City's Attractiveness as Magnet for In-Migration

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Abstract

As the world has entered the 'era of limits', it is quintessential to prioritize and emphasize the importance of limits to growth. Principles of systems thinking along with the system dynamics methodology help delve into the roots of complex system behavior to better predict them. A system is an interconnection of independent but inter-related parts where a positive change in one part of the system may prove to be calamitous for some other part and thereby for the system as a whole. The generic system dynamics model in the paper validates that a strong predictor of city's population growth is in-migration due to rise in attractiveness of a city. The structure of the model has an underlying basis in the fundamental behavior of system archetype and follows the concept and behavior of Relative Control archetype. The paper suggests a caution against rising attractiveness of cities without any apprehension about the stress of population growth on city's limited resources.

Keywords: Cities, In-migration, System Archetypes, Relative Control Archetype, Urbanization

Introduction

Cities are usually conceptualized owing to the mental models that categorize them as cities having industries and employment generating opportunities, some having a focus on IT services & infrastructure, some are classified as tourism oriented and some are termed as education hubs. An important proponent of attractiveness of a city with respect to in-migration is facilities and opportunities in that city. Along with several researches that act as evidences of development as a driver for in-migration, this study adds to the knowledge base of in-migration due to development related dynamics and the effect of causal relationships between the associated variables.

A major cause of rapid population growth experienced by urban areas is migration. Reviewing the effects of inward and outward migration on the population growth within a city and its determinants will be beneficial in understanding the ways to limit them. Migration (in or out) of a city depends on internal conditions of the city along with the population size. Reasons for in-migration in any city include better housing & services, employment, safer atmosphere, low crime rates, quality of life, etc. Presence of these facilities as compared to its environment increase the attractiveness of any area and is a big migration pull. Out-migration is also dependent on population size because larger population, if missing facilities in its area is prone to move out in greater numbers and out-migration will hence decrease the population.

Increased attractiveness of an area support in-migration and increased population puts stress on the existing resources. Till the time the resources are being augmented, the rise in in-migration continues, but limits to growth are eventually ascertained. Continuous growth of population will strain and exceed the resources and ultimately depress the internal conditions of an area, making the area unattractive for potential in-migrants.

Systems thinking enables to appreciate the world as a complex system where parts of the system are interconnected, interrelated and affect each other. System dynamics along with the principles of system thinking equips the vision to identify the parts of complex systems in real world and find answers to system questions like why do we face policy resistance and how it can be avoided & which leverage policy will be beneficial in finding sustainable solutions? (Sterman, 2001). Systems thinking serves as a door opener to initially identify a social problem in terms of parts of a system and relationship between those parts to deeply understand system dynamics (Forrester, 1994). In a dynamic and complex system, the assumptions of the mental models are communication through causal loop diagrams which serve as a qualitative visual aid to graphically represent the system relationships (Dianat et.al., 2021; Sterman, 2000). A form of the causal loop diagrams where generic recurring system structures are visually described are system archetypes (Branz et.al., 2021). System archetypes are a set of well-defined generic structures that illustrate common patterns of behavior reflected by the underlying structure in systems, particularly counterintuitive behavior. These causal feedback structures are formed by the combination of reinforcing and balancing feedback loops that exhibit characteristic outcome behavior over time. Wolstenholme (2003) arrived at a totally generic set of four archetypes by combining the reinforcing and balancing feedback loops into four mutually exclusive ways. The relationship between causal loop diagram and stock-flow diagram helps in identifying the stocks and flows in the system archetypes (Wolstenholme, 2004).

This research presents a generic attractiveness model which is developed initially by conceptually understanding the problem through causal loop diagram. Further, the CLD is mapped onto one of the system archetypes and the stock-flow diagram of that archetype is utilized to present the dynamics of the problem. The purpose of this paper is to bring forth the adverse effects of neglecting the interrelationships and causativeness between parts of the system. A change in one part of the system which is beneficial for that part may prove to be detrimental for some other part if the limits to growth are ignored. The study presents the deleterious effect of meeting the demand of the city and encouraging infrastructural development without considering the stress of the city's population growth due to in-migration on the limited resources of the city.

Literature Review

Cities are consistently expanding and swelling due to population density. New York was the planet's only megacity in 1950 (Tibbetts, 2002), but according to www.worlddata.info, we can count 49 megacities today. Along with the number of births, this population overload in selective cities has in-migration as a major cause. Even in developed countries when population growth was projected to be 3% between 2010 and 2050, the size of the urban population is forecasted to increase by 18%. Rapid urbanization is responsible for turning urban issues like traffic, healthcare, housing, education and public safety into mega challenges (Bélissent, 2010). A similarity in all the megacities can be found in their socio-economic conditions which increase the attractiveness of a place and thereby in-migration. Nefedova, Slepukhina, and Brade (2016) studied the relationship between attractiveness of a place and in-migration and found that high standards of living, better living conditions, economic and educational opportunities make large cities more attractive and prolongs urbanization. Cities are defined by the administrative functions and urban cultural identity driven by distinctive features of cities like commercial and business centres, leisure activities, education, religion, political orientation, etc. (Clark, 2009). Research by Anisimova et.al. (2016) found a correlation between migration and attractiveness of a place and then ranked cities in the level of their socio-economic attractiveness.

