

Overview of the Simulation Modeling Process

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CMPT 858

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Announcements

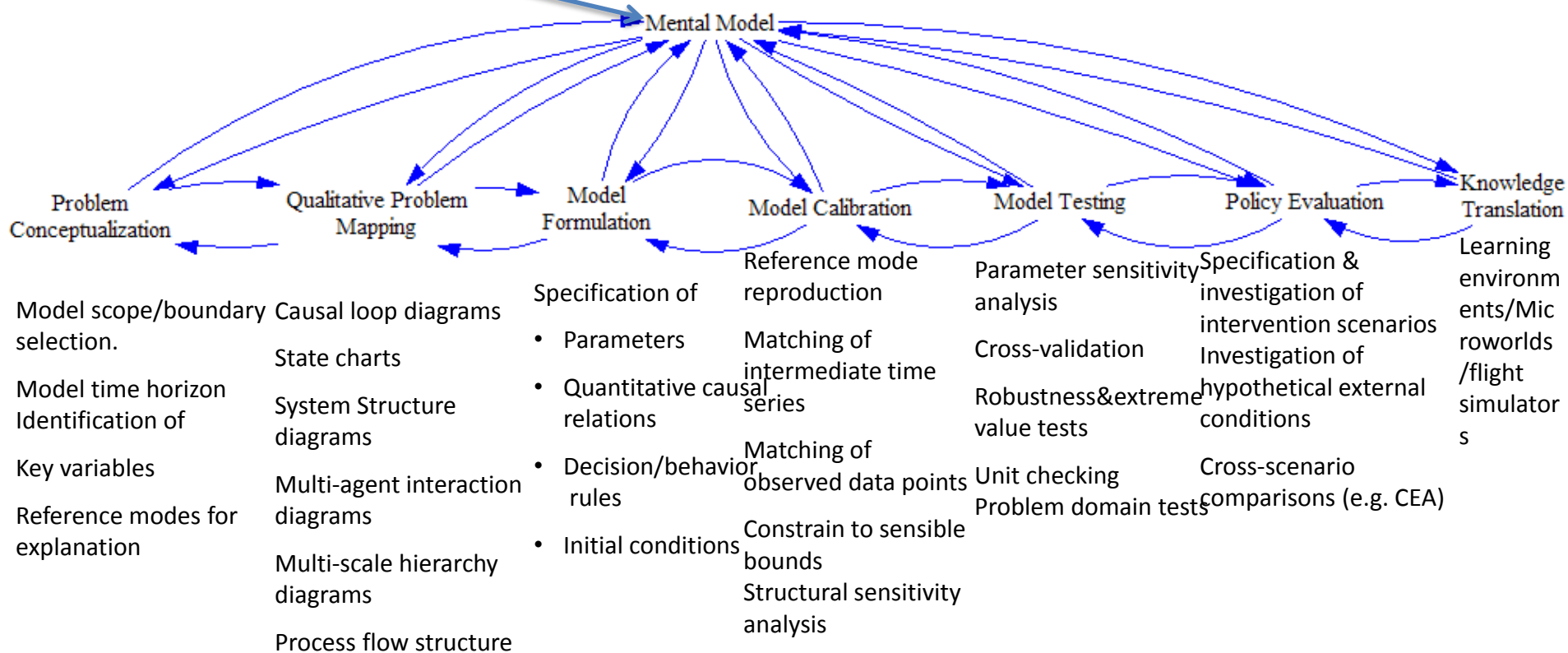
- Tutorial vote link sent
 - Please vote by Wednesday evening
- Download & install Vensim PLE
 - <http://www.vensim.com/freedownload.html>

Overview of Modeling Process

- Typically conducted with an interdisciplinary team
- An ongoing process of refinement
- Best: Iteration with modeling, intervention implementation, data collection
- Often it is the *modeling process* itself – rather than the models created – that offers the greatest value

