measures of central location

While there are three types of measures of central tendency or location, which are mode, mean and average**,** only means were calculated and used to compare data in this study.

4.2.1.3 Dispersion and variability

Due to the nature of data collected, only variance and standard deviations were determined. This was based on the observation that these are the most reliable measures. In this analysis every observation is taken into account, based on the average deviation from a central value. Measures of dispersion provide useful information in judging the reliability of the central value. Widely dispersed observations indicate low reliability and are less representative of the central value. Conversely, a high concentration of observations about the central value increases confidence of reliability and representativeness of the central value.

4.3 Statistical inferences

To enhance interpretation of the empirical data, inferential statistics was juxtaposed with descriptive statistics. Descriptive statistics is solely concerned with properties of the observed data. It does not assume that the data came from a larger population.

Statistical inference on the other hand is the process of deducing properties of an underlying distribution through the analysis of data. It infers properties about a population (Pretorius, 1995), leading to drawing conclusions about the data (Bullard, 2006). This includes testing hypotheses and making conclusions about them. In this study, statistical inferences made were based on Chi-squared and the Analysis of Variance. Any statistical inference requires some assumptions. Assumptions made were that the population growth dynamics in the cities is largely driven by income. Meaning that people migrate to cities with sole purpose of maximising chances of accumulating income and wealth. In systems analysis and modelling the widely appreciated characteristic of statistics is its ability to reduce macroscopic observations into microscopic models, thus offering a mechanistic description of a system's dynamics (Barzel, Liu and Barabàsi, 2014)

4.4 Validity and reliability

In any research, validity clarifies the extent to which a measuring instrument determines what a researcher intends to measure. Reliability is the extent to which a measuring device is consistent in evaluating whatever it measures (Axtell, Axelrod, Epstein and Cohen, 1996). This refers to the repeatability of a test's score on the same test on different occasions, or in different tests with equivalent items, or under different examination conditions (Smith, 2001).

In system models, validity is assessed through comparisons with other, more involved, proven models that exhibit a closer representation of a physical system or by comparisons with measures of collected data from the field (Burton and Obel, 1995; Axelrod, 1997).

Efforts were made to ensure the validity of questionnaires and data obtained. Collected data was thus used as a basis on which reference models can be built and against which the validity of the developed models can be tested (Axtell, Axelrod, Epstein and Cohen, 1996). This was attained by subjecting models to a series of tests which included:

- A model structure test, which included a model parameter test, a boundary adequacy test and an extreme conditions test.
- A model behaviour test consisting of a behaviour replication test, an anomalous behaviour test, a behaviour sensitivity test, a behaviour prediction test, a family member test, and a behaviour boundary test.

4.5 Integration of data into models

After the values collected, variables and their statistical significance was determined using descriptive analysis (Chapter five) the variables were incorporated into models developed. Data generated through simulations led to a generation of two sets of data i.e. real world data (based on fieldwork) and abstract data (based on simulation). This fused plausible behaviour with formalised logics, matched against empirical evidence, which is essential for demonstrating novel patterns of system behaviour.

As migrants take time to adjust before adapting, the duration of adaptation, was seen to be a critical factor. This indicates that the level of adaptation should be measured at time intervals, with similarity in methodology strictly maintained to allow for comparison of results. It should also be safeguarded that the same core set of dimensions are measured (Clarke, Gaydos and Hoppen, 1996), so as to guarantee that differences in results are attributed to settings and not methodology or types of adaptations under study. The time interval chosen was yearly intervals (Barr and Zehna, 1983).

4.6 Discussion and Conclusion

There exist different opinions about the choice of statistics one can use to analyse data. These have been in existence since the beginning of the 19th century (Strauchi, 1970; Bland and Altman, 1988; Ercan, 2007). Statistical analysis is however, essential in furthering scientific knowledge and understanding. There is no prescribed approaches for choosing statistical methods (Strauchi, 1970; Bayarri and Berger, 2004).

It is the primary tool for determining relationships between data and the hypothesis formulated for the study. Unfortunately, statistical tools are often misused, either inadvertently because of lack of planning, or conspicuously to achieve a specified result (Gore, Jones and Rytter, 1977; MacArthur and Jackson, 1984). This include the incorrect application of statistical tests, lack of transparency and disclosure about decisions made. Individually, each of these may completely invalidate result of the study (Porter, 1999; Gardeneir and Resnik, 2002).

To alleviate this, it is always vital to ensure that research design is precise about the levels of measurement, type of variables and associated assumptions. Giving attention to these weaknesses is essential, including the development of an analysis plan and a study specific methodology that help to mitigate statistical offenses.

It can be concluded that although modelling is capable of generating its own data and perform analyses, decision based on any analysis using a model still need support of statistical comparisons. This include the testing of outputs using statistical tools. Real world data incorporated into system behaviour contain in one way or the other a certain degree of uncertainty. Since data collection and data processing is never error free and real system have features that are unaccounted for in measurements and models. In many instances systems exhibit test-to-test variations, unit-to-unit variations and measurement uncertainty. In advancing the significance of data in modelling statistical analyses serve as a precursor to model development and further analysis.

CHAPTER 5

STATISTICAL ANALYSIS OF CITY POPULATION DYNAMICS

5.1 Introduction

This chapter provides an overview of the profiles of inhabitants of the studied cities. The intention is to present through statistical methods features, trends and characteristics of empirical data collected from studied cities. These were collected so as to have real world data, which can be incorporated into models used to generate base modes and behaviours of the models presented.

Patterns obtained were used to frame predictions and inferences about future transformations likely to take place in the studied cities. Possible forms of transformations were attested through inferential statistics. This branch of statistics goes beyond the pictorial representation of data using figures and graphs. It quantitatively summarizes data sets and provides insight into relationships between variables. It entails the use of techniques that assist in making predictions about the unknown aspects of data set.

5.2 Results

5.2.1 Population composition

City populations were found to be composed of five communities (Figure 5.1). For South African cities the communities were dominated by Group I age category. These were mainly students and job seekers. While this could reflect the character of the populations where samples were drawn i.e. city centres and central business districts, it demonstrated that city centre populations in South Africa are composed of young people. Querying what could have brought these people to cities revealed that some were searching for employment (35 percent), others were already employed (25 percent), some were still studying (15 percent) and a small proportion were attempting to start a small businesses (25 percent). A very small proportion (i.e. < 1 percent) was visiting relatives or friends.

Part of this chapter has been published as: Simelane, T. 2010. Interpreting the transformation of the city centres of South Africa through system dynamics: how different are they from other African cities? Africa Insight. 40(4)168-186.

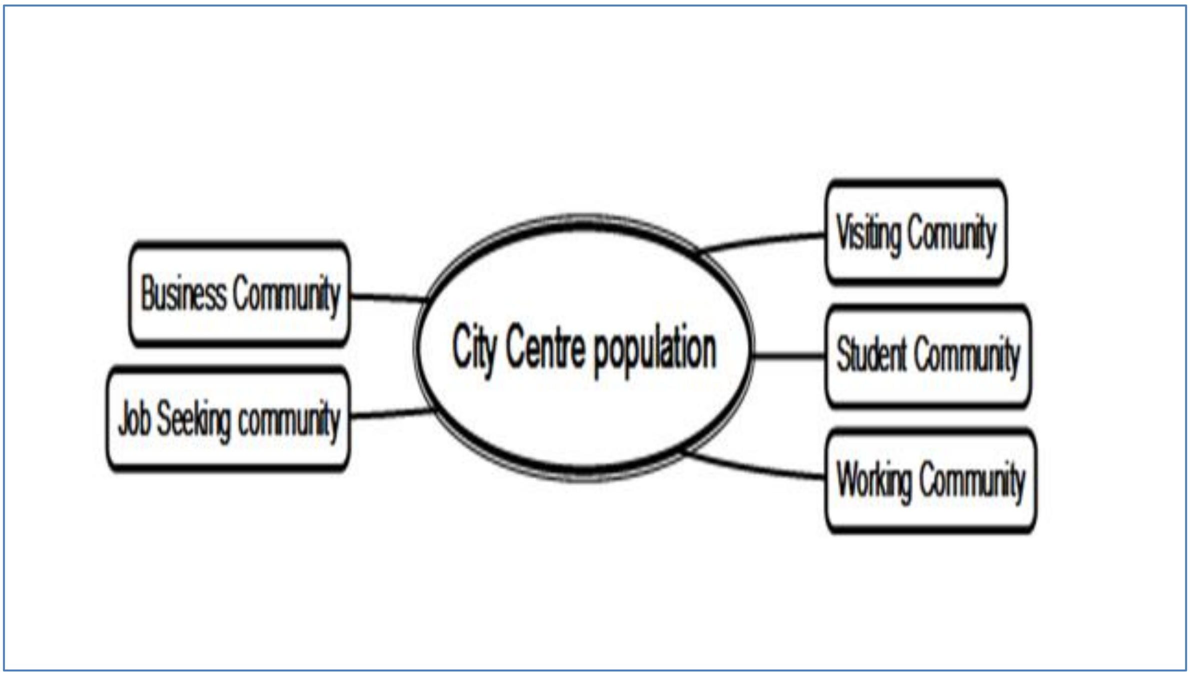

Figure 5.1. Population composition of ten studied cities

5.2.2 Household types

People in the sampled areas were found to reside in two types of households. These were classified as city centre residents and non-city centre residents. City centre residents were those who have chosen to reside permanently in the city centre (Table 5.1). These either own a house or a flat, which demonstrates their long term commitment towards living in the city. Non-city centre residents were those that were found to be in the city temporarily or rent the property they live in.

While South African cities generally had significantly ($F = 32.3$, $df = 9$, $P << 0.005$) higher proportion of non-city residents (Table 6.1), Durban (63 percent) and Pretoria (45 percent), recorded a significantly ($\chi^2 = 16.4$, $df = 4$, $P << 0.005$) higher proportions of city centre residents. Among other African cities only Harare (66 percent), Kinshasa (53 percent) and Nairobi (58 percent) had significantly ($\chi^2 = 20.9$, $df = 4$, $P << 0.005$) higher proportions of permanent city centre residents.

Table 5.1. Type of settlement as indicated by interviewees from ten studied African cities.

	Temporal	%	Permanent	%	N
Durban	83	37	141	63	224
Port Elizabeth	76	68	36	32	112
Johannesburg	72	74	25	26	97
Cape town	88	67	44	33	132
Pretoria	115	55	94	45	209
Windhoek	41	62	25	38	66
Nairobi	42	42	57	58	99
Kinshasa	42	47	47	53	89
Lusaka	49	57	37	43	86
Harare	33	34	63	66	96

5.2.3 Household size and composition

City residents (i.e. <45 percent) (all cities) were either staying in a commune (35 percent, overall), renting a flat (25 percent, overall) or were temporarily staying with their families (Table 5.2). This group was dominated by students (registered in local institutions of higher education), and individuals who were at the early stages of their employment. The number of those who were staying with families was recognisably higher in African cities than that of South African cities (Table 5.2).

Table 5.2. Type of household where interviewees were staying (DBN = Durban, PE = Port Elizabeth, JHB = Johannesburg, CT = Cape town, PRT = Pretoria)

Household type	DBN	%	PE	%	JHB	%	CT	%	PRT	%
Alone	37	31	26	23	7	7	25	22	17	15
With family	46	39	38	34	33	35	35	31	42	36
With relatives	10	8	12	11	24	25	12	11	7	6
With friends	25	21	37	33	31	33	42	37	50	43
N	118		113		95		114		116	

Within South Africa, Pretoria (Mean = 6.10) and Johannesburg (Mean = 5.4) had a significantly (χ^2 = 3.5, df =4, P << 0.05) higher proportion of people per household than all other cities, including other African cities. Among other African cities Lusaka (Mean

= 6.89) appeared to have a significantly (χ^2 = 6.4, df =4, P << 0.05) higher mean number of people per household.

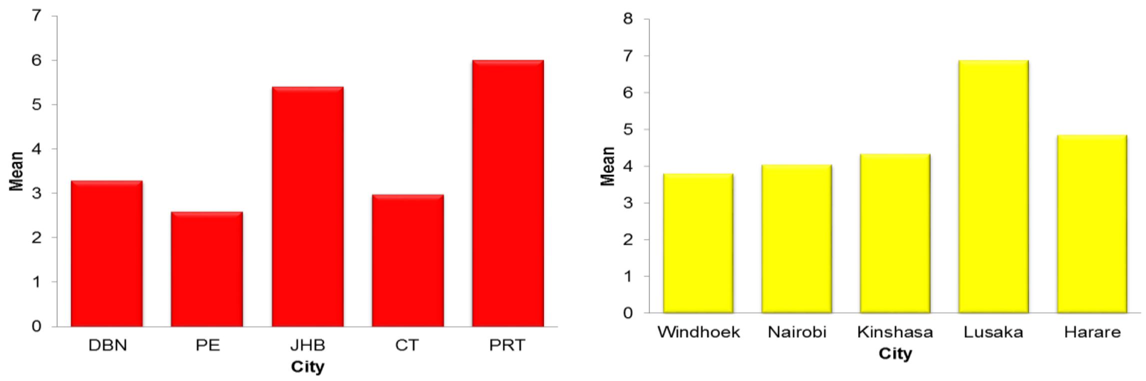

Figure 5.2. Average Number of persons per household in studied cities (BDN = Durban, PE = Port Elizabeth, JHB = Johannesburg, CT = Cape town, PRT = Pretoria)

5.2.4 Gender ratio

Male numbers for Cape Town and Port Elizabeth were significantly higher than that of females (Figure 5.2). Among African cities, this pattern was also observed in Harare, Lusaka and Windhoek (Figure 5.2).

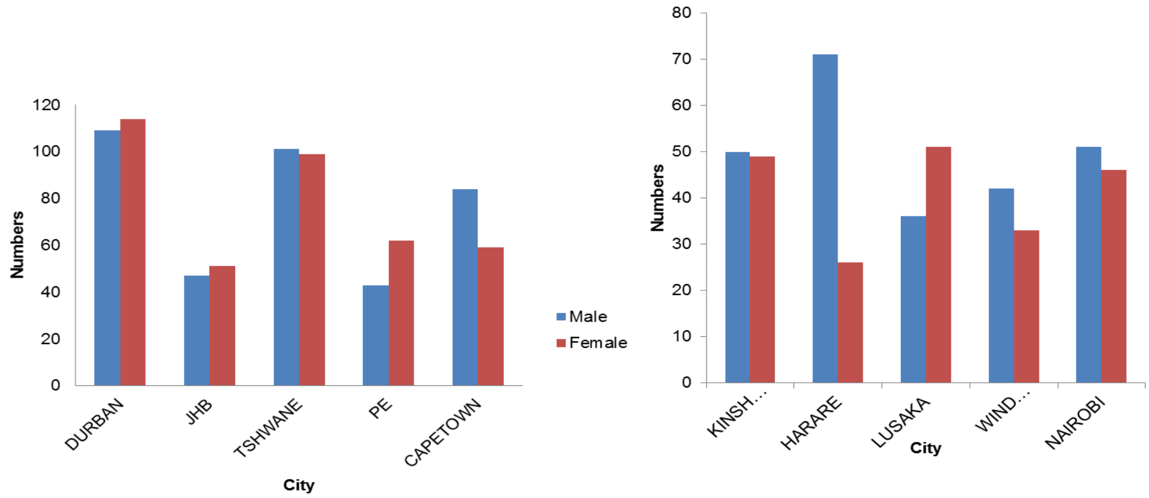

Figure 5.3. Gender ratio of city centre residents from ten studied cities (JHB = Johannesburg, Tshwane = Pretoria, PE = Port Elizabeth).

The pooled statistical analysis of data reflected that there was no significant (F = 34.2, df = 9, P > 0.05) differences between males and females in studied cities. Interestingly, this is disproved the common norm that there are more males than females in the cities, as males are regarded to be more mobile than females.

5.2.5 Age Composition

In all cities the larger proportion of communities was composed of young people i.e Group I and II with ages that ranged between 20 and 39 years. This indicated that city centre communities were composed of a young population.

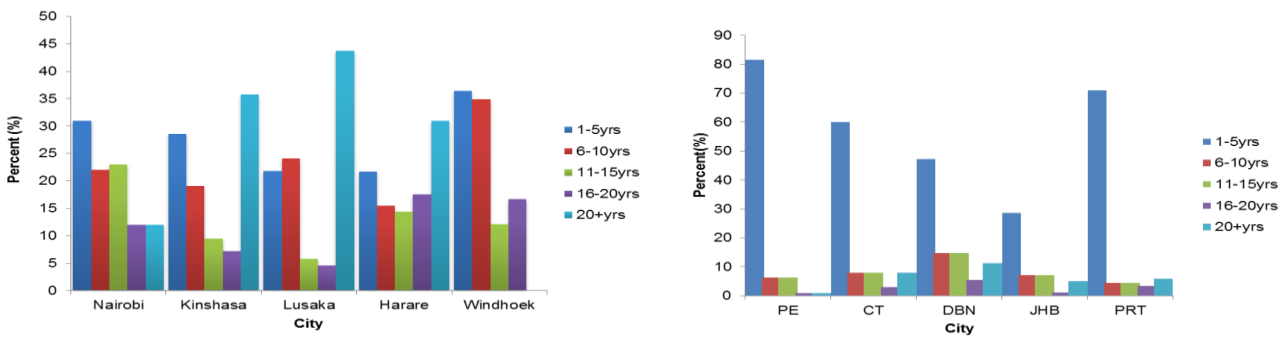

Figure 5.4. Age structures of city centre residents from ten studied cities (JHB = Johannesburg, Tshwane = Pretoria, PE = Port Elizabeth).

5.2.6 Reasons for moving to city centres

As reflected by the frequencies of citation, popular reasons for moving to city centres were:

- looking for employment (Table 5.3 and Figure 5.5),
- Education,
- being employed and
- intending to live closer to work.