Complex societal problems can be intervened through various systems methodologies and critical systems thinking can be effectively utilized to link theory (drawn from social sciences) to practice (systems methodologies) (Jackson, 2010). The systems thinking skills can appropriately be enhanced through system dynamics modelling (Arndt, 2006). System Dynamics methodology is well suited for dealing with such dynamic and complex urban problems where cause and effect are not directly related in time and space. Counterintuitive behavior of social systems was studied by Jay W. Forrester and urban problems were dealt with through a system dynamics model, described in his book Urban Dynamics (Forrester, 1969; Forrester, 1971). The world model was built to investigate the trends and interrelationships of urban concerns- rapid population growth, growing industrialization, depletion of non-renewable resources, malnutrition, and worsening environment and was described in the book titled *Limits to Growth* (Meadows et. al., 1972). System dynamics also proved beneficial in modelling the urban transportation system for analyzing the driving forces and external influences on the system with the help of 7 sub-models. The relationship between the sub-models viz. population, economy, vehicles, environment, travel demand, transport supply and traffic congestion, was recognized and the effects of vehicle policy on development, population, GDP and environmental aspects was studied (Jifeng, Huapu & Hu, 2008). Zarghami and Akbariyeh (2012) used SD methodology to model the urban water system of Tabriz and appreciated the suitability of SD in dealing with the inextricably intertwined cause and effect chains of the water system. Recognizing that cities are complex socio-economic systems, Datola et.al. (2019) adopted system dynamics methodology as a tool to assess how urban resilience can change cities over time. SD methods were applied for generating prediction models for analyzing population migration and urbanization. The study conducted systematic simulation analysis to deduce that disparity in the economic and social levels promote migration (LI, LIU & HE, 2007). Nobel laureate Ilya Progonine, a prominent system thinker concluded from his studies on complex systems that non-linear equations are the only way of describing systems far from equilibrium (Haraldsson, 2000). Therefore, systems dynamics is an appropriate methodology for studying the dynamics of a complex system like cities.

System dynamics broadly encompasses three aspects, causal loop diagrams and system archetypes for qualitative understanding and stock-flow diagramming for quantitative modelling.

The underlying concept of causal loop diagrams is that 'rather than linearly, it is beneficial to observe the world through feedback'. Causal loop diagrams have been instrumental in identifying and organizing principal components and feedback loops of the system under study (Goodman, 1997). In order to provide a clear understanding of the dynamic interconnected nature of the world, causal loop diagrams act as a language (Tip, 2011). On mentioning causal loop diagrams as a 'language', an implicit reference to a proper use of a set of symbols and rules gets associated automatically. In a standard causal loop diagram, a system's dynamic causal structure is represented by a set of symbols: variables, causal links with polarity (arrow with a +/ - sign) and symbols identifying feedback loops with polarity (Reinforcing- 'R'/ Balancing- 'B') (Schaffernicht, 2010).

A form of causal loop diagrams where the system structures recur, is visually represented as System Archetypes. System archetypes are a free-standing solution to complex problems due to their isomorphic properties of recognizing the transfer of systems thinking across domains (Wolstenholme, 2004). System archetypes have been identified in processes of various fields like vehicular systems (d'Angella, De Carlo, and Sainaghi, 2010; Kwon, 2012), water resource systems (Mirchi et.al., 2012; Bahaddin et.al., 2018; Zare et.al., 2019; 2020; Bahri, 2020), land systems (Václavík, 2013; Brzezina, 2017; Levers et.al., 2018), spatial dynamics (BenDor and Metcalf, 2006), healthcare (Garde et.al., 2007; Fernandez-Breis, 2008; Duftschmid, Chaloupka, and Rinner, 2013; Bosca et.al., 2015; Newell and Siri, 2016), energy systems (Mutingi, Mbohwa, and Dube, 2017; Müller et.al., 2019; Bahri, 2020; Beagon, Boland, and Saffari, 2020; Kueppers et.al., 2021) and food systems (Fischer et.al., 2017; Bahri, 2020; Loiseau et.al., 2020; Benninger et.al., 2021). Stock-flow diagrams prove beneficial in exposing the accumulation that exist in system archetypes.

A Stock-Flow model is mathematically a set of first order, non-linear integrations which describe systems in terms of state variables (stocks) and their rates of change with respect to time (flows).

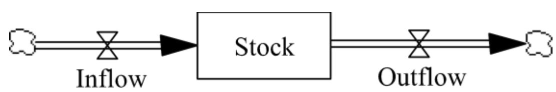

Fig 1. Standard Stock & Flow Combination

A stock is the integral of the net flow added to the initial value of the stock. The net flow is a differential equation and therefore the derivative of the total stock with respect to time is-

$$\frac{d(\text{Stock})}{dt} = \text{inflow}(t) - \text{outflow}(t)$$

In system dynamics, descriptions derived from causal loop diagrams lead to equations in a model, then simulated to appreciate the dynamic behavior, and finally alternative policies are evaluated to arrive at informed decisions (Forrester, 1994). Summarizing the concept of System Dynamics, it can be said that systems thinking and simulations through models are used to hypothesize, test and refine endogenous explanation of system change, which guides policy and decision making (Richardson, 2011). To gain the most advantage of qualitative as well as quantitative understanding of system dynamics methodology, simulating system archetypes prove beneficial. Graphs generated through simulation of system archetypes exhibit possible behavior patterns and guidelines for their applicability to various problems (Dowling et.al., 1995). Further sections of the paper inspect the dynamics between population and infrastructure through a system dynamics model, simulated using Python programming language.

Generic System Archetypes

Wolstenholme (2003), combined the reinforcing and balancing into four mutually exclusive ways and generated 4 generic system archetypes as shown in fig. 2.