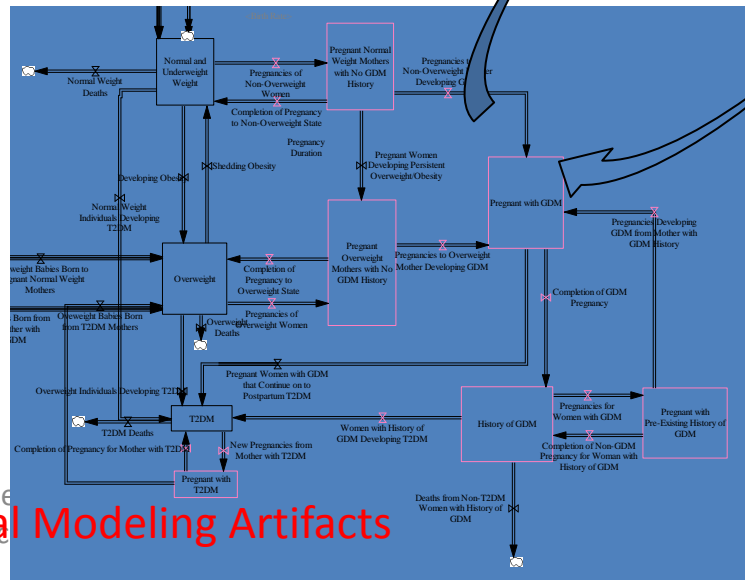
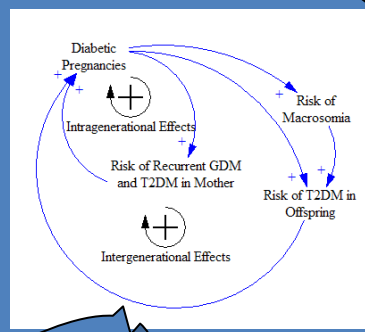
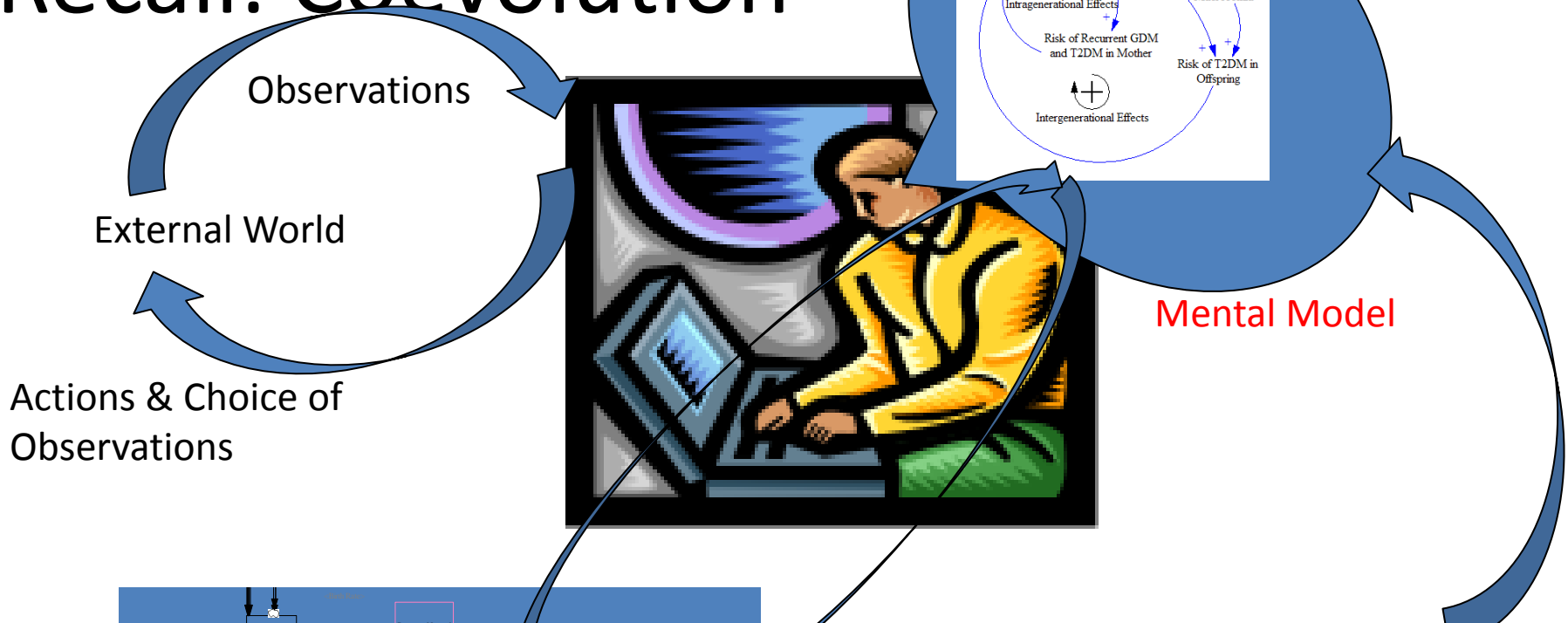
Modeling Process Overview

A Key Deliverable!

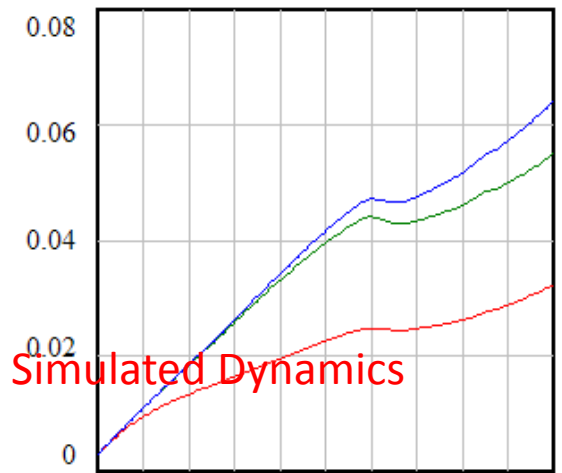


Group model building

Recall: Coevolution

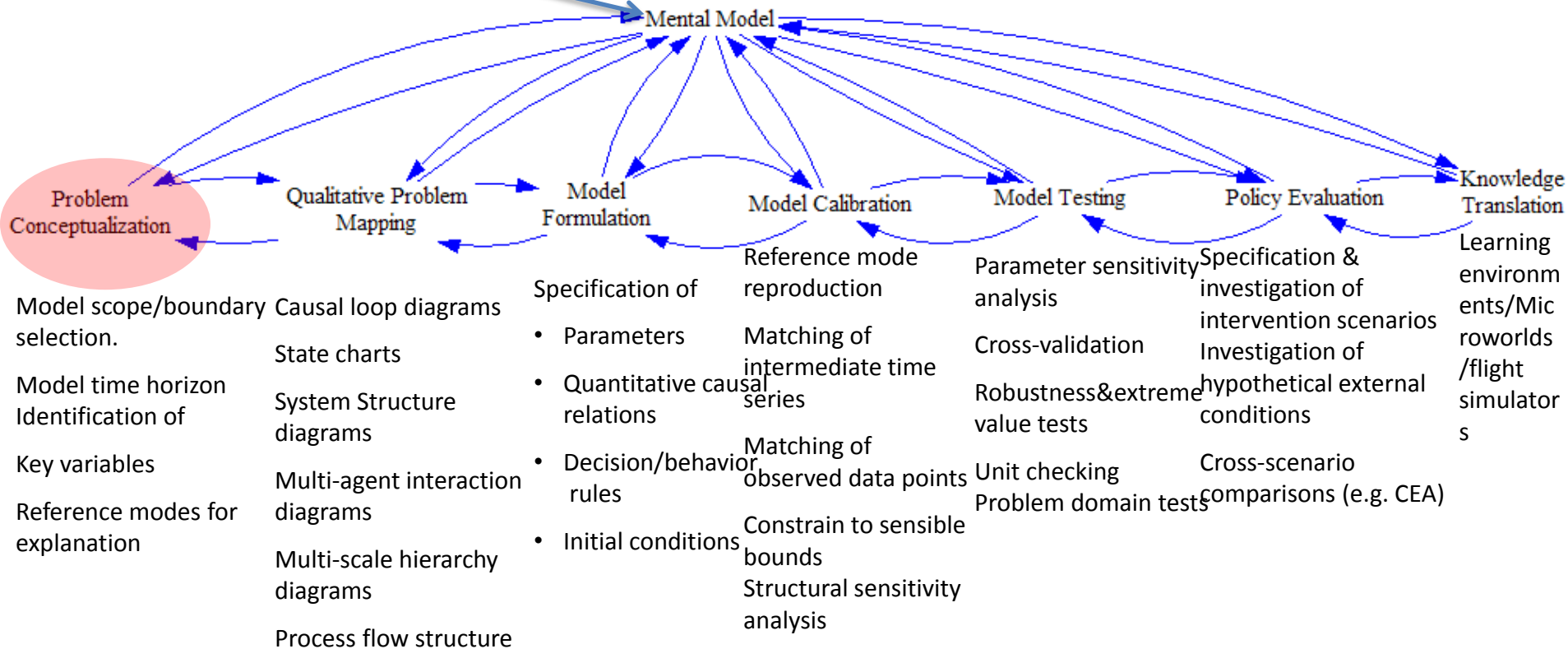


Fractional Prevalence of TD2M



Modeling Process Overview

A Key Deliverable!