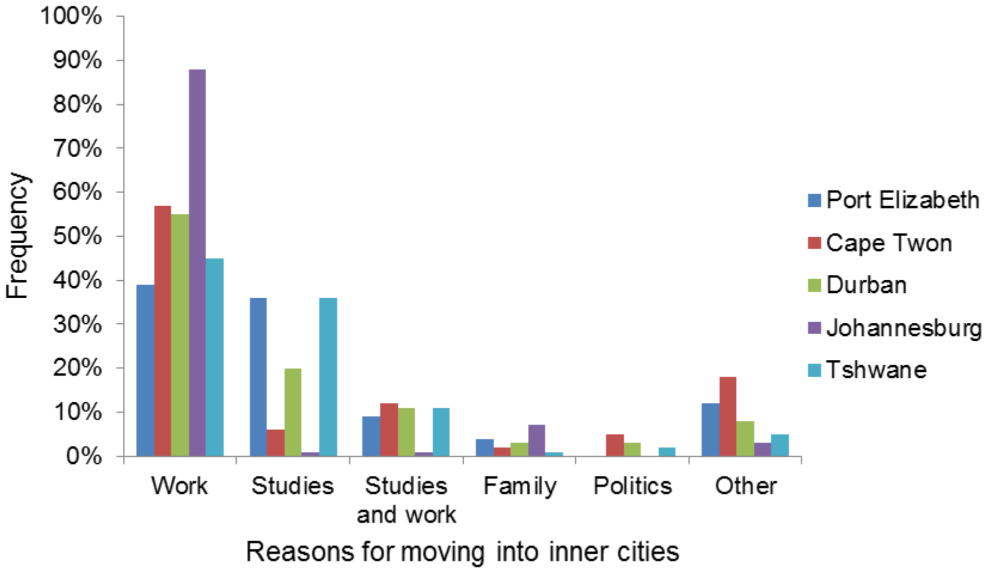

Figure 5.5. Reasons for migrating to cities (Tshwane = Pretoria)

In addition to these reasons,

- seeking better opportunities and
- personal visits, were cited as second choices.

This indicated that employment and education are the pull factors for people to move to cities (Figure 5.5).

Table 5.3. Reasons for people to migrate to cities: five studied other African cities

Reasons	Harare	Lusaka	Nairobi	Windhoek	Kinshasa
Employment	67%	75%	65%	55%	45%
Education	33%	25%	35%	40%	30%
Personal	0%	0%	0%	5%	25%

5.2.7 Areas of origin

Port Elizabeth and Durban had higher proportions of people from local areas that migrated to the city centre (Figure 5.6). However, Johannesburg, Pretoria and Cape Town had higher proportions of local and provincial migrants, with most provincial migrants coming from the nine South African provinces. In addition to recorded migrants, there were those that came from other parts of Africa. These were from Nigeria, Zimbabwe, DRC and Botswana (Figure 5.6).

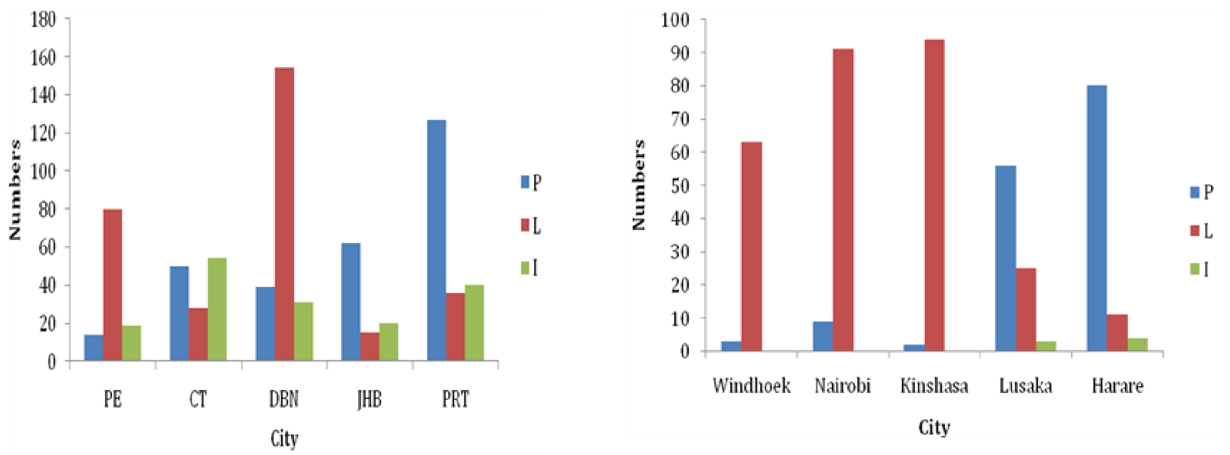

Figure 5.6. Areas of origin for people living in studied city centres (I=International, L= Local and P=Province)(PE = Port Elizabeth, CT = Cape town, DBN = Durban, PRT = Pretoria)

For African cities, most migrants were from local areas, with less of a probability for encountering a person from South Africa (Figure 5.6). Few recorded international migrants were in Lusaka and Harare. This indicated that, just like South Africa, some cities in Africa have substantial numbers of migrants that come from other countries.

5.2.8 Willingness to return to areas of origin

In South Africa, most interviewees expressed interest to return to their areas of origin (Figure 5.7). Among African cities, willingness expressed to return to areas of origin was recorded in Harare, Lusaka and Nairobi, but the willingness to return was very low (Figure 5.7). Windhoek and Kinshasa had higher proportions of city residents unwilling to return to areas of origin.

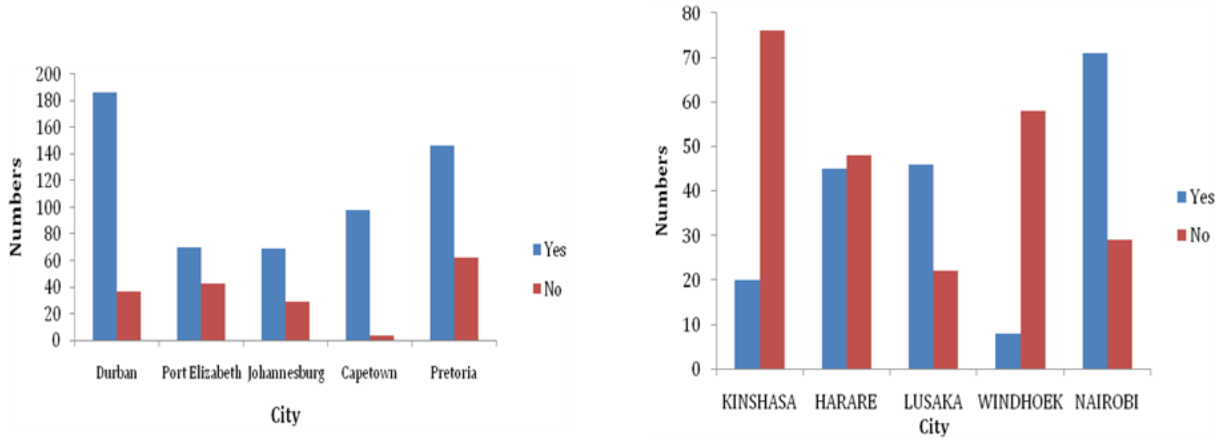

Figure 5.7. Levels if willingness to return to areas of origin expressed by residents of studied cities.

5.2.9 Duration of stay

For South African cities, most people had been living in the cities for periods not exceeding 15 years (Figure 5.8). In Africa, for Kinshasa, Lusaka and Harare, higher proportions of city residents had lived in the city for a period beyond 20 years. This was significantly different from South African cities, where the higher proportions of city residents had been living in the city centres for a period less than five years (Figure 5.8).

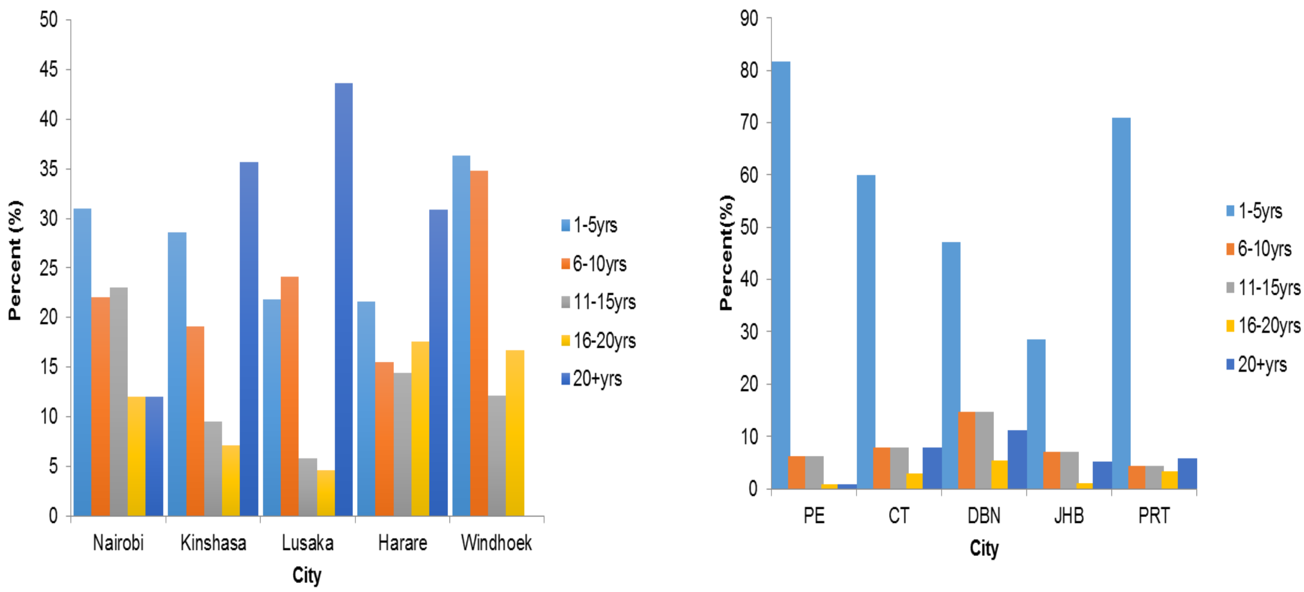

Figure 5.8. Duration of stays in city centres (PE = Port Elizabeth, CT = Cape Town, DBN = Durban, JHB = Johannesburg, PRT = Pretoria)

5.2.10 Education

Within South Africa, Port Elizabeth (66 percent) and Johannesburg (54 percent) had higher proportions of people with Grade 12. In African cities, Windhoek (83 percent) and Lusaka (35 percent) were the two cities where higher proportions of people with Grade 12 were recorded.

Durban (25 percent), Johannesburg (31 percent) and Pretoria (27 percent) had a comparatively significantly higher proportion of people with bachelor's degrees, while among African cities, Nairobi (eight percent) had a comparatively significantly higher proportion of people with post graduate qualifications (Table 5.4).

Table 5.4. Education levels of interviewees from ten studied African cities

	Matric	**%**	**Diploma**	**%**	**Bachelor degree**	**%**	**Post grad uate**	**%**	**N**
Durban	91	41	54	25	58	26	17	8	220
Port Elizabeth	75	66	26	23	10	9	3	3	114
Johannesburg	52	54	29	30	12	13	3	3	96
Cape town	55	31	54	31	54	31	13	7	176
Pretoria	84	43	70	36	27	14	14	7	195
Windhoek	54	83	10	15	1	2	0	0	65
Nairobi	26	27	36	37	28	29	8	8	98
Kinshasa	17	18	40	41	38	39	2	2	97
Lusaka	30	35	38	45	11	13	6	7	85
Harare	26	27	15	15	27	28	29	30	97

5.2.11 Employment

Among African cities, Kinshasa (87 percent) had the highest proportion of unemployed people. In general, there were high proportions of interviewees who were still studying (Table 5.4).

Table 5.5. Employment conditions of interviewees from ten studied African cities

	Employed	%	Unemployed	%	N
Durban	116	67	57	33	173
Port Elizabeth	55	48	59	52	114
Johannesburg	65	67	32	33	97
Cape town	113	80	28	20	141
Pretoria	114	56	91	44	205
Windhoek	47	71	19	29	66
Nairobi	72	73	27	27	99
Kinshasa	13	13	84	87	97
Lusaka	51	59	35	41	86
Harare	64	65	34	35	98

5.2.12 Income

In all cities, the majority of residents were within the low income bracket i.e. (R1 000-5 000)($133.3-666.7) for South Africa (Figure 5.9) and $100-300 for other African cities (Figure 5.9). Within South Africa, Durban had a significantly higher proportion of city residents that fell within the R6 000-8 000 ($800-1 066.7) income range, while Pretoria had a comparatively higher proportions that fell within the R3 000-5 000 ($400-666.7) income bracket than four other cities. Generally, it can be said that South African city residents earn more than their counterparts elsewhere in Africa (Figure 5.9).

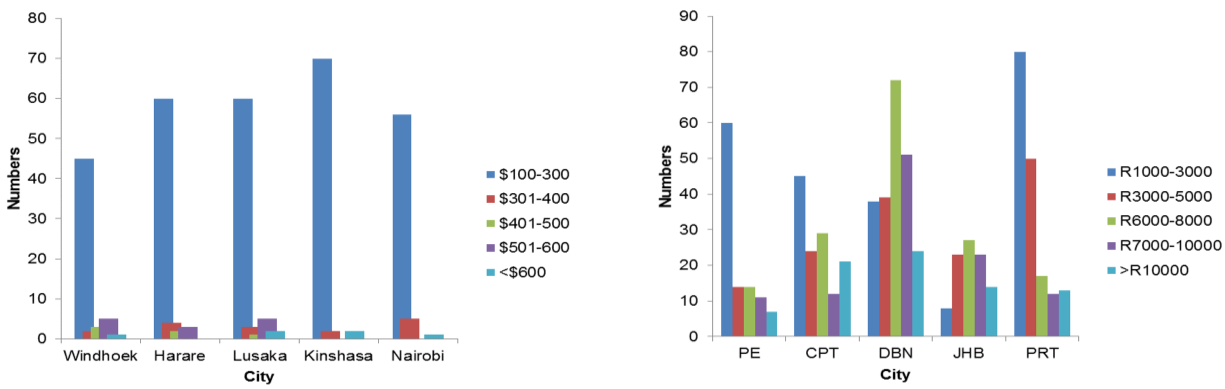

Figure 5.9. Income categories of city centre residents from five studied South African cities (PE = Port Elizabeth, CPT = Cape town, DBN = Durban, JHB = Johannesburg, PRT = Pretoria).

5.2.13 Expenditure

In South Africa, it emerged that city residents spend most (>60 percent) of their income primarily on accommodation and food (Figure 5.11). For other African cities, it larger portion of income is spent on food. For both South African and African cities, the remaining portion of income (in most cases) is spent on transport (± 20 percent), energy (± 15 percent) and relatives (± five percent). Through this observation it can be deduced that city residents are normally left with little disposable cash, which may not be sufficient to maintain a sustainable and healthy life in the city.

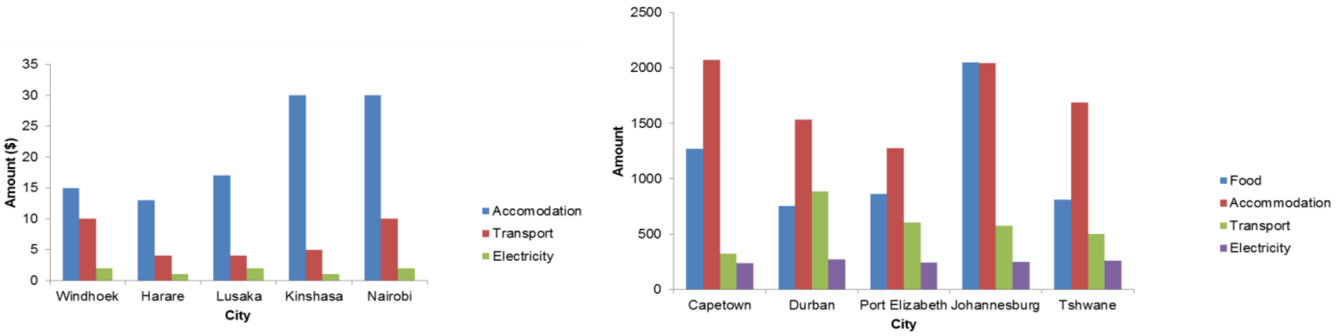

Figure 5.10. Expenditure patterns of ten studied cities

5.3 Discussion

The analysis showed that while there is a general perception that males migrate more than females, this trend has changed as it has been found that the gender parity (in terms of proportions) among the residents of studied cities is not significantly different (Lucas, 2006). There are a number of possible explanations for this. One being that due to emerging social policies and efforts of narrowing income gaps between genders across the World, females have taken to themselves to pursue economic prosperity and they now equally migrate to cities.

The analysis also revealed that populations of studied cities, especially in South Africa, are composed of young persons. These have migrated to cities to either look for employment, obtain an education or attempt to establish a business. This is realistic as young people are the ones who have high aspirations of establishing themselves through securing stable income and start to accumulate assets such as a house.

This finding mirrors a population that has a potential to grow through births as young people a likely to start families once they have stable income. Placing this finding in the context of complex evolving system, it can be said that it gives agents found in the studied cities a character of being young, highly active and are in search of opportunities to generate income so that they can adapt in their new environment.

It was further revealed that the composition of household falls within two categories. Residents either stay in a communal household, where a group of young individuals, mostly of the same age live together or as a family or alternatively, where a male and female stay together, with their children or relatives, as a family. This outlines a situation where a shortage of accommodation could be a limiting factor to population growth, a character that represents constraint to population dynamics.

While a high willingness to return to areas of origin was recorded among South African cities, this appears not to be the case with other African cities. This could probably be linked to the duration of stay in the city, which for historic reason might be greater in other African cities, and is thus indicative of the fact that, once a person adapts to a city lifestyle, the desire to return to the area of origin declines (Kruger, 1998).

Within the context of systems analysis this demonstrate that agents adapt to environment over time. This confirms the affirmation of complex adaptive systems, which postulates that agents learn their environment and adapt. It represents contagion, which is a character of social systems, meaning that as people become familiar with each other they form social networks through which they may influence each other to stay permanently in the city.

Generally, city residents are people who have completed a basic education, some having a degree and, to a certain extent, a post graduate qualification. Depending on the type of employment, income categories range from $100 (min) -300 (max) in the case of African cities, with $133 (min) -1 000 (max) in the case of South African cities. Most of the income earned, especially in South Africa is spent on food and accommodation, with African city residents spending most of their income mostly on food (Lado, 1990; Jones and Nici, 1999; Maxwell, 1999; Lindenberg, 2002). This is in line with findings of Bettencourt (2013), who implied that there is a direct correlation between income and expenditure among the cities. He specified that rich cities (i.e. cities with high per capita income of an individual) offer opportunities of making more income, which in return can be linked to higher expenditures. What this reveal is that if one lives in a city where one earns more money, this does not necessarily translates into accumulation of wealth as there is a direct correlation between income and expenditure.

The finding that most migrants are from the surrounding areas concurs with Ravensteins theory of migration (1889). In addition, the discovery that people migrate with a sole purpose of seeking employment opportunities, confirms the premise on which the Harris-Todaro model (1970) is based. The overarching question that derives from these findings is how empirical data collected reflects the real patterns of population dynamics of the studied cities.

Linked to this is the observation that the development policies in South Africa are skewed towards urban areas. This inevitably fuels rural urban migration. People consider migrating to urban areas as a short cut towards accessing opportunities and resources. This style developmental planning is not unique to South Africa, other developing countries like China and India seem to follow similar process. This could indicate the implementation of wrong intervention towards a prevailing problem.

