APPENDIX – APPENDIX – APPENDIX – APPENDIX

The cases presented in this paper can be used for self-study and for teaching and testing purposes at other universities **if and only if** the authorship is fully respected and the cases are correctly referred to (e.g. 'developed by Erik Pruyt,. . . ' or after sufficient changes 'based on a case developed by Erik Pruyt,. . . ') even for exam cases. The corresponding SD models and answers will be sent upon request to colleagues willing to exchange cases, not to their students. All models are available in Vensim and some in Powersim; all cases are available in Dutch and in English.

A Prostitution and Human Trafficking (/25) ©Erik Pruyt & András Kővári

This Case was inspired by one of the student projects for the MSc SD project course (Kovari 2011). A slightly more advanced analysis is available in (Kovari and Pruyt 2012).

For centuries, prostitution has been highly cyclic but also amazingly constant. In the 17th century, brothels were openly present in Dutch cities. Between 1806 and 1911 Dutch brothels were regulated and registered. But Christian campaigns lead to the illegalization of Dutch brothels in 1911. Some cities went even further by forbidding any form of prostitution (window prostitution and streetwalking). From the 1970s on, Dutch governments started to recognize that repression of prostitution does not make prostitution disappear. This gradual recognition lead to different policies across different cities, from tolerance to fierce prosecution. The ambiguous status of prostitution in the Netherlands was resolved on 1 October 2000 by the abolishment of the general Dutch brothel prohibition. From 2000 on, prostitutes of age and of their own free will are allowed to work under strick conditions. Although the abolishment of the brothel prohibition partly brought prostitution back to the straight world, it did not end the underlying human trafficking and organized crime. Lodewijk Asscher, Martijn Roessingh and Perdiep Ramesar claim that even in the legalized and regulated business more than half of the women work against their own will and are exploited, and do not use the rights reserved to them. For a few years, several communes and the national government are again more restrictive in view of fighting the underlying human trafficking and organized crime.

Suppose the Dutch government asks you to build and use an explorative SD model in order to investigate the possible consequences of new policies, measures, and actions. Closely follow the description below when constructing your model.

A.1 The Population

The *demand for prostitutes* emanates from the group of *sexually active adults*, initially equal to 12 million: suppose thus that there is no sex tourism. Suppose that this group –that is to say the group of *sexually active adults*– only increases through a flow *from minor to adult* and decreases through a an outflow *loss of sexual activity* after an average *sexual lifetime* of about 45 years. Set the flow variable *from minor to adult* for now equal to the *children* divided by the *age of consent* of 18 years. The number of *children*, initially equal to 4 million, only increases through *births*, equal to the number of *sexually active adults* times the *birth rate* of 0.017 children per person per year.

1. (/2) Model the above description. And make both a detailed and an aggregated causal loop diagram of this model.

A.2 Demand for and supply of commercial sex services

The *demand for prostitutes* is the product of half the *sexually active adults*, the *normal percentage of Johns*, the *effect of societal acceptation on the percentage of Johns*, and the *price effect on the* *demand for prostitution*, divided by an average of 50 *clients per prostitute.* The *normal percentage of Johns* in the Netherlands amounts to 12% (in other words: 12% of Dutch men frequent prostitutes). The *price effect on the demand for prostitution* is a function of the *average price of sex services* connecting following couples: (0, 4), (50, 1.5), (100, 1), (200, 0.5), (400, 0.2), (800, 0.1), and (1200, 0.1). In other words, the *price effect on the demand for prostitution* is equal to 1 if the *average price of sex services* is €100, et cetera. The *average price of sex services* could be modeled as a third order delay of (2 * *naked costs per sex service* * *supply demand effect on the price of sex services*), with a delay time of a year, and an initial value equal to (2 * *naked costs per sex service*). The average *naked costs per sex service* amount to €20.

The *supply demand effect on the price of sex services* is equal to 5 if the *supply demand ratio* equals 0, the *supply demand effect on the price of sex services* is equal to 3 if the *supply demand ratio* equals 0.05, the *supply demand effect on the price of sex services* is equal to 2 if the *supply demand ratio* equals 0.25, the *supply demand effect on the price of sex services* is equal to 1 if the *supply demand ratio* equals 1, the *supply demand effect on the price of sex services* is equal to 0.6 if the *supply demand ratio* equals 2, the *supply demand effect on the price of sex services* is equal to 0.5 if the *supply demand ratio* equals 3. De *supply demand ratio* calculates the *supply of prostitutes* divided by the *demand for prostitutes.*

Suppose that the *effect of societal acceptation on the percentage of Johns* equals (0.5 + *societal acceptation of prostitution*/1.5), with the *societal acceptation of prostitution* equal to a third order delay of the function (1 - *supply of prostitutes*/100000), with an average delay time of 3 years. In other words, societal nuisance increases and societal acceptation decreases from 0 to 100000 prostitutes, and from 100000 prostitutes on nuisance is so big that societal acceptation is 0. Model the *societal acceptation van prostitution* such that it is always between 0 and 1.

In the year 2000, there were 28254 prostitutes in the Netherlands –in other words, the *supply of prostitutes* was equal to 28254 prostitutes. The *supply of prostitutes* increases through *new Dutch prostitutes* as well as through *new foreign prostitutes*, and decreases through the *prostitution outflow.* Suppose the nonnegative flow of *new Dutch prostitutes* equals the product of half the flow *from underage to adult from underage to adult*, de *normal fraction of young Dutch adults open for a job in prostitution*, the *profitability of prostitution*, and the *societal acceptability of prostitution.* Suppose that the *normal fraction of young Dutch adults open for a job in prostitution* –that is, if the circumstances are favorable– equals 1 in 1000. The *prostitution outflow* is equal to the *supply of prostitutes* divided by an *average lifetime in prostitution* of 10 years. The *expected gap between demand and supply* then equals the sum of the *demand for prostitutes* and the *prostitution outflow* minus the *supply of prostitutes.* Model the nonnegative number of *new foreign prostitutes* as the product of the *expected gap between demand and supply* and the *profitability of prostitution.* Foreign prostitutes are likely to be 'supplied' by traffickers. The average '*delivery time*' in women trafficking is on average about a year. And the *profitability of prostitution* is close to the difference between the *average price of sex services* and the *naked costs per sex service*, divided by the *naked costs per sex service.*

Total annual prostitution revenues are then the product of the *supply of prostitutes*, the average *frequency of prostitution visit* per client, the number of *clients per prostitute*, and the *average price of sex services.* Suppose that clients have an average *frequency of prostitution visit* of 24 times per year.

1. (/6) Create a SD simulation model based on the above description and answer the corresponding MC questions.

2. (/1) Simulate the model from 2000 to 2040 and answer the corresponding MC question.

3. (/1) Change the flow variable *from minor to adult* now so that reach majority exactly 18 years after having been born. Use an initial value equal to 222222 persons per year for this flow *from minor to adult.* Save the model, and answer the corresponding MC question.

4. (/2) According to Asscher cs, the Netherlands should consider a ban on prostitution if the situation does not improve with the new prostitution law. Suppose the government asks you

to simulate what would happen if the *supply of prostitution* is made completely illegal (not the demand as in Sweden and requested by Asscher) on 1 January 2013. Add therefore two variables: an outflow variable *reduction of supply through illegalisation* in order to completely empty the *supply of prostitutes* early 2013; and a variable '*influence of illegalisation on the societal acceptability of prostitution* which equals 1 till early 2013, after which it suddenly falls to, and stays, 0.7. Multiply this last variable with the formula (1 - *supply of prostitutes* / 100000) in the *societal acceptability of prostitution.* Model the above and answer the corresponding MC questions.

5. (/2) Verify the model and answer the corresponding MC questions.
6. (/2) Validate the model: cite two different suitable validation tests (different from sensitivity analysis), perform them, draw the necessary conclusions, and describe them briefly.
7. (/2) Simulate the validated model, save your results, and draw the correct model behavior of the following variables: (1) the *demand for prostitutes* and the *supply of prostitutes*, (2) the *average price of sex services*, and (3) the *total annual prostitution revenues.*
8. (/1) Interpret this dynamic: What are the implications for organized crime, trafficking, and victims of trafficking?
9. (/3) Make an extremely aggregated causal loop diagram (CLD) of this model with this policy. Explain the relationship between structure and behavior of this model with this policy using this causal loop diagram.
10. (/2) Perform the necessary sensitivity analysis: test the sensitivity of model and policy for two important assumptions or parameters. Describe briefly (which factors or parameters, what conclusions).
11. (/1) Suppose you advice against this policy: propose an effective policy to address especially the trafficking and serious crime related to prostitution? Describe your policy, its effect, and the robustness thereof.

B Stop Housebreaking! (/25) ©Erik Pruyt

Housebreaking (HB) is a complex societal issue. Each 73 seconds there is an attempt at housebreaking somewhere in the Netherlands. Intervention, investigation, prosecution and punishment of perpetrators cost our society many millions annually. The Dutch policy force totals 55,000 policemen. Only part of the police force is allocated to HB, both to intervention (intervention on the spot during or just after a burglary) and to investigation (the whole process post-burglary process focused on finding offenders and stolen goods). Compared with detection, intervention is priority and prerequisite.