Group model building

Identification of Questions/ “The Problem”

- All models are simplifications and “wrong”
- Some models are useful
- Attempts at perfect representation of “real-world” system generally offer little value
- Establishing a clear model purpose is critical for defining what is included in a model
 - Understanding broad trends/insight?
 - Understanding policy impacts?
 - Ruling out certain hypotheses?
- Think explicitly about model boundaries
- Adding factors often does not yield greater insight
 - Often simplest models give greatest insight
 - Opportunity costs: More complex model takes more time to build=>less time for insight

Importance of Purpose

Firmness of purpose is one of the most necessary sinews of character, and one of the best instruments of success. Without it genius wastes its efforts in a maze of inconsistencies.

Lord Chesterfield

The secret of success is constancy of purpose.

Benjamin Disraeli

The art of model building is knowing what to cut out, and the purpose of the model acts as the logical knife. It provides the criterion about what will be cut, so that only the essential features necessary to fulfill the purpose are left.

John Sterman

Common Division

- Endogenous
 - Things whose dynamics are calculated as part of the model
- Exogenous
 - Things that are included in model consideration, but are specified externally
 - Time series
 - Constants
- Ignored/Excluded
 - Things outside the boundary of the model

Example of Boundary Definition

Fiddaman

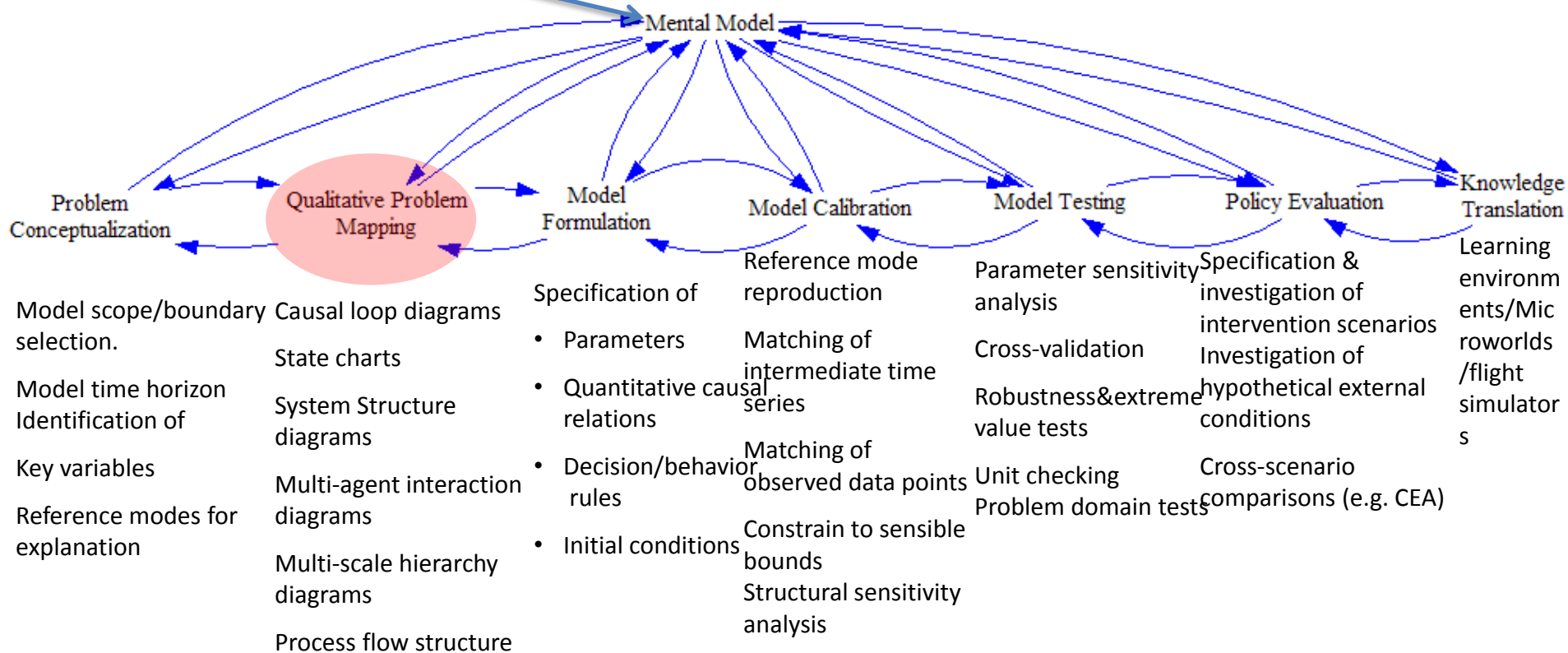
A Feedback-Rich Climate-Economy Model (1998)

Table 1: Model Boundary

Endogenous	Exogenous	Excluded
Economic output	Population	Labor mobility and participation
Consumption	Factor productivity	Money stocks and monetary effects
Interest rates	Autonomous energy efficiency improvement	Non-energy resources
Investment	Oil/gas and coal prices (1960-1990)	Regional disaggregation
Embodiment of energy requirements in capital	Nonenergy CO ₂ emissions	Sectoral disaggregation (other than energy)
Energy prices	Greenhouse gases other than CO ₂	Fossil-fired electric power generation
Energy production		Inventories and backlogs
Energy technology		
Depletion		
CO ₂ Emissions		
Carbon Cycle		
Atmosphere and ocean temperature		
Climate damages		

