Regional Economic Growth and Municipal Financial Planning: An Application of a System Dynamics Model to Calgary[1]

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Abstract

Over the past two decades, Calgary – a midwestern Canadian City of approximately 1 million inhabitants – has experienced periods of rapid resource-driven economic growth and attendant municipal growing pains interspersed with periods of relative stasis. Effective municipal financial planning in this environment imposes profound challenges, particularly due to the presence of feedbacks, delays, non-linearities. To facilitate improved municipal financial planning, the City of Calgary has constructed the detailed multi-sectoral Calgary Impact Assessment Model (CIAM). CIAM – whose structure draws inspiration from previous peer reviewed models – includes an articulated representation of population demographics, migration, the labor market, the domestic and commercial property market and taxes thereon, infrastructure, finances, and the budget, recreational land, service levels, and quality of life. CIAM was parameterized using data from City databases and reports. Model construction incorporated a variety of best practices, and underwent a through a rigorous peer review. CIAM was subsequently calibrated to dozens of time series, leading to further model structural refinement and parameter estimation; the resulting model reproduces quite well a wide variety of historical municipal dynamics. CIAM has been used to investigate several scenarios important for municipal financial planning, and offers the potential to serve as an important decision-making tool for future city financial planning.

Keywords

impact assessment, municipal finance, public service, municipal revenue resource, municipal expenditure, city index, population, employment, real estate, housing price, property tax, office rent, assessment value, city index, municipal financial planning, Calgary, Alberta, Canada

1. Introduction

Calgary is the largest city in the Province of Alberta, and the fifth largest census metropolitan area in Canada. It has a population of over 1.07 million according to the 2010 municipal census. With the oil and gas being the dominant industry, Calgary's economy has been growing at an annual rate of 4 per cent in the past decade.

The core mission of the municipality is to deliver sustainable public services to its citizens. Consequently, long-term financial health becomes a crucial element in the financial planning and delivery of municipal services over time. Maintaining the financial health of a municipality is challenging as the effects of decisions are manifested over time in complex ways, with some effects being felt quickly, and others playing out over longer periods. Such decision making is particularly confounded by complications associated with delays, nonlinearities, feedbacks and uncertainties. The effects of financial planning therefore have ramifications for service delivery that are broad but difficult for even trained financial managers to anticipate.

Delays complicate full accounting for a project's impact and the adaptation of decisions based on observed results. For example, both the impact of investments on operating costs, and the desire to hire individuals can be associated with long delays. For example, a major capital investment in a project can shape the city in many ways, including imposing shorter-term capital costs on the municipality, and more slowly elevating the city's attractiveness (thereby bringing additional migrants – and ultimately service demands) and lowering some costs, while imposing others (such as the associated operating costs).

Non-linearities are commonly seen when considering that the impact of a combination of policies can be very different from the sum of the impact of each policy in isolation. In some cases, the policies may be synergistic in impact; in other cases, they may work at cross-purposes.

As is seen elsewhere, feedbacks in the municipal financial planning context reflect situations where a given change in the system (say, an increase in the price of housing) leads to changes that either amplify the original change (e.g. investments by speculators) or "push back against it" (e.g. triggering the development and market entry of new housing, and efforts to convert rental housing to condominiums.) In some cases, the situation can evolve in a way that confounds the original motivations for the plan. For example, while new development projects may net additional property tax revenue for the city, the costs of service provision may ultimately negatively impact city coffers – yielding added perception of need for revenue from future developments.

The difficulty of decision making in the context of these behavioral complexities is magnified further by the presence of ongoing uncertainties – uncertainties in the future evolution of the prime rate, oil industry fortunes, unemployment elsewhere in Canada. The quality of decision benefits greatly from understanding how such external factors interact with the delays, nonlinearities and feedbacks discussed above. For example, while the original trigger for a difficult situation may come from factors outside the city's control, the roots of the fundamental vulnerability being exposed typically lies in patterns of decision making and relationships among factors within the system itself – here, within the city. Absent a clear recognition of the complex dynamics of the system, well-intentioned decisions can lead to highly adverse outcomes.

In the context of dynamic complexity and uncertainty, many professionals – pilots, doctors, engineers, construction management, etc. – turn to simulation environments. By capturing a simplified representation of "how the world works", such models can help us ask "what if" questions involving counter-factual situations – situations that have not yet been experienced, but whose consequences we seek to better anticipate and manage. Such tools can serve many functions, including lending insight into the tradeoffs between different choices, into the impact of our choices on our vulnerability to possible eventualities outside of our control, and shedding light on the importance of collecting certain types of information for improving decision making. By making explicit hypotheses concerning the mechanisms operating (e.g. factors related to city operations and finance), such models offer an opportunity to explicitly document, critique and refine assumptions. By providing a runnable "microworld" with which diverse stakeholders can experiment, such models can also aid in communicating the nature of the challenges confronting those managing the systems, and the textured tradeoffs that make for difficult choices.

Systems simulation models maintain increasing popularity in the management decision making area, particularly for their ability to support more judicious decision making. This paper describes the Calgary Impact Assessment Model (CIAM), a System Dynamics simulation model built to aid municipal financial planning for the City of Calgary.

The remainder of the paper is structured as follows. The next section will introduce the related literature. The paper then provides an overview of model scope. In section 4, we will explain the structure of the model, including the design of the five major modules and their interlinking. Section 5 talks about the parameterization and calibration of the model and its testing. Section 6 discusses some applications and possible model uses, and limitations of the model. The paper then concludes with remarks on the potential for this model to influence municipal financial planning and operations in Calgary

2. Literature Review

The CIAM model is an articulated, grounded model for confronting the challenges of municipal financial planning. The model was produced by an extended modeling process that drew heavily both on best practices in the modeling area and on pre-existing models. The CIAM model underwent a rigorous processing of model testing, including unit tests, variable-by-variable peer review, and calibration.

The construction of the Calgary Impact Assessment Model (CIAM) drew inspiration from two separate modeling efforts. While Forrester's seminal *Urban Dynamics* [Forrester 1969] initiated the application of System Dynamics (and likely of dynamic modeling more generally) to issues of urban sustainability, The most notable influence was the "BOOM1" model and its extensions from Los Alamos National Laboratories, which is described in several technical reports as well as peer-reviewed external papers [Ford 1976b, 1976c, 1977a, 1977c, 1978a; Rink & Ford 1978; Monts 1978]. This stylized model investigated the dynamics of municipal "boom and bust" phenomena associated with the development of large energy projects on small municipalities, including consideration of construction-driven economic growth, city services, housing, retail and service space, migration, and municipal financing. The second important precursor models were financial planning models developed for The City of Edmonton in the early 1990s [Walters & Jamal 1996, Walters, & Jamal 1999] and The City of Calgary [Walters, Kongnetiman & Jamal 2002]. The CIAM model also builds on general principles of System Dynamics modeling [Sterman 2000] as well as econometric relationships.