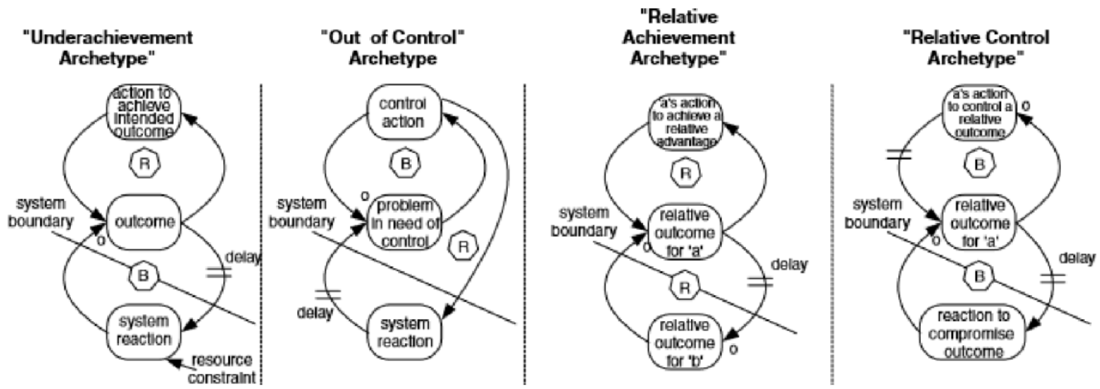

Fig 2. Generic System Archetypes

In each of the archetypes the upper loop addresses the intended consequence of the action and the lower loop represents the side effect or unintended consequence which is triggered by execution of the upper loop.

- **Underachievement Archetype:** The underlying concept of this archetype is that the intended achievement fails to be realized. The upper loop presents an action to achieve the intended outcome but it triggers a reaction in another sector which creates a balancing loop that limits the outcome.
- **Out of Control Archetype:** Here, the intended control fails to be realized. A balancing loop is initiated in one sector of the organization/ system to control the problem, i.e., the intended consequence is to control the problem. But, the unintended consequence manifests itself alongside, which is a reaction from another sector creates a reinforcing loop which results in further worsening of the problem.
- **Relative Achievement Archetype:** This archetype presents a situation where achievement for each party is gained at the expense of another. A system reaction in other part of the system, say B, on whose expense the advantage is achieved, gets triggered by the relative outcome of A & B. When B tries to achieve advantage at the expense of A, the outcomes get balanced and the two reinforcing loops form a zero-sum game
- **Relative Control Archetype:** A balancing loop intends to control a relative outcome, but a reaction in another sector of the system compromises the outcome of the initiator through another balancing loop. The underlying concept of this archetype is that control is gained at the expense of another.

Problem Under Study

This paper focuses on finding the reasons for high in-migration rates in some cities. The literature brings before us the similarity, in most of the cities where in-migration is high, which is an increase in attractiveness of the city due to infrastructural development. Therefore, the research studies and builds the relationship between the sector where infrastructure development is undertaken, population and in-migration. This study follows the below mentioned steps to arrive at a system dynamics model to decipher the problem of high in-migration in some cities and the reasons thereof.

- Create a causal loop diagram to depict the cause-and-effect links and associated feedback loops.
- Identify the generic system archetype in the causal loop diagram by checking that the combination of reinforcing/ balancing feedback loops falls under which generic archetype.
- Verify if the causal loop diagram is exhibiting the same behavior as the identified archetype.
- Create a standard method of simulating the generic system archetype to which the CLD of the problem corresponds to.
- Map the variables of the CLD onto the stock-flow diagram of the corresponding archetype's stock-flow diagram to arrive at the System Dynamics model of the problem.

Theoretical Conceptualization of the Problem through CLD

The causal loop diagram in fig. 3 supports the theoretical understanding of relationship, cross-impact of variables related to population, development and in-migration and the corresponding feedback loops. The developmental initiative in a sector is presented by the upper loop, where high *demand vs supply ratio* drives the construction of infrastructure. In turn, the increased supply of infrastructure lowers the *demand vs supply ratio*, creating a balancing feedback loop. The lower loop is also a balancing feedback loop where availability of facilities and opportunities in any city, i.e., increased supply increases attractiveness of the city which encourages in-migration and thereby population. As a consequence, growing population and their requirements increase demand thereby increasing the *demand vs supply* ratio. The two interlocked balancing loops are bound by the condition that infrastructure development cannot be encouraged without lowering *demand vs supply ratio* which attracts in-migrants. Population increase due to in-migration cannot be controlled without increasing the *demand vs supply ratio* which catalyzes the upper loop.

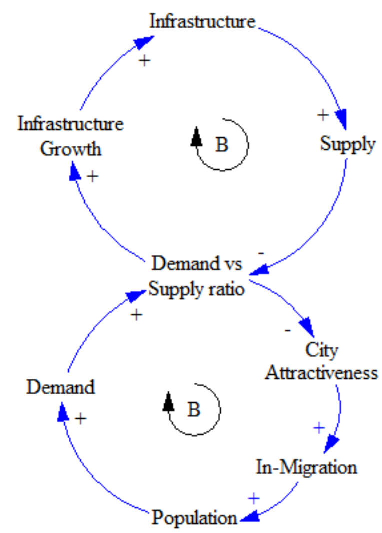

Fig 3. CLD representing In-Migration Dynamics

As the causal loop diagram in fig. 3 is a combination of two balancing feedback loops and follows the same concept of the *Relative Control* archetype. The problem under study can be considered as a case of this archetype and a standard way of simulating the corresponding archetype can be utilized to arrive at the system dynamics model of the problem.