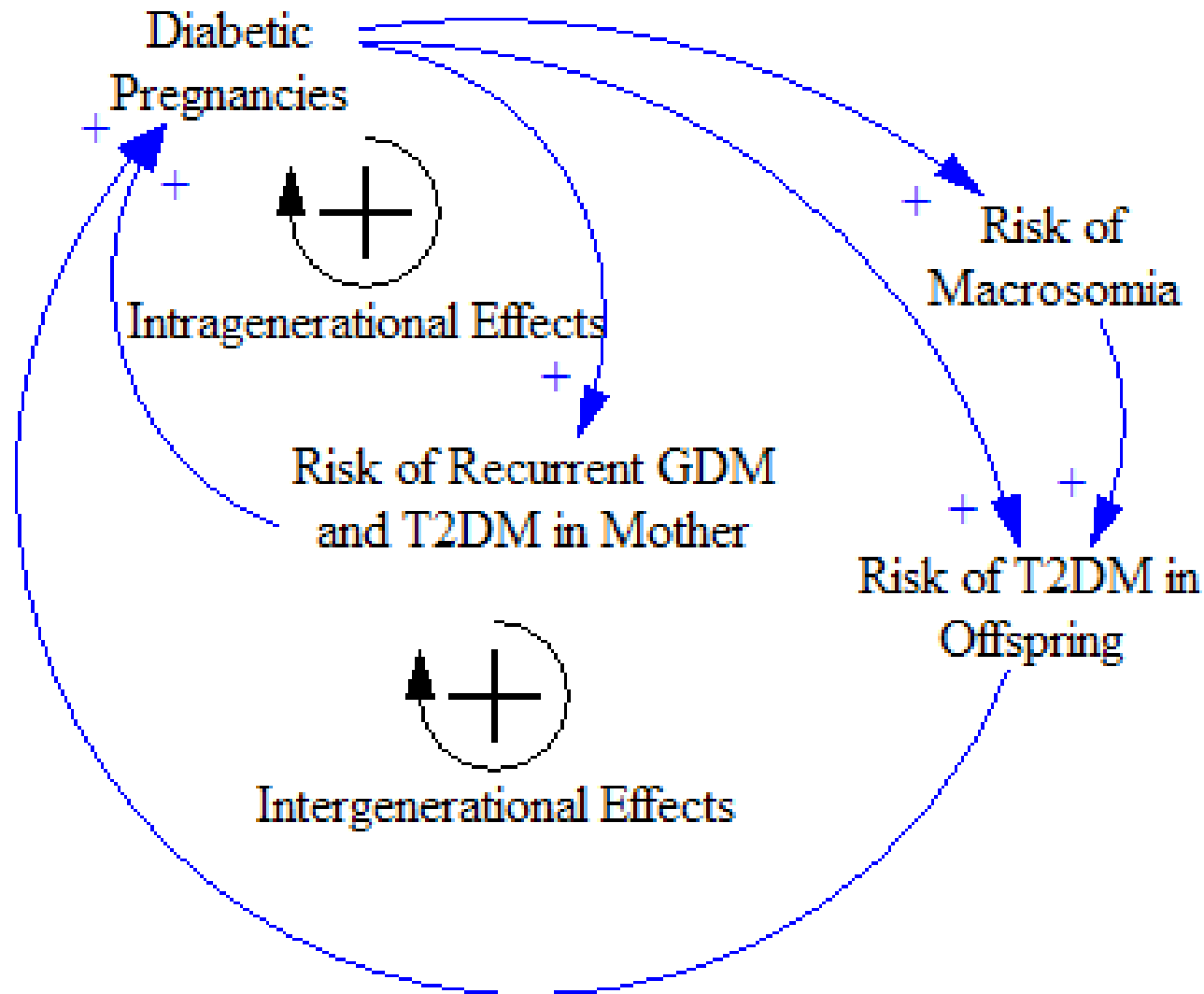
Modeling Process Overview

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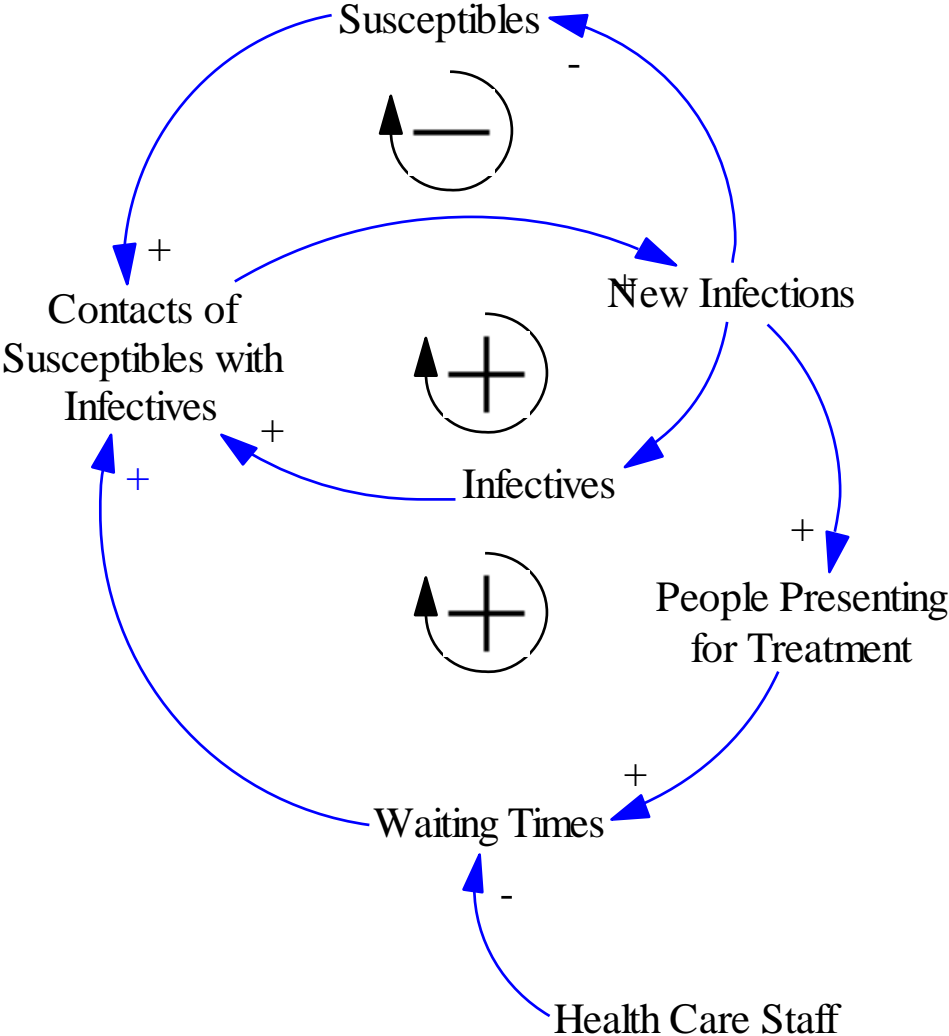