Despite all the resources and measures, burglary seems to be a recurring phenomenon, which may be solved if we understand it ... That is why you are instructed by the Chairman of the Board of Police Commissioners to develop a simulation model relating to burglaries in the Netherlands, to simulate it over a time horizon of 120 months, and use the model to test the suitability of policies. Use the information below for your model:

Burglaries

Burglaries are committed both by casual thieves as well as by organized criminals: the *total number of HB* is thus the sum of the number of *HB by members of the OC* (OC stands for '**O**rganized **C**rime') and the number of *HB by occasional thieves.*

Let's start with the submodel related to *HB by occasional thieves.* The number of *HB by occasional thieves* the *percentage occasional thieves among 'coincidental' passers*, and the *monthly percentage HB by occasional thieves in houses with opportunities for HB.* Suppose there are 7 million houses, that the *monthly percentage HB by occasional thieves in houses with opportunities for HB* equals 20 percent, and that the *percentage occasional thieves among coincidental passers* equals 5 percent. The *percentage houses with opportunities for HB* is seasonal: model it as the *seasonality of HB* times (1 - *vigilance regarding HB*). The *percentage houses with opportunities for HB* is never smaller than 10%. Model the *seasonality of HB* such that its value oscillates annually between 25% and 75% with its annual peak at the end of January (darkness provides cover) and the annual low at the end of July (holiday season, even for burglars). Model the *vigilance regarding HB* as a third order delay of the *relative media attention wrt HB* with an average delay time of 3 months and an initial value of 70%. The *relative media attention wrt HB* should be modelled as a function of the *total number of HB* divided by the *acceptable number of HB*, connecting following couples (0,0), (2,0.2), (4,0.8), (6,1), (8,1), (12,1). Suppose that the *acceptable number of HB* amounts to about 4500 HB per month.

Now, let's model the HB by OC. The number of *HB by members of the OC* is determined by the *members of OC active in HB in the Netherlands* and the average of 4 *HB per member of the OC per month.* The number of *members of OC active in HB in the Netherlands*, starting from 2450 members in 2000, gradually changes through the *net increase of active members of OC in HB in the Netherlands.*

The *net increase of active members of OC in HB in the Netherlands* may be modelled as the product of the *normal size of OC in HB in the Netherlands*, and the *chance of being caught for HB in neighboring countries* divided by de *effective chance of being caught for HB in the Netherlands*, minus the *members of OC active in HB in the Netherlands.* Suppose that the *chance of being caught for HB in neighboring countries* is about 20%, and the *normal size of OC in HB in the Netherlands* amounts to 2500 (mostly) men.

The Police

The *effective chance of being caught for HB in the Netherlands* is a function of the *total available hours for investigating HB* divided by de *total man-hours required for HB investigation*: the *effective chance of being caught for HB in the Netherlands* is equal to 0% if that fraction equals 0, the *effective chance of being caught for HB in the Netherlands* is equal to 20% if that fraction equals 1, the *effective chance of being caught for HB in the Netherlands* is equal to 30% if that fraction equals 2, the *effective chance of being caught for HB in the Netherlands* is equal to 40% if that fraction equals 4, and the *effective chance of being caught for HB in the Netherlands* is equal to 50% if that fraction equals 8.

The *total man-hours required for HB investigation* equals the number of *HB under investigation* times 40 *man-hours required for investigation of a HB under investigation per month.* Model the variable *HB under investigation* as the integral of the *opening of new HB investigations* minus the *closing of old HB investigations*, with an initial HB under investigation of 32725 cases. The *opening of new HB investigations* is equal to the *total number of HB*, and the *closing of old HB investigations* is equal to the number of *HB under investigation* divided by the *average time under investigation* of 2 months.

Intervention has absolute priority; the *total available hours for investigating HB* therefore equal the difference between the *total available man-hours for HB* and the *total man-hours required for intervention wrt HB.* The *total man-hours required for intervention wrt HB* equal of course the *total number of HB* times the *man-hours required for intervention per HB* of 2 man-hours per intervention. The *total available man-hours for HB* correspond to the number of *policemen assigned to HB* times 160 available *man-hours per policeman per month.* The number of *policemen assigned to HB* is equal to the integral of the *net formation of teams of policemen assigned to HB*, with an initial value of 8760 policemen. This *net formation of teams of policemen assigned to HB* is simply the difference between the *policemen required for HB* and the number of *policemen assigned to HB*, divided by the *conversion time to HB* of 1 month. Assume that HB policemen only deal with HB interventions and HB investigations; the number of *policemen required for HB* then equals the sum of the *total man-hours required for intervention wrt HB* and the *total man-hours* *required for HB investigation*, divided by the *man-hours per policeman per month.*

1. (/7) Create a SD simulation model based on above description, save it, and answer the corresponding multiple choice questions.
2. (/3) Verify the model and answer the corresponding multiple choice questions.
3. (/2) Validate the model: name two suitable validation tests (different from sensitivity analysis - see Question 4), perform them, draw conclusions, and describe briefly.
4. (/2) Simulate the model, save your results, and draw the correct model behavior of following variables: (1) the *total number of HB*, the *HB by members of the OC* and the *HB door occasional thieves*, and (2) the *effective chance of being caught for HB in the Netherlands* and the number of *members of OC active in HB in the Netherlands.*
5. (/2) Perform useful sensitivity analyses: test the sensitivity of the model and policy for two important assumptions or parameters. Describe briefly (which two, results, conclusions).
6. (/3+1) Make an extremely aggregated causal loop diagram of this model. And explain the relationship between structure and behavior of this model with this policy briefly on the basis of this causal loop diagram. Keep it as simple as possible. Very few Chief Commissioners have a SD background. . .
7. (/3) During your explanation to the previous question, the Chairman noted that your explanation is not entirely correct because in reality a maximum of 9000 agents is assigned to HB. How do you solve this on the spot, in other words, what is the fastest way possible to adapt the model to this criticism. Do this. Save the model. Draw the effects on the *HB by members of the OC* and the *HB by occasional thieves.* Explain.
8. (/2) Describe a set of possible policies which allows to substantially reduce the number of HB. Implement this set of policies in the model and test it. What are the consequences of this set of policies for the citizens and the police?

C De/Radicalization II (/25) ©Erik Pruyt

After having modelled a generic model about de/radicalisation, you are asked to make a more specific de/radicalisation model focused on 'homegrown' animal rights activism and extremism (and by extension terrorism).

Citizens, Activists, and Extremists

Just as in the generic model, you can simplify the population submodel by assuming that the population remains constant (no migration, no births and no deaths). Suppose that there were 16 million citizens in the country in 1980, of which about 3 million *citizens that cannot be convinced*, 12900000 initially *unconvinced citizens*, about 100000 initially normal *convinced citizens*, and no *activists* nor *extremists. Unconvinced citizens* become *convinced citizens* through '*persuasion*'. *Convinced citizens* could possibly become –still law-abiding– *activists* through *activation.* Some *activists* start to operate after some time outside the legal framework and thus become *extremists.* The latter process may be called *extremization.*

The *persuasion* variable could be modelled as the product of the *contact rate of convinced with unconvinced* citizens, the *fraction of all convinced citizens*, the *unconvinced citizens* that are not (yet) convinced but possibly could, the *persuasion rate* of 1%, and the *reinforced visibility of animal distress* divided by the *average transition time* of 10 years. This variable cannot be greater than the number of *unconvinced citizens* divided by the *average transition time.* Set the *contact rate of convinced with unconvinced* citizens equal to the *frustration of all convinced citizens* times the *normal contact rate of convinced* of 1000 contacts per convinced citizen per year.

Simplify the *activation* and *extremization* flows: assume the *activation* flow is equal to the difference between the *potential number of activists* and the number of *activists*, divided by the *average transition time*, and that the *extremization* flow is equal to the difference between the *potential number of extremists* and the number of *extremists*, divided by the *average transition time*.

Set the *potential number of activists* equal to the product of the *potential fraction of activists* of 5%, the number of *convinced citizens* and the *frustration of all convinced citizens*. And model the *potential number of extremists* as the product of the *potential fraction of extremists* of 5%, the number of *activists*, the *frustration of all convinced citizens*, and the *frustration through marginalization*.

Human Distress

The *frustration of all convinced citizens* –always between 0% and 100%– could be modelled as the product of the *perceived animal distress* and the sum of the *frustration through marginalization* and the *frustration through inertia*.

The *frustration through marginalization* transforms the values of the *fraction of all convinced citizens* by means of a continuous function connecting following couples: (0, 1), (0.025, 0.50), (0.10, 0.20), (0.25, 0.04), (0.5, 0), (1, 0). The *fraction of all convinced citizens* is of course equal to the sum of convinced citizens, activists, and extremists, divided by the total population.

The *frustration through inertia* equals the difference between the *maximum attainable rate of decrease through societal change* of 5% and the *rate of decrease through societal change*, divided by the *maximum attainable rate of decrease through societal change*, but then delayed with exactly one year (because statistics are always delayed and news papers report statistics after publication).

This *rate of decrease through societal change* equals the *fraction of all convinced citizens* times the *maximum attainable rate of decrease through societal change*.

Animal distress and Visibility

Perceived animal distress could be modelled as the real *animal distress* divided by the *societal acceptation threshold wrt animal distress*, but then smoothed (third order over a year). Suppose that the *societal acceptation threshold wrt animal distress* changes over time from 100 in 1980, to 80 in 2000, to 40 in 2020, to 20 in 2040, to 12 in 2060, and to 10 in 2080.

Real *animal distress* –in 1980 equal to the reference value 100– increases (or decreases) through the *net increase of animal distress* – which could be modelled as the product of *animal distress* and the difference between the *exogenous rate of increase of animal distress* and the *rate of decrease through societal change*. The *exogenous rate of increase of animal distress* amounts to -0.1%, in other words, animal distress decreases exogenously.