What can be concluded is that concentrating development to urban areas serve as a basic mechanisms through which cities can get transformed as this leads to efficiency losses due to misallocation of resources. This creates a large income gap between rural and urban areas and subsequently fuels city migration. South Africa's process of urbanisation is still largely influenced by rural areas and can thus be considered to be at the transitional phase. This will continue for a while and thus serve as a driver behind the transformation of cities in South Africa. This poses a challenge to urban planners, city engineers and other organs of state responsible for urban management. Having described the type of agents found in the studied city systems and outlined the mechanism through which city population dynamics influences city transformation, the outstanding question to address is how a factor like income influence the attractiveness of a city. This question is addressed in the next chapter.

CHAPTER 6

MATHEMATICAL MODEL OF EFFECTS OF INCOME ON CITY ATTRACTIVENESS

6.1 Introduction

The previous chapter reflects that two factors i.e. employment and education opportunities serve as the main attractions to South African cities. Both are linked to migrants' pursuit of maximising chances of generating income in the city (Harris and Todaro, 1970). Income and city life are thus two matching factors that may determine the attractiveness of a city. Understanding how this contributes to the transformation of a city is important for urban management aligned towards restoring city attractiveness.

In this chapter the relationship between city attractiveness and income was measured through mathematical models. Equations produced provide basis for quantitative urban dynamic modelling. This type of modelling is relevant in urban planning (Harris, 1962), research and policy analysis (Herbert and Stevens 1960; Robinson, Wolfe and Barringer, 1965) as well as for those who are interested in urban dynamics (Lowry, 1967).

Deducing from empirical observations presented in Chapter five, income serves as a primary driver for city transformation. It is an indicator that mirrors the mechanism through which cities get transformed, either as a result of population growth or through people flocking into an attractive city. Income can thus be considered to be one of the indicators that can reliably be used to assess city transformation.

Considering the existence of differences in income levels between the cities (Chapter five), the key determinant for how income influences the attractiveness of a city over time and how this can be used to define changes (transformations) that have taken place in the cities of South Africa is to incorporate work attractiveness in mathematical models. Because of heterogeneity (Chapter eight) among the cities, other African cities were found not to have similar link between work attractiveness and city transformation. This probably being due to socio-economic dynamics in these countries.

6.2 Mathematical modelling of city attractiveness

The basic consideration was that the relation between income (i.e. real income) and city attractiveness is linear (Forrester, 1980), even though the actual income distributions might be non-linear (Forrester, 1987; Nel, 1980; Miller, 1998; Hanafy, 2010). This assumption was based on the observation that, while the actual income distributions can be dependent on a host of factors that are peculiar to a city (hence the non-linear distribution), the effects of these distributions on an individual's desire to migrate to the city are much more direct (hence linear) (Harris, 1962; Wheaton, 1974; Caswell, 1978; Ekamper, and Keilman, 1993; Bonneuil, 1994).

With this consideration, the following linear model was generated:

$$WA = a_1 I_3 + a_2 I_{35} + a_3 I_{57} + a_4 I_{710} + a_5 I_{10} \qquad (1)$$

Where WA is work attractiveness, I_3, I_{35}, I_{57}, I_{710}, I_{10} are categories of income levels per month i.e. < R3 000, R3 000 – R5 000, R5 001 – R7 000, R7 001 – R10 000 and > R10 000, respectively and a_1, a_2, a_3, a_4, a_5 are the parameters, for relative rates of influence of the different income levels, on attractiveness. This approach assumed that South African cities are considered equally by people for migration and thus are attractive in ways that are comparable.

Equation 1 was solved using the following set of simultaneous linear equations with parameter values for the percentage contributions of income category (percentages of people in each category) taken from Figure 5.9. The resulting effect on migration for each city is based on percentages of people who migrated for work, taken from Figure 5.5.

$$\begin{aligned}
0.56a_1 + 0.13a_2 + 0.13a_3 + 0.10a_4 + 0.07a_5 &= 0.39 \\
0.34a_1 + 0.18a_2 + 0.22a_3 + 0.09a_4 + 0.16a_5 &= 0.57 \\
0.47a_1 + 0.29a_2 + 0.10a_3 + 0.07a_4 + 0.08a_5 &= 0.45 \\
0.17a_1 + 0.17a_2 + 0.32a_3 + 0.23a_4 + 0.11a_5 &= 0.55 \\
0.08a_1 + 0.24a_2 + 0.28a_3 + 0.24a_4 + 0.15a_5 &= 0.88
\end{aligned} \qquad (2)$$

The link between Durban's income distribution and work attractiveness did not fit the trend of the other cities. For this reason the system was solved without Durban. The method requires the number of variables to be equal the number of equations. To make the system symmetrical one of the variables have to be excluded. As a result, the income level > R 10000 was thus excluded because it is a very broad category and had a low response and is therefore the least instructive.

The reduced equation thus looked as follows:

$$WA = 0.8I_{35} + 1.5I_{57} + 1.0I_{710} \quad (3)$$

where WA is work attractiveness and parameters are rounded to one decimal place.

Equation (3) was incorporated into an equation to estimate the overall effects of income on the attractiveness of a city (Equation 4). Equation 4 is based on a simple regression of how people perceive a cities work potential against the migration rates.

$$\text{Migration} = 0.11WA - 0.03 \ (R = 0.83) \quad (4)$$

6.3 Results

One of the key drivers of migration to a city was found to be the desire to find employment or education in the city (Chapter five). For South Africa, if one considers the proportion of people who migrated only for work, then this was more evident for Johannesburg, where 88 percent of respondents indicated that they moved to Johannesburg in search of work (Figure 6.1). Income between cities and countries appeared to differ significantly (Chapter five).

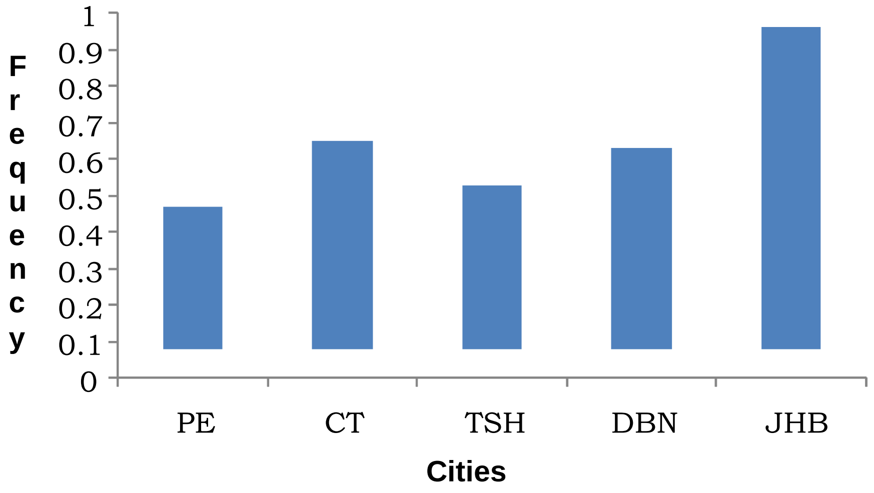

Figure 6.1. The percentage frequencies of people moving to city centres in South Africa for work (Port Elizabeth (PE), Cape Town (CT), Tshwane (TSH), Durban (DBN) and Johannesburg (JHB)).

These fell into three broad categories i.e. a) those that peaked in the very low income bracket (Figure 6.2) and b), those that peaked in the middle of the range (Figure 6.3) and b) and those that peaked in the very low income bracket (such as other African cities).

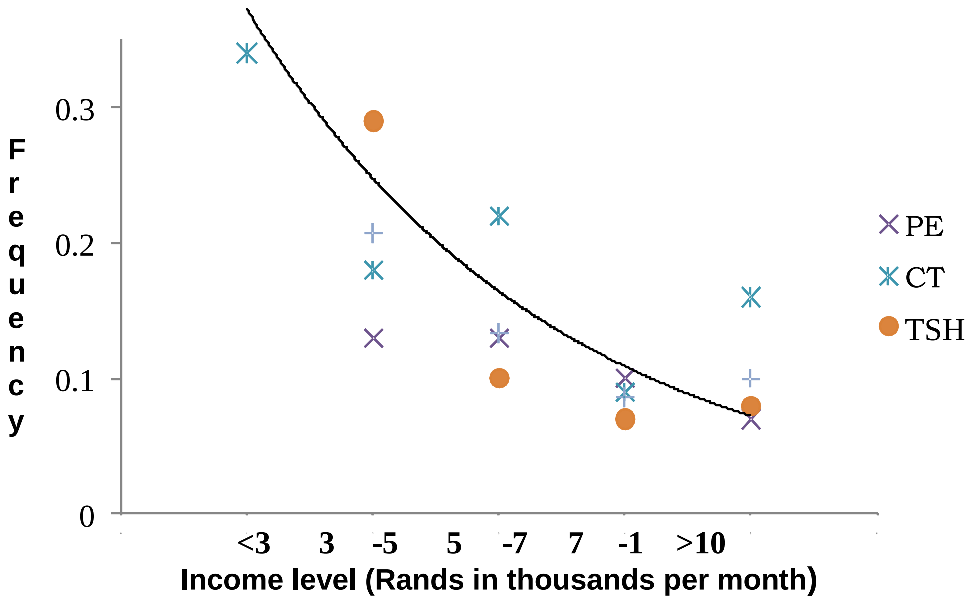

Figure 6.2. Distribution of income levels from the South African city centers of Port Elizabeth (PE), Cape Town (CT), and Tshwane (TSH), (cities grouped because their distributions are skewed to lower incomes). The line is an approximate fit.

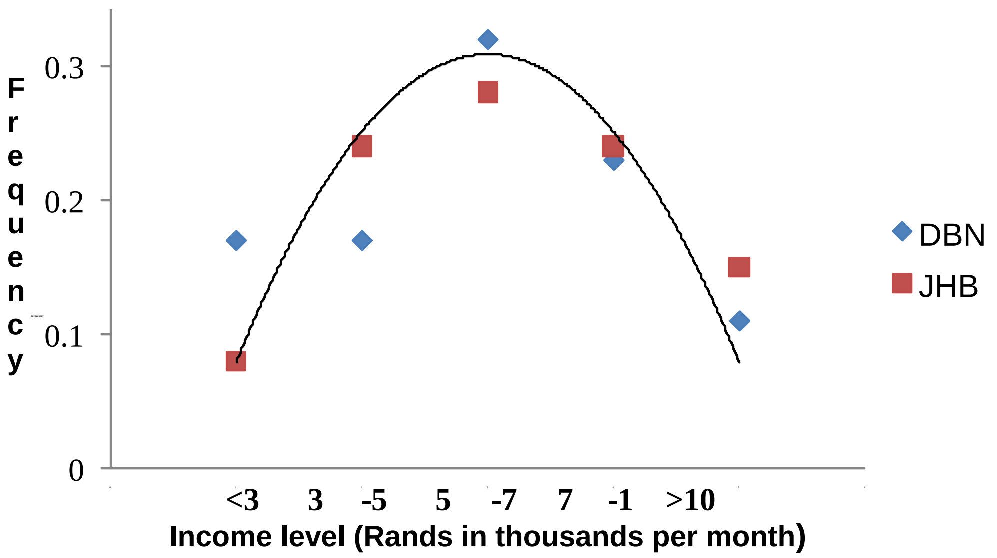

Figure 6.3. Distribution of income levels from the South African inner cities of Durban (DBN) and Johannesburg (JHB). Cities grouped because their distributions are more normally distributed. The line is an approximate fit.

In general, results reflected that most city residents fall within the low income category. While this was more expressed among the other African cities, in South Africa, the cities of Port Elizabeth, Cape Town and Pretoria had more respondents that fell within the low income group than those of Durban and Johannesburg, which by comparison had a higher percentage of work in relatively higher income brackets. With this finding, it can be said that one would expect Johannesburg and Durban to be more attractive than Port Elizabeth, Cape Town and Pretoria.

Equation (3) indicates that moving to the city centre because of its attractiveness as a place of work, is based on the city having sufficient employment opportunities in the income brackets of R3000–R5000, R5000–R7000 or R7000–R10 000, with the greater emphasis on the middle of these income brackets (i.e. R5000-R7000). Notably, the income bracket that is lower than R3000 (< R3000) has no influence on city attractiveness, i.e. its parameter equalled to zero in the analysis.

To visualize the relationship between the probability of obtaining a particular income and the attractiveness of a city, equation (3) was plotted on a three dimensional diagram (Figure 6.4). Through this, it became apparent that city attractiveness is non-existent at income levels in the range of R3000–R5000 (I_{35}), but rises sharply with increased incomes in the range of R5000–R7000 (I_{57}). Interestingly, the range of R7000–R10000 (I_{710}) had an insignificant effect, similar to I_{35}. With this observation, it was noted that it is in fact the actual shape of the distribution that is important and not only the numbers. Thus, very low and higher incomes are insignificant drivers of in-migration, unlike middle income categories. However, high incomes might also drive migration but because the numbers in this income bracket are lower this might not have significant effect on population numbers. Another possibility could be that the surveys might be biased to lower incomes as they were carried out in the inner cities, which are comparatively dominated by low income earners.

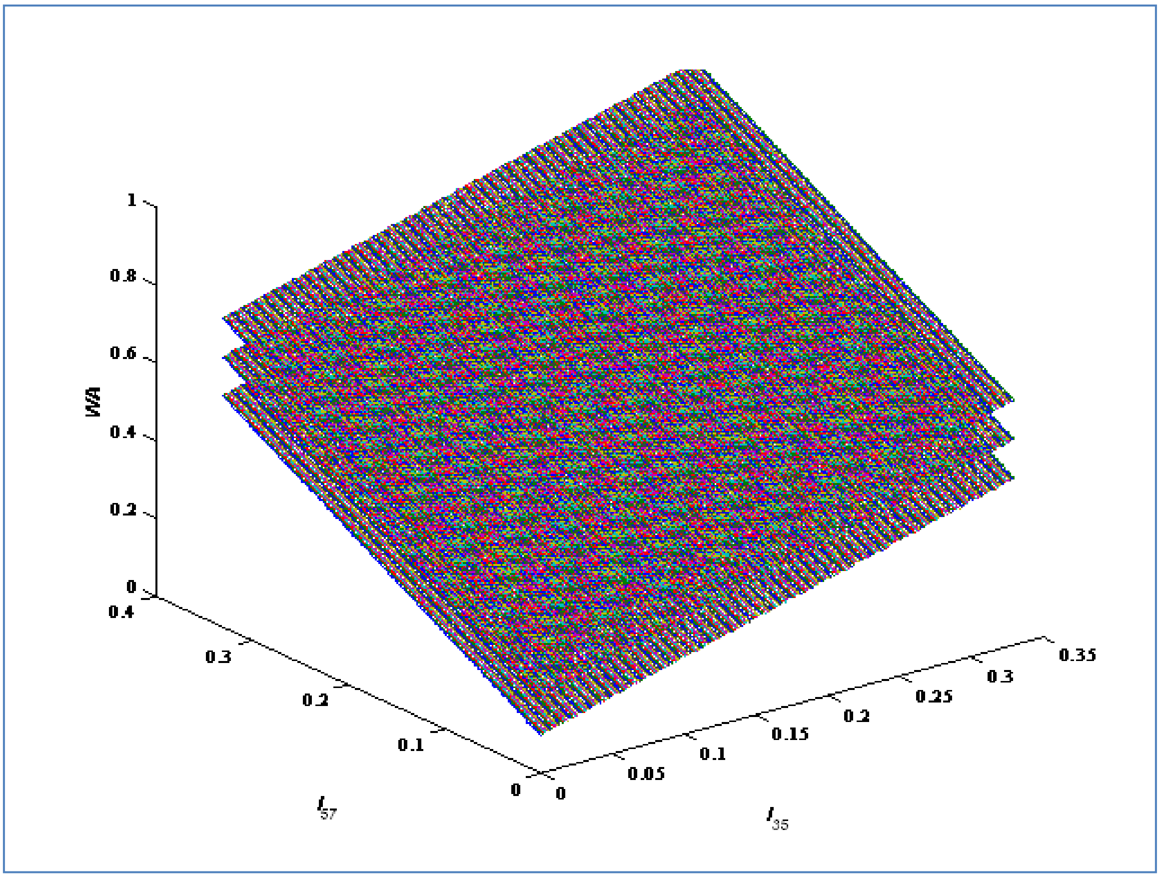

Figure 6.4. Work attractiveness (*WA*) as a function of the relative amount of incomes, in the ranges R3000–R5000 (I_{35}), R5000–R7000 (I_{57}) and R7000–R10000 (I_{710}), using equation (3). I_{710} is depicted using the layers in the figure.

For other African cities, equation (4) indicated that migration is more affected by work attractiveness, as the slope of the equation appeared to be steeper than that of South African cities.

6.4 Discussion

The analysis, to a large extent, confirmed key aspects of Harris-Todaro Model (Harris and Todaro, 1975; Todaro 1976b). The model asserts that migrant's movements to urban areas, is a reaction to economic attraction, earning differentials and the probability of obtaining employment in the urban area. From the findings presented in Chapter five, most respondents stated that they have moved to cities in search for employment opportunities and to improve their chances of getting employed through education.

Using empirical data obtained through surveys, equations relating work attractiveness to migration have been produced. While definitive equations like these have not been used to directly link income to the attractiveness of cities, they can be employed to probe scenarios of city transformation and be incorporated into larger system dynamic models as they appear to be representative of the real world situation.

What has been found to be intriguing is a lack of attractiveness for cities with very low income paying jobs. This makes some sense in that these cities are unable to provide real income. On the other hand, very high income paying jobs were also found not to be attractive. This might be because these are perceived to be impossible to attain. However, it is possible that this result is due to the number of wealthier respondents being less. Regardless, cities with income distributions higher in the middle income brackets are the ones that are attractive and have effect on a person to migrate to a city. Could this be reason why people prefer certain cities? Deriving from Durban, which did not fit the set trend, it can be surmised that there are additional factors that influence people to migrate to cities.

Simple equations developed here that relate work attractiveness to city population dynamics are beneficial to further investigate forces behind city transformation and to develop scenarios for urban planning and development to counteract negative effects of unprecedented population growth. Using models presented here, it has been demonstrated that over an estimated period of fifty years city attractiveness and associated population dynamics in South Africa will be determined by abilities of cities to provide real income, which in terms of current estimations in the income bracket of between five thousands and seven thousand rands. In this case, monitoring the distributions of income in South African cities will be critical. If the income distributions are approximately normal with a peak in the middle income levels such as in Johannesburg then the populations will grow faster (due to heightened migration) than for distributions which are skewed to lower income bracket. In general, this illustrate the importance of income as the key driver of city transformation through population dynamics. It can thus be concluded that models presented here have potential of being further enhanced and have the ability of benefiting city management in Africa.