3. Model Scope

The CIAM model focuses on municipal financial planning on the multi-decade timeframe, and includes a wide variety of factors relevant to such planning. Table 1 describes some of the more important factors considered within the model. Within that table, we make use of a traditional distinction between three sorts of factors:

- **Endogenous factors:** Factors whose behavior over time is calculated by the model, based on values of other quantities with the model. As a result, the particular trajectory followed by endogenous factors will change in response to various "what if" scenarios.
- **Exogenous factors:** Elements that are explicitly represented in the model, but which adhere to fixed assumptions – that is, the values that they take on are independent of the evolution of other factors in the model. Perhaps the most common such situation is the assumption that a given factor remains constant over time – for example, we may assume that labour force participation rates by those of

different ages remain the same over the simulation timeframe. Alternatively, we may assume that a variable is pre-specified by a time series that remains the same regardless of changes in other model assumptions or interventions. For example, in running a specific scenario within the model, we may assume a certain trajectory of West Texas intermediate crude oil price.

- **Ignored factors.** All models are incomplete, and of necessity omit a variety of factors from consideration altogether. Factors classified in the "Ignored" category are not represented in the model, and any assumptions made regarding such factors may be stated explicitly, or left implied by the handling of other factors. Conscious consideration and explicit specification of the factors that are ignored can spur more reflective model evolution.

A list of some model factors in each category is given in Table 1. As suggested by the table, the model seeks to capture the dynamics associated with many key factors related to municipal financial planning. While any of the factors incorporated in the model could be used in judging policy outcomes, measures of particular relevance and perceived importance include the quality of life (via the city index), revenue, expenditures, debt, staffing, population, and housing prices.

Endogenous	**Exogenous**	**Ignored**
Housing stock	Canadian unemployment rate	Traffic dynamics
Population age structure	Labour participation	City geography
Migration	Oil prices	Speculative behavior
Staffing	Interest rates	Differential development density
Debt	City economic balance	
Business unit growth	Employment (via oil prices and interest rates)	
Expenditure	Economic and housing balance between City and surrounding economic region	
City infrastructure		
Calgary unemployment rate		
Non-residential space stock		
Property tax revenues		
Mill rate		
Non-tax revenue		
Recreational land		
Quality of life		
Labour market		
Operating costs		

Table 1: Model scope.

The model captures a variety of important feedbacks that (variously) drive rapid change or stabilize aspects of Calgary's economic situation. Balancing feedbacks are particularly numerous. For example, a labour shortage will tend to increase the attractiveness of the Calgary region, thereby elevating net in-migration, and lowering the shortage. Conversely, a labour surplus will enhance out-migration.

As another example, an increase in the population base will increase the need for additional staff, thereby triggering the hiring of full-time equivalent employees (FTEs), thereby restoring a similar service level and reducing the need for hiring additional staff. Frequently, the effects of such changes are varied and proceed via many pathways. For example, greater housing demand will provide upwards pressure on housing prices, thereby leading to lower housing demand. Higher house prices will also tend to depress the city index, thereby lowering net migration into the Calgary economic region. However, the higher prices involved may also trigger further housing starts, thereby contributing (in the medium term) to a lowering of prices and supporting further demand. As with many situations, while the balancing loops act to maintain system stability for the municipal region, the fact that their strength is limited and that the time constants over which they operate may be sufficiently long combine to allow for significant disequilibrium behavior. Municipal financial planners face significant challenges in recognizing, managing, and communicating the drivers of such disequilibria; a model that represents such underlying factors can be of considerable assistance in these tasks.

4. Model Structure

Within the model, the city is represented as a system consisting of a number of interacting parts, of which the municipal government is a component [Alfeld et al., 1976; Josza et al., 1981; Myers 1995; Hamilton 1968]. As is illustrated by the schematic model depiction of figure 1, these components are linked through material and information flows. The bidirectional arrows in the diagram show two-way causation: cause to effect to cause. These influences do not occur simultaneously and are separated in time. For example, as labor markets conditions change, individuals do not respond immediately to perceive job opportunities since there are information delays. In addition, in the housing market, the decision to construct new housing does not result in the immediate completion of the proposed units since the housing market experiences planning and construction delays.

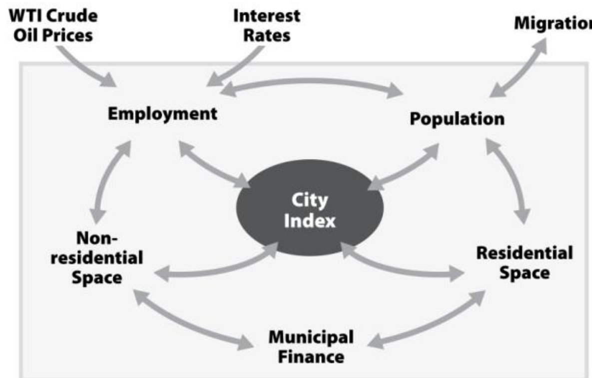

Figure 1: Schematic model.

Population growth creates an increase in demand for municipal services. The municipality draws on its tax assessment base to finance the payments for the services it provides and attracts businesses and population by the availability of municipal services, jobs and housing. The tax assessment base is comprised of houses and non-residential structures. The values of the residential and non-residential tax assessment bases are determined in their respective markets. The product of the quantity demanded and the associated price in the property markets result in the total assessed value for a given market.