Simulating the Relative Control Archetype using Stock-Flow Diagramming

The stock-flow diagram of the *Relative Control* archetype shown in fig. 4 can be understood as follows:

Intended Consequence Loop- A's outcome is achieved for controlling problems in a system. '*A's action*' is an inflow to the stock *'Outcome for A'* that increases the outcome, i.e., reduces a problem. Relative Outcome is computed as the difference between the stocks *'Outcome for A'* and '*Compromising System Reaction'*. '*Impact of relative outcome on A's outcome*' is a graphical function with a negative slope, which forms a relationship that, the more the *relative outcome for A*, less will be *A's action*. This forms the balancing feedback loop.

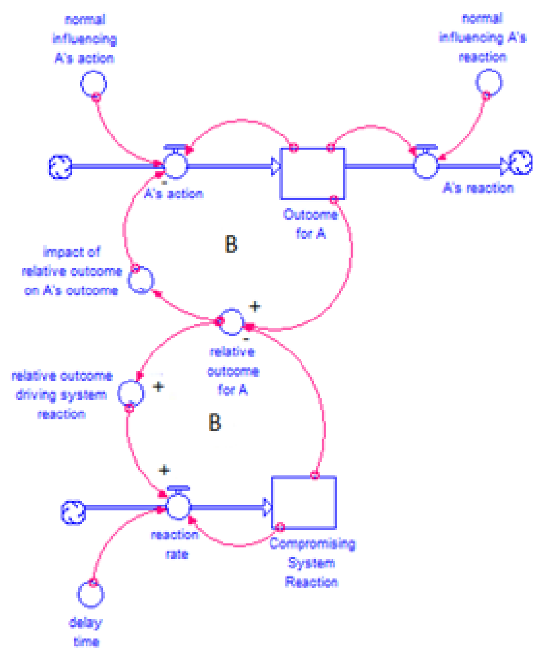

Fig 4. Stock-Flow Diagram of Relative Control Archetype

Unintended Consequence Loop- '*Relative Outcome for A*' influences the stock '*Compromising System Reaction*' through a graphical function '*relative outcome driving system reaction*'. The graphical function *'relative outcome driving system reaction*' has a positive slope, where the more the *relative outcome for A,* the more will be the inflow *'reaction rate'*. The link from the stock '*Compromising System Reaction*' to '*relative outcome for A*' completes the balancing loop because the more the value of '*Compromising System Reaction'* less will be the '*relative outcome for A'* due to its formula being the difference of the two stocks.

The graph shown in fig. 5, generated by simulating the stock-flow diagram of *Relative Control* archetype exhibits the same behavior which Wolstenholme (2003) has described. Assuming the initial value of the stock *Outcome for A* to be 10 and *Compromising System Reaction* to be 1, the model is simulated for 50 years. The normals influencing the stock *Outcome for A* are taken as 0.50 so that the behavior is a result of the structure and not values. The delay time is taken as 10 years to show that the action does not instantly trigger a reaction but after a delay, the side effects are observed. It can be easily

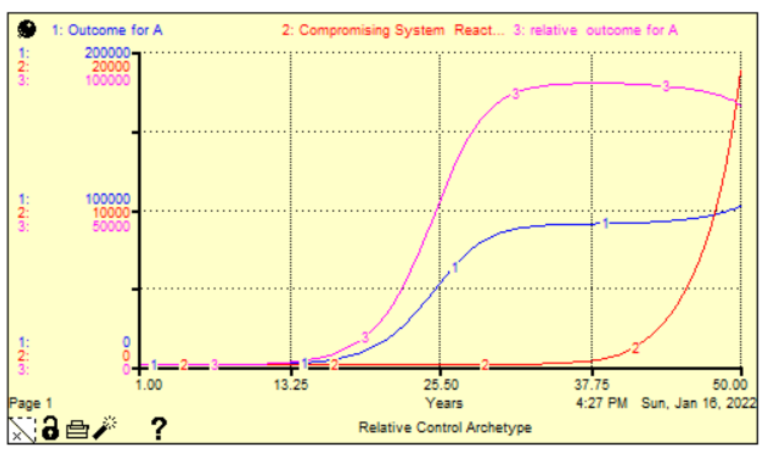

Fig 5. Behavior over Time Graph of Relative Control Archetype

interpreted from the behavior over time graph in fig.5 that the outcome as well as the relative outcome are increased till the time the compromising system reaction starts increasing. As the compromising system reaction starts increasing, the outcome starts approaching equilibrium creating a sigmoidal growth and relative outcome starts declining.

Mapping Attractiveness Model onto Stock & Flow Diagram of Relative Control Archetype

The system dynamics model of the problem, referred as *Attractiveness Model*, is constructed by mapping the variables of the problem under study presented through the causal loop diagram in fig. 3 onto the stock flow diagram of the *Relative Control* archetype of fig. 4.