CHAPTER 7

SYSTEM DYNAMICS MODEL FOR CITY POPULATION DYNAMICS

7.1 Introduction

Chapter five presents features of agents (i.e. persons) of city population in the studied cities. These either come from rural areas, surrounding areas (townships) or elsewhere in Africa. They have been attracted to a city of choice by different appeals, which include studying, seeking employment, attempting to establish a small business, visiting a friend or a family. Responding to each of these appeals is a mechanism through which an agent attempts to enter the city system and start generating income. Once the agent succeeds in establishing himself in the city he/she develops other needs like accommodation (housing), which is one of the primary needs in city environment. This highlights the significance of housing on city population dynamics.

Chapter six demonstrates a link between income and the attractiveness of a city. It displays that certain attributes of a city derive from relationships that exist between two or more factors. Various authors have investigated these relationships. For an example Alberti (1991) investigated the relationship between urban development and the environmental performance, Batty (2008) analysed the size, scale and shape of cities in relation to population sizes, Duffy, Makhoabenyane and Simelane, (submitted) investigated the effects of income on the attractiveness of cities using mathematical models and Simelane (2012) determined the influence of rural-urban relationships on the cities.

These provide examples of mechanisms of city transformation, which could derive from relationships that exist between factors. The critical task is to outline these interactions at individual levels and to explain how they make cities acquire characteristics that cause them to change over time.

Parts of this chapter have been published as: Simelane, T., Duffy, K. J. and Pearce, B. 2013. Notable drivers of city transformation in the 21st century: African perspectives. Conference proceedings: Growth, Transformation and Reform –emerging economies in the next decades 348-356pp.
Simelane, T., Duffy, K. J. and Pearce, B. 2013. Magnifying Drivers of City Transformation through System Dynamics Models. *Advanced Materials Research* 780:1176-1179.

The purpose of this chapter is to present framework of city transformation through system dynamics models. System dynamics models are developed for purposes of magnifying relations between components of the system (Smith and Thelen, 1993; Schȍner, 1994). The theoretical consideration is that multitude of variables existing in a system are causally related in feedback mechanisms, that themselves interact to produce patterns of system behaviour. The systemic interrelationship between feedbacks constitute the structure of the system and it is this structure that is the prime determinant of system behaviour.

Capturing these and present them through causal loops diagrams enables one to envision the system as a whole. It is a technique that uses computer simulations to analyse complex interactions among that factors of the system. Generally, System dynamics is concerned with building models of complex nature and then experimenting with their behaviour to obtain an insight of the structure and behaviour of the system (Caulfield and Maj, 2001).

Through system dynamics models, this chapter sought to demonstrate a relationship between migration, income and housing and determine how these influence population growth dynamics of a city. In today's estimates of population growth trends in the cities, determining city population dynamics has become central to planning and designing management strategies for cities. Estimating how cities respond to population growth requires models that can capably highlight the unintended consequences of any form of population growth.

7.2 Urban Dynamics Models as a basis for model developed

Systems dynamic modelling methods are used to study the nonlinear behaviour of complex systems over time and are based on the initial work of Professor Jay Forrester of the Massachusetts Institute of Technology.

In urban dynamics, Forrester (1969) defined forces that control populations, housing and industry within cities. Urban dynamics contains a thorough population sub-model that accounts for births, deaths, immigration and emigration. A similar model is developed here which provides a measure of the effect of migration, income and housing on population dynamics of a city. The power of using a system dynamic approach is that knowledge of the system can be enhanced by considering the importance of linkages between the factors that bring the dynamical behaviour of the system.

7.3 Model description and assumptions

Deducing from population growth trends of the cities in the World (Demographia, 2014), it is assumed that populations of the cities studied here, like those of most African cities, will grow significantly between now and 2030. It is assumed here that this growth is logistic. While not completely valid this assumption has been used by many scientists and is useful as a general framework for incorporating other features whose effects can be tested dynamically (Turchin, 2009). The population dynamic model developed here is depicted in Figure 7.3. The assumptions of this model are that:

- The population will grow according to births and migration into the city. It will decline due to deaths and emigration.
- Migration into the inner city is influenced by city attractiveness which is has average inner city income as an important determining factor. This assumption is based on the findings presented in Chapters five and six.
- In the process of population growth; emigration, births and deaths are ameliorated by a city's carrying capacity. This can be expressed through a density dependant term. Its general form is 1-p/K, where p is the population size per area and K is the carrying capacity for the same area specification.

The primary variable is population density with units of people per km^2. Estimated parameter ranges (with references) and their units are given in Table 7.1. The simulation time step is annual (i.e. per year).

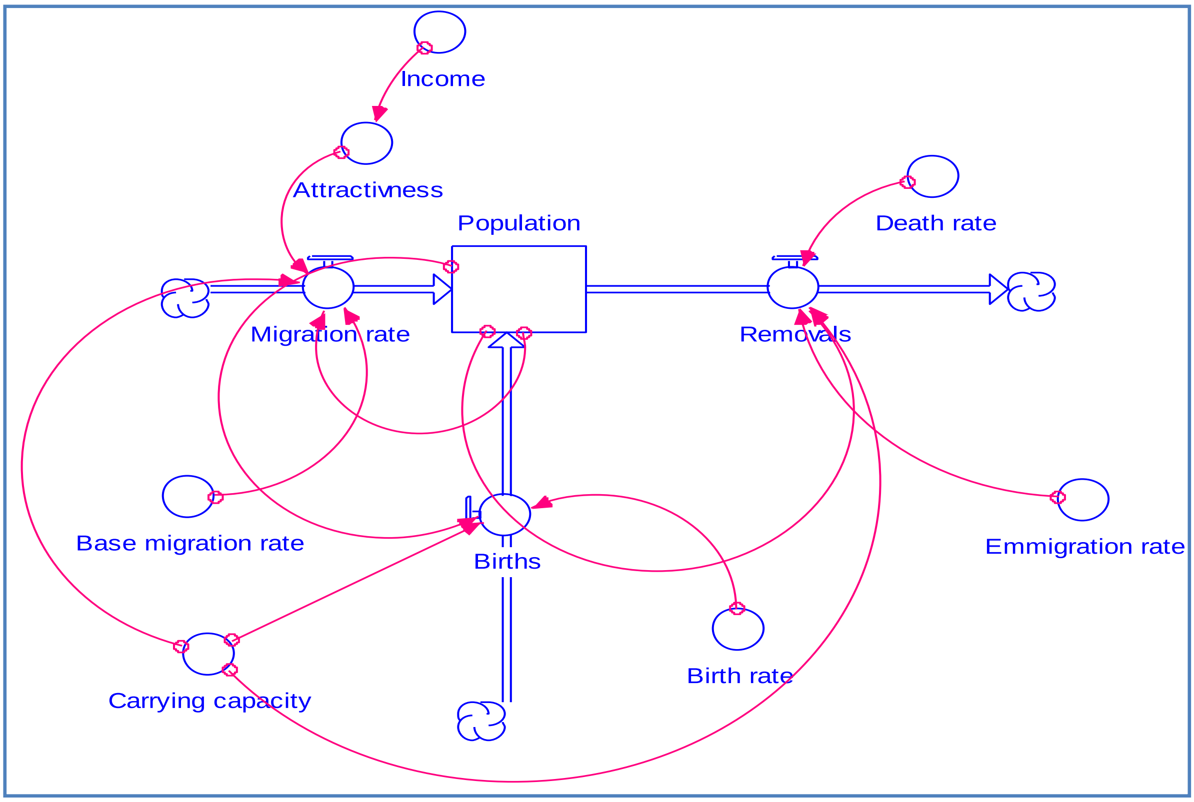

Figure 7.1. System Dynamics model for estimating population growth in the city

Table 7.1. Parameter ranges of the Model

Variable	Units	Lower limit	Upper limit	References
Birth rate	/year	0.02	0.03	Stats SA
Death rate	/year	0.01	0.014	Stats SA
Base migration rate	/year	0.01	0.02	Stats SA
Emigration rate	/year	0.003	0.01	Stats SA
Income average	Rand/month	3000	7000	Chapter 5
Carrying capacity	Persons/km^2	2000	4000	estimated

The rate of people migrating into the city is based on a rate of increase in the population and is directly linked to attractiveness due to effect of income on migration as indicated in chapters five and six. This rate is subject to constraints that create a density dependant effect of a city's carrying capacity.

Factors incorporated into the model are defined as follows:

Attractiveness = Lookup (Income, Attractiveness): (6000 or 4000, 0.75) (3000 or 7000. 0.3) (5000, 1)

Migration rate = Population*Base_migration_rate*Attractiveness

The formula for births is also density dependant and is defined by:
Births = Population*Birth-rate.

Subtractions (removals) from the population include death and emigration rates, which are defined by:
Removals (subtractions) = Population*(Emmigration_rate+Death_rate).

The **population** is the integral of Migration rate + Births - removals over time. A density dependant factor that constrain growth based on the carrying capacity is given by: 1-Population/Carrying capacity.

7.4 Model validation and verification

Focus for verification was on achieving consistency. The significance for model verification and validation is that if a model is not verified it becomes difficult to accept and use in decision-making (Olivia, 2003).

Verification ensures that:

- the model is programmed correctly,
- the algorithms have been implemented properly and
- the model does not contain errors.

It also makes sure that the specifications are complete and that mistakes have not been made in implementing the model. Through verification, the model gains strength as more tests are performed, errors identified, and corrections made to the underlying model, often resulting in retesting requirements to ensure code integrity. Most of the verification process involved the use of established System Dynamics software, STELLA. Thus, the model was built and tested until it ran successfully with realistic results.

Model validation is understood to be striving to increase confidence about the model (Barlas, 1989; Barlas, 1996). Validation ensures that the model meets its intended requirements, in terms of methods employed and results obtained (Barlas, 1996). Two types of validations exist namely, structural and outcome validation. Structural validation examines whether the mechanisms in the model correctly represent real world mechanisms, i.e. determining if the exogenous components of the model are representative of the system under study. Outcome validation determines if the model outputs or findings conform to data derived from the real world system.

The ultimate goal for validation is to make the model useful in the sense that:

- the model addresses the right problem,
- provides accurate information about the system being modelled, and
- makes the model actually useable.

These points were addressed by considering the results in the thesis and interaction with other academics in the field. Further validations were done by running simulations for short (<10 years), medium (10-20 years and long term 50 -100years) estimations with the parameter values averaged. As can be seen in the results below realistic starting point for populations gives results that match the assumptions of basic model development. What is observable is that there is an increase in population in short and medium term), which is ameliorated over time (long term) as the population growth approaches carrying capacity. Running the model with a particular South African city, Durban, for ten years (Short term interval) gives realistic population growth.

7.5 Model Simulations

7.5.1 Determining effects of migration

To determine the effect of migration over a long period of time a 200 years simulation was run using parameter values averaged as inputs (Table 7.1). As can be seen in Figure 7.2 starting with an initial population of 300 people/km^2 or 1500 people/km^2 gives results that are provide difference rates of growth initially but reach similar population numbers over time.

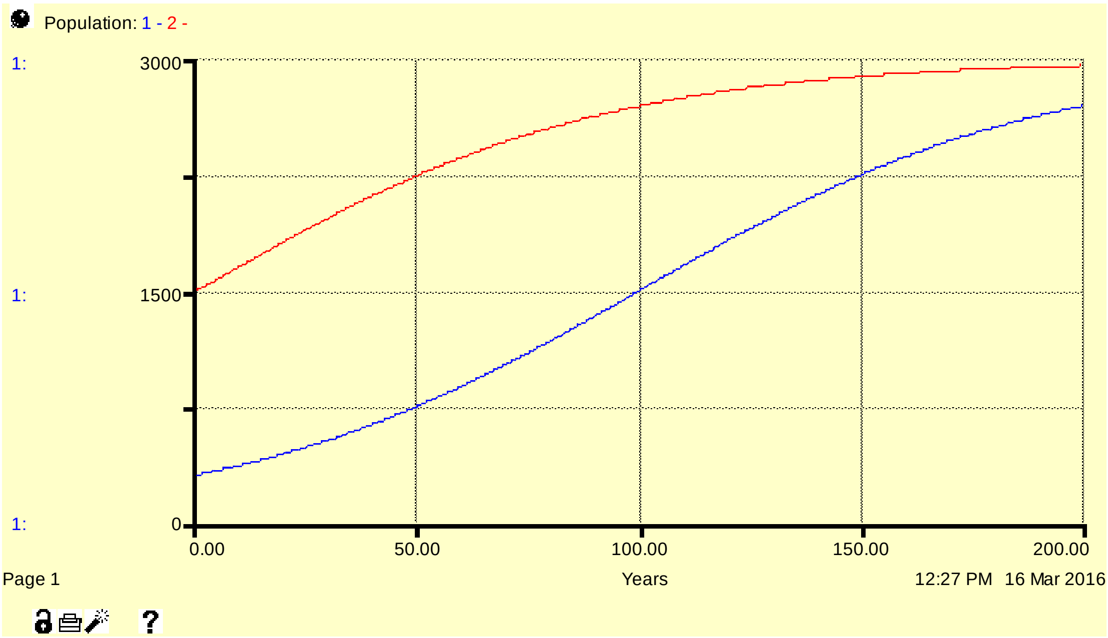

Figure 7.2. Population growth curves representing stabilisation of population growth

The model showed that at early stages (short term) of transformation there is increase in the population growth, which starts to stabilise over time (medium to long term) as the population approaches the carrying capacity (Figure 7.2). This could be through emigration, deaths or reduction in birth rate.

To further test the dynamic behaviour of the system, the population growth measured using the city of Durban was run over a period of 10 years. This represent population dynamics over a short term. This assumed the initial population density of 1440 people/km^2, which increased to approximately 1490 people/km^2 after ten years. Using parameters within the range of values presented in Table 7.1, it seemed that during the transient stage of transformation, population grows linearly (Figure 7.3). This apparently results from the heighted migration, which takes place at early stages of the transforming city.

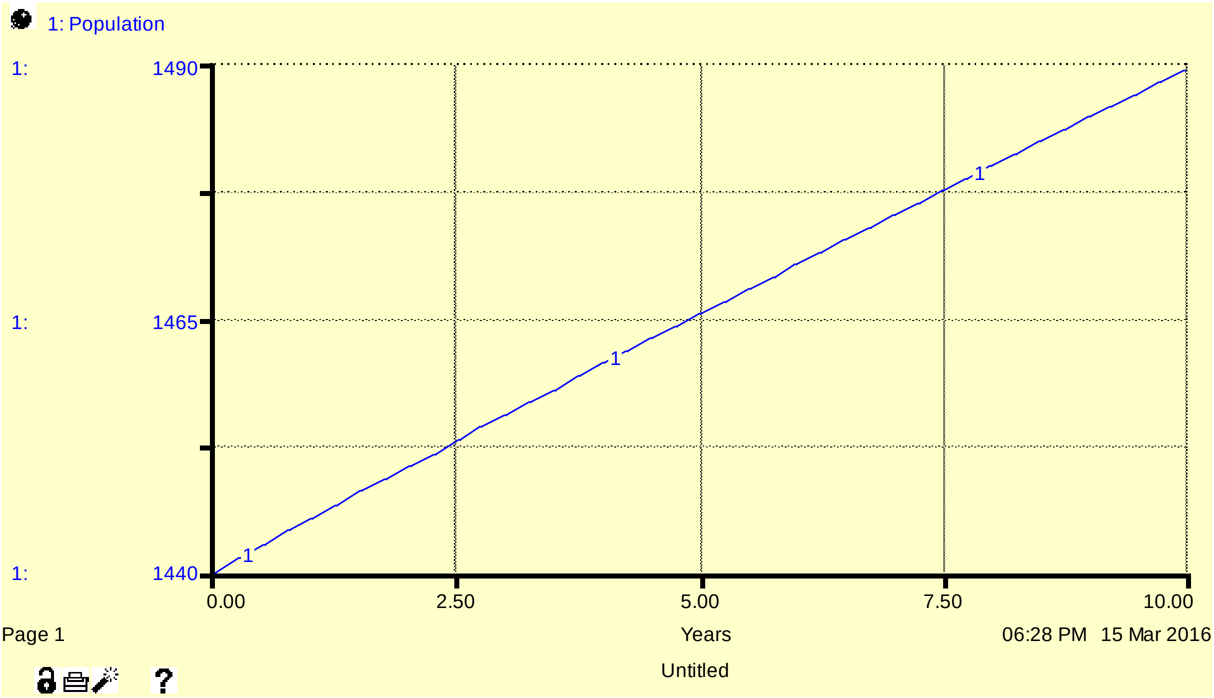

Figure 7.3. Population dynamic depicting linear growth that take place within the early stages of city transformation

Running the same model for over a period of 100 years (long term) produced a growth curve that illustrates how the population will eventually stabilises (Figure 7.4). This seems to start to take place after fifty years (mid-term period), when there is probably a reduction in migration. Reduction can be due to a number of causes, which include income and houses and the overall effect of this on population dynamics is presented in the next sections.

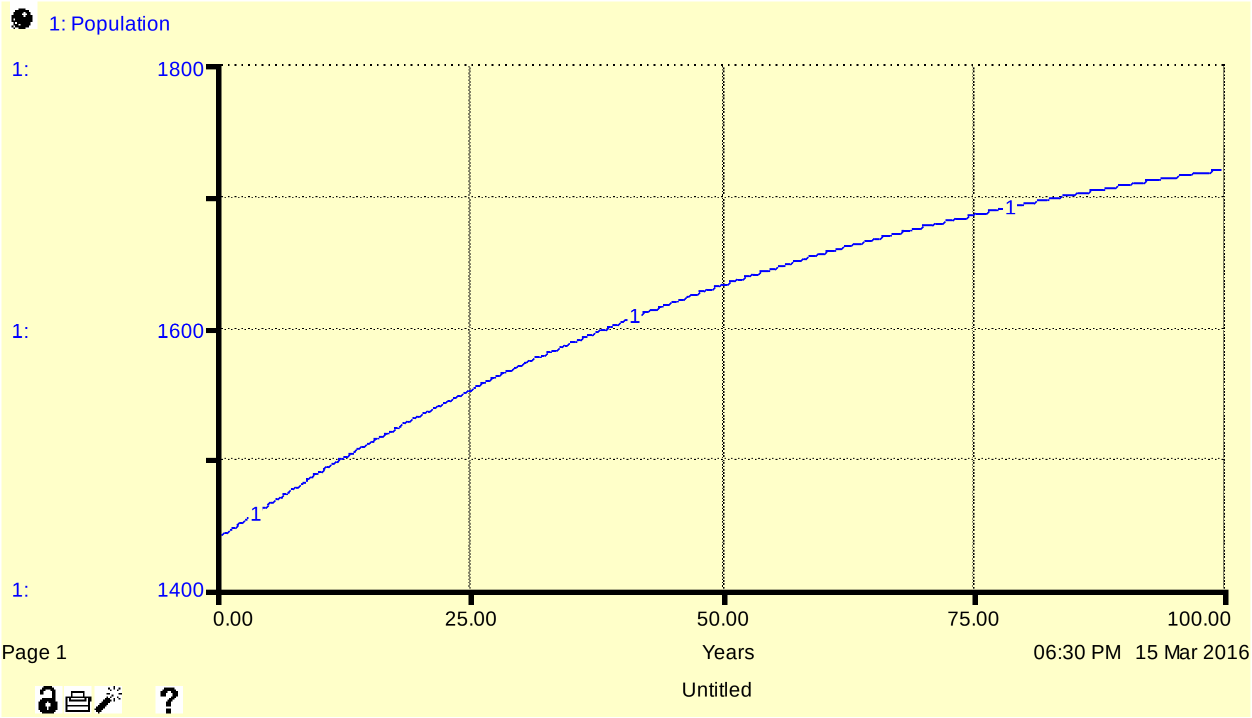

Figure 7.4. Growth curve depicting population stability over a long period of growth.