Group model building

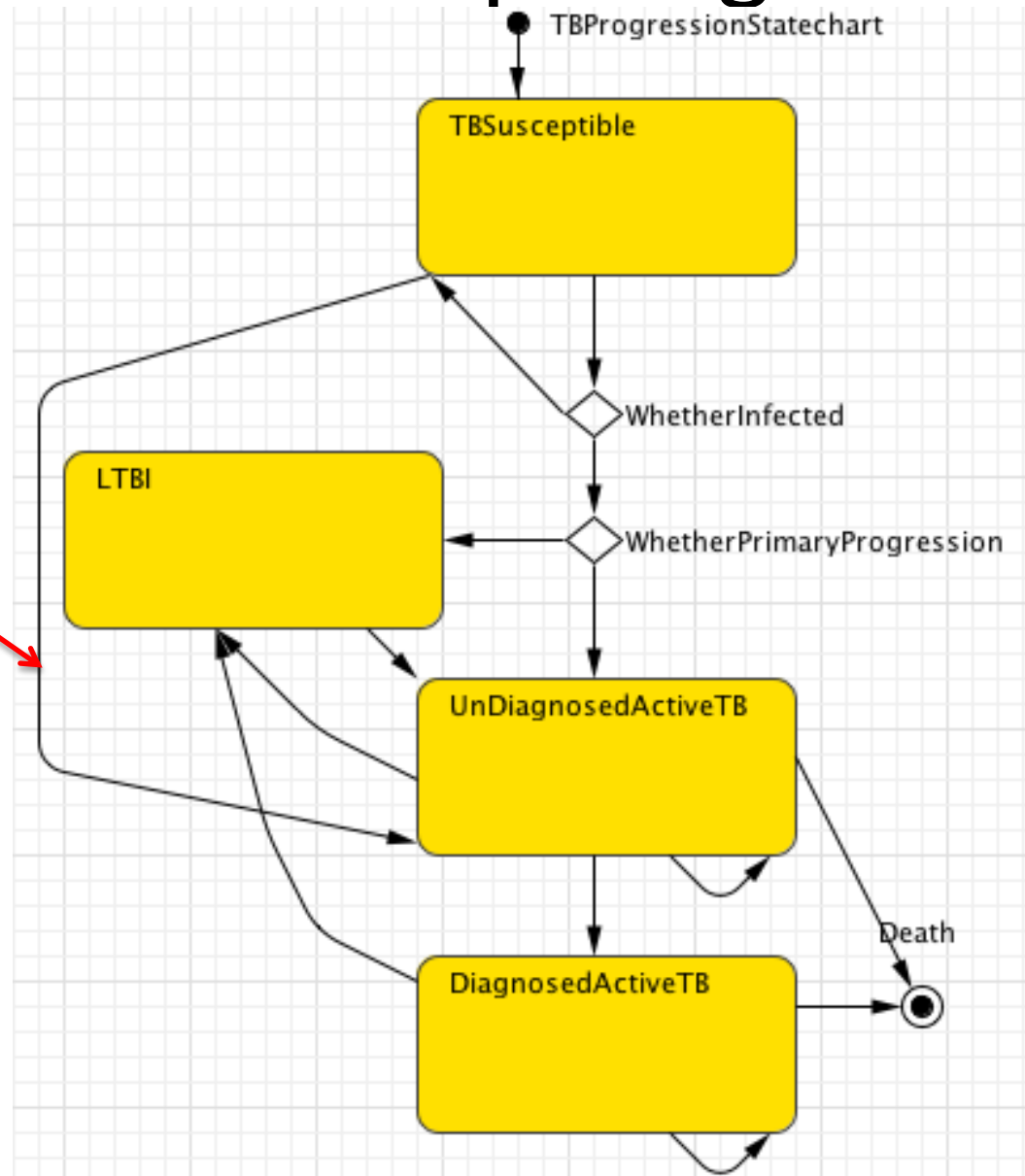
Example Causal Loop Diagram



A Second Causal Loop Diagram



Qualitative Causal Loop Diagram

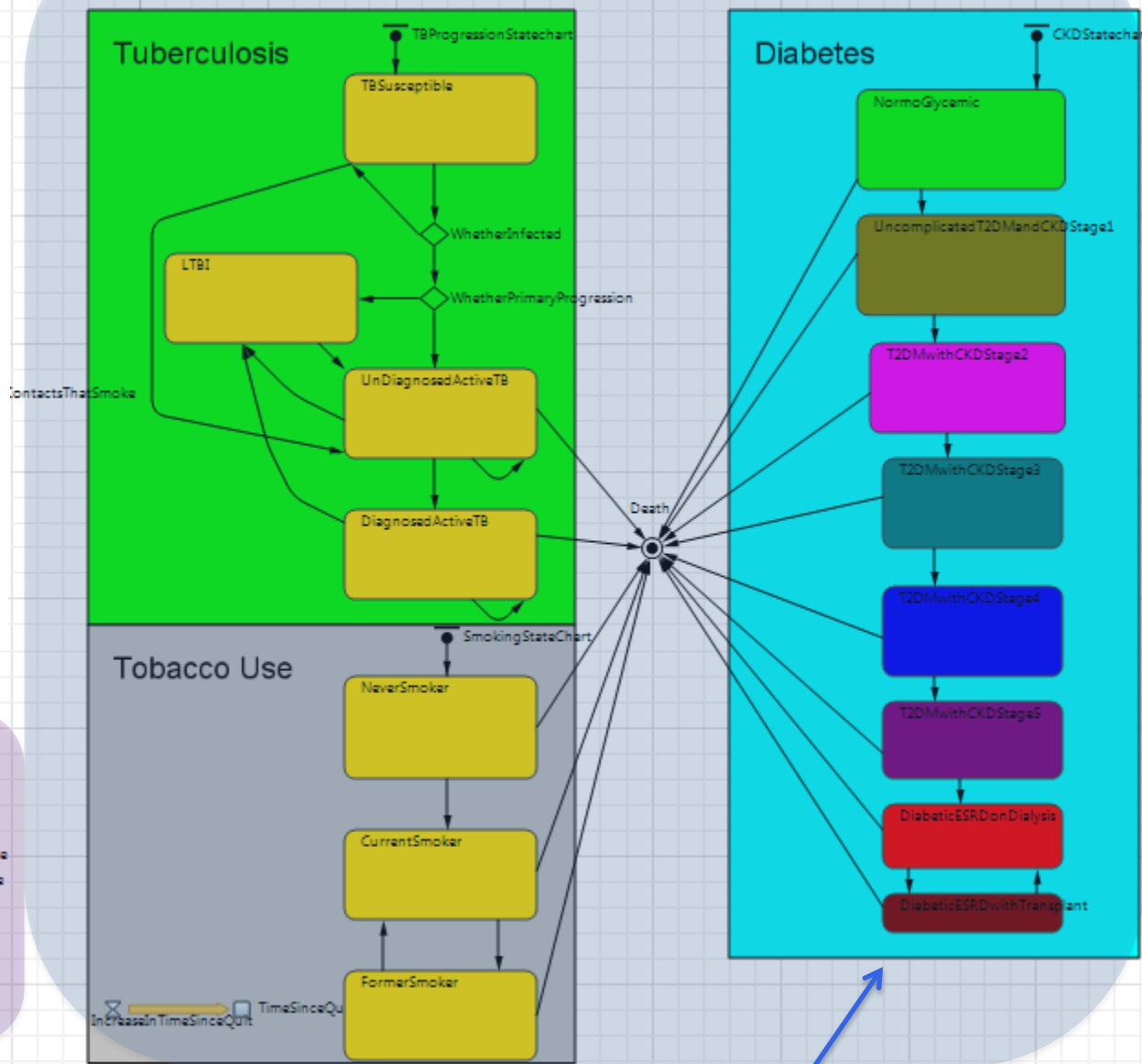


Qualitative
Transitions
(no likelihood
yet specified)

These variables are aspects of *state*.

- Ⓟ Weight
- Ⓟ Cumulative Cigarettes Smoked
- Ⓟ Age

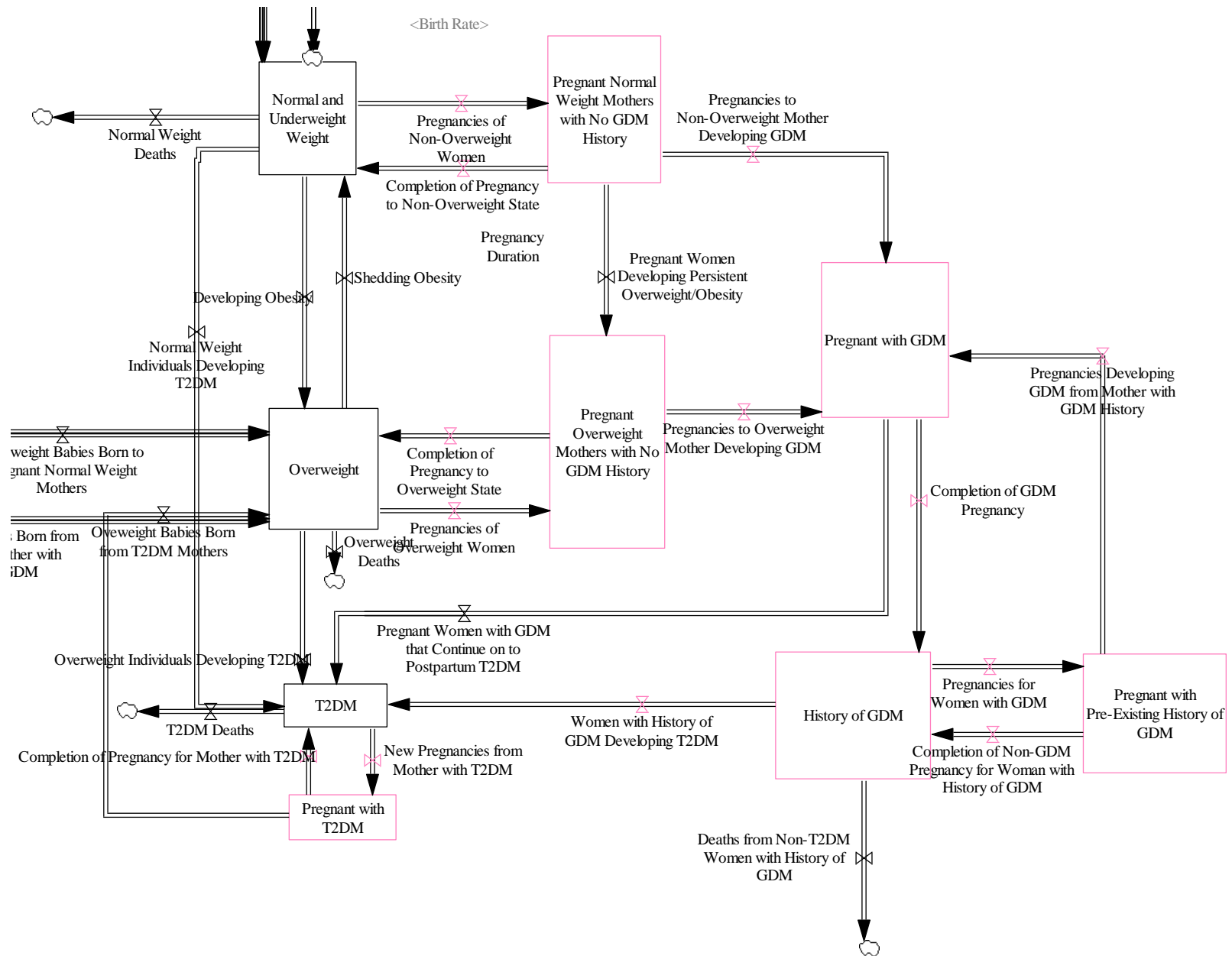
- Ⓟ Sex
- Ⓟ Ethnicity
- Ⓟ MeanDaysToNaturallyClearInfection
- Ⓟ ReactivationRateForNormoGlycemicPeople
- Ⓟ SmokingInitiationHazardLogisticSteepnessCoefficient
- Ⓟ SmokingInitiationHazardLogisticValueWhenNoContactsSmoke
- Ⓟ SmokingInitiationHazardLogisticValueWhenAllContactsSmoke
- Ⓟ ReactivationRateHazardForNeverSmoker
- Ⓟ ReactivationRateHazardForCurrentSmoker
- Ⓟ RapidnessOfDecreaseInReactivationRateWithTimeSinceQuit
- Ⓟ SmokingInitiationHazardLogisticMidpoint
- Ⓟ RapidnessOfDecreaseInChanceOfRelapseWithTimeSinceQuit
- Ⓟ DaysPerTimeUnit