Model the *visible animal distress* as the difference between *animal distress* and the *societal acceptation threshold wrt animal distress*, divided by the *societal acceptation threshold wrt animal distress*. The *visible animal distress* should always be non-negative. The *visible animal distress* multiplied by the *radical action level* results in the *reinforced visibility of animal distress*. The *radical action level* is equal to the number of *extremists* times the *frustration of all convinced citizens* times the *fraction of all convinced citizens*.

Model and Analysis

1. (/10) Make a model of the description above. Verify the model. Save the model. Simulate the model over a time horizon of 100 years, starting in 1980. Answer the multiple choice questions below [note: dimensions/units are not printed].

Multiple Choice Question 1 (/ 1)

What is the best formulation for the '*persuasion*' rate? (Note: only indicate the answer similar to what you modelled)

(a) min((contact rate of convinced with unconvinced*fraction of all convinced citizens *persuasion rate *reinforced visibility of animal distress * unconvinced citizens) / average transition time, unconvinced citizens/average transition time)

(b) MAX((contact rate of convinced with unconvinced*fraction of all convinced citizens * persuasion rate * reinforced visibility of animal distress * unconvinced citizens) / average transition time, unconvinced citizens/average transition time)

(c) (contact rate of convinced with unconvinced*fraction of all convinced citizens * persuasion rate * reinforced visibility of animal distress * unconvinced citizens) / average transition time, unconvinced citizens/average transition time

(d) MAX(min((contact rate of convinced with unconvinced*fraction of all convinced citizens * persuasion rate * reinforced visibility of animal distress * unconvinced citizens) / average transition time, unconvinced citizens/average transition time),1)

Multiple Choice Question 2 (/ 1)

What is the best formulation for the '*frustration of all convinced citizens*'? (Note: only indicate the answer similar to what you modelled)

(a) MIN(0,(MAX(1,perceived animal distress * (frustration through inertia + frustration through marginalization))))

(b) MIN(0,(MIN(1,perceived animal distress * (frustration through inertia + frustration through marginalization))))

(c) MAX(0,(MAX(1,perceived animal distress * (frustration through inertia + frustration through marginalization))))

(d) none of these formulations is any good

Multiple Choice Question 3 (/ 1)

What is the best formulation for the variable '*visible animal distress*'? (Note: only indicate the answer similar to what you modelled)

(a) SMOOTH3(animal distress/societal acceptation threshold wrt animal distress,1)

(b) MAX(0,(animal distress-societal acceptation threshold wrt animal distress)/societal acceptation threshold wrt animal distress)

(c) MAX(0,(societal acceptation threshold wrt animal distress-animal distress)/societal acceptation threshold wrt animal distress)

(d) DELAY FIXED(animal distress/societal acceptation threshold wrt animal distress, 1, animal distress/societal acceptation threshold wrt animal distress)

Multiple Choice Question 4 (/ 1)

What is the best formulation for the variable '*frustration through marginalization*'? (Note: only indicate the answer similar to what you modelled)

(a) a succession of STEP functions

(b) a lookup function / graph function that interpolates between following couples: (0,1), (0.025,0.5), (0.1,0.2), (0.25,0.04), (0.5,0), (1,0)
(c) a lookup function / graph function that interpolates between following couples: (1,0), (0.5,0.025), (0.2,0.1), (0.04,0.25), (0.5,0), (0,1)
(d) none of these formulations is any good

Multiple Choice Question 5 (/ 1)

What is the best formulation for the variable '*frustration through inertia*'? (Note: only indicate the answer similar to what you modelled)

(a) (maximum attainable rate of decrease through societal change-rate of decrease through societal change)/maximum attainable rate of decrease through societal change
(b) (rate of decrease through societal change-maximum attainable rate of decrease through societal change)/maximum attainable rate of decrease through societal change
(c) DELAY3((maximum attainable rate of decrease through societal change - rate of decrease through societal change)/maximum attainable rate of decrease through societal change, 1) (or the corresponding third order DELAYMTR in Powersim)
(d) none of these formulations is any good

Multiple Choice Question 6 (/ 1)

What is the best formulation for the variable '*societal acceptation threshold wrt animal distress*'? (Note: only indicate the answer similar to what you modelled)

(a) 100 - STEP(2000, 20) - STEP(2020,40) - STEP(2040,20) - STEP(2060,8) - STEP(2080,2)
(b) A lookup / graph function with argument Time and following couples: (1980,100), (2000,80), (2020,40), (2040,20), (2060,12), (2080,10)
(c) 100 - STEP(20, 2000) - STEP(40, 2020) - STEP(20, 2040) - STEP(8, 2060) - STEP(2, 2080)
(d) none of these formulations is any good

Multiple Choice Question 7 (/ 1)

What is de most appropriate name for the structure composed by the variables *unconvinced citizens*, *convinced citizens*, *activists*, and *extremists*? (Note: only indicate the answer similar to what you modelled)

(a) an '*aging chain*'
(b) a '*pull chain*'
(c) a '*third order material delay*'
(d) a '*supply chain*'

Multiple Choice Question 8 (/ 1)

What is the best formulation for the variable '*perceived animal distress*'? (Note: only indicate the answer similar to what you modelled)

(a) DELAY FIXED(animal distress - societal acceptation threshold wrt animal distress,1) [or the corresponding DELAYPPLINF in POWERSIM]

(b) SMOOTH3(animal distress - societal acceptation threshold wrt animal distress,12) [or the corresponding DELAYINF in POWERSIM]
(c) DELAY3(animal distress - societal acceptation threshold wrt animal distress,12) [or the corresponding DELAYINF in POWERSIM]
(d) none of these formulations is any good

Multiple Choice Question 9 (/ 1)

How many 'unit errors' are there in the model? (Note: indicate the answer that corresponds to the number of unit errors in your model – an additional penalty of -5 will be applied if your answer does not correspond to the number of unit errors in your model)

(a) 0 unit errors
(b) 1 to 3 (included) unit errors
(c) 4 to 8 unit errors
(d) more than 8 unit errors

Multiple Choice Question 10 (/ 1)

What combination of integration method and time step is best for this model? (Note: only indicate the answer similar to what you modelled)

(a) INITIAL TIME = 1980 ; FINAL TIME = 2080 ; Integration type = RK4 ; Units for time = Year ; Time Step = 1
(b) INITIAL TIME = 0 ; FINAL TIME = 100 ; Integration type = EULER ; Units for time = Year ; Time Step = 1
(c) INITIAL TIME = 1980 ; FINAL TIME = 2080 ; Integration type = RK4 ; Units for time = Year ; Time Step = 0.125
(d) INITIAL TIME = 1980 ; FINAL TIME = 2080 ; Integration type = EULER ; Units for time = Year ; Time Step = 0.00000000001

2. (/2) Make a graph of the *convinced citizens*, *activists*, *extremists*, and a graph of the *persuasion* rate and the *frustration of all convinced citizens*.
3. (/2) Validate the model: name, briefly describe and perform 2 different validation tests (except sensitivity testing – see following question) and briefly conclude.
4. (/3) Test the sensitivity of the model for parameters and lookup/graph functions. Briefly describe the tests performed and the major insights.
5. (/2) Make different consistent and interesting (thus behaviorally different) scenarios starting from your conclusions in the previous question. Simulate these scenarios and draw graphs for two scenarios of the *convinced citizens*, *activists*, *extremists*, and the *persuasion* rate and the *frustration of all convinced citizens*.
6. (/4) Make a highly aggregated causal loop diagram of this model that could be used to explain the link between structure and behavior of one of the scenarios. Explain that behavior.
7. (/1) Formulate some policy advice –based on this exercise– wrt animal right activism.
8. (/1) This model is of course but a first simple model, and the analysis is explorative at most. Provide advice wrt future extensions and refinements of the model.

D Long Term Planning of New Towns (/25) ©Erik Pruyt

This case is based on a modified version of George Richardson's URBAN1 model[6].

The world will see in the next decades without a shadow of a doubt an increasing urbanization. Part of it will –especially in Asia and Africa– be caused by so-called 'New Towns'. The concept of 'New Towns' is used for a particular type of urban development: a more or less independent new town relatively distant from existing cities. New urban developments within existing (older) urban areas (New Town in Town) or large urban extensions to the edges of the major cities is generally referred to as urban renewal, not as New Towns. The New Town concept is not new. Worldwide, there are hundreds of new cities (Brasilia, Chicago, San Francisco, Milton Keynes, many Eastern European, Russian, South American, Chinese, Korean and French cities) and many new ones are under construction (especially in Asia and Africa). Although the number of inhabitants of these cities varies from less than 50000 to more than a million, and although they are very different in objective function and design, there are interesting dynamic parallels and the same 'mistakes' made over and over again. One of the System Dynamics classics –Urban Dynamics by Jay W. Forester– shows that System Dynamics is an appropriate method to help to understand New Town structures and dynamics and to test policies to solve undesirable behaviors. Suppose that you are hired as an adviser-modeler by a few rising new towns to test policies to solve the 'root causes' of undesirable dynamics. Since you just followed one of the best SD courses in the world, you decide to make and subsequently use a SD model. Use the information below.

The 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%. And suppose that there is constant *emigration* with a *normal emigration rate* of 7% per year. *Immigration* could be modelled as the product 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*, in that part of the world still 4. Suppose that the *normal immigration rate* equals 10%.

Houses

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 modelled as a third order delay (being 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

[6] URBAN1 is available at `http://www.albany.edu/faculty/gpr/PAD624/urban1.mdl`.

all houses, divided by the *total area*. Suppose that the useful *total area* of the new town is 5000 hectare, that the *land per house* is 0.05 hectare per house, and that the *land per business* (ie for each business structure) is 0.1 hectare per business.

Businesses and labor force

The number of *businesses* (ie 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%.