7.5.2 Determining effects of income

The findings of chapter six show that for Durban and Johannesburg the effect of income on migration is distributed around middle income values. This fact is implemented in the model by adding an income factor (Figure 7.1). Income affects population growth by changing the migration dynamic through an attractiveness factor (Figure 7.5). As expected, in agreement with chapter six, situations with a higher proportion of middle income jobs increases migration more than for those situations with higher numbers of lower or middle income jobs.

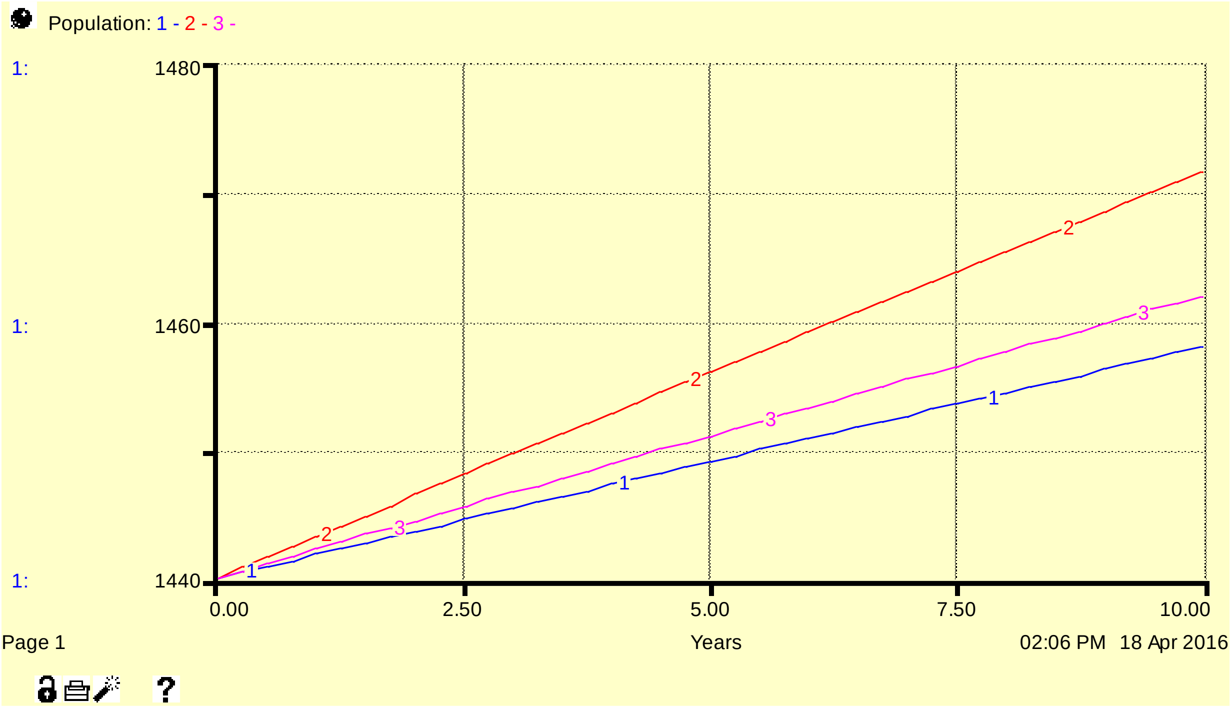

Figure 7.5.Population growth trends that result from income dominated by 1) lower income, 2) middle income and 3) higher income, brackets.

7.5.3 Determining effects of housing

To determine the effects of housing, a model for housing was added to the basic population growth model (Figure 7.6). The simulations were run to establish how housing demand interacts with the population growth dynamics. The model allows for strategic management decisions on required housing construction rates that will match the population growth.

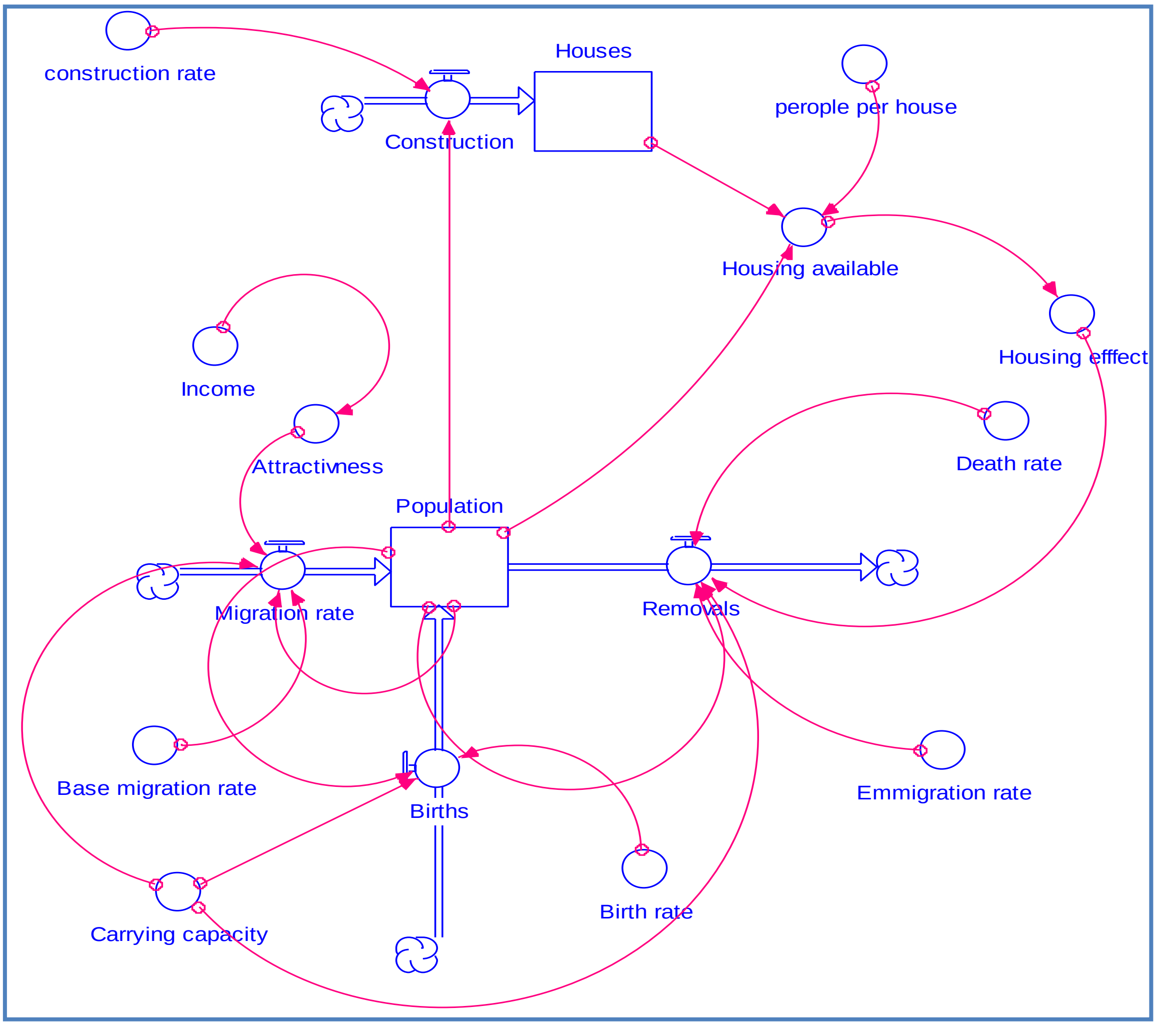

Figure7.6. Model for determining the effects of housing

For this model the assumptions were:

- Houses are constructed at a rate that is influenced by the population size because of demand. This is defined by:

Construction = construction rate*Population

- Houses increase linearly and this can be represented through a linear function at the construction rate (Figure 7.7).
- Houses available are dependent on the population size. Houses taken can be estimated at an average number of people per household. Then this is subtracted from the houses available. This is defined by:

Housing_available = Houses - (Population/people_per_house)

- Emigration rate is heightened by a new factor which is determined by the houses available. The relation of this factor to population growth is unknown but possible scenarios are tested using the formula below:

Housing_efffect = Housing_available/(Housing_available-1).

This formula can represent an increase in the emigration rate as the number of houses decline. This also applies to immigration which subsequently decreases due to shortage of houses. Both subsequently reduce population growth (Figure 7.8).

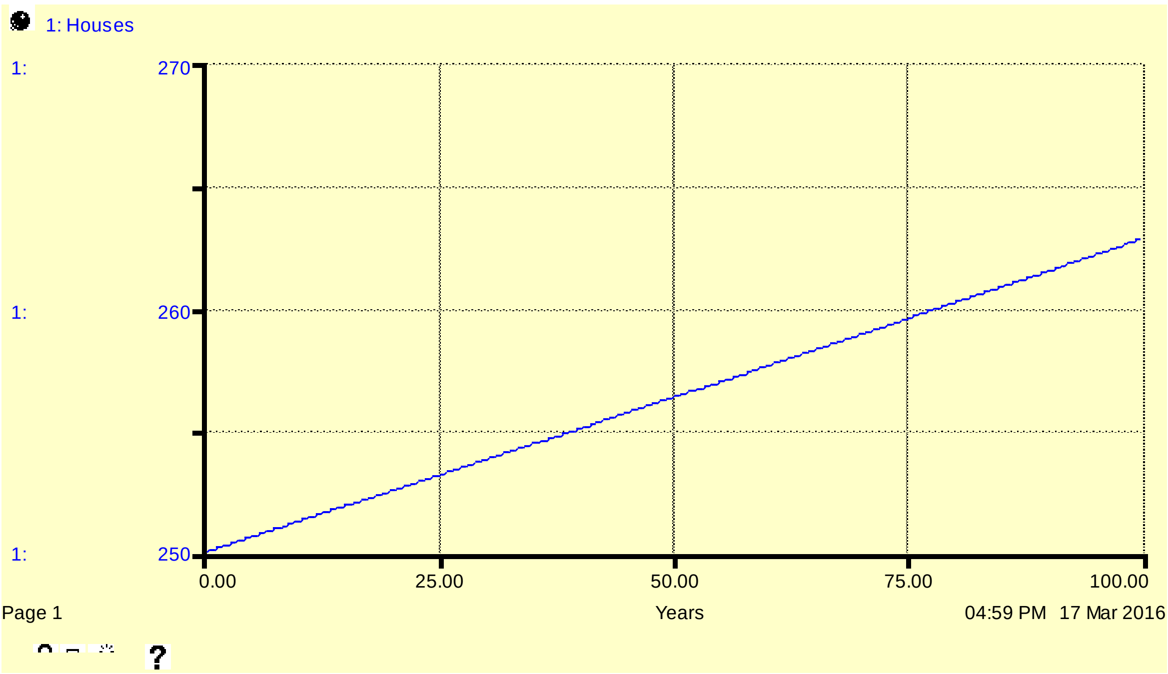

Figure 7.7. Linear increase in houses through construction

If a situation is considered where housing availability is not a limiting factor, with a initial population of 1400 people/km^2, initial number of houses 300 /km^2 and a carrying capacity of 1200 people/ km^2 and running the simulation for 100 years (medium to long term), the simulation yielded a housing availability with population growth scenario as given in Figure 7.7.

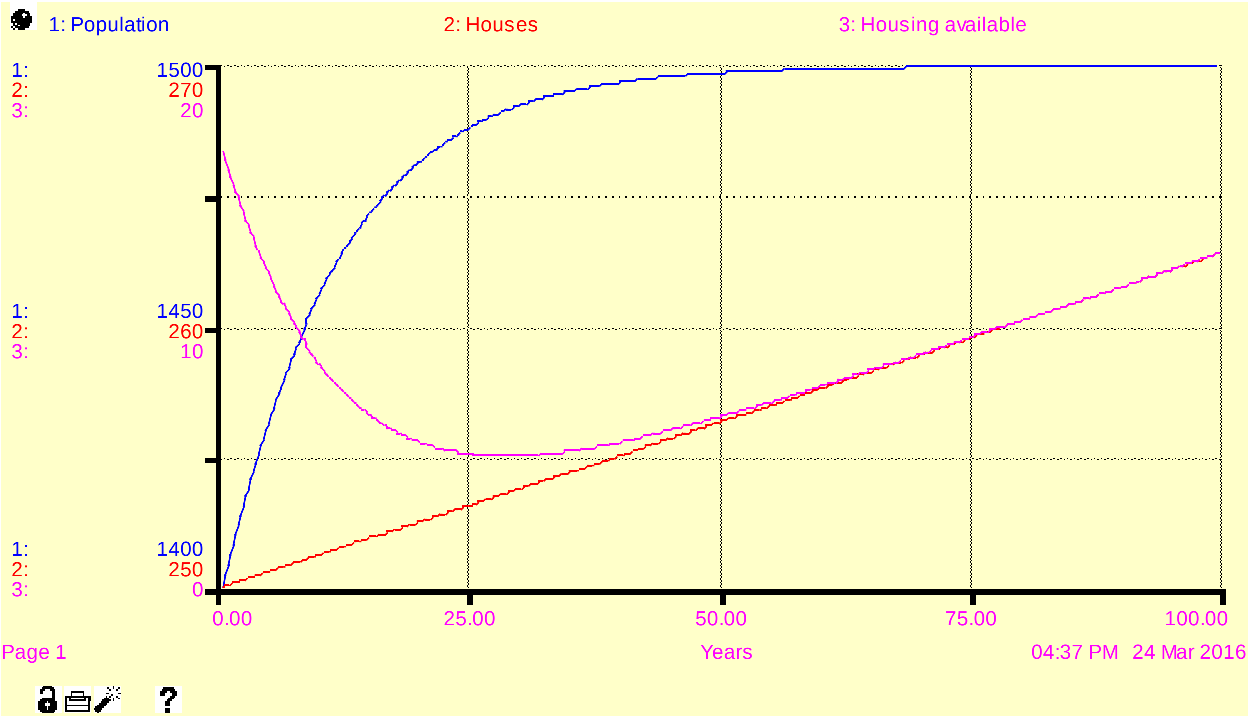

Figure 7.8. A relationship where available houses drop due to an increase in population

Depending on the construction rate or the initial number of houses, the available houses can drop significantly (pink line) as the population grows. In other words, if the construction rate is such that construction of houses does not meet the demand, houses available drop and this has a direct effect on the population growth (Figure 7.8, blue line). Interestingly, the effect of housing is shown here to have a feedback effect on population growth (through migration) and this eventually stabilises the population.

Querying the effect of other possible factors that might bring dynamics behaviour of the model, change in birth rate as an influencing factor on population growth demonstrated was tested. The lowering of birth rate reduced that population growth, drastically (Figure 7.9). This scenario represented a situation where other factors other than houses pose influence on the transformation of a city through population dynamics. As could be the case with many cities in Africa, little expansion (in terms of infrastructure development) is taking place in the form of new houses being built, there is thus a high likelihood that population dynamics in these cities result from other drivers that include births.

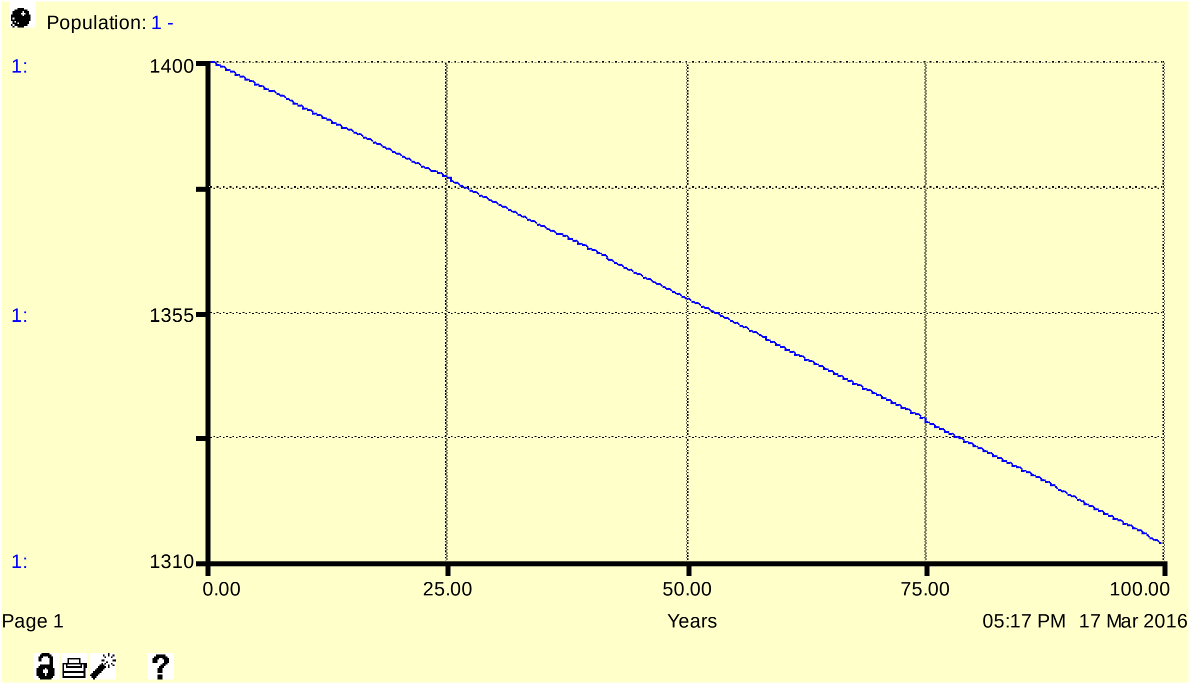

Figure 7.9. Decline in population growth that results from slow birth rate

7.6 Discussion and conclusion

The model validates existing hypotheses about the growth patterns of city populations (Wolman, 1965; Boyden, Millar, Newcombe, O'Neill-Canberra, 1981; Kennedy, Pincetl, Bunje, 2011.). This is despite the fact that the model is constructed out of data acquired from cities located within the developing world. Thus, cities across the World experience similar challenges of population growth driven by income (Zhang, Yang, Yu, 2009). The results of this chapter point to the existence of similarities between low, middle and high income cities with regard to effects of income, migration and houses on population dynamics of the cities (Hardoy, Mitlin, Satterwaite,1995).