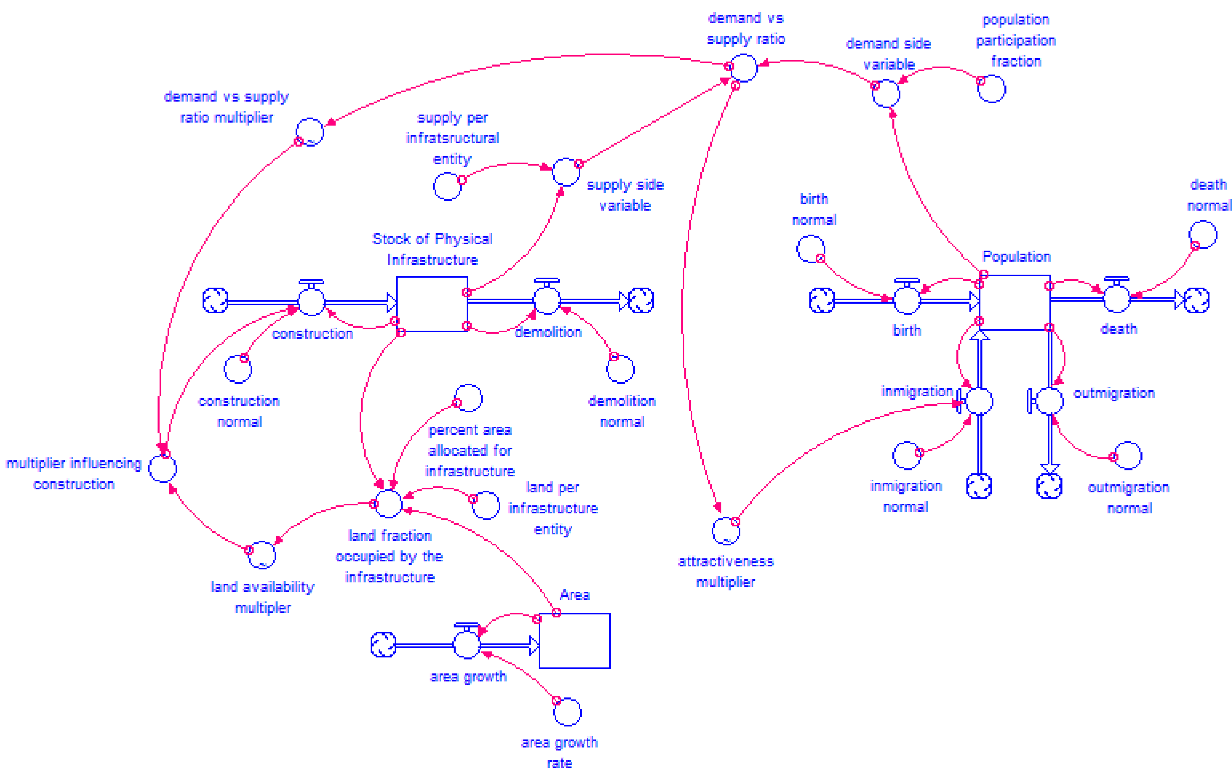

Fig 6. Stock & Flow Diagram of the Attractiveness Model

The two accumulator stocks, '*Population*' and '*Stock of Physical Infrastructure*' are connected by the variable '*demand vs supply ratio*' as shown in the attractiveness model in fig. 6. The '*demand vs supply ratio*' is computed by the demand-side and supply-side variable and is responsible for impacting both the stocks. The '*demand vs supply ratio*' links both the stocks and exhibits circular causality, i.e., it influences the same stocks which are its input. On one side it influences the construction of infrastructure and on the other side, the variable modulates the attractiveness multiplier and encourages in-migration. Increase in the stock of physical infrastructure is determined by the two multipliers- '*land availability multiplier*' & '*demand vs supply ratio multiplier*'. As the land of the city is limited and construction cannot continue forever, the multiplier initially promotes the construction of physical infrastructure, but as the limits on land are faced, the multiplier becomes ineffective. The other multiplier, *demand vs supply ratio* *multiplier* encourages construction of physical infrastructure with the rising demand. The rise in demand is responsible for the intended consequence loop of the *Relative Control* archetype.

The unintended consequence is created when increase in supply makes the city more attractive and the attractiveness multiplier encourages in-migration in the city. The result is the population swelling in the city. The infrastructure development improves the situation of the city with respect to availability of that infrastructural entity but the challenges it poses for the city cannot be overlooked. As the rising population puts stress on the resources of that city, high population density will be detrimental for the city.

The behavior produced by simulating this generic model of attractiveness can be analyzed only when stocks are initialized and some values are provided to the exogenous variables. To accomplish the same, the study takes an example of a sector of a city.

Attractiveness Model Example- Housing in Delhi

In order to understand and validate the behavior produced by the attractiveness model, taking an example of the sector of a city will be beneficial. The simulation environments for the model have been implemented by using Python programming language in Jupyter Notebooks.

The structure of the population equation follows the natural process of births, deaths and people entering and leaving the city. The stock equation relating to infrastructure is increased by construction and decreased by demolition of each unit. Literature supports that urban areas are constructed or expanded but never demolished or reduced and hence outflow is not included in the equation. As Delhi is popularly known as the migration capital of India due to high in-migration, the city is chosen to understand the factors responsible for the same. Housing is taken as the stock of infrastructure as an example and variables are accordingly substituted in the attractiveness model. As the example of housing is considered, other aspects that encourage in-migration like job opportunities, higher education opportunities, transportation facilities, etc. are not explicitly mentioned but included in the *in-migration* normal. The structures of the real-life processes were studied to come up with the following stock equations in the model-

$$Population(t) = Population(t_0) + \int_{t_0}^{t} (births - deaths + inmigration - outmigration) * dt$$

$$Houses(t) = Houses(t_0) + \int_{t_0}^{t} (Housing\ Construction - Housing\ Demolition) * dt$$

$$Area(t) = Area(t_0) + \int_{t_0}^{t} Area\ Growth * dt$$

Initial stock values at t_0 are taken from the census data of 1961. The values of the following exogenous variables are computed by taking the average of the rates from the six census years- 1961, 1971, 1981,1991, 2001 & 2011.