Construction of business structures could be modelled as the product 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% land fraction occupied, it equals 1 for 0% land fraction occupied, and it equals 1.5 for 50% the land fraction occupied. The *business labor force multiplier* is a function of the *labor force to jobs ratio* connecting following points: (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. Model following two key performance indicators too: the *unemployment ratio* and the *housing vacancy ratio*. Both are per definition between 0 and 100%.

Questions

1. (/7) Model and verify the model and answer the following multiple choice questions related to the model.

Multiple Choice Question 11 (/ 1)

What is the best formulation of the variable '*construction of houses*'? (Note: you only get this point if you correctly modelled it.)

(a) DELAY3(construction rate of houses * land availability multiplier for houses * housing scarcity multiplier * houses, 2)

(b) SMOOTH3(construction rate of houses * land availability multiplier for houses * housing scarcity multiplier * houses, 2)

(c) SMOOTH3I(construction rate of houses * land availability multiplier for houses * housing scarcity multiplier * houses, 2, 0)

(d) none of the formulations above is appropriate

Multiple Choice Question 12 (/ 1)

What is the best formulation of the variable '*housing vacancy ratio*'? (Note: you only get this point if you correctly modelled it.)

(a) MAX(MIN((1-households to houses ratio),0),1)

(b) MAX(MIN((households to houses ratio),0),1)

(c) MIN(MAX((households to houses ratio),0),1)

(d) none of the formulations above is appropriate

Multiple Choice Question 13 (/ 1)

What is the best formulation of the variable '*unemployment ratio*'? (Note: you only get this point if you correctly modelled it.)

(a) MIN(MAX((1 - 1/labor force to jobs ratio),0),1)
(b) MAX(MIN((1 - labor force to jobs ratio),0),1)
(c) MIN(MAX((1 - labor force to jobs ratio),0),1)
(d) none of the formulations above is appropriate

Multiple Choice Question 14 (/ 1)

What is the best formulation of the variable '*housing availability multiplier for immigration*'? (Note: you only get this point if you correctly modelled it.)

(a) a with lookup function with as argument (1 / *households to houses ratio*) and points (0, 1.4), (0.5, 1.3), (1, 0.9), (1.5, 0.05), (2, 0)
(b) a with lookup function with as argument *households to houses ratio* and points (0, 1.4), (0.5, 1.3), (1, 0.9), (1.5, 0.05), (2, 0)
(c) a with lookup function with as argument *households to houses ratio* and points (1.4, 0), (1.3, 0.5), (0.9, 1), (0.05, 1.5), (0, 2)
(d) none of the formulations above is appropriate

Multiple Choice Question 15 (/ 1)

What is the best formulation of the variable '*land availability multiplier for houses*'? (Note: you only get this point if you correctly modelled it.)

(a) a first with lookup function with as argument *land fraction occupied* and points (0, 0.4), (0.25, 1), (0.5, 1.5) and a second with lookup function with as argument *land fraction occupied* and points (0.75, 1), (1, 0)
(b) the following sum of step functions: STEP(0, 0.4) + STEP(0.25, 1) + STEP(0.5, 1.5) + STEP(0.75, 1) + STEP(1, 0)
(c) a with lookup function with as argument *land fraction occupied* and points (0, 0.4), (0.25, 1), (0.5, 1.5), (0.75, 2.5), (1, 2.5)
(d) none of the formulations above is appropriate

Multiple Choice Question 16 (/ 1)

What is the best formulation of the variable '*land fraction occupied*'? (Note: you only get this point if you correctly modelled it.)

(a) businesses * land per business * houses * land per house / total area
(b) (businesses * land per business + houses * land per house) / total area
(c) total area / (businesses * land per business + houses * land per house)
(d) none of the formulations above is appropriate

Multiple Choice Question 17 (/ 1)

How many 'unit errors' are there left in your model? (Note: you only get this point if you honestly answered the question and your answer is a or b.)

(a) 0 unit errors (including unit errors of delay or smooth functions)
(b) 1 unit error (including unit errors of delay or smooth functions)
(c) 2 to 5 unit errors (including unit errors of delay or smooth functions)
(d) more than 5 unit errors (including unit errors of delay or smooth functions)

2. (/3) Simulate over a long time horizon of 200 years. Make graphs on your exam sheet of the evolution of businesses, houses and population and of the effects thereof on the *unemployment ratio* and the *housing vacancy ratio*. What are the problems you can derive from these graphs?

3. (/3) Make on your exam copy a strongly aggregated causal loop diagram (CLD) of this system model that could be used to explain the model behavior. Do it (ie use the CLD to explain the model behavior).

4. (/2) 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 through 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*, and answer following multiple choice questions.

Multiple Choice Question 18 (/ 1)

Now, what is the best formulation of the variable '*emigration*'? (Note: you only get this point if you correctly modelled it.)

(a) population * normal emigration rate * (1 - slum multiplier for migration)
(b) population * normal emigration rate * (1 + slum multiplier for migration))
(c) population * normal emigration rate * (1 + (1-slum multiplier for migration))
(d) none of the formulations above is appropriate

Multiple Choice Question 19 (/ 1)

Now, what is the best formulation of the variable '*immigration*'? (Note: you only get this point if you correctly modelled it.)

(a) population * normal immigration rate * job availability multiplier for immigration * housing availability multiplier for immigration * slum multiplier for migration
(b) population * normal immigration rate * job availability multiplier for immigration * housing availability multiplier for immigration * (1 + slum multiplier for migration)
(c) population * normal immigration rate * job availability multiplier for immigration * housing availability multiplier for immigration * (1- slum multiplier for migration)
(d) none of the formulations above is appropriate

5. (/2) Forrester's Urban Dynamics shows that additional demolition in case of high housing vacancy ratios could prevent urban decay to kick in. Thus add a variable *additional demolition rate* to demolish 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. And answer following multiple choice questions:

Multiple Choice Question 20 (/ 1)

What is the best formulation of the variable '*additional demolition rate*'? (Note: you only get this point if you correctly modelled it.)

(a) a with lookup function with as argument the *housing vacancy ratio* and going through following points (0.1, 0), (0.15, 0.05), (1, 0.5)
(b) a with lookup function with as argument the *housing vacancy ratio* and going through following points (0, 0), (0.1, 0), (0.15, 0.05), (1, 0.5)
(c) a with lookup function with as argument the *households to houses ratio* and going through following points (0.1, 0), (0.15, 0.05), (1, 0.5)
(d) none of the formulations above is appropriate

Multiple Choice Question 21 (/ 1)

What is the best formulation of the variable '*demolition of houses*'? (Note: you only get this point if you correctly modelled it.)

(a) demolition rate of houses * houses + additional demolition rate * houses
(b) demolition rate of houses * additional demolition rate * houses
(c) demolition rate of houses + additional demolition rate
(d) none of the formulations above is appropriate

6. (/1) Draw on your exam sheet the effect on the two key performance indicators? Is the combination of these endogenous effects and this policy a solution for the problems encountered earlier? Explain.

7. (/1) Land and buildings are used more efficiently in case of land scarcity. Model therefore following endogenous relation: the *effect of land scarcity on intensity of use of business structures* being a with lookup function with argument *land fraction occupied* and following couples (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.

Multiple Choice Question 22 (/ 1)

Now, what is the best formulation of the variable '*jobs*'? (Note: you only get this point if you correctly modelled it.)

(a) initial number of jobs per business structure * businesses * (effect of scarcity of land available on intensity of use of business structures * switch jobs + (1 - switch jobs))
(b) INTEG(businesses * effect of scarcity of land available on intensity of use of business structures * switch jobs, initial number of jobs per business structure)
(c) initial number of jobs per business structure * businesses * (effect of scarcity of land available on intensity of use of business structures * switch jobs + (switch jobs - 1))
(d) none of the formulations above is appropriate

8. (/1) Draw on your exam sheet the effects of all these extensions together on the two key performance indicators. Is this endogenous effect a solution for the initial problems? If not, briefly explain how these problems have changed.

9. (/2) Briefly validate the model. Name minimally 2 validation tests (with the exception of sensitivity analysis), perform them, describe and conclude briefly on your exam sheet.

10. (/2) Perform two sensitivity analyses to find policies to solve the remaining problems. Describe them, perform them (describe the effects), and conclude.

11. (/1 + 1 bonus) Propose a set of policies to solve all identified problems. You can gain a bonus point if you model this set of policies, the set indeed solves the problems , and you show this in graphs for both key performance indicators.

E Project Management (/25)

Project planning is a successful System Dynamics application field. Let us therefore make a System Dynamics project models to see how and why System Dynamics could be useful for project planning and 'project litigation'(using SD models before or in court to show the causes of project delays, cost overruns, and hence, who is responsible and should bear the costs). Suppose that you are appointed project manager in a large company specializing in project management and project implementation. Your main tasks consist planning and managing relatively large projects. Because of your background in System Dynamics, you decide to make a System Dynamics model to help you plan and manage your projects.

Use the information below, which is based on a modified version of George Richardson's Project models[7].

Project Management I (/6)

A typical project consists *initially* of 1200 *project tasks* to be completed. A typical project model thus starts with a stock of 1200 *remaining project tasks*. During the project, *project tasks that are properly completed* become part of the *properly completed project tasks*. At the start of a project, the number of *properly completed project tasks* equals 0. The *project tasks that are properly completed* is equal to the *progress* made during the project. *Progress* made during the project is equal to the *gross productivity of project personnel* times the size of the *workforce* assigned to the project. The *gross productivity of project personnel* depends on the number of *remaining project tasks*: with a project of, say, 1200 tasks to be completed, the *gross productivity of project personnel* is maximal –that is to say 100%– from 1200 remaining taken until there are some 100 remaining tasks, after which the *gross productivity of project personnel* decreases to 95% at 75 remaining tasks, 85% at 50 remaining tasks, to 20% at 0 remaining tasks. The last mile the hardest.