The evolution of the population is calculated by the cohort-survival method. The cohort-survival method was first proposed by the English economist Edwin Cannan (1895), and was then re-introduced by Whelpton (1936), formalized in mathematical terms by Leslie (1945), and first employed in producing a global population projection by Notestein (1945). Since then, this method has become the dominant means of projecting population and has remained essentially unchanged. A fundamental feature of the method is that the projected size and age structure of the population at any point in the future depends entirely on the size and age structure at the beginning of the period and the age-specific fertility, mortality, and migration rates over the projection period. The module is described by the following mathematical equations:

$$POP_{s,0}^{t} = B_{s}^{t} - D_{s,0}^{t} + NM_{s,0}^{t}, \forall s \in \{female, male\}$$
$$POP_{s,a}^{t} = POP_{s,a-1}^{t-1} - D_{s,a}^{t} + NM_{s,a}^{t}, \forall a \in [1,89]$$
$$POP_{s,a\geq 90}^{t} = POP_{s,a\geq 89}^{t-1} - D_{s,a\geq 90}^{t} + NM_{s,a\geq 90}^{t}$$
$$POP^{t} = \sum_{s}\sum_{a} POP_{s,a}^{t}$$
$$BAB_{a}^{t} = POP_{f,a}^{t} * FR_{f,a}^{t}, \forall a \in [13,45]$$

$$B_s^t = \left(\sum_{a \in CB} BAB_a^t\right) * SF_s^t, with\ CB = \{13, 14, \dots, 45\}$$

$$B^t = \sum_s B_s^t$$

$$D^t = \sum_s \sum_a D_{s,a}^t = \sum_s \sum_a (POP_{s,a}^t * DR_{s,a}^t)$$

$$NM^t = \sum_s \sum_a NM_{s,a}^t = \alpha_{NM} * TLFC^{t-1} * (UR_R^t - UR_C^t)$$

where:

$POP_{s,a}^t$: population of gender s at age a at time t

POP^t: total population of both genders at all age level at time t

BAB_a^t: babies born at time t by mothers at their age a

B_s^t: births of gender s at time t; and B^t: total births at time t

D^t: deaths at time t

CB: child bearing age group

$FR_{f,a}^t$: fertility rate for female at their age a at time t

$DR_{s,a}^t$: death rate for gender s at their age a at time t

SF_s^t: sex factor for gender s at time t

$NM_{s,a}^t$: net in-migration of gender s at age a in period t; and NM^t is the total in-migration in period t

α_{NM}: multiplier of net in-migration, constant

$TLFC^{t-1}$: total labor force of Calgary in previous period

UR_C^t and UR_R^t: unemployment rates in Calgary and the rest of the country at time t respectively

Net in-migration is a major driver of population change in Calgary, and is itself largely driven by the local labour market conditions relative to the remainder of Canada. For example, if the unemployment rate in Calgary is lower than that in the rest of the country, then the local market would attract people from other cities, provinces, or even overseas. Additional factors affecting migration include aspects of quality of life (as quantified in the model through the “City Index”), such as recreational space, safety, affordability of housing, etc.

Employment in Calgary within the model is calculated by a simple econometric model. As a small open economy, Calgary has a specific industrial structure which depends on the production of oil and gas in Alberta. As a result, the price of natural resources – and especially crude oil price[2] – disproportionately impacts the employment market in Calgary. Higher oil price leads to more business investment in oil production and services industries, which generates greater demand for employment in Calgary. The interest rate[3] is also included in the econometric analysis, since it measures the costs of investment. The relationship between these factors is specified as follows:

$$Employment = \alpha_0 + \alpha_1 * WTI_{price} + \alpha_2 * (WTI_{price})^2 + \alpha_3 * Interest_{rate} + \epsilon^t$$

where WTI_{price} denotes the price of West Texas Intermediate Crude oil.

By using time series data from 1990 to 2009, ordinary least squares regression yields the estimation results for the coefficients in the above equation, which are substituted into the formula for employment in Calgary Economic Region in the CIAM model.

For ease of representation, the business structures and the housing sectors are visually grouped together as a real estate sector; separate sets of stocks are maintained for each sector. Both real estate markets are represented by two internal feedback loops: demand and supply. These loops are driven by vacancy rate and the market price (figure 2). An increase in the vacancy rate exerts downward pressure on the market price and causes adjustments to both the demand and supply sides of the market. On the supply side, this causes property developers to adjust their future price expectations downwards. Because of lower than forecasted profit margins, developers will scale back on the amount of new construction. As a result, the amount of new space that will be added to the stock of space over time will be reduced. However, construction is associated with significant delays, and the model captures the presence of a stock of real estate under construction.

[2] Oil prices are set in international markets and consequently, oil prices were deemed to be exogenous to the model

[3] Short-term interest rates, in Canada, are set by the Bank of Canada and therefore were considered to be exogenous to the model.

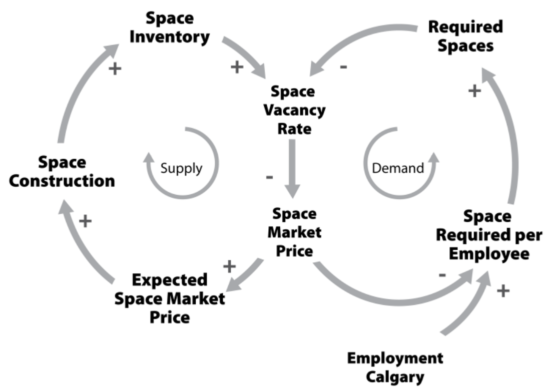

Figure 2: Non-residential space module.

The housing market (represented below) is used to illustrate the workings of the real estate sector. The paper adopted the stock-flow methodology from previous studies to simulate the unstable and cyclic behavior of price and to show that the lag in the supply is the major reason causing cycles [Wheaton, 1999; Ford, 2009; Hanieh et al., 2010]. The formulation of the stocks on the supply side in the model follows work by Mashayekhi et al. (2009) and Atefi et al. (2010). On the supply side, an increase in completed residential housing construction increases the vacancy stock on the market, which depresses the market price for housing. A lower price level results in a reduction in the number of housing units started, which leads to lower levels of the vacancy stock. If the demand for residential housing is the same, a lower vacancy stock will cause an increase in the price. The model is able to simulate the cycles in price changes in the residential market.

The demand for residential housing comes from the number of families in need of housing and the price of housing. The number of families who are in need of houses is determined by the difference between the total households in Calgary and the households which have housing. On the demand side, assuming that all other things are equal, an increase in the total number of families will result in an increase in demand for housing which reduces the vacant stock of residential housing and causes the vacancy rate to decline. At a lower vacancy rate, upward pressure is exerted on the market price for housing. The higher housing price will cause the average mortgage payments to increase, thus resulting in a higher qualifying income for new home purchasers. As the qualifying income increases, the fraction of families that are qualified declines and as result, the demand for housing will fall.

Reflecting pricing "inertia", the price of housing is shown as an accumulation of price changes over time: price is modeled as a stock variable whose flow reflects changes is determined by the demand-supply ratio. The change in house prices is represented as an inverse function of the vacant stock: the lower the vacant stock, the higher the price increase. Housing demand and supply affects the equilibrium of the model through the changes of residential housing price.