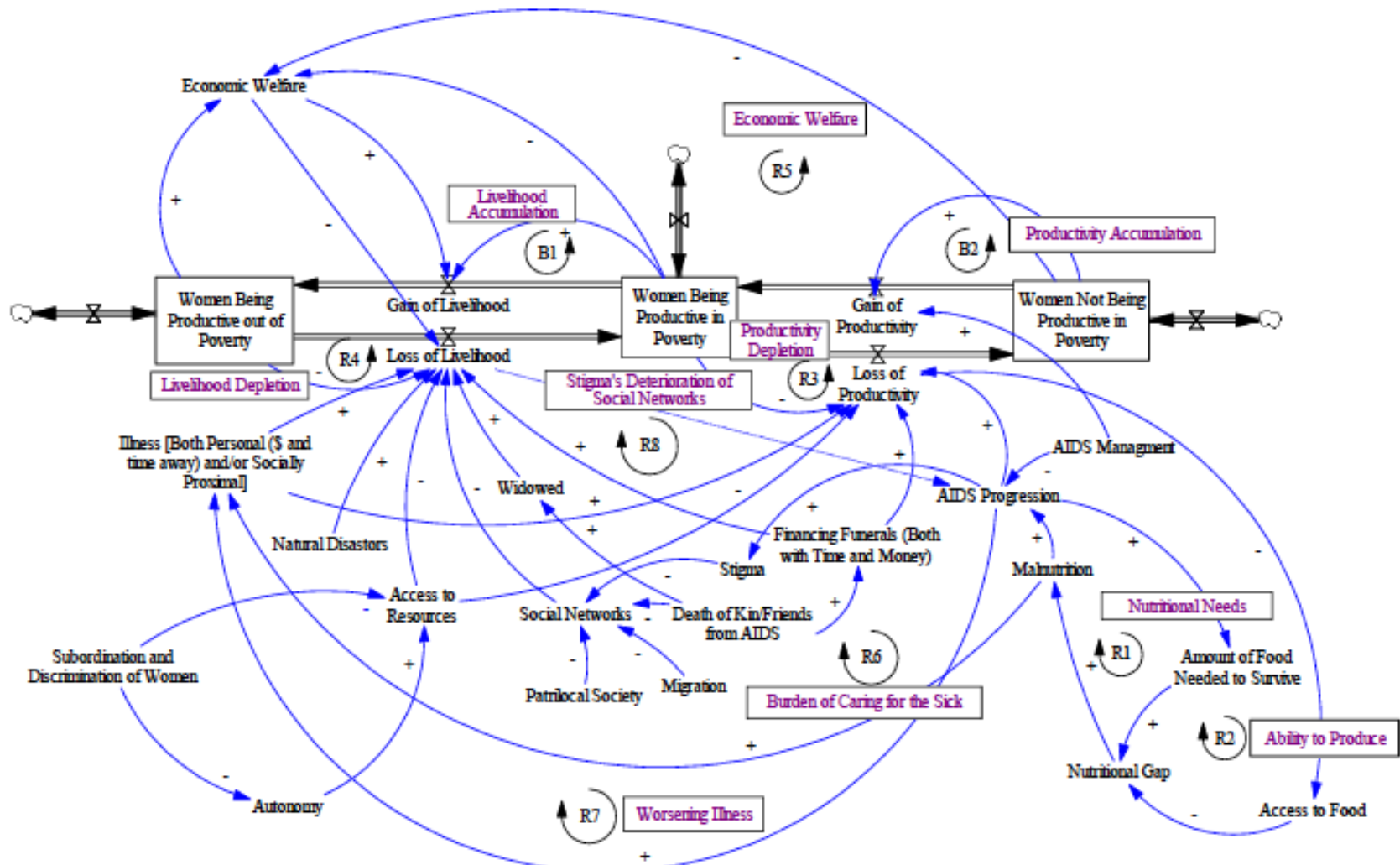
These “parameters” give static characteristics of the agent