When you become project manager, it is not common practice to hire *test personnel* (see below), only *project personnel*. Suppose that the number of *project personnel* is equal to the size of the *workforce*, equal to 2 (the project manager –you– and the Assistant Project Manager –your secretary) at the start of the project. However, much more manpower is needed to complete projects. The *workforce* of your company assigned to a particular project increases and decreases through *net hiring of personnel* equal to the difference between the *desired workforce* and the *workforce*, divided by the *time to adapt the workforce*. Suppose the according to the project workforce policy of your company, the *desired workforce* equals the *perceived effort remaining* divided by the *perceived time remaining*.

Model the *perceived time remaining* as: '-Time' plus a first order information delay with argument *Time + perceived effort remaining / desired workforce*, with a delay *time to adjust the project schedule*, and with as initial value the *initially remaining project time*. Make sure that the *perceived time remaining* is larger than a quart month: experience shows that such projects always have a time overrun of at least a week. Since the company you work for mainly implements projects of the same kind, permanent staff is mainly moved between projects which makes that the *time to adapt the workforce* is relatively short – about a month.

The *initially remaining project time* of such projects typically amounts to 40 months, and the *time to adjust the project schedule* to 1 month. The *perceived effort remaining* equals the *remaining project tasks* divided by the *perceived productivity*. In order to avoid dividing by zero, you need

[7] Available at `http://www.albany.edu/faculty/gpr/PAD624/project1v3.mdl`.

to make sure that the denominator never becomes smaller than 1. The *perceived productivity* corresponds to the *perceived cumulative progress* over the *cumulative effort delivered*. The *perceived cumulative progress* could in this first version of the model assumed to be equal to the amount of *properly completed project tasks*. Suppose that the *cumulative effort delivered* initially equals 0.1%. The *cumulative effort delivered* increases by means of the *additional effort delivered* by the workforce, which therefore simply equals the *workforce*.

In order to ensure the model simulates exactly as long as needed, you can represent the system variable *Final Time* as a shadow variable and change its argument into 'IF THEN ELSE(*perceived fraction completed* < 0.999, 200, *Time*). But before doing so, you need to set the *perceived fraction completed* to the *perceived cumulative progress* divided by the *initial number of project tasks*.

1. (/5) Make a SD simulation model based on the description above, save it using an appropriate file name, verify the model, and answer the corresponding multiple choice questions.

Project Management II (/19)

Despite the timely completion of your first project, the client appears to be very unhappy about its quality. After some inquiries you find out that that all former project clients are rather dissatisfied: either the quality is perceived to be poor, or there were enormous time and/or budget overruns. According to your client the quality of the completed project is not half of what he expected. From your own investigation it appears that only about half of all tasks well executed properly, and, perhaps even worse, severely defective tasks are not detected and therefore not appropriately addressed. After reporting this to the Vice President Projects, you are instructed to use your System Dynamics skills to get to the bottom of it, more precisely to improve the Vice President's and your understanding of this largely invisible problem and to experiment in your virtual reality (the model) in order to prevent such problems in the future. You decide to add undiscovered the model you made before (in Project Management I) and to test some strategies.

Start by adding a stock variable *undiscovered rework*to the model. Two flows connect this new stock to the stock of *remaining project tasks*: the flow *poor completion of project tasks* and the flow *detection of undiscovered rework*, ie inappropriately completed work. The *detection of undiscovered rework* depends on the number of *test personnel* times the average *productivity of testing*.

Poor completion of project tasks happens according to the complement of the *fraction properly completed* times the *progress*.The *project tasks that are properly completed* from the previous model version therefore needs to be updated to the *progress* times the *fraction properly completed* of about 50%. The *perceived cumulative progress* from the previous model version needs to be updated too: this variable now adds the *properly completed project tasks* and the *undiscovered rework*.

The *productivity of testing* equals the *fraction undiscovered rework* times the *maximum productivity of testing* of 2 tasks per person per month. The *fraction undiscovered rework* is of course equal to the *undiscovered rework* divided by the *perceived cumulative progress*. Ensure that the denominator in the previous equation cannot be equal to zero.

Model the *reported fraction of detection of undiscovered rework* as the third-order information delay of the *detection of undiscovered rework* over the sum of the *project tasks that are properly completed* and the *detection of undiscovered rework*, with a delay time of 1 month.

The size of the *test personnel* equals the *fraction of personnel for testing* multiplied by the total *workforce* assigned to the project. Model the *fraction of personnel for testing* (in view of adding later on an endogenous test strategy to the system) an endogenous function of a a model variable going through the following couples (0,0.1), (0.2,0.15), (0.4,0.3), (0.6,0.6), (0.8,0.75), and (1,0.8). As for now use a constant, more specifically 0.5, as argument of this function: which results in an assignment to testing of 45% of the workforce assigned to the project. Since test personnel is selected from the total workforce, assigning personnel to testing of completed project tasks influences the number of employees assigned to project tasks. Update the variable *project personnel* accordingly.

A first *key performance indicator* (KPI) is of course the *Final Time* of the project. Add a second KPI to monitor the *average quality of completed project tasks*: this KPI could be defined as the *properly completed project tasks* divided by the sum of *properly completed project tasks* and *undiscovered rework*. Ensure the denominator cannot become zero.

1. (/4) Extend the SD model based on the description above, verify the model, and answer the corresponding multiple choice questions.

2. (/2) Validate the model: list to appropriate validation tests (sensitivity analysis excluded), perform them, conclude, and briefly report on your exam sheet.

3. (/3) Simulate the validated model, save your results, and draw the correct behavior of following variables on your exam sheet: (1) the *perceived cumulative progress* including the end of the projects; (2) the *average quality of completed project tasks* and the *cumulative effort delivered*; (3) and the *workforce*, as well as the *project personnel* and the *test personnel*. Draw in dotted lines or in pencil for the sake of comparison the behavior of the first model on the corresponding indicators.

4. (/1) Interpret these graphs: what are the consequences of the testing on the quality and final time of such a project?

5. (/3) Make the variable *fraction of personnel for testing* truly endogenous, ie replace the constant by a model variable that is or could also be observed in the real world such that the variable becomes part of one or multiple feedback loops. Which input variable do you use? Why? Draw the consequences of your endogenous testing strategy (preferably in another color on the previous graph) for (1) the *perceived cumulative progress* including the end of the projects; (2) the *average quality of completed project tasks* and the *cumulative effort delivered*; (3) and the *workforce*, as well as the *project personnel* and the *test personnel*. What does it mean for such projects, in other words, is this strategy an improvement?

6. (/3) Draw on your exam sheet a strongly aggregated causal loop diagram of this model including your endogenous strategy.

7. (/2) Perform the sensitivity analyses in view of improving planning and managing such projects. Test the sensitivity of the model with your endogenous strategy for changes in following assumptions: the *gross productivity of project personnel* and the *fraction of personnel for testing*. Do it, briefly explain what you did, and conclude.

8. (/1) Manage extreme fluctuations in staff is always difficult. So it would be better if a strategy is used where the workforce assigned to a project has less extreme fluctuations. Propose a strategy for doing so, model it and test it. What can you conclude?

F The 'Cod' Project Case ©Erik Pruyt

The cod population off the coast of Nova Scotia in Eastern Canada, south of New Foundland, is recovering from previous overfishing (Frank, Petrie, Fisher, and Leggett 2011). The dramatic collapse of this cod population is the perfect example of the dangers of overfishing, and more generally, of the *problem of the commons* archetype. After a fortunate period of uncontrolled fishing, the stock of large predatory fish such as cod, haddock, pollock and hake near Nova Scotia almost completely collapsed within three years round 1990. The fishing was banned in 1993, but recovery of predatory fish populations did not occur. However, it appeared that smaller prey fish cod hunts for like herring, capelin and sandeel, greatly increased in number. These smaller prey fish live on zooplankton (tiny floating animals) and it was assumed that they also ate larvae of the –now rare– predators. Ecologists call this phenomenon predator-prey reversal. It was feared that the restoration of the ecological situation would be blocked forever.

But the disappearance of large predatory fish lead to a trophic cascade. The numbers of prey fish increased, resulting in a reduction of zooplankton, which in turn led to an increase in phytoplankton (algae). The prey fish have been the victims of their own gluttony, there is shortage of zooplankton, and their populations decrease since 1999. Consequently, more cod larvae survive and gradually encounter more zooplankton, their primary food. This damped oscillation could be captured by SD models. The cod and haddock populations have been on the rise since 2005.

1. Make a simple System Dynamics model of this ecosystem based on the description above. Elicit and justify specific modeling choices (esp. the uncertain ones). Verify, validate, and simulate the model.

2. Extend the model using additional resources such as (Frank, Petrie, Fisher, and Leggett 2011) (see `http://www.nature.com/nature/journal/v477/n7362/full/nature10285.html`).

3. Whether the old situation will return remains to be seen. In the transition period, new (exotic) species may also take over part of the ecosystem. Or jellyfish. And then there is climate change... Extend your model in view of studying plausible consequences of exotic species invasion, jellyfish take-over, and climate change.

4. Look at the comment related to the article by Frank et al posted on the web site of Nature. Model this perspective too. Use both models for policy testing. What are your conclusions?