The supply side of the housing market is shown as a supply chain representing housing stock at various stages, where each stage is subject to a time delay. Structures tend to go through a life cycle that is similar to that of people. Buildings are constructed; age, and eventually they are demolished as they become obsolete. This process is depicted in figure 3, which shows that the stock of buildings will remain constant if the rate of demolition equals the rate of construction. If construction exceeds demolition, the overall building stock will increase, and the opposite will occur if demolition outstrips construction.

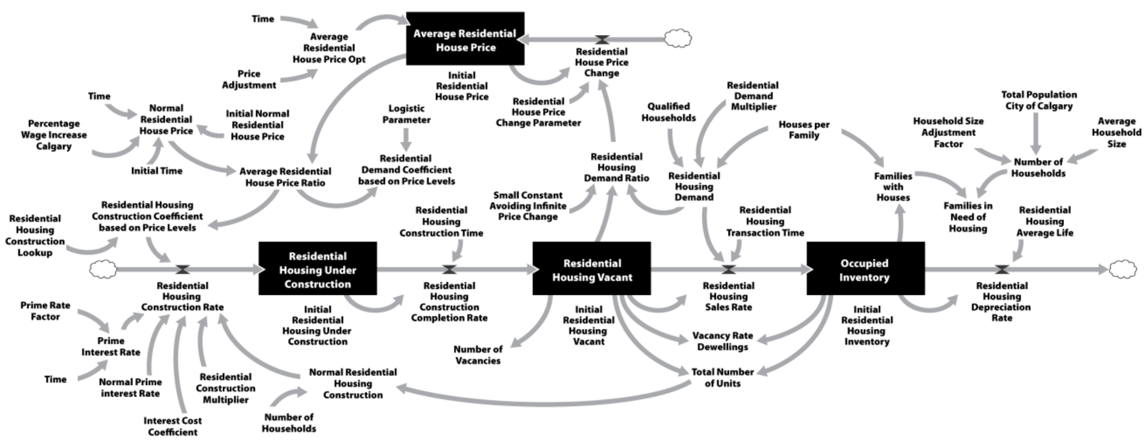

Figure 3: Residential housing module.

This supply sub-structure is represented by the following equations:

$$RH_C^t = RH_C^{t-1} + HC_R^t - CC_R^t = RH_C^0 + \sum\nolimits_{i=1}^{t} (HC_R^i - CC_R^i)$$

$$= RH_C^0 + \sum\nolimits_{i=1}^{t} (F_3\left({HP_R^i}\Big/{HP_R^0}\right) * \overline{HC} + \alpha_{IC} * (\overline{PIR} - PIR_i) - \frac{RH_C^i}{T_{HC}})$$

$$RH_V^t = RH_V^{t-1} + CC_R^t - HS_R^t = RH_V^0 + \sum\nolimits_{i=1}^{t} (CC_R^i - HS_R^i) = RH_V^0 + \sum\nolimits_{i=1}^{t} (\frac{RH_C^i}{T_{HC}} - \frac{RH_V^i}{T_{HT}})$$

$$RH_O^t = RH_O^{t-1} + HS_R^t - DR_R^t = RH_O^0 + \sum_{i=1}^{t}(HS_R^i - DR_R^i)$$
$$= RH_O^0 + \sum_{i=1}^{t}(\frac{RH_V^i}{T_{HT}} - \frac{RH_O^i}{T_{DR}})$$

$$RH_I^t = RH_V^t + RH_O^t$$

$$VR^t = \frac{RH_V^t}{RH_V^t + RH_O^t} = \frac{RH_V^t}{RH_I^t}$$

$$HP_R^t = HP_R^{t-1} + PC_R^t = HP_R^0 + \sum_{i=1}^{t} PC_R^i$$

$$PC_R^t = \alpha_{P1} HP_R^t * Ln(\frac{\alpha_{P2} + HD^t}{\alpha_{P3} + RH_V^t})$$

$$HC_R^t = F\left({HP_R^t}\middle/{HP_R^0}\right) * \overline{HC} + \alpha_{IC} * (\overline{PIR} - PIR_t)$$

$$CC_R^t = RH_C^t / T_{HC}$$

$$HS_R^t = RH_V^t / T_{HT}$$

$$DR_R^t = RH_O^t / T_{HDR}$$

$$HD_R^t = QH_t * HPF_t * RDM$$

$$FNH^t = NH^t - RH_O^t / 1$$

where:

RH_C^t: number of residential housing under construction at time t

RH_V^t: number of vacant stock of residential housing at time t

RH_O^t: number of occupied residential housing at time t

RH_I^t: number of total completed residential stock at time t

VR^t: vacancy rate of residential housing at time t

HP_R^t: average residential house price at time t

PC_R^t: residential house price change at time t

α_{P1}: residential house price change parameter, constant

α_{P2} and α_{P3}: small positive constants to avoid infinite price change in the ratio of residential housing demand HD^t/RH_V^t

HC_R^t: residential housing construction in period t, while $\overline{HC}$ represents normal residential housing construction

α_{IC}: coefficient of interest costs, constant

PIR_t: prime interest rate at time t, while $\overline{PIR}$ represents the normal prime interest rate

CC_R^t, HS_R^t, and DR_R^t: construction completion rate, sales rate, and depreciation rate of residential housing in period t

T_{HC}, T_{HT}, and T_{HDR}: time of construction, transaction and depreciation respectively for residential housing

FNH^t: number of families in need of housing at time t

NH^t: number of households at time t

HD_R^t: residential housing demand at time t

QH_t: qualified households in Calgary which could afford a residential house at time t

HPF_t: number of houses per family at time t

RDM: residential demand multiplier, constant

On the demand side of the housing market, the variable ‘qualified households’ (QH_t) is endogenous, and reflects housing affordability in Calgary. The house payments depend on mortgage payments, property taxes and utility costs. All of the three cost components are determined by the average residential housing price. Mortgage payments are calculated by the average house price and the mortgage rate. Municipal taxes are calculated by multiplying the assessed value of the dwelling by the mill-rate in effect for residential housing. The utility bill for an average household is assumed to be the utility cost rate multiplied by the assessed value of the property. The total house payment further determines the minimum annual income required to purchase a property (which equals to house payment dividing by 0.32, the debt ratio, which is usually around 32 per cent). Comparing this minimum requirement with the household income distribution table for

Calgary shows the percentage of households who are judged as able to afford to buy a house.