As demonstrated in Figure 7.1 the model was run with the selected parameters and results were found to represent assumed conditions of the studied cities. Results reflect that changes observed in South Africa while in transient stage are likely to have occurred elsewhere and are thus comparable to other cities of the World. As observed from the analysis of empirical data, the mechanism is such that income poses direct effects on migration into a city, which in turn influences the population growth. The success of the model to demonstrate this enhanced its validity. With high levels of population growth, limited resources like houses become a trigger for population to stay within the boundaries of city's carrying capacity (Figure 7.8). The demonstrable mechanism for this is that if it is assumed that houses are constructed annually, such that their increase is incremental and match the demand, population increase becomes linear (Figure 7.7). However, if the effect of houses on population is introduced over a long period (i.e.100 years) it emerges that an increase in available houses depend on the construction rate (Figure 7.9) and this eventually affects population growth (Figure 7.8).

In this case it is likely that available houses start to be an influencing factor on migration into the city, especially if the number of available houses starts to drop. To demonstrate this a term was introduced that increased emigration from the city when there were no available houses. Here housing was found to have direct effect on the rate of population growth (Figure 7.8). This effect on population growth was also appropriate for the number of available houses, which stabilises over time. What this demonstrates is that population growth dynamics can be limited by factors such as houses by imposing a direct influence on population growth. In particular, one example shows how feedback from housing availability could establish a stable population. Basically, a lack of houses results in people leaving and/or not arriving. Of-course this is a simple example but demonstrates how factors such as housing, income and other conditions can alter city population growth through feedback to migration rates.

As could be deduced from international trends, population dynamics across the world reflect inclinations of high growth rates within the developing countries. This is more obvious in African countries. The consequential effects are population growths that are concentrated in the cities. This will create developmental strains especially in poor economic conditions. Models such as the one developed here can be used to predict and plan for these problems. On the other hand not all cities are necessarily growing and the reverse can be true. For example, low birth rates can lead to a decreasing population (Figure 7.9) and this could lead to a potentially wasteful production of houses if the scenario predictions are wrong.

In conclusion it can be stated that simple system dynamics models are capable of demonstrating how cities could be transformed due to parameters such as income, migration and houses. What this has drawn to our attention is that urban systems are open and susceptible to the effects of different factors (Ghaffarzadegan, 2008). This could be one of the mechanisms through which cities attain some of their characteristics (Williams, 1999; Bryceson, 2002b). Considering that urban systems are composed of subsystems that also get affected during the transformation process (Richardson, 1991), it can be concluded that there is a cryptic relationship between the factors that influence the transformation of a city (Saeed, 1992).

In relation to the formulated objective, models presented here are not exhaustive but have gone some way in fulfilling the objective set out in Chapter one, which is to demonstrate the possibility of developing system dynamic models that can be used to predict the effect of city population dynamics. With the ability of system dynamics models to magnify relationships between factors (Forrester 1994), the mechanism through which cities attain new characteristics can be demonstrated. Drawing from the number of complex interactions that can be magnified through system dynamics models, one can argue that this technique, by virtue of being able to highlight subtle relationships between variables and elements of the system (Ford, 1999; Zander and Kächele, 1999), is able to generate mental models that ultimately enhance logical planning and management of cities (Richardson, 1996).

CHAPTER 8

MATHEMATICAL MODELLING OF CITY POPULATION DYNAMICS UNDER HETEROGENEITY

8.1 Introduction

The previous chapters reflect that city population growth in studied cities derives from young people migrating to cities for employment, studying or attempting to start a business. This reflects attempts by young people to maximise chances of generating income in the city. What this indicates is that if a city is able to provide opportunities of generating income it becomes attractive to young people. This ultimately affects the system of the city both in short and long term

If in-migration is greater than out-migration the net effect is population growth (Odularu, 2014; Onwe, 2013). What the literature emphasizes is that responses of cities to effects of population growth differs from one city to the other. This probably being linked to unique characteristics of the cities.

This chapter attempts to demonstrate this claim by examining heterogeneity among cities. It sought to demonstrate the nature of relationships that exist between income and city population dynamics as a basis for heterogeneity. In real terms, cities in Africa are experiencing substantial growth of middle income class (Deloitte, 2014; Gounden and Nkhumeleni, 2013) and their populations are on the rise. This reflects a direct relationship between income, migration and the transformation of cities.

As it could be deduced from different studies, any form of economic growth leads to increased migration, which is accompanied by the transformation of cities (Todaro, 1997). The mechanism through which this takes place and how it differs among the cities, is the subject of this chapter and models developed.

A version of this chapter has been submitted to the International Journal of Mathematical Demography.

Mathematical models that incorporated heterogeneity were used as a platform to demonstrate any relationship between income and city population dynamics and how this reflects heterogeneity among the cities. The aim was to present to city planners that there is a direct correlation between income, attractiveness of a city and population growth.

Heterogeneity has been largely considered when studying the dynamics of infectious diseases. For instance, Robertson, Eisenberg and Tien (2013) investigated the heterogeneity in multiple transmission pathways of waterborne diseases and Collins and Govinder (2014) formulated a heterogeneous waterborne cholera disease model for use in Haiti.

Even though cities are known to exhibit heterogeneity, as it was also noted by Forrester (1980) this concept and its relevance to city transformation has not been fully explored. The aim here is to apply the concept by formulating mathematical models that incorporates heterogeneity. The purpose is to emphasize that although countries like South Africa and others in Africa are facing a phenomena of population growth, each city will respond differently and this will be reflected through unique characteristics that emerge in the city.

8.2 Model formulation

As could be deduced from Chapter five, city populations are comprised of five sub-populations. These are workers, job seekers, business owners, students and visitors. Visitors can include immigrants or tourists who do not fit in one of the other categories. Groups or sub populations may overlap slightly but this is ignorable. People who fit none of the identified categories were taken as dependents. Each of these sub-communities can be represented as a function of time t. In doing this let the populations of working community, business community, student community, visitor's community and job seeking community with their dependents at time t denoted by $W(t)$, $B(t)$, $S(t)$, $V(t)$ and $J(t)$ respectively. Therefore, the total city population at time t denoted by $N(t)$ becomes $N(t) = W(t) + B(t) + S(t) + V(t) + J(t)$.

As reflected in Chapter six, people earn different incomes and to take different income categories into account it was assumed that all the individuals on a particular income level form a homogeneous sub population of a particular population. To represent this let S_i be a sub population of the student community S, then $S = \sum_{i=1}^{n} S_i$ where n is the total number of different income levels. For the remaining communities, let $(B_{i,}\ J_i,\ W_i,\ J_i)$ be homogeneous sub populations of business men (B), job seekers (J), workers (W) and visitors (V) in the city that fall within the same income level such that $B = \sum_{i=1}^{n} B_i,\ J = \sum_{i=1}^{n} J_i\ ,\ W = \sum_{i=1}^{n} W_i$ and $V = \sum_{i=1}^{n} V_i$.

Since what a person can spend is directly proportional to his/her income, it was assumed that each sub population is categorized by individuals that fall within the same income and expenditure level. The subscript i was used to denote the income level, i.e. income level i. Based on these assumptions, it was noted that there are two types of dynamics within the city i.e. the global and internal dynamics. Part of the internal dynamics is between income levels which represents a form of heterogeneity necessary for a proper description. Considering heterogeneity in this way is more realistic and should give a better representation of population dynamics of any city.

In the model, the populations of the communities $(S_{i\ ,}B_i,\ J_i,\ W_i,\ V_i)$ were assumed to change constantly over time. This assumption although simplistic suffices for the investigation of any heterogeneity driven by the internal dynamics. For instance, it was assumed that individuals at income level i enter the student community (S_i) at a rate Λ_i^S and upon graduation some migrate into business at a rate β_i, some migrate to seeking for job at a rate σ_i, while others will leave the city at a rate λ_i^S.

Consideration was given that some people will enter a city for business purposes while others will re-locate for economic or financial reasons. Thus, it was assumed that individuals are recruited into the business community at a rate Λ_i^B and also leave the business community at a rate λ_i^B. Another possible primary reason for people to migrate to cities is employment. For this factor, it was assumed that individuals enter into the working community W_i at a rate Λ_i^W or leave (due to retirement, loss of a job or death) at a rate λ_i^W. Note that some people migrate to cities for work since they are perceived as having (or have) more jobs but these people do not always find jobs. Thus, recruitment rate for job seeking is Λ_i^J but those finding a job do so at rate σ_i while those who could not find a job leave the city at a rate λ_i^J. Finally, visitors recruit at rate Λ_i^V and leave the city at a rate λ_i^V. Visitors obtain jobs at rate δ_i or start studying at a rate γ_i. Note that communities also have dependents and relatives. Thus, the recruitment terms are assumed to cover birth or death in and out of the city.

Deriving from Chapter six and seven, income serve as a primary driver of migration. To understand the effects of income on city population dynamics, it is necessary to incorporate these into the model. As emerged in Chapter six it can be assumed that cities with more income attract individuals and those with less do not. To present this let $\left(I_i^S, I_i^B, I_i^J, I_i^W, I_i^V\right)$ be measures of attraction due to potential income by each of the communities at income level i. Also, let $\left(E_i^S, E_i^B, E_i^J, E_i^W, E_i^V\right)$ be measures of repulsion due to expenditure potential or lack of income of each community.

For the internal dynamics, it should be noted that workers can move from one category to the other through promotion or securing a better paying job or lose their job. Therefore, it can be assumed that workers in income level i can move to income level j as their income changes at rate w_{ij}. Similarly, business people in income level i can move to income level *j* as their income changes through making more profit or loss at rate b_{ij}. Since students, job seekers and visitors in any income level have limited opportunity to make more income, it should be assumed that they remain in their respective income levels.

Putting these formulations together, the following equations can be generated:

$$\begin{aligned}
\frac{dS_1}{dt} &= \Lambda_1^S + \gamma_1 V_1 - (\beta_1 + \sigma_1 + \lambda_1^S + E_1^S - I_1^S)S_1, \\
\frac{dB_1}{dt} &= \Lambda_1^B + \beta_1 S_1 - (\lambda_1^B + E_1^B - I_1^B)B_1 - \textstyle\sum_{i=1}^n b_{1i} B_1 + \sum_{i=1}^n b_{i1} B_i, \\
\frac{dJ_1}{dt} &= \Lambda_1^J + \sigma_1 S_1 + \delta_1 V_1 - \left(\alpha_1 + \lambda_1^J + E_1^J - I_1^J\right)J_1, \\
\frac{dW_1}{dt} &= \Lambda_1^W + \alpha_1 J_1 - (\lambda_1^W + E_1^W - I_1^W)W_1 - \textstyle\sum_{i=1}^n w_{1i} W_1 + \sum_{i=1}^n w_{i1} W_i, \\
\frac{dV_1}{dt} &= \Lambda_1^V - (\delta_1 + \gamma_1 + \lambda_1^V + E_1^V - I_1^V)V_1, \\
\frac{dS_2}{dt} &= \Lambda_2^S + \gamma_2 V_2 - (\beta_2 + \sigma_2 + \lambda_2^S + E_2^S - I_2^S)S_2, \\
\frac{dB_2}{dt} &= \Lambda_2^B + \beta_2 S_2 - (\lambda_2^B + E_2^B - I_2^B)B_2 - \textstyle\sum_{i=1}^n b_{2i} B_2 + \sum_{i=1}^n b_{i2} B_i, \\
\frac{dJ_2}{dt} &= \Lambda_2^J + \sigma_2 S_2 + \delta_2 V_2 - \left(\alpha_2 + \lambda_2^J + E_2^J - I_2^J\right)J_2, \\
\frac{dW_2}{dt} &= \Lambda_2^W + \alpha_2 J_2 - (\lambda_2^W + E_2^W - I_2^W)W_2 - \textstyle\sum_{i=1}^n w_{2i} W_2 + \sum_{i=1}^n w_{i2} W_i, \qquad (1) \\
\frac{dV_2}{dt} &= \Lambda_2^V - (\delta_2 + \gamma_2 + \lambda_2^V + E_2^V - I_2^V)V_2,
\end{aligned}$$

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$$\frac{dS_n}{dt} = \Lambda_n^S + \gamma_n V_n - (\beta_n + \sigma_n + \lambda_n^S + E_n^S - I_n^S)S_n,$$
$$\frac{dB_n}{dt} = \Lambda_n^B + \beta_n S_n - (\lambda_n^B + E_n^B - I_n^B)B_n - \sum_{i=1}^{n} b_{ni} B_n + \sum_{i=1}^{n} b_{in} B_i,$$
$$\frac{dJ_n}{dt} = \Lambda_n^J + \sigma_n S_n + \delta_n V_n - \left(\alpha_n + \lambda_n^J + E_n^J - I_n^J\right)J_n,$$
$$\frac{dW_n}{dt} = \Lambda_n^W + \alpha_n J_n - (\lambda_n^W + E_n^W - I_n^W)W_n - \sum_{i=1}^{n} w_{ni} W_n + \sum_{i=1}^{n} w_{in} W_i,$$
$$\frac{dV_n}{dt} = \Lambda_n^V - (\delta_n + \gamma_n + \lambda_n^V + E_n^V - I_n^V)V_n,$$

with initial conditions $S_i(0) \geq 0$, $B_i(0) \geq 0$, $J_i(0) \geq 0$, $W_i(0) \geq 0$ and $V_i(0) \geq 0$. Note that $b_{ii} = w_{ii} = 0$.

8.3 Model analysis

Mathematical analysis of model (1) is presented with the aim of presenting city population dynamics described by the model. To gain insight into the population dynamics of a city as well as determine the effects of income and expenditure on population dynamics, the analysis is started by considering the homogeneous version of model (1).

8.3.1 Homogeneous version of model (1) without income and expenditure

If $n = 1$ is set in the model (1) and $E^S - I^S = E^B - I^B = E^J - I^J = E^W - I^W = E^V - I^V = 0$, following output was obtained:

$$\frac{dS}{dt} = \Lambda^S + \gamma V - (\beta + \sigma + \lambda^S)S,$$
$$\frac{dB}{dt} = \Lambda^B + \beta S - \lambda^B B,$$
$$\frac{dJ}{dt} = \Lambda^J + \sigma S + \delta V - (\alpha + \lambda^J)J,$$
(2)
$$\frac{dW}{dt} = \Lambda^W + \alpha J - \lambda^W W,$$
$$\frac{dV}{dt} = \Lambda^V - (\delta + \gamma + \lambda^V)V,$$

with initial conditions $S(0) \geq 0$, $B(0) \geq 0$, $J(0) \geq 0$, $W(0) \geq 0$, $V(0) \geq 0$.

8.3.1.1 Analysis of model (2)

Analysis of this model is fundamental since it captures the basic city population dynamics. For simplicity, let $\mu = \delta + \gamma + \lambda^V$, $\xi = \alpha + \lambda^J$ and $\rho = \beta + \sigma + \lambda^S$. Equation (2) has an equilibrium point given by:

$$(S^0, B^0, J^0, W^0, V^0) = \left(\frac{\Lambda^S + \gamma V^0}{\rho}, \frac{\Lambda^B + \beta S^0}{\lambda^B}, \frac{\Lambda^J + \sigma S^0 + \delta V^0}{\xi}, \frac{\Lambda^W + \alpha J^0}{\lambda^W}, \frac{\Lambda^V}{\mu}\right). \quad (3)$$

Since model (2) is a system of linear differential equations, its exact solution can be determined and is given by:

$$V(t) = V^0 + K^V e^{-\mu t},$$
$$S(t) = S^0 + \frac{\gamma K^V}{\rho - \mu} e^{-\mu t} + K^S e^{-\rho t},$$
$$B(t) = B^0 + \frac{\beta \gamma K^V}{(\rho-\mu)(\lambda^B - \mu)} e^{-\mu t} + \frac{\beta K^S}{\lambda^B - \rho} e^{-\rho t} + K^B e^{-\lambda^B t},$$
(4)
$$J(t) = J^0 + \frac{\sigma \gamma K^V}{(\xi-\mu)(\rho-\mu)} e^{-\mu t} + \frac{\sigma K^S}{\xi - \rho} e^{-\rho t} + \frac{\delta K^V}{\xi - \mu} e^{-\mu t} + K^J e^{-\xi t},$$
$$W(t) = W^0 + \frac{\alpha \sigma \gamma K^V}{(\xi-\mu)(\rho-\mu)(\lambda^W-\mu)} e^{-\mu t} + \frac{\alpha \sigma K^S}{(\xi-\rho)(\lambda^W-\rho)} e^{-\rho t} + \frac{\alpha \delta K^V}{(\xi-\mu)(\lambda^W-\mu)} e^{-\mu t} + \frac{\alpha K^J}{\lambda^W - \xi} e^{-\xi t} + K^W e^{-\lambda^W t},$$

Where

$$K^V = V(0) - V^0,$$
$$K^S = S(0) - \left(S^0 + \frac{\gamma K^V}{\rho-\mu}\right),$$
$$K^B = B(0) - \left(B^0 + \frac{\beta \gamma K^V}{(\rho-\mu)(\lambda^B-\mu)} + \frac{\beta K^S}{\lambda^B - \rho}\right),$$
$$K^J = J(0) - \left(J^0 + \frac{\sigma \gamma K^V}{(\xi-\mu)(\rho-\mu)} + \frac{\sigma K^S}{\xi-\rho} + \frac{\delta K^V}{\xi-\mu}\right),$$
$$K^W = W(0) - \left(W^0 + \frac{\alpha \sigma \gamma K^V}{(\xi-\mu)(\rho-\mu)(\lambda^W-\mu)} + \frac{\alpha \sigma K^S}{(\xi-\rho)(\lambda^W-\rho)} + \frac{\alpha \delta K^V}{(\xi-\mu)(\lambda^W-\mu)} + \frac{\alpha K^J}{\lambda^W-\xi}\right),$$

are constants of integration.

Theorem 8.3.1: Model (2) is globally asymptotically stable.