G Examples of Multiple Choice Questions

G.1 SD PHILOSOPHY, SD METHODOLOGY, OR 'SD SPEAK'

Multiple Choice Question 1 (/ 1)

Which of the following quotes related to System Dynamics modeling is wrong?

a. '[SD model] testing is often designed to 'prove' the model is 'right', an approach that makes falsification possible and, hence, adds to the utility of the model and the credibility of the modeler. [...] Model testing should be designed to cover up errors so that models become unquestioned tools for making important decisions.' (Sterman 2000, p846)

b. 'Models could be used to develop social visions far more internally consistent than those generated by mental models alone. They could point the way to critical, decisive experiments, and actively test social theories at far less cost than the costs of imposing those theories in ignorance and arrogance upon the whole society. They could be used to search for imprecise policies that are robust against uncertainties rather than precise policies that try to optimize something that is not understood. Perhaps most important, they could simply serve as communication devices in which different, partial, mental models of the social system could be expressed and integrated.' (Meadows and Robinson 1985, p429)

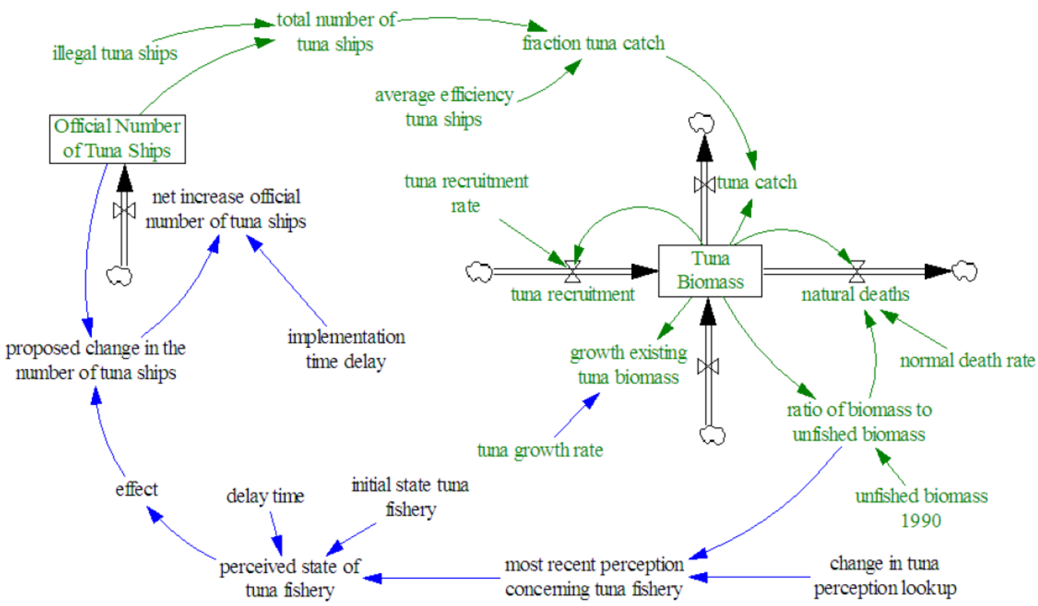
c. 'The world certainly needs system dynamics now more than ever. While a cliché, it is certainly true that our social systems are more complicated, more interconnected and likely more fragile than at any previous point in the history of humankind.' (Repenning 2003, p325)

d. 'I am suggesting that we do indeed know enough to make useful models of social systems. Conversely, we do not know enough to design the most effective social systems directly without first going through a model-building experimental phase.' (Forrester 1971, p126)

G.2 SD DIAGRAMMING (LOOPS, SFD to CLD to SFD)

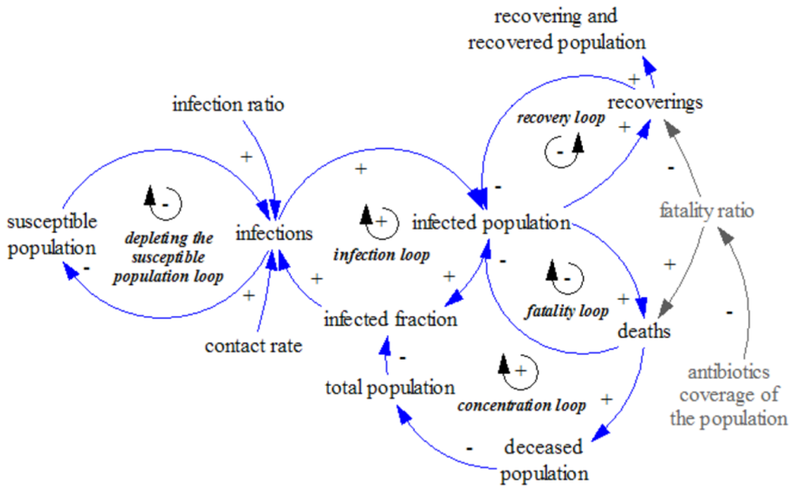
Multiple Choice Question 2 (/ 1)

What is the minimum number of independent feedback loops in the following simulation model on overfishing of bluefin tuna?

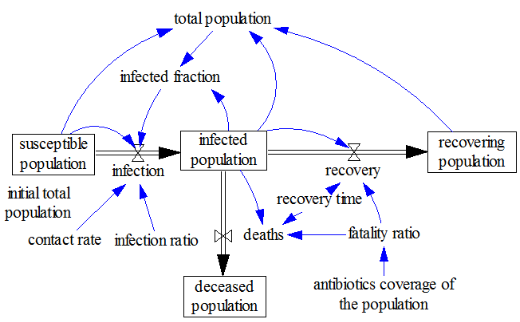


a. 1 feedback loop b. 5 feedback loops c. 6 feedback loops d. 7 feedback loops

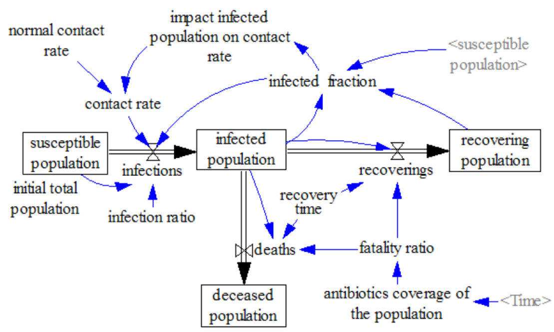
Multiple Choice Question 3 (/ 1)



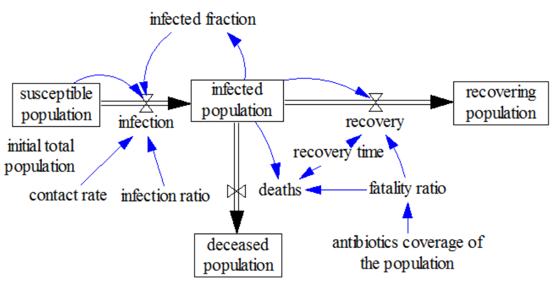
Consider the above causal loop diagram on the outbreak of a disease. Which of the following stock-flow diagrams corresponds best to this causal loop diagram?



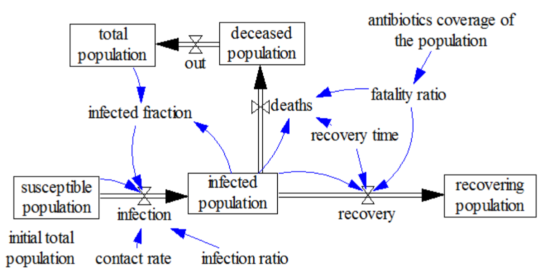
(a)



(b)



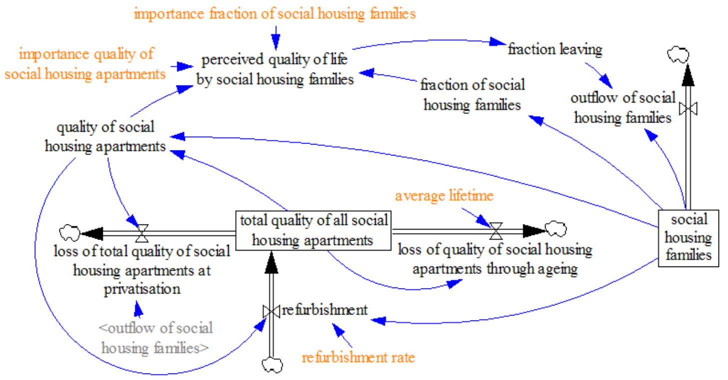
(c)

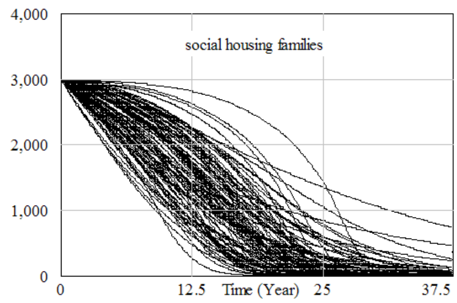


(d)

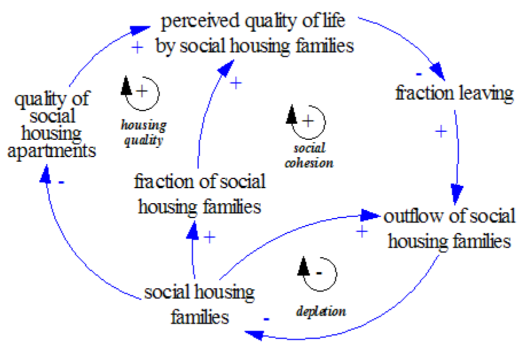
Multiple Choice Question 4 (/ 1)

Some time ago, we made a SD simulation model about the exodus of social housing districts because of loss of social cohesion. Simulation of the SD model leads –even for very different values of the parameters in orange (see 100 very different runs in the graph)– to exponential decrease of the original population followed by balancing decrease to 0.

