This simple model captures basic interactions between population, housing and businesses. Constructing the model should take 45 to 60 minutes if you follow the instructions carefully. To help you out, italics highlight the model variables. Considering there is limited time, don't bother commenting the variables – but do ensure they have units! It is also not necessary to include link polarities, loop identifiers or any other form of documentation. Just to be sure, this assignment has 10 questions! Submission criteria are on the last page. Tip: brevity is a virtue in your writeup. It is also not necessary to show all output and display dozens of graphs in your document.

Population
The size of the *population* of a new town changes through *immigration*, *births*, *emigration*, and *deaths*. Suppose that the new town you are about to model already has 50000 inhabitants, and has a *birth rate* of 3%, and a *death rate* of 1.5%. Assume that there is constant *emigration* with a *normal emigration rate* of 7% per year. *Immigration* could be modeled as the product (multiplication) of the current *population*, the *normal immigration rate*, the *job availability multiplier for immigration*, and the *housing availability multiplier for immigration*. This *housing availability multiplier for immigration* is a function of the *households to houses ratio*: suppose that if the *households to houses ratio* equals 1, the multiplier equals 1, that if the *households to houses ratio* equals 1.5, the multiplier equals 0.25, that if the *households to houses ratio* equals 2, the multiplier equals 0, that if the *households to houses ratio* equals 0, the multiplier equals 1.4, and that if the *households to houses ratio* equals 0.5, the multiplier equals 1.3. The number of *households* depends on the size of the *population* and the *average size of households*, equal to 4. Suppose that the *normal immigration rate* equals 10%.

Housing
The number of *houses*, initially equal to 14000, increases by means of *construction of houses* and decreases through *demolition of houses*. The average *demolition rate of houses* (without additional policies) equals 1.5% per year. The *construction of houses* could be modeled as a 3*rd* order delay (delayed with 2 years) of the product of the *land availability multiplier for houses*, the *housing scarcity multiplier*, the number of *houses*, and the *construction rate of houses* of 7% per year. The *housing scarcity multiplier* is a function of the *households to houses ratio* connecting following points (0, 0.2), (0.5, 0.3), (1, 1), (1.5, 1.7), and (2, 2). The *land availability multiplier for houses* is a function of the *land fraction occupied*: for a *land fraction occupied* of 0% the multiplier equals 0.4, for a *land fraction occupied* of 25% the multiplier equals 1, for a *land fraction occupied* of 50% the multiplier equals 1.5, for a *land fraction occupied* of 75% the multiplier equals 1, and for a *land fraction occupied* of 100% the multiplier equals 0. The land fraction occupied corresponds to the sum of the land use of all businesses and the land use of all houses, divided by the *total area*. Suppose that the useful *total area* of the new town is 5000 hectare, that the amount of *land per house* is 0.05 hectare, and that the amount of *land per business* (i.e. for each business structure) is 0.1 hectare.

Business and Labor Force
The number of *businesses* (i.e. business structures), initially 1000 business, increases through *construction of business structures* and decreases through *demolition of business structures* with an average *demolition rate of business structures* of 2.5% per year.
Construction of business structures could be modeled as the multiplication of the *land availability multiplier for business structures*, the *business labor force multiplier*, the number of *businesses*, and the *construction rate of business structures* of 7% per year.

This *land availability multiplier for business structures* is a function of the *land fraction occupied*: the multiplier is of course 0 for 100% of the land fraction occupied, it equals 1 for 0% of the land fraction occupied, and it equals 1.5 for 50% of the land fraction occupied. The *business labor force multiplier* is a function of the *labor force to jobs ratio* connecting (0, 0.2), (0.5, 0.3), (1, 1), (1.5, 1.7), and (2, 2). The aforementioned *job availability multiplier for immigration* is also a function of the *labor force to jobs ratio* connecting following points (0, 2), (0.5, 1.75), (1, 1), (1.5, 0.25), and (2, 0.1). This *labor force to jobs ratio* depends of course on (i) the size of the *labor force* which equals the product of the *population* and the *labor force to population ratio* of 35%, and of (ii) the number of *jobs* which equals the number of *businesses* times the *initial number of jobs per business structure* which amounts to 18 FTEs.

Model the following two key performance indicators too: the *unemployment ratio* and the *housing vacancy ratio*. Both are per definition between 0 and 100%.

1.Create the model.

2. Simulate over a long time horizon of 200 years. Make graphs of the evolution of businesses, houses and population as well as their effects on the *unemployment ratio* and the *housing vacancy ratio*. What behavior mode do you observe?

3. Too high a *housing vacancy ratio* leads to urban decay (of entire districts and towns), which in turn influences *immigration* and *emigration*. Hence, model a *slum multiplier for migration*: this multiplier is a function of the *housing vacancy ratio* and connects following points (0, 1), (0.2, 1), (0.4, 0.5), (0.6, 0.1), and (0.8, 0). Adapt the formulations of *emigration* and *immigration* to include this effect (multiply!).

4. Forrester's Urban Dynamics shows that additional demolition of empty bad quality housing in case of high housing vacancy ratios and rezoning could prevent urban decay to kick in or worsen. Thus add a variable *additional demolition rate* to demolish beyond normal demolishing above a 10% housing vacancy ratio. Let the *additional demolition rate* increase linearly from 0% per year for a 10% vacancy ratio to 5% per year for a 15% vacancy ratio, and linearly from 5% per year for a 15% vacancy ratio to 50% per year for a 100% housing vacancy ratio. Add this additional effect to the *demolition of houses* too.

5. Is the combination of these endogenous effects and policy a solution for the problems encountered earlier? Explain. (Have a look at the two performance indicators as well)

6. Land and buildings are used more efficiently in case of land scarcity. Include the following endogenous relation: the *effect of land scarcity on intensity of use of business structures* being a nonlinear function with argument *land fraction occupied* and connecting following (x,y) pairs: (0, 1), (0.5, 1), (0.75, 1.15), (1, 2). This variable has a multiplicative effect on the *jobs* variable. Add a switch (name it '*switch jobs*') that could be used to activate/deactivate this endogenous effect.

7. Plot the two key performance indicators. Is this endogenous effect a solution for the initial problems? If not, briefly explain how the problems have changed.

8. Perform sensitivity analysis to the model by modifying the following variables with +- 30%:
Construction rate of business structures (CBS)
Demolition rate of business structures (DBS)
Jobs per business structure (JPBS)
Labor force to population ratio (LFJR)

Please summarize the outcome of these analyses in the following table by stating the values of the variables of interest (left column), versus parameter changes (right)

Variable of interest:	Base Run	CBS higher	CBS lower	DBS lower	DBS higher	JPBS lower	JPBS higher	LFPR lower	LFPR higher
Land Fraction Occupied (end of simulation)									
Business Structures (end of simulation)									
Population (end of simulation)									
Labor force to jobs ratio (end									

of simulation)									

9. Using your current knowledge of some tested policies and sensitivity of key parameters, propose a set of policies to solve all identified problems. Model this set of policies and show the outcome. (Hint: the overshoot in businesses and houses is not fully resolved with the base policies. How can their growth be tamed?)
10. Name at least 2 different validation tests (excluding sensitivity analysis!) you could perform on this model . Apply these validation tests and briefly describe their results. Hint: Business Dynamics pp. 859-861 contains a table with all validation tests so you don't need to memorize the validation video; keep it simple to save time!

Submission:

- **Model file (dimensionally consistent!)**
- **Solutions document.**