The values of the normals (Area Growth Normal & Housing Construction Normal) which are not included in census data, are computed using Compound Annual Growth Rate (CAGR) of the stock values through the following formula-

$$\text{CAGR} = \left(\frac{Value\ of\ Stock\ at\ t = 2011}{Value\ of\ Stock\ at\ t = 1961}\right)^{1/50} - 1$$

The values of the following exogenous values were found through the following sources-

Table 1. Data Sources of some Exogenous Variables

Percent area allocated for Housing	http://des.delhigovt.nic.in/wps/wcm/connect/DOIT_DES/des/home/
Land per House	http://des.delhigovt.nic.in/wps/wcm/connect/DOIT_DES/des/home/
Housing Demolition Normal	https://censusindia.gov.in/2011census/Hlo-series/HH01.html; http://lsi.gov.in:8081/jspui/handle/123456789/1/browse?type=censusyear&sort_by=3&order=ASC&rpp=20&etal=-1&value=1971&offset=160;

The endogenous variables in the model were computed through functions, which either considered an exogenous variable or another endogenous variable:

- Housing Demand- Population/ Household Size
- Housing Demand vs Supply Ratio- Housing Demand/ Houses
- Land Fraction Occupied by Houses- (Houses * Land per House)/ (Area * Percent Area allocated for Housing)

There are some graphical variables as well in the model. A graphical or table function is a graphical tool used to model a causal, usually nonlinear relationship between two variables in a model that would be difficult to specify in mathematical terms. A table function represents an effect of one variable on another variable. In such cases, the function is referred to as a multiplier

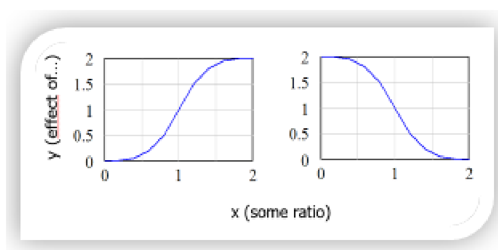

Fig 7. Graphical/ Table Functions

because it multiplies a normal, or reference value of a variable. When formulating a table function, several important characteristics of the function should be determined: slope, shape, reference points, and reference lines. The following endogenous variables in the model were computed through g graphical functions, which either considered an exogenous variable or another endogenous variable:

- Housing Availability Multiplier- This graphical/ table function represents the effect of 'housing demand vs supply ratio' on housing construction taking into consideration the housing availability in the city. As Housing demand encourages construction (Tipple & Korboe, 1998), this variable observes a positive slope. The situation of concern is when housing demand vs supply ratio keeps on increasing and excessive housing requirement is observed in the city. Continued housing requirements will eventually put brakes to housing construction that is when housing availability multiplier starts to level off.

- Housing Land Multiplier- This multiplier is an auxiliary variable that reflects the influence of land occupancy on housing construction. The amount of land occupied (denoted by housing land fraction occupied) determines the value of housing land multiplier. This graphical function observes positive slope in the first quadrant and negative slope in the second quadrant. When there is sparse land occupancy, increasing land occupancy tends to increase the housing construction (denoted by increasing housing land multiplier). The reason behind the initial increase in housing construction in response to increasing land occupancy is the accessibility to services like schools, hospitals, educational institutes, job opportunities, etc. But, as more than 60% of the land is occupied, the housing land multiplier starts decreasing, representing decline in housing construction (Forrester, 1969).
- Attractiveness of Housing Multiplier- This variable regulates the inflow in-migration that affects the stock 'Population'. Attractiveness of housing modulates with respect to the housing demand vs supply ratio. As supply of housing increases the attractiveness of a city (Glaeser, Gyourko, & Saks, 2006), this graphical function observes a negative slope, which means, as the ratio of housing demand versus supply decreases, attractiveness of a city increases.
- In-Migration Normal- Apart from housing there are other infrastructure development initiatives related to employment, education and transportation that are responsible for increasing the attractiveness of the city and thereby in-migration. As the example of the housing sector is taken, other attractiveness multipliers like *attractiveness of job multiplier, attractiveness of higher education multiplier* and *attractiveness of mobility multiplier* responsible for increasing the in-migration are included in the *in-migration normal.*

Validation

Secondary data was used to perform behavioral validation from the following sources-

- Census data from the year 1961 to 2011
- Economic Survey of Delhi 1961 to 2018-19
- Handbook of Statistics of Indian States released by RBI (1961 onwards)

Mean Absolute Percentage Error (MAPE) was used as a measure of prediction accuracy of forecasting by using the following formula-

$$\textbf{MAPE} = \frac{100\%}{n} \sum_{t=1}^{n} \left| \frac{At - Ft}{At} \right|$$

MAPE is the most appropriate goodness of fit measure for system dynamics model forecasting (Sterman et. al., 2012).

Barlas (1989) has suggested examining the 'Percent error in the means' to see the discrepancy between the means and 'Percent error in the Variations' which is computed through the following formula-

$$(|S_S - S_A| / S_A) * 100\%$$

where S_S & S_A are Standard Deviations of simulated and reference data

The interpretation of typical MAPE values is done as in table 2 (Lewis, 1982).

In order to develop confidence in the model, the model is simulated for 50 by considering the historical data from the period 1961 to 2011 and the output from the model is compared with the real data.