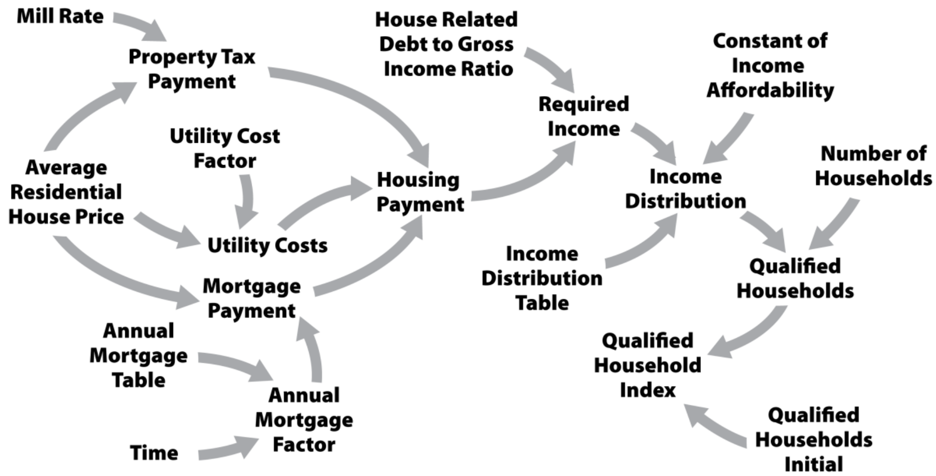

Figure 4: Residential house payment and qualified households.

In the above module, we have the setup in the following mathematical equations:

$$PT_R^t = HP_R^t * MR_R^t$$

$$UC_R^t = HP_R^t * UCF^t$$

$$MP^t = HP_R^t * AMF^t$$

$$HPM^t = PT_R^t + UC_R^t + MP^t = HP_R^t * (MR^t + UCF^t + MF^t)$$

$$RINC^t = DBR * HPM^t$$

$$INCD^t = f_{Inc}(RINC^t) * \alpha_{INC}$$

$$QH^t = INCD^t / NH^t$$

$$QHI^t = QH^t / QH^0$$

where:

PT_R^t: property taxes for a residential building at time t

UC_R^t: utility costs for a residential building at time t

MP^t: mortgage payment for a residential building at time t

HPM^t: total house payment for a residential building at time t

MR_R^t,UCF^t, and AMF^t: residential mill rate, utility cost factor and annual mortgage factor respectively

$RINC^t$: required income level to afford a house at time t

α_{INC}: income affordability adjustment coefficient, constant

DBR: house related debt to income ratio which is used to measure the affordability of a household for a loan, constant

$INCD^t$: income distribution determined by the required income at time t

QH^t: qualified households with the affordability to buy a house at time t

QHI^t: qualified households index at time t

The municipality provides services for the public, collects property taxes and business taxes, and charges service fees to maintain its fiscal budget. Services are produced by a combination of labour and capital stocks, spread across a broad set of business units. In each business unit of the municipality, the capital stock module is based on the stock adjustment principle and "goal seeking behaviour" typical of a first-order delay: the actual stock is constantly adjusting to bring it closer to the "ideal" stock. This is shown in figure 5. The required capital stock is determined by multiplying the city's population times a service standard. The actual capital stock is increased by investment and reduced by depreciation. A comparison of the required capital stock against the actual (or "available") capital stock provides an estimated of the gap or surplus of the capital for the business unit. Since the municipality faces a budget constraint, investing in new and replacement capital would be limited by the size of the funds that is available to fund capital investment.

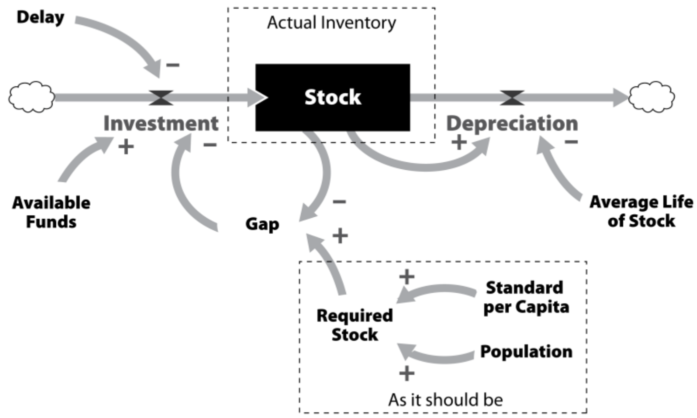

Figure 5: Summary of the municipal finance system.

The municipal debt module is represented in the figure 6. The amount of debt outstanding is increased by the amount of new debt issued and decreased by the amount of debt repayment. The municipality's ability to issue new debt is limited by its debt capacity, which is a function of the overall assessment base. Payment of the city's debt results in a reduction of the amount of money that the city sets aside each year to meet the payments on the principal (debt obligation) and interest (cost of debt) [Ansah 2010].

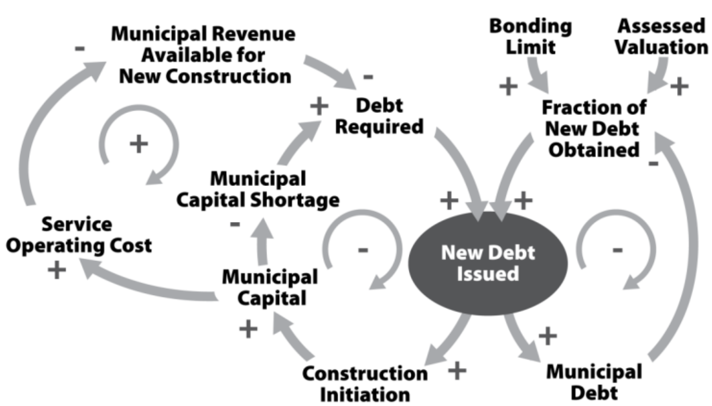

Figure 6: The municipal debt module.

The municipal mill rate is generally set annually by Calgary's City Council at budget finalization. As a result, at the conceptual level, the mill rate serves as a policy variable. However, the model currently assumes that the City's budget is always in balance and as a consequence, the mill rate is modelled as an endogenous variable. The City taxes property to close the gap between total operating expenditures and total revenues from non-tax sources. The mill rate is therefore defined as the ratio of the tax levy to the total property assessment base.

The City capital funding requirement is determined within this sector of the model. It represents the money value of the total of all the service gaps in the municipality. The model assumes that the gap would be funded through municipal taxes and the remainder through the issuance of debt. The model assumes that the City's debt at a given time cannot exceed twice its revenues. As a result, the City faces a budget constraint in the funding of its capital deficiency.