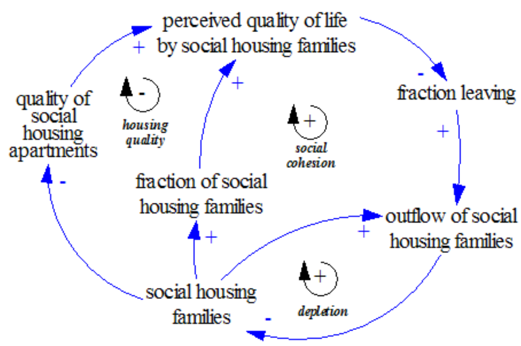




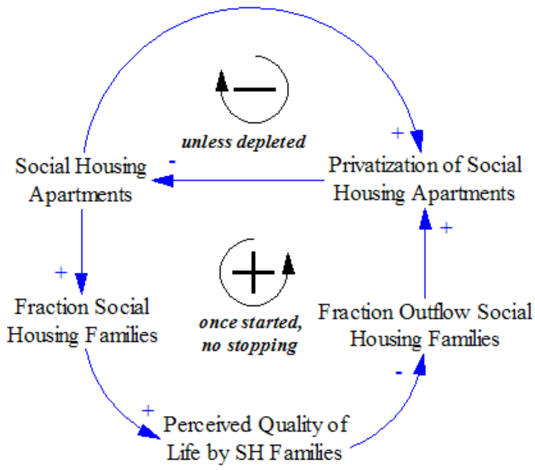
Which of the following aggregated '*Causal Loop Diagrams*' is the best diagram to communicate the essential link between structure and behavior of the social housing district model?



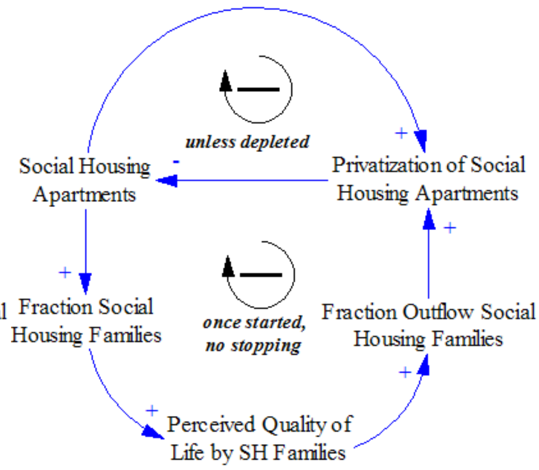
(a)



(b)



(c)



(d)

G.3 SPECIFICATION (DELAYS, SPECIAL FUNCTIONS, ...)

Multiple Choice Question 5 (/ 1)

Average TPM students finish their study at Delft University of Technology in about 7 years. A few exceptional students finish in the minimum time of 5 years. Some take more than 15 years.

But most students finish in little under 7 years. Suppose there are no drop-outs. What would be the best way to model the outflow of students who all started at the same time?

a. with a '*Delay Fixed* (or '*Pipeline Delay*') of 7 years

b. first a '*Delay Fixed*' of 5 years followed by a third-order '*Delay Material*' of 2 years

c. with a third-order '*Delay Material*' of 2 years followed by a '*Delay Fixed*' of 5 years

d. first a first-order '*Delay Material*' of 2 years followed by a '*Delay Fixed*' of 5 years

G.4 CALCULATION/SIMULATION

Multiple Choice Question 6 (/ 1)

On January 17 2012, it was announced that in 2011 the Chinese economy grew at its slowest pace in two years. The gross domestic product in 2011 nevertheless rose faster than expected – at an annualized increase of 9.2 %. When will the Chinese economy doubles if the Chinese economy continues to grow at this pace?

a. In 2015. b. In 2018. c. In 2021. d. Voor 2015 of na 2021.

Multiple Choice Question 7 (/ 1)

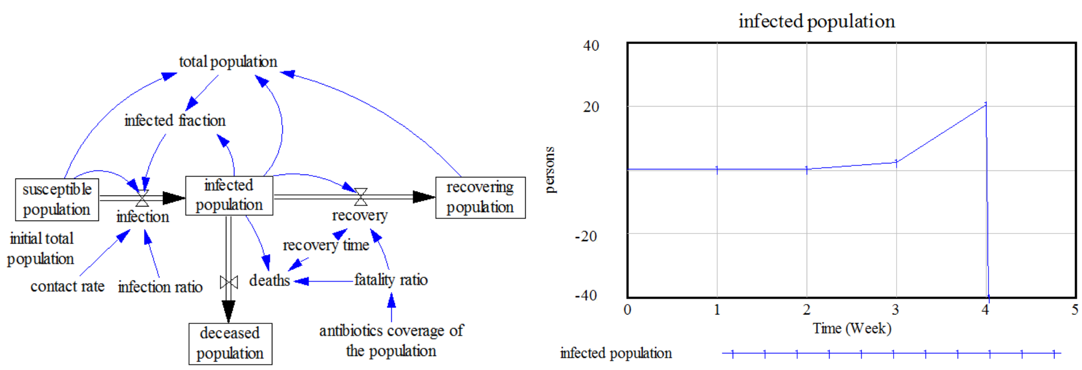
Starting from a simple dynamic model, it can be calculated that the currently known gas reserves and resources will be depleted in about 55 years from now if the gas demand continues to increase by 2% per year. Suppose that the gas reserves and resources all of a sudden quadruple (revolutionary technologies become available to mine shale gas and gas hydrates). How many years would it take for the continuously increasing demand to deplete this quadrupled amount?

a. ± 110 years; b. ± 200 years; c. ± 220 years; d. ± 230 years.

G.5 VERIFICATION, VALIDATION, SETTINGS, UNITS

Multiple Choice Question 8 (/ 1)

The simple SD model below is about the outbreak of pneumonic plague in an isolated community (more precisely a remote Chinese village with 10000 inhabitants). The behavior on the right hand side of the Stock-Flow Diagram is generated with this model. Which of the following statements is correct?



(a) (b)

a. The model is wrong because of a specification error: the *infection* flow must be modeled as non-negative.

b. The model is wrong because of a numeric integration error: it looks as though the Euler integration method is used with too big a time step.

c. The model is wrong because of a numeric integration error: it looks as though the Runge-Kutta4 integration method is used with too small a time step.

d. The model is wrong because of a specification error: the *recovery* flow and *deaths* flow should be modeled as non-negative flows.

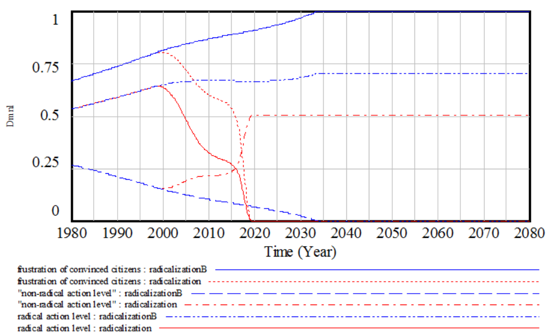
Multiple Choice Question 9 (/ 1)

The unit of time in a model concerning the large-scale introduction of electrical vehicles (EVs) is expressed in *month*. The production capacity of a company that produces EVs is modelled as a stock variable with units expressed in $EV/month$. The enormous growth of the expected demand for new EVs leads to an increase of the production capacity of EVs. What unit needs to be used for this increase of the production capacity?
a. $\frac{EV \, * \, month}{1}$; b. $\frac{EV}{month}$; c. $(\frac{EV}{month})^2$; d. $\frac{EV}{month^2}$.

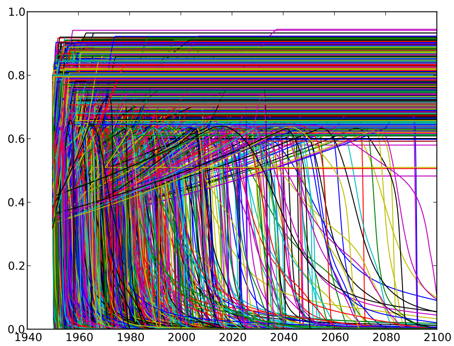
G.6 SENSITIVITY ANALYSIS AND UNCERTAINTY ANALYSIS

Multiple Choice Question 10 (/ 1)

A quick sensitivity/uncertainty analysis on a model about de/radicalization generates only two types of behaviors (see left figure below): either radicalization or deradicalization. A deep uncertainty analysis confirms this conclusion: this model only generates these two modes of behavior even with 10000 runs and enormous uncertainty bands. Further analysis shows that a particular set of counter-intuitive policies wrt radicalization has a robust influence on the modes of behavior: this appropriate set of proactive policies should allow to nip undesirable radicalization in the bud, that is to say, in the model. What do you conclude in terms of sensitivity?



(a) deradicalization (red) versus radicalization (blue)



(b) radical action level (uncertainty analysis with 10000 runs)

a. Real-world de/radicalization is behaviorally sensitive, not policy sensitive for this set of proactive policies.

b. Real-world de/radicalization is behaviorally sensitive as well as policy sensitive for this set of proactive policies.

c. This de/radicalization model is behaviorally sensitive, not policy sensitive for this set of proactive policies.

d. This de/radicalization model is behaviorally sensitive as well as policy sensitive for this set of proactive policies.