The proof of Theorem 8.3.1 is straight forward. From the solution of model (2), it can be observed that:

$$(S(t), B(t), J(t), W(t), V(t)) \rightarrow (S^0, B^0, J^0, W^0, V^0) \text{ as } t \rightarrow \infty. \quad (4)$$

Equation (4) implies that model (2) is globally asymptotically stable completing the proof. An implication of Theorem 8.3.1 is that communities and the entire city population will be restricted by some constraints, which can be imposed by limits of resources available. This agrees with logistic population growth which does not exceed the carrying capacity (Verhulst, 1838; Pearl and Reed, 1920; Tsoularis, 2001). Another interesting implication of the theorem is that the initial population size of the city does not determine the size of the ultimate population but rather the parameters do. For example, migration rates within and across the communities are important determinants of the final population size in this model. This agrees with other studies where migration is the major factor that influences city population dynamics (Goldstein, 1990).

8.3.2 Homogeneous version of model (1) with income and expenditure

Here a homogeneous version of model (1) is presented in the presence of income and expenditure. By setting $n = 1$ in model (1), following output was obtained:

$$\begin{aligned}
\frac{dS}{dt} &= \Lambda^S + \gamma V - (\beta + \sigma + \lambda^S + E^S - I^S)S, \\
\frac{dB}{dt} &= \Lambda^B + \beta S - (\lambda^B + E^B - I^B)B, \\
\frac{dJ}{dt} &= \Lambda^J + \sigma S + \delta V - (\alpha + \lambda^J + E^J - I^J)J, \qquad (5) \\
\frac{dW}{dt} &= \Lambda^W + \alpha J - (\lambda^W + E^W - I^W) W, \\
\frac{dV}{dt} &= \Lambda^V - (\delta + \gamma + \lambda^V + E^V - I^V)V,
\end{aligned}$$

with initial conditions $S(0) \geq 0,\ B(0) \geq 0,\ J(0) \geq 0,\ W(0) \geq 0,\ V(0) \geq 0.$

8.3.2.1 Analysis of model (5)

Analysis of (5) and in particular by comparing its solutions with the solutions of model (2) will help to determine the effects of income and expenditure in the city population dynamics. Note that model (5) is also linear, therefore its exact solution can also be computed. In fact, if one set $\hat{\mu} = \delta + \gamma + \lambda^V + E^V - I^V,\ \widehat{\lambda^B} = \lambda^B + E^B - I^B,\ \widehat{\xi} = \alpha + \lambda^J + E^J - I^J$ and $\hat{\rho} = \beta + \sigma + \lambda^S + E^S - I^S,$ then model (5) reduces to model (2). Thus, the solution of model (5) can easily be obtained from the solution of model (2). Therefore, solution for model (5) will not be presented to avoid repetition of similar analyses and solutions.

However, investigating the long term dynamics of solutions of model (5) will help to determine the impacts of income and expenditure in the city population dynamics.

Unlike model (2), the long term dynamics of solutions of model (5) will not be easily determined since it was not known whether $\hat{\mu}$, $\hat{\xi}$, $\hat{\rho}$ and $\widehat{\lambda^B}$ are positive or negative.

8.3.3 Effects of income and expenditure

To improve the understanding on the effects of income and expenditure in the city population dynamics, it is necessary to investigate the long term dynamics of the solutions of model (5). This investigation will be carried out for only the student community $S(t)$ but similar analyses can be done for other communities. Analytically, the effects of income and expenditure in the population dynamics of the student community can be explored by investigating the long term dynamics of the solutions of model (5) for the three possible cases below.

Case (i) Income *greater than expenditure*

If in the student community $\beta + \sigma + \lambda^S + E^S - I^S < 0$, (i.e., income far greater than expenditure), the analysis reveals that $S(t) \rightarrow \infty$. In reality $S(t)$ is likely not to reach infinity, but this analysis shows that if student incomes in the form of bursaries or scholarships are greater than expenditure, then students' numbers will grow. This is partially explained by increasing populations in some cities where incomes are high or better funding or study opportunities exist.

Case (ii) *Income less than expenditure*

On the other hand if $\beta + \sigma + \lambda^S + E^S - I^S > 0$, (i.e., income less than expenditure), then $S(t) \rightarrow S^0$ at infinite time. That is the number of students become constant.

Case (iii) Income *and expenditure approximately equal*

The final case when income and expenditure are approximately equal reverts to model (1) that has already been discussed. These results also hold for the other categories of business people, workers, job seekers and visitors. To clarify further, case studies of the three major cities in South Africa: Cape Town, Durban and Johannesburg are presented.

8.4 Case studies: Cape Town, Durban and Johannesburg

In this section, realistic case studies for the cities of Cape Town, Durban and Johannesburg are presented. Data for the case studies was obtained from two sources i.e. primary (Chapter four) and secondary (from published literature and data bases). The secondary sources of data are published data mostly from Statistics South Africa (Stats SA, 2014). Parameters and data used are available on request.

By using available data, parameter values of the homogeneous model (5) including measures of income and expenditure for the cities of Cape Town, Durban and Johannesburg were estimated. The estimated parameter values $(\gamma, \beta, \sigma, \delta, \alpha)$ for these cities together with the estimated measures of income and expenditure were estimated by fitting model (5) to match the population values from the data of Statistics South Africa. These estimates were carried out using a built-in MATLAB least-squares fitting routine 'fmincon' in the optimization tool box of Mathworks, Version, R2012b (MATLAB, 2012). The model fitting for the three cities are presented in Figures 8.1 to 8.3. From the figures, it can be deduced that the model accurately describes the population dynamics of each of the chosen cities. Therefore, the model can be used to study as well as predict future population dynamics of the chosen cities.

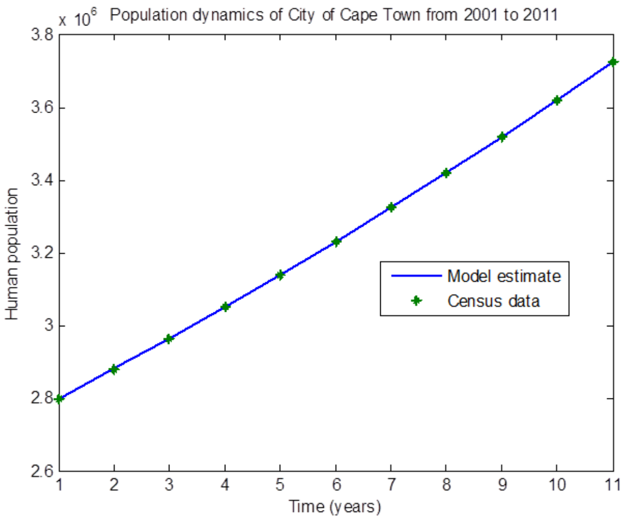

Figure 8.1. Model fitting for the population dynamics of Cape Town. The blue lines represent the model fitting while the green asterisk represent the population values from the Statistics South Africa (Census 2001 and 2011).

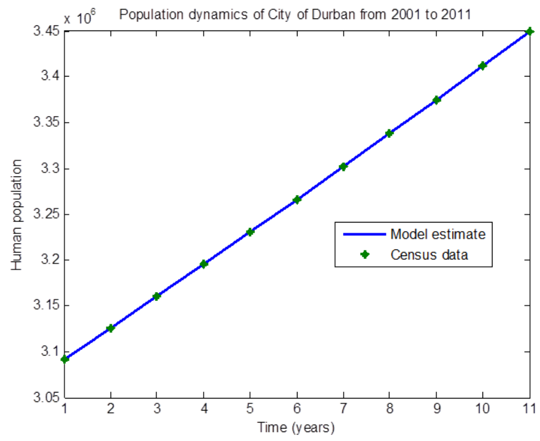

Figure 8.2. As in Figure 8.1 except for the population dynamics of Durban.

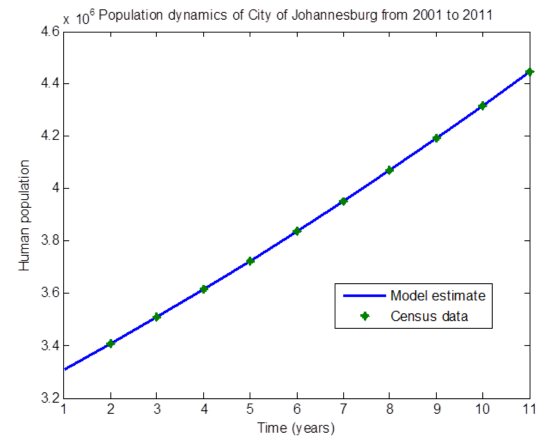

Figure 8.3. As in Figure 8.1 except for the population dynamics of Johannesburg.

To determine the impacts of income and expenditure in the population dynamics for the cities, model (5) must be solved numerically. Again, student communities were used to illustrate the methods. The numerical solution for $S(t)$ in the presence or absence of a measure for income and expenditure are presented in Figures 8.4 to 8.6. These results demonstrate that considering income and expenditure leads to a decrease in the population of the student community across the three major cities of South Africa. Income and expenditure has a negative impact on student populations in the three cities. Furthermore, from the same figures, student populations were projected to 2022 (i.e., 20 years from 2001), illustrating how future population trends can be estimated. Similar analyses is possible for the remaining communities.

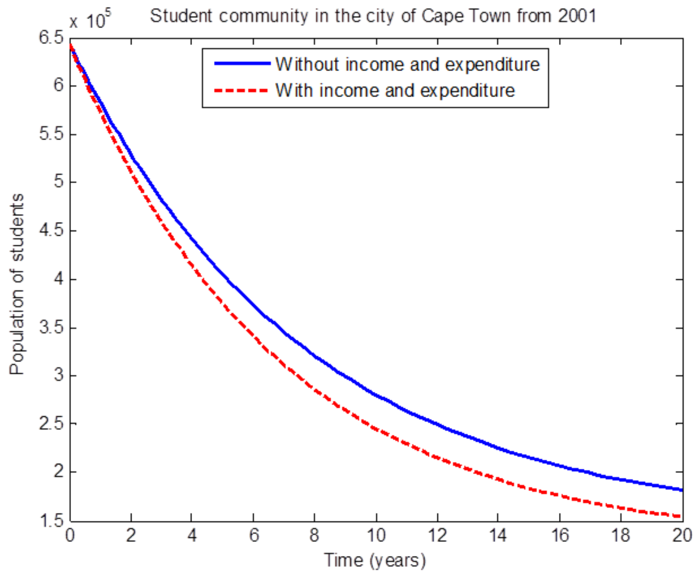

Figure 8.4. Graphical illustration of the effects of income and expenditure in the student community in the city of Cape Town. The blue lines represent the population dynamics of students in the absence of income and expenditure while the red dashed line represents the population dynamics of students in the presence of income and expenditure.

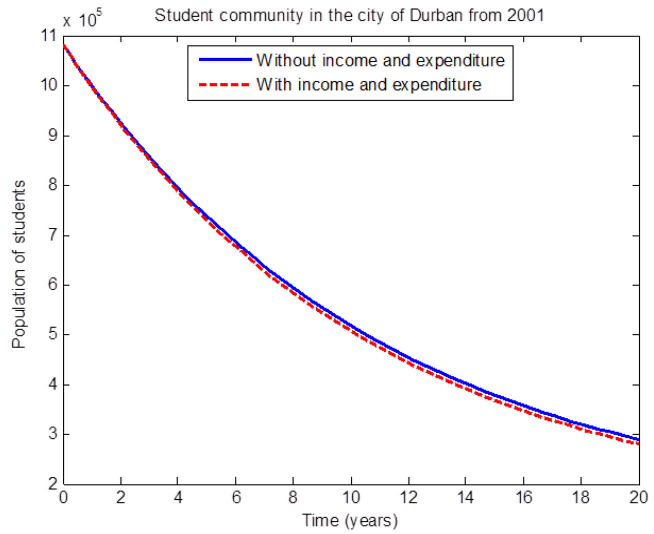

Figure 8.5. Graphical illustration of the effects of income and expenditure in the student community in the city of Durban. The blue lines represent the population dynamics of students in the absence of income and expenditure while the red dashed line represents the population dynamics of students in the presence of income and expenditure.

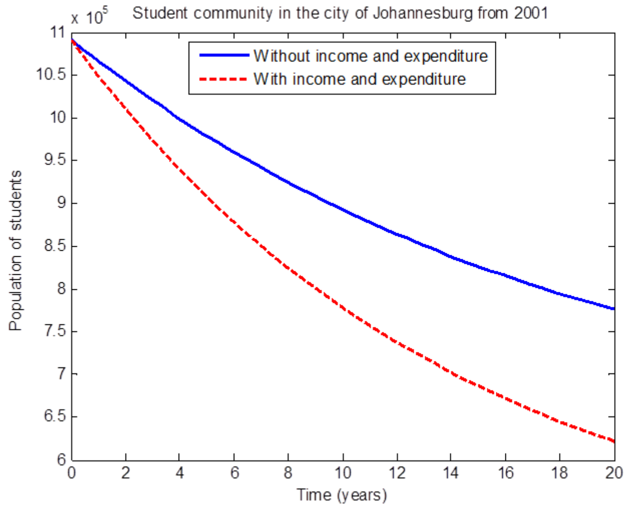

Figure 8.6. Graphical illustration of the effects of income and expenditure in the student community in the city of Johannesburg. The blue lines represent the population dynamics of students in the absence of income and expenditure while the red dashed line represents the population dynamics of students in the presence of income and expenditure.

Analytical computation of the effects of income or expenditure in the population dynamics of the model only indicate whether the population diverges to infinity or not for different ranges of values of a particular measure of income and expenditure. Unfortunately, this analysis does not give information about the exact values for the measures of income, expenditure or the population size. Using numerical simulations, it was possible to determine the exact values of the measure of income and expenditure. For instance, it was discovered that for the city of Cape Town, the measure of expenditure is greater than the measure of income in the student community, job seeking community, working community and visitors' community. This implies that for Cape Town individuals are likely to be attracted to migrate into the student, job seeking, working and visitors community. On the other hand, the measure of expenditure is less than the measure of income in the business community. This shows that individuals in the business community will probably on average move out from the city of Cape Town. The general population dynamics of the city of Cape Town is governed by a combination of each of these dynamics. This gives a better presentation of the population dynamics of the city of Cape Town. Similarly, the general population dynamics of the city of Durban and Johannesburg can also be determined.

8.4.1 Sensitivity analysis

To understand the relative importance of the different parameters (factors) responsible for city population dynamics, it is useful to carry out a sensitivity analysis of model (5). For this, sensitivity indices for model (5) were calculated so as to reveal the relative importance of each parameter on population dynamics.

In general terms, the normalized forward sensitivity index of a variable u that depends differentiably on a parameter p is defined as (Chitinis, Hyman and Cushing 2008):

$$\Upsilon_p^u = \frac{\partial u}{\partial p} \times \frac{p}{u}. \qquad (6)$$

When $\Upsilon_p^u > 0$, the accompanying proposition is that p increases the value of u as its value increases, while if $\Upsilon_p^u < 0$ it can be said that p decreases the value of u as its value increases.

Since an explicit solution of model (6) has been developed, an analytical expression for the sensitivity indices of these solutions with respect to each of the parameters using the above definition can be derived. To determine the magnitude of the sensitivity indices the estimated parameter values were used. This method of calculating the magnitude of the sensitivity indices has been successfully implemented for the dynamics of infectious diseases (Mwasa and Tchuenche, 2011; Hove-Musekwa *et al*., 2011). By a similar approach, the sensitivity index of $S(t)$ with respect to each of the parameters of model (5) for the three cities was determined. In general, $E^S,\ \beta,\ \sigma$ decrease the student populations as their values increase while I^S increases the student populations as its value increases for all the three cities. For the city of Cape Town, the rate σ at which students migrate in search of jobs is the most sensitive parameter followed by the measure of expenditure E^S. This is then followed by the rate β at which students migrate into the business community and finally the measure of income I^S.

Thus, the most important parameter that has the influence of changing the student population in Cape Town is the rate at which students migrate in search of jobs. Furthermore, in the city of Durban and Johannesburg, the sensitivity analyses revealed that the rate σ at which students migrate in search of jobs is the most important parameter followed by the rate β at which, students migrate into the business class. This shows that in these cities, most students are migrating into the job seeking and business communities.

Having presented the sensitivity analysis of $S(t)$, it becomes apparent that similar analysis can be carried out to compute the sensitivity indices of $B(t)$, $J(t)$, $W(t)$ and $V(t)$. Even though the sensitivity indices of these remaining solutions are critical, they will not be presented individually to avoid repetition.

8.4.2 Incorporating heterogeneity

Analysis of the homogeneous version of the model reveals that the populations of each of the studied South African cities are growing fast. However, this analysis did not reflect the growth rate of each income category of the city residents. Understanding the population dynamics of different income categories of city residents will be helpful for policy makers to construct better urban management policies.

In this study population dynamics of the city of Cape Town, Durban and Johannesburg under the assumption of homogeneous income and expenditure, has been analysed. However, real time data analysis showed that individuals in these cities fall within different income levels. Taking these differences in income levels into account gives a better description of the population dynamics. Here, population dynamics in the presence of this heterogeneity using the case study was explored so as to help determine the effects of income.

8.4.2.1 Parameter estimation for the heterogeneous model

To investigate income level population dynamics the parameter values in the heterogeneous model (1) were estimated from the data collected and the primary and secondary data for three cities. The estimated internal migration rates of workers w_{ij} and business men b_{ij} implies that the rate at which workers and business men migrate internally have a large influence on the population dynamics of the chosen cities. These internal migration rates are thus critical as they help to improve the understanding of city population dynamics with different income levels. Furthermore, it can be noted that there are also significant differences in the estimated parameter values, measures of income and expenditure across different income levels. These differences indicate the presence of heterogeneity in the population dynamics. Therefore, to accurately determine population variations between any two income levels, it is necessary to define an appropriate measure of heterogeneity.

8.4.2.2 Quantifying heterogeneity

From model (1), it was observed that there are three main sources of heterogeneity between any two income levels. These are:

(i) Heterogeneity due to differences in income and expenditure.

(ii) Heterogeneity due to variation in the movement rates$(\gamma_i,\ \beta_i,\ \sigma_i,\ \delta_i\ ,\ \alpha_i)$ from one community to another.

(iii) Heterogeneity due to differences in movement rates of business men b_{ij} and workers w_{ij} across income levels.