Table 2. Interpretation of MAPE values

MAPE	Interpretation
< 10	Highly accurate forecasting
10 to 20	Good Forecasting
20 to 50	Reasonable Forecasting
> 50	Inaccurate Forecasting

Table 3. MAPE & Percent Error of Deviation of 'Houses' stock

Year	Historical Data	Simulated Data	MAPE
1961	472	472	0
1971	710	750	5.634
1981	1152	1177	2.170
1991	2210	2058	6.878
2001	3135	2922	6.794
2011	4481	4558	1.718
			3.866
Percent Error of Deviation			
SD (σ)	1426.03	1412.49	**0.949**

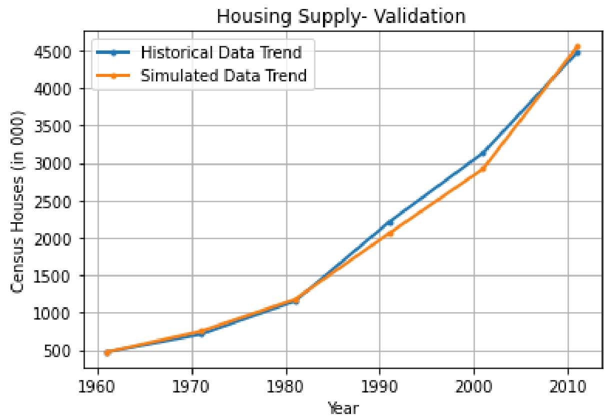

Fig 8. Behavior Reproduction (Houses Stock)

Table 4. MAPE & Percent Error of Deviation of 'Area' stock

Year	Historical Data	Simulated Data	MAPE
1961	327	327	0
1971	446	419	6.054
1981	592	537	9.291
1991	685	689	0.584
2001	891	883	0.898
2011	1114	1132	1.648
			3.079
Percent Error of Deviation			
SD	264.546	276.083	**4.361**

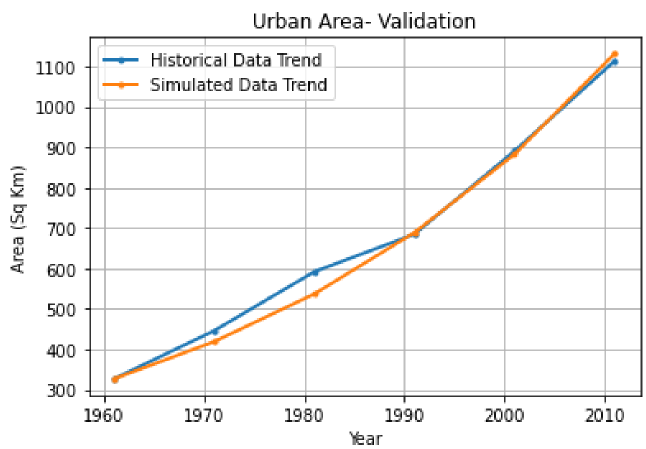

Fig 9. Behavior Reproduction (Urban Area)

Forecasting through Model Simulation

With the confidence that the model is able to simulate real life behavior, the model is simulated for 100 years to forecast the growth of houses and population in the city. The graph in fig.11 presents an s-shaped trajectory where growth reaches an equilibrium when a limit to growth is encountered due to area constraints.

Table 5. MAPE & Percent Error of Deviation of 'Population' stock

Year	Historical Data	Simulated Data	MAPE
1961	2359.408	2359.408	0.000
1971	3647.023	3610.526	1.001
1981	5768.200	5525.071	4.215
1991	8471.625	8454.838	0.198
2001	12905.780	12938.170	0.251
2011	16368.899	16798.858	2.627
			1.382
Percent Error of Deviation			
SD	4994.92	5143.72	**2.979**

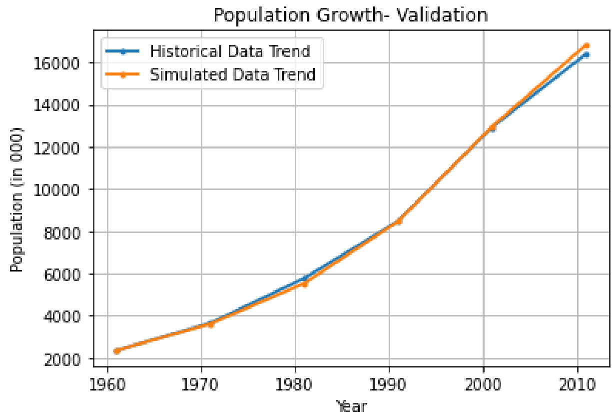

Fig 10. Behavior Reproduction (Population)

Urban land expansion is one of the fundamental aspects of urbanization. It is a process of creating a built environment to accommodate the population and their activities. Fig. 12 shows how Delhi has experienced urban expansion since 1960 and considering the same expansion scale, further expansion has been forecasted. As per census 2011, out of the total 1483 km^2 area of Delhi, 25% was rural and 75% had already urbanized. Every 10-year census brings before us the speed of urbanization in Delhi, where the rural area decreased from 54% in 1991 to 38% in 2001 to 25% in 2011. Taking into consideration the present trends of urbanization, fig. 12 presents a forecast that expansion cannot continue beyond 2030, even if all the designated rural areas are urbanized.