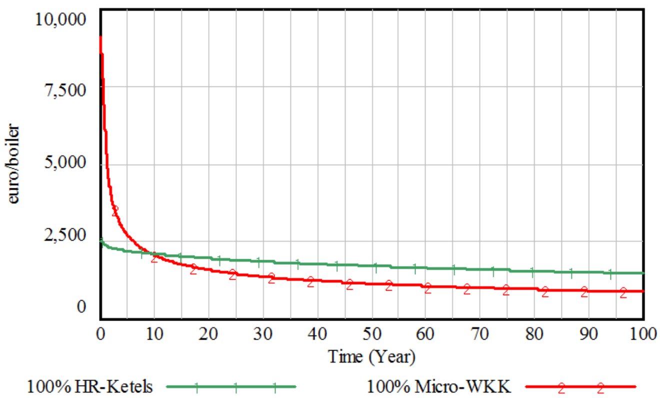
G.7 READING GRAPHS, DERIVING BEHAVIOR, LINKING STRUCTURE AND BEHAVIOR

Multiple Choice Question 11 (/ 1)

As manager of a large Dutch housing corporation, you must decide on the types of boilers that will be installed by the housing corporation in the next 100 years. Suppose you can only choose from two types of boilers: HE-boilers or micro-CHP installations. Micro-CHP installations are still very expensive to buy, €9100 per unit (one unit corresponds to one boiler), but recent cost reductions have been spectacular. Experience with micro-CHP so far, 20000 micro-CHP units in total, shows that the '*progress ratio*' equals 0.75. HE-boilers nowadays only cost €2500 because of years of experience (equivalent to 7.5 million installed HE-boilers), and are characterized by a '*progress ratio*' of 0.75 too.

The graph below shows a perfect prediction of the cost reduction of both types of boilers if all 14 million boilers to be installed in the next 100 years by your housing corporation are either of the micro-CHP type (red curve) or of the HE-boiler type (green curve). The red curve is much steeper because micro-CHP is new and there is still much room for descending the learning (hence the marginal cost) curve.

The 'learning curve effect' is the relationship between production costs and the cumulative production over time: the *progress ratio* provides insight into the cost reduction for each doubling of cumulative production. So, if a boiler has a progress ratio of 75% and it costs €10000 to produce the 1000th unit, then it will cost €7500 to produce the 2000th unit.



The red curve (or green curve) in the graph is thus the perfectly predicted production cost per micro-CHP device (or boiler) if you install 100% in micro-CHP (or HE-boilers) the next 100 years. Note: the surfaces between the curves provide insight into the cumulative cost advantages of one technology over another.

Suppose that you are the only one installing boilers (hence, the destiny of your housing corporation is fully under control), and the future is perfectly predictable (no surprises, perfect foresight), and discounting is not required (€1 now is worth as much as €1 in 100 years and at any time in between), which of the following strategies minimizes the total investment costs over the full 100 years (or 14 million boilers)?

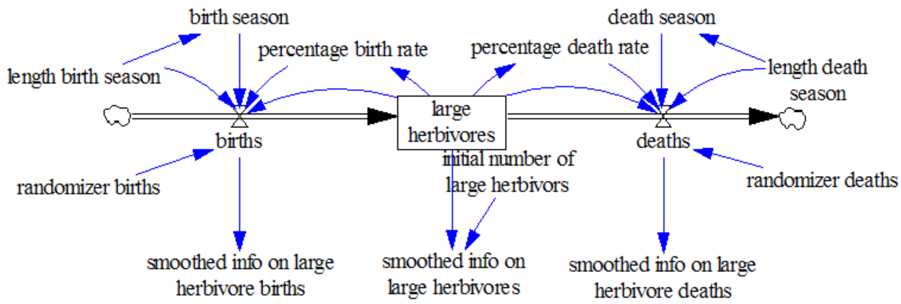
a. 100% in HE-boilers: HE-boilers are cheaper and will always be cheaper

b. 100% in micro-CHP: the surface area to the right of the intersection point is much larger than the surface area to the left

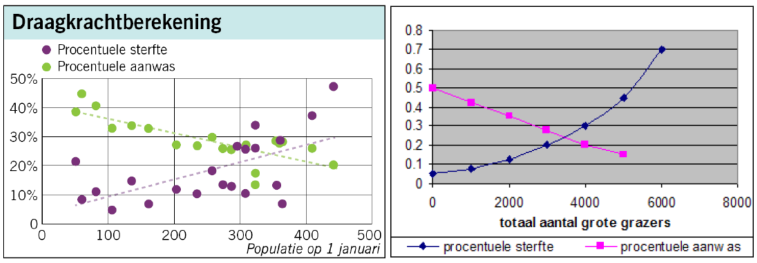
c. 100% HE-boilers for the first 10 years and 100% micro-CHP afterwards in order to take advantage of the lowest cost over the full 100 years

d. not 100% in HE-boilers nor 100% in micro-CHP, but somewhere in between (which could be calculated), in order to fully profit from the evolution of both technologies.

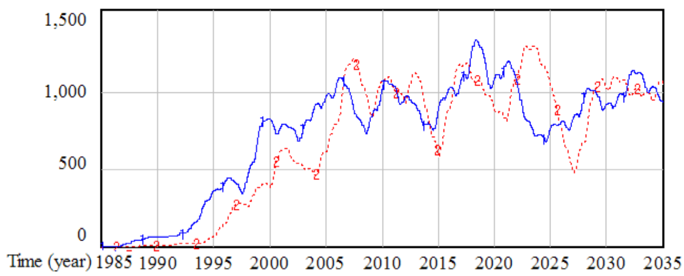
Multiple Choice Question 12 (/ 1)



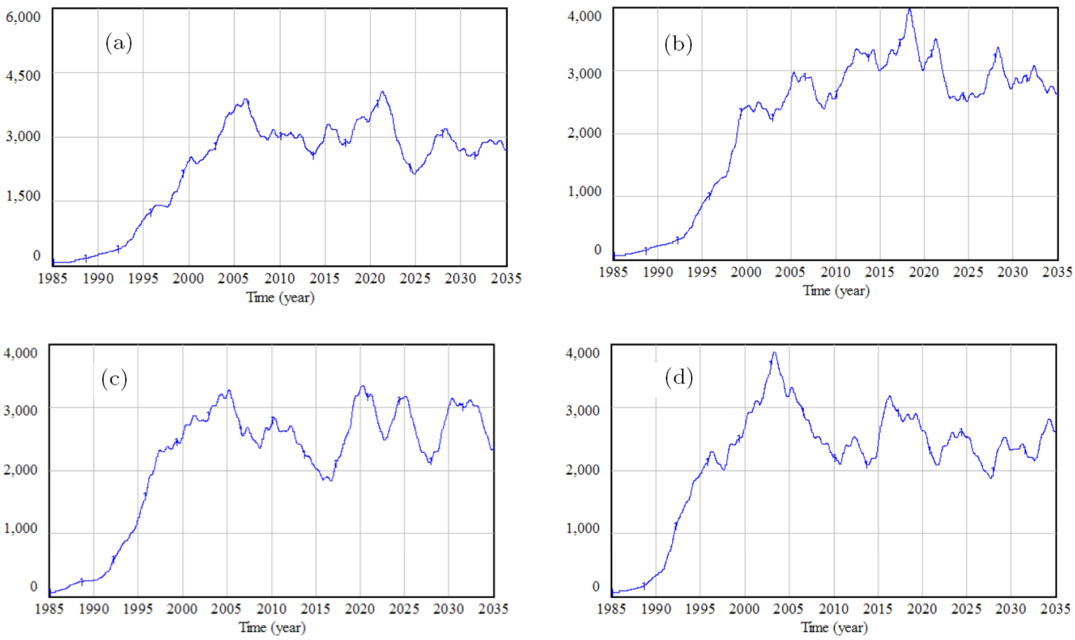
Suppose you made the SD model above concerning the large herbivores population in the 'Oostvaardersplassen' (OVP), and that you used the carrying capacity calculation in the graphs below (left for the population of Heck cows and right for all large herbivores).



Left: Carrying capacity for Heck cows in the OVP (Source: NRC Handelsblad 11/12/2010) – Right: Generalized carrying capacity curves for all large herbivores in the OVP



The graph above shows the smoothed (3^{rd} order information delay of 1 year) values of the *flow* variables (in blue: 'smoothed info on large herbivores births'; in red: 'smoothed info on large herbivores deaths'. Which of the following graphs is the graph of the corresponding smoothed *stock* variable ('smoothed info on large herbivores')?



G.8 MODEL USE AND POLICY ANALYSIS

Multiple Choice Question 13 (/ 1)

Which of the following statements about SD model use wrt potential pandemic shocks is correct?

a. SD models can be used to perfectly predict the dynamics of a future pandemic shock.

b. SD models can be used to generate all sorts of plausible dynamics of pandemics, and policies can be tested over all these dynamics.

c. SD models cannot be used to study, and test policies for, very uncertain issues like possible future pandemic shocks.

d. None of the answers above is correct.

G.9 APPLIED SYSTEMS THINKING, AND ARCHETYPES

Multiple Choice Question 14 (/ 1)

Some of the hurdles to tackle worldwide anthropogenic climate change are *(i)* the fact that the average atmospheric lifetime of CO_2 amounts to some 100 years, *(ii)* the relationship between CO_2 emissions and (development of) welfare, *(iii)* the enormous transition/effort that will be necessary to reduce worldwide emissions by 90%, and *(iv)* that the contribution to total emissions or reductions of any single actor –even the most polluting– is negligible compared to the whole. Hence, each and any actor needs to contribute, else we will collectively destroy our own world. Which archetype corresponds to this problem?

a. the '*shifting the burden*' archetype;

b. the '*fixes that fail*' archetype;

c. the '*growth and under-investment*' archetype;

d. the '*tragedy of the commons*' archetype.