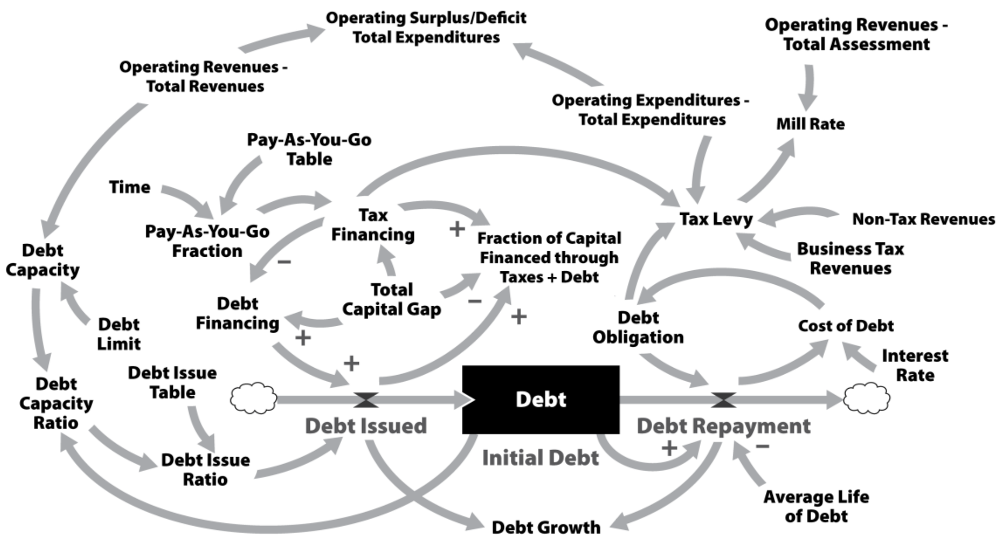

Figure 7: The municipal finance system.

In the above module (figure 7), the relationships are given by the following mathematical equations:

$$DB^t = DB^{t-1} + DBI^t - DBP^t = DB^0 + \sum_t (DBI^t - DBP^t)$$

$$DBG^t = DBI^t - DBP^t$$
$$DBP^t = DB^t/ALD$$
$$CDB^t = DBP^t * I^t$$
$$DBO^t = DBP^t + CDB^t$$
$$FCG^t = (DBI^t + TF^t)/GAP^t$$
$$DBF^t = GAP^t - TF^t$$
$$TF^t = PAYG^t * GAP^t = PAYG(t) * GAP^t$$
$$TL^t = DBO^t + OE^t + TF^t - BTR^t - R_{NT}^t$$

$MR^t = TL^t/ORA^t$
$OSD^t = OR^t - OE^t$
$DBC^t = DBL * OR^t$
$DBCR^t = DB^t/DBC^t$
$DBIR^t = f_{DB}(DBCR^t)$
$DBI^t = DBF^t * DBIR^t$
where:
DB^t: total debt of municipality of Calgary at time t
DBI^t: debt issued at time t
DBP^t: debt payment at time t
DBG^t: debt growth at time t
ALD: average life of debt
CDB^t: costs of debt caused by interest payment at time t
DBO^t: debt obligation at time t
FCG^t: fraction of capital gap financed at time t
TF^t: tax financing at time t
$PAYG^t$: pay-as-you-go fraction of the total capital gap at time t
MR^t: mill rate at time t
OSD^t: operating surplus or deficit at time t
DBC^t: debt capacity at time t
DBL: debt limit
$DBCR^t$: debt capacity ratio at time t
$DBIR^t$: debt issue ratio at time t

The municipal employment sector functions in the same manner as the capital stock sector; it is based on the stock adjustment process. The need for municipal personnel within a particular business unit is estimated by taking the product of the population and the average number of personnel needed to serve a citizen. The demand for city personnel is compared against the existing pool of employees – including those distinguished as junior, experienced and senior level employees. If at any time the demand for city personnel exceeds the supply (the current level of employees), there exists a personnel gap. This gap could widen if the population grows at a faster pace than the supply of personnel. The cost of the personnel gap is estimated by taking the product of the personnel gap and an average salary per personnel.

The five modules of the model are connected by City Index, which measures the local area's attractiveness to individuals and businesses. The index is a weighted average of seven variables including safety, transportation, municipal infrastructure, recreation conditions, housing affordability, employment market conditions, and office abundance in the city:

$$CI^t = \sum_{i=1}^{7} CI_i^t * W_i$$

Where i represents the above seven aspects, respectively. W_i indicates the weight of each aspect which affects the living conditions, and CI_i^t represents the sub-index of each aspect which is constructed by taking the ratio of the current (per capita) value with the initial per-capita level.

5. Model Parameterization & Calibration

While simulation models evolve according to model structure, the particulars of that evolution are shaped by model parameter values. Model parameters might give, for example, the elasticity of the price of housing based on demand, the cost required to construct 1km of a 1-lane road way, or the amount of office space required for a single full-time employee. The behavior exhibited by the model in the first years of simulation will also tend to be significantly affected by the starting point of the model – the initial values of model stocks that capture the current state of the model. Because model behavior – and the relative desirability of policies – will generally depend on parameters and initial state, the construction of models to be used in planning seeks reliable estimates for these quantities.

As is typical for systems models, data required for the CIAM model (in the form of model parameters and initial model states) was estimated from a variety of sources. Particularly important sources include City of Calgary annual reports, census-based demographics data, oil price history, etc.

While parameterization can provide much valuable data for model construction, it is common for a modeler to lack direct data on certain model parameters or certain aspects of model state. At the same time, it is common to have data on some (and sometimes many) "resultant" aspects of system behavior proximally or distally related to such parameters. For example, the CIAM model includes an articulated representation of the staff progression, promotion, hiring and retirement across each of multiple business units. However, we currently lack direct data on certain factors, such as the breakdown of Full-time Equivalent (FTEs) by experience level in each business unit. However, we do have data on overall staffing levels, and some sense of the demand that drives hiring, and of the general dynamics of staff progression. While no one piece of such miscellaneous data permits direct deduction all of the parameter values of interest, the fact that the observed phenomena are *influenced by those parameters*, means that they implicitly provide information on – and constraints regarding – the underlying values of parameters that shape them.

In such circumstances, System Dynamics commonly seek to use *calibration* to estimate model parameters. Within the calibration process, we seek to adjust model parameters for which little data is available so as to allow the resulting model output to best match observed patterns of historic data. In certain cases, this process can yield a good fit to the historic data. While the parameter values so derived are not guaranteed to be correct, they serve as at least a plausible assignment of values for the parameters – one that is consistent with what has been observed within the system. As a result, he resulting model as a whole can be viewed as a plausible dynamic hypothesis regarding the processes at work within the real world.

This process can not only aid us in estimating parameter values, but also commonly provides insight on the need for model refinement, and helps identify research priorities.