Therefore, to determine a measure of heterogeneity between any two income levels, one must consider the above three sources of heterogeneity. Using an effective measure of heterogeneity (Robertson *et al*., 2013; Collins and Govinder, 2014; Wilson and Martinez, 1997) and defining the distance between two points as Euclidean, a measure of heterogeneity between two income levels is defined as follows:

The first measure of heterogeneity between any two income levels (i and j) due to differences in measure of income and expenditure can be defined as

$$H_{ij}^{I} = \sqrt{h_{ij}^{S} + h_{ij}^{B} + h_{ij}^{J} + h_{ij}^{W} + h_{ij}^{V}} \tag{7}$$

where $h_{ij}^{S} = \left(E_i^S - E_j^S\right)^2 + \left(I_i^S - I_j^S\right)^2$, $h_{ij}^{B} = \left(E_i^B - E_j^B\right)^2 + \left(I_i^B - I_j^B\right)^2$, $h_{ij}^{J} = \left(E_i^J - E_j^J\right)^2 + \left(I_i^J - I_j^J\right)^2$,

$h_{ij}^{W} = \left(E_i^W - E_j^W\right)^2 + \left(I_i^W - I_j^W\right)^2$ and $h_{ij}^{V} = \left(E_i^V - E_j^V\right)^2 + \left(I_i^V - I_j^V\right)^2$. The quantity h_{ij}^{S} is the measure of heterogeneity between the student community in income levels i and j due to differences in their income and expenditure. Similarly, h_{ij}^{B}, h_{ij}^{J}, h_{ij}^{W} and h_{ij}^{V} are heterogeneity measures for the business people, job seekers, workers and visitors respectively.

The second measure of heterogeneity between any two income levels (i and j) which is due to variation in movement rates
(γ_i, β_i, σ_i, δ_i , α_i) can also be defined as

$$H_{ij}^{II} = \sqrt{(\gamma_i - \gamma_j)^2 + (\beta_i - \beta_j)^2 + (\sigma_i - \sigma_j)^2 + (\delta_i - \delta_j)^2 + (\alpha_i - \alpha_j)^2}. \quad (8)$$

The third source of heterogeneity between any two income levels which is due to differences in movement rates of business men b_{ij} and workers w_{ij} across the income levels can be defined as

$$H_{ij}^{III} = \sqrt{\sum_{k=1}^{5}\left((b_{ik} - b_{jk})^2 + (w_{ik} - w_{jk})^2 + (b_{ki} - b_{kj})^2 + (w_{ki} - w_{kj})^2\right)}. \quad (9)$$

Based on the above definitions, the total measure of heterogeneity between any two income levels (i and j) automatically becomes the summation of the above three measures of heterogeneities given by

$$H_{ij} = H_{ij}^{I} + H_{ij}^{II} + H_{ij}^{III}. \quad (10)$$

Using the above definition heterogeneity between the city income levels was computed. It was discovered that there are significant differences between any two income levels in the cities particularly in the cities of Cape Town and Johannesburg. This indicates that the understanding of city population dynamics using a mathematical model requires that heterogeneity be taken into consideration.

8.5 Discussion and Conclusion

The qualitative analyses of the homogeneous version of the model in absence of income and expenditure reflected that the model is globally asymptotically stable. Under this condition the population of a city can be kept within the city's carrying capacity. The analysis of a homogeneous version of the model in the presence of income and expenditure reflected that without constraints the population may exceed the carrying capacity. Querying this together with results obtained demonstrated that income is one of the key factors that influence population dynamics and this has a potential to keep the population within the boundaries of city's carrying capacity. This unfortunately is not the case in real world, especially Africa where people enter the informal economic sector should it appears that they are unable to generate the required income through formal means such as employment or businesses. The effect of this is the negative transformation of cities. This can be expressed through a city losing its attractiveness.

When individual analysis of three major cities in South Africa (Cape Town, Durban and Johannesburg) was done using data obtained from existing records (Census 2001 and 2012) and empirical data collected during fieldwork an investigation using sensitivity analyses revealed that the rate at which students population migrate in search for jobs and business opportunities have direct contribution on the population dynamics of a city.

Since the effects of income on city population dynamics is found to be demonstrable (as has also been done in Chapters six and seven), further analyses required the use of heterogeneous version of the model to explain the mechanism through which income influence the transformation of a city. The second part of these analyses that used the heterogeneous version of the model reflected that income levels have varying effects on the population dynamics of a city, in particular, the rate at which people migrate internally. This was found to have a direct influence on the city population growth.

To determine the level of heterogeneity between any two income levels, a heterogeneity measure was used. By using the estimated parameter values and selected measures of heterogeneity, it emerged that there are significant differences in the dynamics of population that could derive from any two income levels in the cities. Based on this observation the maximum heterogeneity was established at different income levels depending on the cities involved.

As a conclusion, it can be specified that for a better description of a city's population dynamics, which is essential for planning, budgeting and provision of limited resources, it is essential to incorporate heterogeneity in the planning and management of cities. Analyses conducted here partially reveal that city population dynamics can be precisely described by models that incorporate heterogeneity. This justifies the approach used in this thesis, which combines systems thinking with mathematical models.

CHAPTER 9

CONCLUSION AND RECOMMENDATIONS

9.1 Introduction

Unintended effects of South Africa's transition to Democracy, although presented here as being the possible trigger of the transformation of cities, in fact goes beyond that. They include slow economic growth, increased immigration, rising urbanisation, growing inequality and socio-cultural transformation, to mention the few. These conditions represent different subsystems that were not be accommodated in this study. As indicated in Chapter one the scope of this thesis is limited to the transformation of cities in South Africa and the characteristics that have emerged and how these derived from the selected parameters that have been investigated in this study.

There are number of systems approaches that could have been used to explore how changes that have taken place in the cities of South Africa have come about (Sayer, 1976, Wilson, 2000; Chen and Zhou, 2003 and 2004). The common limitation in most systems approaches is that these focus on endogenous behaviour of the systems (Sayer, 1981; Anderson, 1991). Bearing in mind that a model is the simplification of reality, the key consideration is to determine the limits between what to model as the trigger and what should be modelled as the driver of the behaviour of the system (Feng, 2002).

This thesis focussed on two presumed drivers i.e. income and population dynamics. These were modelled as endogenous drivers of city transformation. The fact, however, is that there are many factors that have influenced the transformation of cities in South Africa whose effects are dependent on the locations of the studied cities. This study demonstrates how income could affect the attractiveness of a city (Chapter 6). This was demonstrated through mathematical models. What can be deduced from these models, which contributes to systems modelling is that success of modelling city transformation (White, Engelen and Uljee, 1997), pose an insidious test, which is to determine the scope of the behaviour of the model (Bussiere and Snickers, 1970). As Sayer (1976) noted, most urban dynamics models serve as techniques, i.e. as computational devices rather than as an embodiment of theories about the targeted system (Sterman,1988). This calls for the development of rigorous theoretical frameworks that can used to guide processes of interpreting the transformation of cities using systems thinking and models (Forrester, 1980). Combining approaches like system dynamics, mathematical and statistical models appear to address this concern. This opens a window of ushering in new techniques of systems thinking and analysis. The critical question, is how effective this can be in yielding alternative options to policies that can enhance the management of cities. The validity of results presented here gives a glimpse of success of using models developed to interpret real world situation. The methodology used reflects that we live in a world that is interconnected as complex systems. To predict the behaviour of these systems, it is necessary to start with mathematical description of patterns as presented by real world data (Vespignani, 2009). These descriptions form the basis of models that can then be developed and used to anticipate emerging trends.

As the transformation of the cities takes place at different stages (Sayer 1976 and 1983), the design of the models should integrate precise factors presumed to be drivers of the identified change (Simelane 2012). This is not always easy (Sterman, 2000). This thesis just demonstrated that income, migration and houses are possible drivers of the transformation that is being witnessed in the cities of South Africa. This can be limited to geographical location and thus may not be reflective of the entire African continent (De Villa and Westfall, 2001).

Through models developed, the aim of providing systems modelling platform that can be used to access the transformation of cities was accomplished. The platform is essential for the design of urban management plans that can promote resilience and sustainable development in the cities (White and Engelen, 1994; Girardin, Vaccari, Gerber, Biderman and Ratti, 2009). The lesson derived from the process of developing these models is that if supplied with the right data, computational modelling and analysis provides the requested level of predictability.

What has also transpired during the process of developing models is that urban planning in South Africa is the direct cause for city migration that eventually cause city transformation. It is biased towards urban areas. This pose challenges for urban development (Duncan, 1989; Todaro, 1976). While it may be argued that this is not unique to South Africa (Harvey, 1987), as other developing countries like China, India, Brazil etc. are experiencing similar situations. The task is to strengthen the industrial segments of countries where urban influx is on the rise. In this regard extra skills that are constantly supplied by people from rural areas who obtain training in tertiary institutions that are located in major cities can be absorbed. Industrialisation therefore is one of the mechanisms that can be used to reduce the increase of the informal sector and ultimately enhance the overall effectiveness of a city to grow and be economically stable. In order to reduce the flow of people from rural to urban areas, it might also be necessary to consider the creation of a balance in the allocation of resources between rural and urban areas (Simelane, 2012).

As could be observed, not all changes that have taken place in the cities in South Africa were successfully captured and presented here. For instance, the shift in the racial profile in cities could not be explicitly demonstrated. This calls for the development of models that capture all elements of urban systems (Sayer, 1991; Longley, 1999; Simelane, Duffy and Pearce, 2013), including those that are cryptic. Despite these shortcomings, the modelling platform developed can be used to predict effects of other factors that could be behind the transformation of cities in South Africa. Building on results obtained through this study the next generation of models may entail Agent Based Models. These can be based on the characteristics of agents outlined in this thesis.

Overall, the study managed to highlight the following:

- Income is a primary driver behind the transformation of cities. As a confirmation, Glaeser and Sacerdote (1999) observed a direct correlation between income and expenditure in the city and how cities respond to this. They concluded that there is a circular relationship that derives from observation that in a city people make money and also spend it. In cases of cities with high income, these will always be attractive to people. While this seems to apply to most cities of the world, the differentiating factor with studied cities that African communities maintain strong links with their areas of origin through extended families. Once a family member is established in the city, he/she keep sending money back home in the form of remittances. This means that income generated in the city should be extended beyond city boundaries to sustain lives of the relatives back home. Because of this city based people will always find it difficult to have sufficient income.

- Education is a secondary driver of the transformation of cities. As could be deduced from results presented in Chapter five, people migrate to cities with the primary aim of gaining exposure to education institutions and acquire some education levels. Once they have acquired this they then attempt to secure income by looking for employment in the city. This has a direct influence on the age and the structure of the population of the cities.
- Compared to other cities in the continent, South African cities are more attractive. This could be due to prospects of providing higher income. This may be real or perceived thus studies that seek to compare differences in income levels across cities in the continent is recommended.
- It is possible to develop system models that capture the reality of what is happening in the cities of Africa. These can assist in developing strategies for managing cities and urban areas based on predictions of population dynamics and income levels.
- As income is a prime driver of urban migration and that there are different income levels among city populations planners, in their planning need to take into account the heterogeneity that exist among the cities and population dynamics that is driven by income and other associated effects.

The study further provided insights, which clarifies that:-

- The main driver behind the attractiveness of cities for people to want to migrate to cities is income. Unfortunately, many people cannot be accommodated by the formal sector and the result of this is that most people resolve to participate in the informal sector as a coping mechanism. This illuminates why there is a character of emergence of informal traders in the studied cities.

- Although South African cities are under threat of increased informal activities, South African cities are still able to provide employment opportunities that offer better income than most other cities in the continent. As a result, South African cities have a higher attractiveness than other African cities, which might also explain why South African cities attract people from other parts of developing economies.

- Since most institutions of higher learning are located in cities, migrating to a city for study purposes is a pull factor for young people to migrate to the cities (Chapter 5). This has transformed the population of the cities in such a way that it is now dominated by young people. These are different stages of their studies, once finished with their studies they start to look for employment. This emphasises a need to develop strategies for urban areas of South Africa that will ensure the absorption of extra skills produced by institutions of higher learning.

9.2 General critique for the study

The study adopted systems thinking as a basis for analysing changes that have taken place in the studied cities. The approach considered cities as complex adaptive systems. A key characteristic of complex adaptive systems is that their behaviour is influenced by the interplay between their environment and their dynamics. Unlike other systems such as physical systems, whose interactions are defined through a set of fundamental rules, in complex systems such rules remain to be discovered. This limits one's ability to fully rely on theoretical assumptions made about the system's components.

With this limitation, the common approach of analysing complex adaptive systems is to extract portions of the system and analyse them individually. This again acknowledges the intrinsic limitations of systems analysis. To ensure that most features of the targeted system are successfully extracted studied cities were viewed as evolving systems that exhibit characters of heterogeneity.

The overarching question left is how findings presented in this study reflect the future look of other cities in Africa? In answering this question it can be re-emphasized that the purpose of the study was not to provide a longer range projection of the transformation of cities but to capture transformation trends that have taken place in South African cities with the view of using them to develop platform for modelling the process of transformation of cities. In doing this the study focussed on the influence of income and population growth as triggers of city transformation. The behaviour of each of these factors as components of complex adaptive system were interpreted as such. In doing this, it was appreciated that they may not necessarily reflect the overall behaviour of the whole city system, which is composed of many interacting sub-systems.

To augment the predicting competencies of models developed, a combination of mathematical and system dynamics models was employed. System dynamics, as an analytical technique, appeared to be able to magnify interdependencies among the components of the system (Forrester, 1961; Alfeld, 1995). Drawn from complexities that can be magnified through system dynamics analysis, this technique, by virtue of being able to magnify cryptic relations in the system, enhances mental models (Batty and Kim, 1992).

The models enhance the decision making process and planning, taking various possible scenarios into consideration (Wolstenholme, 1990). Scenarios serve as descriptions of alternative futures, enabling a systematic consideration of uncertainties inherent in planning and to select robust alternatives (Forrester, 1958; Wilson, 1972; Ackoff, 1971).

9.3 Concluding remarks

Prior to Democracy, urbanization processes in South Africa were constrained. This together with urban management policies implemented post Democracy, have exposed urban areas to difference influencing factors. This process has led to the transformation of cities. To establish if features that have emerged in South African cities reflect global trends, it will be important to conduct a study that tracks the transformation of cities within the emerging economies, which are of interest to researchers at the moment. This will assist in providing lessons from elsewhere in the world.

As Africans were purposefully restricted from settling in cities, the inflow of these communities to cities have changed the social structure and composition of cities in South Africa. This has inevitably led to the demand of resources such as houses that were limited by the architectural design of the cities.

A notable trend is that with the subsequent increase in urban influx, metropolitan systems in South Africa have been transformed into new complex forms, where factors like birth, death, emigration and immigration now act synergistically to produce new features of the city. This has since increased the complexity of the social organisation of the cities in South Africa. The question that arises, is what the future outlook of the cities will be in decades to come. In this thesis a number of possible scenarios have been tested using dynamic variables. The models presented, although simple may be used to provide further analyses of future look of cities in South Africa.

9.4 Possible future research areas

The obvious limitation of this study is that it relied on two selected parameters. While these were chosen based on the observation of the problem at hand, the manner in which this happens depend on the fact that urban systems are open, flexible and subject to change that can derive from a variety of causes. City transformation can therefore be presumed to result from other factors that were not studied in this thesis. Testing how these are likely to produce features observed in South African cities is desirable. Studies that can incorporate these parameters and thus enhance methodology developed through this thesis are highly recommended. These should consider the following questions:-

- How can a balance, between business and industrial development in the cities, be correlated to generate employment that will meet the constant population growth that derive from migration?
- By what means can the supply of limited resources be ensured in the cities in the face of heightened population growth that result from migration?
- In what manner can the trends of dilapidating infrastructure in the cities be improved to maintain the attractiveness of cities?
- How can general improvements to city systems be brought about, with the aim of ensuring sustainable development of the cities?

Addressing these questions may be helpful in shedding light on why most African cities, although exhibiting some similarities, deteriorate at different rates. Providing a synopsis of how cities transform using a similar set of indices, will be beneficial in answering some of the above questions. In addition, developing a generic approach of tackling challenges faced by cities might improve urban environment of the developing countries. One way of doing this could be to adopt a reductionist approach, which can magnify all levels of system transformation at a basic level. The idea is that the ability of cities to function as social and economic centres is shaped by various factors whose dynamics can be interpreted using similar methodologies and approaches. It is through analysing systems at a very low level that an understanding of the overall behaviour of the system can be successfully established.

In consideration of this, further interesting areas of research that can be pursued include:

- Investigating economic dynamics linked to social change in order to determine whether economies of transforming cities are able to promote urban adaptation and provide financial gains required to sustain an urban lifestyle.
- Investigating the resilience of city systems in the face of perturbations that derive from external pressures. This can be considered in relation to the levels of congestion and how overloaded systems serve as a catalyst for the transformation of a city.

Lastly, taking the levels of education of the city populations into consideration, it needs to be established whether current rates of economic development in the cities are able to create sufficient jobs to absorb surplus labour that is constantly produced by training institutions that are located in the cities. The critical question here is to investigate the capacity of city economies to absorb available labour. If not, to determine the kind of intervention measures needed to mitigate the effects of the impact of an unemployed city population, a character that is evident in most African cities.

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APPENDIX I Equations for System Dynamics Models developed

Equation for basic Model

Population(t) = Population(t - dt) + (Migration rate + Births - Removals) * dt

INIT Population = 1440

INFLOWS:

Migration rate = Population*Base_migration_rate*Attractivness*(1-Population/Carrying_capacity)

Births = Population*Birth-rate*(1-Population/Carrying capacity)

OUTFLOWS:

Removals = Population*(Emmigration_rate+Death_rate)*(1-Population/Carrying_capacity)

Attractiveness = if (Income=6000) or (income=4000) then 0.75 else if (Income=3000) or (Income=7000) then 0.3 else 1

Base_migration_rate = .01

Birth-rate = 0.02

Carrying capacity = 2000

Death rate = 0.012

Emmigration_rate = 0.01

Income = 6000

Equation for Model used to test effect of selected parameters

Houses(t) = Houses(t - dt) + (Construction) * dt
INIT Houses = 250

INFLOWS:
Construction = construction rate*Houses
Population(t) = Population(t - dt) + (Migration rate + Births - Removals) * dt
INIT Population = 1400

INFLOWS:
Migration rate = Population*Base_migration_rate*(1-Population/Carrying_capacity)*Attractivness
Births = Population*Birth-rate*(1-Population/Carrying capacity)

OUTFLOWS:
Removals = Population*(Emmigration_rate+Death_rate)*(1-Population/Carrying_capacity)*Housing_efffect
Attractiveness = Income/5000
Base_migration_rate = .01

Birth_rate = 0.01
Carrying_capacity = 2000
construction_rate = 0.0005
Death_rate = 0.012
Emmigration_rate = 0.01
Housing available = Houses-(Population/perople_per_house)
Housing_efffect = Housing_available/(Housing_available-1)-
Housing_available/(Housing_available-1)+1
Income = 5000
perople_per_house = 6