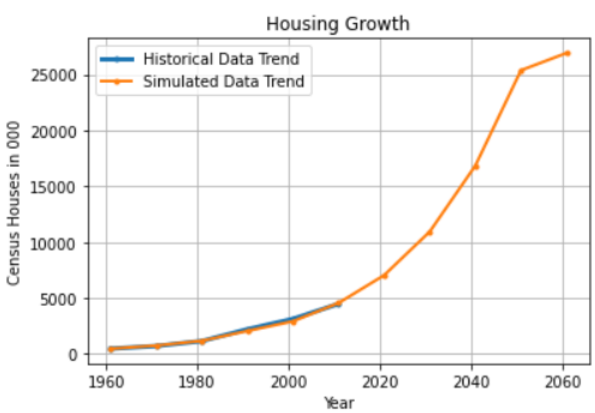

Fig 11. Housing Growth Forecast

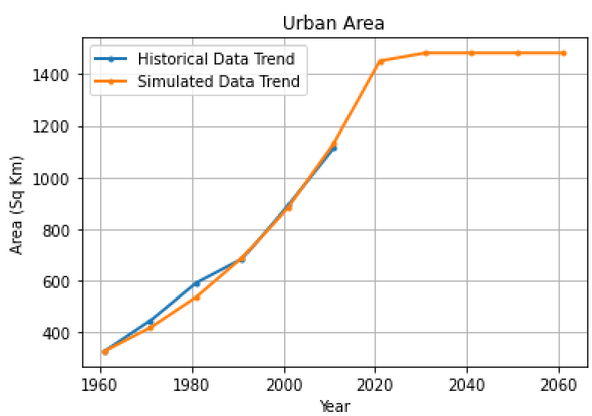

Fig 12. Urban Area Growth Forecast

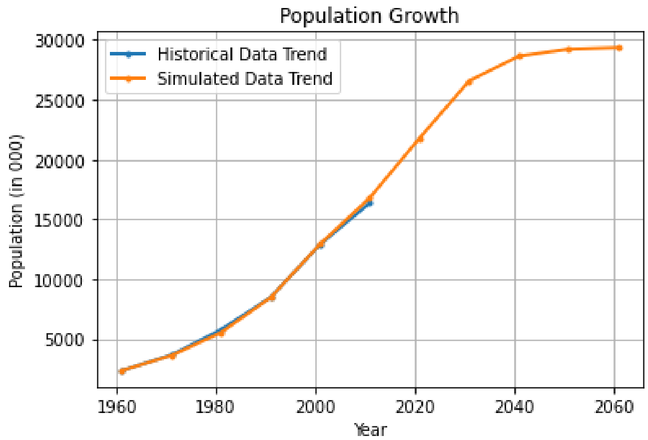

Fig 13. Population Growth in Delhi Forecast

Housing construction is encouraged by the increasing demand of houses and in-turn increase in supply of houses attracts in-migrants to the city, which is a vicious cycle of growth. When developmental initiatives in any sector are carried on without bounds, it increases the attractiveness of that city and in-migration and consequently the population in the city increases. As there is limited land area in cities, infrastructure construction cannot continue forever and it can be seen in fig. 11 that the stock of houses is forecasted to approach equilibrium around year 2060. The effect of the decrease and halt in housing growth due to land constraints can be seen in fig. 13, where population growth in the city also increases very gradually and approaches equilibrium around the year 2050.

Conclusion

Important lessons need to be learnt from the dynamics presented by the SD model in the paper representing the relationship and causativeness between population and infrastructure.

This study helps in understanding a way of identifying system archetypes in the causal loop diagrams of urban models. The method is as follows-

- Identify reinforcing and balancing feedback loops in the system under study.
- Check that the combination of the identified loops follows the structure of which generic archetype.
- Verify if the causal loop diagram is exhibiting the same behavior as the identified archetype.

This method provides a way of understanding that the recurring problem in any system has its root in the feedback structure and the archetype can clearly present the underlying reason. This research also introduced a standard way of converting the causal loop diagrams of Relative Control archetype into stock & flow diagrams. Further, the stock and flow diagram was simulated to exhibit similar behavior as exhibited through the Relative Control archetype.

The study provides us a means to understand the unintended consequence of unbounded infrastructure construction in advance through a simulator so that alternate strategies can be considered. The study also presents strong evidence that the model is structure dependent and data independent. The model verifies that the system behavior is dependent on the structure and not data by replacing the initial stock values and other variables with the data for Delhi and observing the similar model behavior as that of the relative archetype. The graphs of the stocks- Houses and Population exhibited sigmoidal growth patterns where limits to growth of land in Delhi applied brakes on housing construction. The reason pertaining to the stabilizing behavior is the initial increase in the number of infrastructure units due to land availability but the limits of the city force the growth to progress towards equilibrium. Infrastructure development increases the attractiveness of a city which attracts in-migrants and increased population puts stress on the limited resources and hampers the livability of that city. The cross-impact of housing growth on in-migration and growth of population demand on construction of houses justifies the causal loop diagram of generic infrastructure growth and in-migration in fig. 3.

Therefore, this research is a glimpse of the detrimental effects caused by the counterintuitive behavior of social and complex systems. It also teaches us the significance of limits to growth and consequences of not considering the city as a whole and ignoring the relationships and causativeness of parts of the system. This paper offers an approach for policy makers to understand the counterintuitive behavior of policies that they propose. The existing reinforcing and balancing loops that drive the system should be considered with an eye on the limits to growth. The approach illustrated in the study enables urban planners and policy makers to look for the unintended consequences in other parts of the system while taking any action related to infrastructure construction.

Scope for Further Research

The findings of this research have to be seen in the light of some limitations. This study has described a standard way of identifying the system archetypes in the causal loop diagrams of urban problems but the stock-flow representation of only the relative control archetype has been undertaken. However, it will be beneficial to convert the causal loop diagrams of other archetypes into stock-flow diagrams and each can be validated.

It will also be interesting to explore different combinations of archetypes and observe the dynamics of the behavior generated by simulating the combination of system archetypes.

For each of the generic system archetypes, which is a problem archetype, Wolstenhome (2003) has also identified the solution archetype. This study focuses on simulating one of the generic problem archetypes but future studies can simulate the corresponding solution archetypes along with the problem archetype.

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