Far from being a routine, standardized procedure, the calibration process typically forces close scrutiny of many model assumptions and data sources. A model's structure determines the broad classes of behavior to which it can give rise. Despite adjusting a variety of model parameters, an initial model structure frequently fails to match the given historic data – at all, or within plausible ranges for model parameters. Because an initial first match is rare, modelers commonly scrutinize and revise model structure and the relationships between model variables, and/or double-check and correct any problems in the assumed historic data. One of the greatest values of calibration is its capacity to signal the necessity of further refinement of model structure.

In other cases, model calibration may be adequate, but there are many possible ranges of one or more parameters that give satisfactory matches. This suggests many possible interpretations of the available data. Identifying such ambiguities often aids in prioritizing research.

The Calgary model went through an extensive and rigorous procedure to arrive at model parameter estimates, including an extensive parameterization phase and an iterated and intensive calibration phase. Calibration was conducted over the period 1990-2008 with respect to several dozen time series, spanning a wide variety of aspects of City of Calgary operations and aspects of the economic context. Different time series were given different weight, to reflect the perceived importance of the data being matched to model purpose, and the reliability of the data.

5.1 Model Testing

In addition to being subjected to an extensive and prolonged calibration procedure, the CIAM model went through a rigorous set of additional checks, including unit testing and peer review. Unit tests on the model were conducted to confirm that model calculations were semantically sensible. Such tests can identify some of the most common – but insidiously latent – forms of model error. Peer review was conducted during the summer of 2010by a 4-person graduate-level modeling team at the University of Saskatchewan, and involved systematic variable-by-variable inspection across the model. Criteria considered in critiquing the model included not just outright model errors, but also aspects of model transparency and risks, such as vulnerabilities to misunderstandings and exposure to future errors. Specifically, the review considered the model scope, formulation issues, ambiguities, unit concerns, transparency, naming, subscript inconsistencies, fragility of the representation, documentation, stylistic inconsistencies, dependency on manifest constants, and visual layout. This peer review process involved close study of model design and implementation, and identified items that required resolution. The model was revised to reflect the findings of the peer review, yielding a far stronger final model.

Adapting best practices from software development area, the model was also adjusted to incorporate an "assertions" sector so as to notify the modeler of and terminate problematic scenarios – specifically, cases where values of stocks went negative in a non-physical fashion. This sector proved particularly useful during the model calibration process, by allowing for the early termination of scenarios that yielded infeasible trajectories for model stocks.

6. Model Applications

The model was used to simulate the effects of the following: (1) higher oil prices and (2) the imposition of a one per cent payroll tax. The effects of these changes were measured by comparing how a given variable would change when compared against its baseline value. The baseline values were the estimated values from the 1990-2009 period. The study therefore asked the counter-factual question of how history would have been different if a particular policy was in place. In this case, such an (ex-post) analysis is superior to the alternative approach (ex-ante) because the analyst is able to sidestep challenges about the reasonableness of various assumptions surrounding the base case.

6.1. Higher economic growth

- Higher economic growth was achieved over the 1990-2009 period by assuming higher oil prices.

- **Policy**. This simulation examines the financial impact on the municipality if the price of West Texas Intermediate (WTI) crude oil would have been ***20 per cent higher*** during the analysis period (1990 - 2009).

- **Assumption**. The model assumes that crude oil price would have an impact on total employment since Calgary is home to most of the energy companies operating in Alberta.

- **Results. In a result that is counter-intuitive from a layperson's perspective,** higher crude oil prices would have placed additional pressure on The City's budget:

    - Total population would have grown faster relative to the base case. An increase in crude oil prices would have increased economic activity in the province and this would demand an increased level of employment. Increased economic activity in the city would attract migrants from outside the region and this would have increased total population.

    - Total operating expenditures would have been higher than in the base case. Providing services to a higher level of population would have required increased investments in capital, causing operating expenditures to increase.

    - Total debt would have been higher relative to the base case as The City finances capital through taxes and debt. This scenario would require an increase in borrowing to finance the increased level of capital due to an increase in population.

    - The simulation shows higher economic growth and has a more adverse effect on The City's financial position.

    - Total gap would grow faster under this scenario. The City would have been unable to close the gap as population growth would have outpaced investment in capital.

6.2 Impose a one per cent payroll tax on the total wage bill

- The simulation in the previous section suggests that The City does not benefit from economic growth. The current simulation illustrates how this could be rectified by using a growth sensitive revenue source.

- **Policy**. This scenario examines the financial impact on the municipality if The City had received ***1 per cent*** of the total wage bill in Calgary during the analysis period

(1990-2009). This revenue would have been distributed evenly between financing capital projects and non-tax revenues.

- **Assumption**. The model assumes that an increase in funding and revenues would increase investment in capital and reduce The City's total debt.
- **Results.** Increased level of funding and revenues would have placed less pressure on The City's budget:
    - Total tax financing would have increased significantly compared to the base case. This would allow The City to fund major capital projects and thereby reduce the total gap.
    - Total operating expenditures would have been higher than in the base case. Providing services to a higher level of population would have required increased investment in capital, causing operating expenditures to increase.
        - Total debt would have been lower relative to the base case as The City finances capital through an increase in funding. This scenario would require a decrease in borrowing.
        - Total gap would grow slower under this scenario. The City would have been able to close some of the gap.

6.3 Possible Model Uses

The CIAM model is a rigorously calibrated, carefully constructed, and relatively detailed quantitative model. Such a model supports a wide variety of uses. These uses include – but are not limited to – the following:

- **Comparing anticipated outcomes of different policies.** Policies under examination could impact any number of factors represented in the model – for example, changes in tax regimes (such as different types of taxes or balance of taxes gathered), investment in types of infrastructure (e.g. LRT or roads), levels of developer contribution for development, changes in FTE hiring thresholds or salary structure, etc.
- **Identifying vulnerabilities to changes in external conditions.** For example, the model could be run to examine the impact of changes in oil prices, to interest rate variation, to unemployment rates externally, to the relative level of speculation involved in the real estate market, etc.
- **Finding the most effective ways to respond in an ongoing way to unfolding changes in external conditions over time.** While the driving factors underlying

external factors such as oil prices, interest rates, and Canada-wide employment patterns lie outside the scope of the model, such factors both change significantly over time and are highly uncertain in their evolution. In evaluating the tradeoffs between different policies, it is thus prudent to examine policy outcomes with respect to multiple "possible futures" involving such external factors. Moreover, given that the likelihood that the effectiveness of different policies will in general depend on the trajectories assumed for such external factors, it makes sense to revisit policy decisions on an ongoing basis, as factors such as changes in oil price, interest rate variation and Canada's employment situation unfold over time. A model such as that introduced here can be combined with well-established decision analytic techniques to do exactly that [Osgood 2005, Osgood and Kaufman 2003]. Such techniques can allow the user to identify the ways in which the apparent best choice of policy depends on external conditions on an ongoing basis – and, most importantly, the best choice of policy now in light of the future uncertainties and policy opportunities that lie ahead.

- **Identifying key uncertainties that would motivate collection of additional information.** The assumption of particular values or fixed trajectories for model parameters is often associated with some degree of uncertainty. However, not all of this uncertainty regarding a parameter's value is of equal concern. Variation in some parameters will have a disproportionate impact on the likely future path of evolution of Calgary's municipal finances, while a corresponding level of variation in other parameters may have modest or negligible effect. Even more importantly, such variation can have very different levels of impact on the apparent desirability of different possible policies. Sensitivity analysis using a model such as that presented here can help us evaluate the degree to which it is worth making an investment in staff time to reduce uncertainty associated with a parameter.
- **Assessing the timing with which a given policy would be expected to demonstrate results, or with which a change in external eventualities would yield an impact.** As noted in the introduction to this paper, municipal financial planning in the City of Calgary must operate in the presence of myriad delays. The effects of policies will typically play out at different timescales, with some effects being manifested soon, and some later. Failure to understand these effects can lead to serious policy missteps. For example, many highly effective policies manifest the phenomenon termed "worse before better": The immediate effects of the policy experienced may be primarily negative and only later do the benefits arrive, and only then overwhelm the initial negative impression. The inability to quantify the delays involved can lead to misinterpreting the early typical impacts of a policy success as a policy failure, to overreaction, and to premature changes or discontinuation of the policy. Conversely, the ability to recognize such effects can

allow appropriate notifications to be given, so as to set expectations in line with likely policy dynamics.

- **Identifying ways that the relationship between different agencies or organizations could be shifted so as to yield greater efficiencies, or reduced vulnerabilities to eventualities.** Municipal operations within the City of Calgary involve a wide variety of business units, both customer-facing and otherwise. Such offices are linked through a variety of mechanisms and feedbacks (both material and informational). The model could be used to examine the impact of changing those relationships. For example, we could assess the benefits for decision making (and potential cost savings) accruing from making investments so as to lower reporting delays.
- **Serving as a communication tools with external stakeholder groups.** There is a long tradition of engaging diverse stakeholders using "flight simulator" interfaces for models. Such systems —sometimes termed "learning support systems"— can aid even highly non-technical stakeholders in understanding challenges associated with decision making regarding complex systems.
  While the CIAM model contains diverse technical details, it could be provided with such a user-friendly interface. Such an interface could allow users to explicitly change model assumptions using familiar language and show results in terms they can understand (e.g. debt levels, size of the housing pool, city index, kilometers of LRT or of roads, etc.), while hiding the implementation details underlying such calculations. An interface such as this could be used to communicate the challenges associated with municipal financial planning in Calgary to other groups – both external groups (e.g. community organizations, Chamber of Commerce, etc.), and potentially other business units within the City.

While the above list offers a wide variety of possible model uses, there are other uses for which that the existing model is ill-suited. The most important type of model use to avoid is one that seeks to use the model as a "crystal ball" of sorts, offering future point-predictions of trends. It is only rarely that models can be successfully used in this capacity. This reflects two major facts about models.

Firstly, like most models, the CIAM model depends in important ways on some exogenous factors – factors whose evolution lies outside the control of the municipal government (see Table 1). As is commonly the case, the prediction of key exogenous factors for the CIAM model is difficult: Oil prices, unemployment rates and interest rates are all the subject of considerable speculation among economists and within the financial industry. Given the dependence of the model on assumptions regarding such factors, any simulation of the model will of necessity need to make some assumption regarding the pattern of changes in these exogenous factors over time. If it turns out that the exogenous factors evolve in a significantly different fashion than is assumed in the particular scenario run, the model predictions of future evolution will likely be significantly off. If the original scenario was used to assess the tradeoffs obtaining between different policies, those tradeoffs may be quite far off from what obtains in practice, because of the discrepancies in external conditions involved. (We note that the decision analytic methods proposed above can help to address some, but not all, of such concerns.)

Secondly, while they can still be useful, all models are incomplete. Even given correct guesses as to how major exogenous factors (such as oil prices) will evolve, looking to a model to provide a point-prediction of the system behavior far in the future will almost certainly eventually lead to disappointment. Even for the most well-considered and well-calibrated model, it is to be expected that the model will increasingly diverge from observations at a quantitative level. There are areas where the model formulation would be known to benefit from further refinement; examples would be the representation of speculative investment in the real estate market (which may miss some relevant feedbacks), and possible limitations of the econometric representation linking employment with oil prices and others factors (which may, for example, inadequately capture the feedback and ripple-through effects whereby new jobs help stimulate additional jobs, both directly and through clustering and other phenomena). The model may at present constitute the least bad of the alternatives for examining issues related to future evolution of the system, but it is critical that it still be used with caution and evolve in response to learning about the system, problems and reference modes whose dynamics it seeks to characterize.

7. Conclusion

The model described in this paper opens up considerable opportunities for the City of Calgary. If properly used, it could serve as the initial step in a series of contributions of thinking tools to empower municipal financial planning, aid inter-unit coordination, and to identify key gaps in knowledge that could improve decision-making in the context of an external environment of growing complexity and uncertainties. The successful creation and ongoing use of a quality decision-making tool such as CIAM requires an investment of staff time, training efforts, and initiatives to update, critique and refine the model, etc. While these investments impose opportunity costs and offer benefits that may be less tangible and immediate than for some other types of efforts, these costs are likely to be far outweighed by the benefits stemming from increases in the clarity of municipal decision making. In addition to the benefits conferred for decision-making by the availability of the model itself, the modeling process itself can offer significant value by supporting ongoing reflection on the state of understanding of operations across the city. An investment by the City of Calgary in a modeling process such as that documented in this paper could also contribute to a broader shift towards becoming a “learning organization” – an organization seeks to move beyond reactive response to external conditions, that consciously makes proactive investments to better understand the nature of the choices that stand before it, that considers more clearly the tradeoffs associated with those choices, and which invests to refine this learning process over time. In an environment fraught with dynamic complexities and uncertainties, the model described in this paper could be an important first step in the City of Calgary seizing the capacity opportunity to set its direction with greater effectiveness and confidence.

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