These describe the “behaviours” – the mechanisms that will govern agent dynamics

Stock & Flow Structure

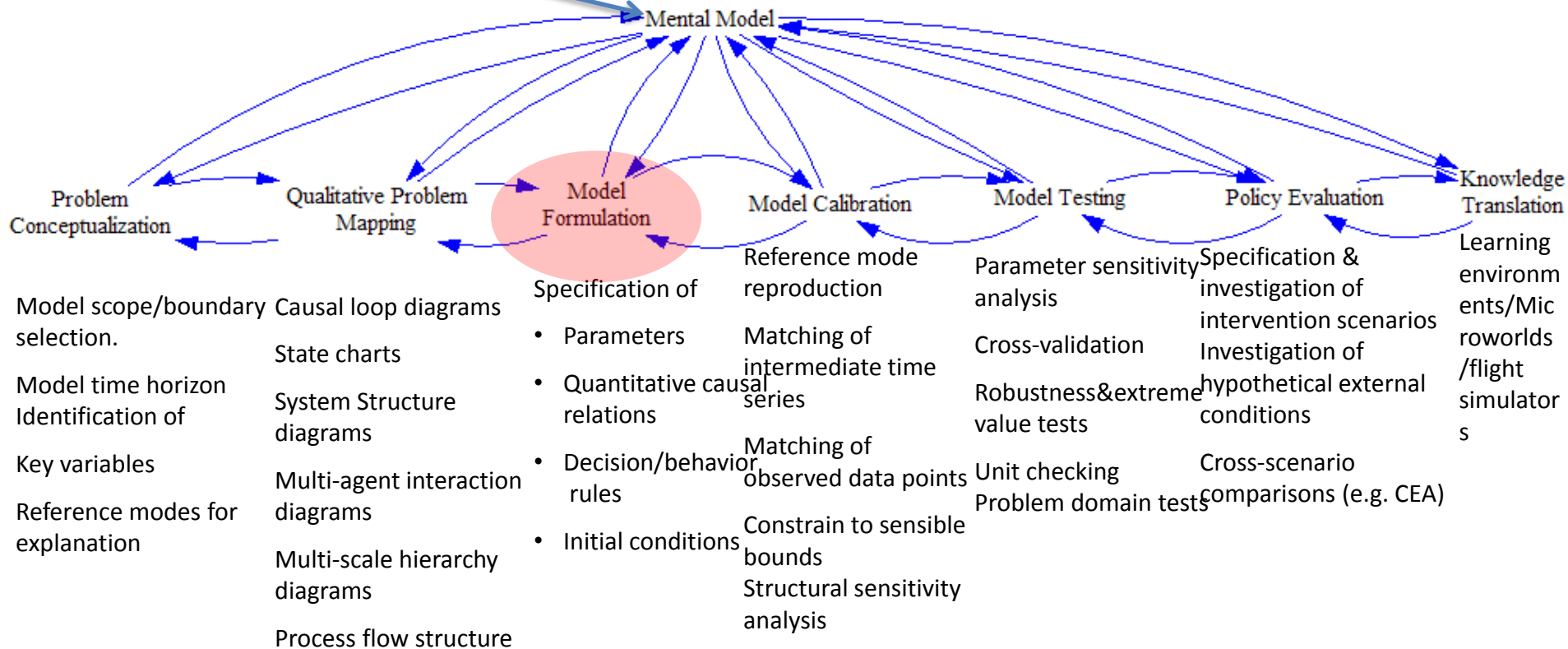


Problem Mapping: Qualitative Models (System Structure Diagram)



Modeling Process Overview

A Key Deliverable!

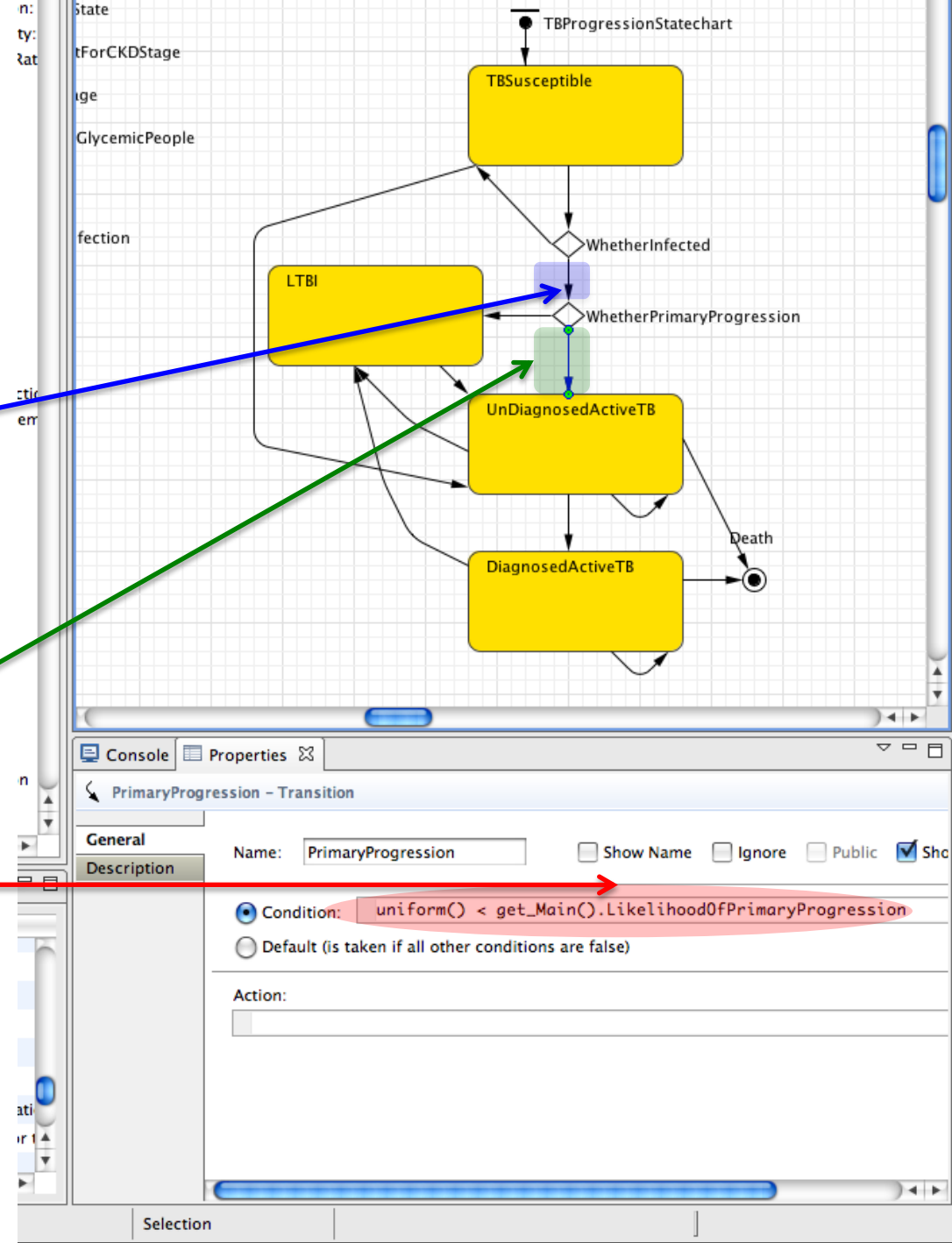


Group model building

Model Formulation

- Model formulation elaborates on problem mapping to yield a quantitative model
- Key missing ingredients
 - Specifying formulas for
 - Statechart transitions
 - Flows (in terms of other variables)
 - Intermediate/output variables
 - Parameter values

Example Conditional Transition



The **incoming** transition into "WhetherPrimaryProgression" will be routed to this **outgoing** transition if **this condition** is true

PrimaryProgression - Transition

General

Name: PrimaryProgression Show Name Ignore Public Show

Description

Condition: `uniform() < get_Main().LikelihoodOfPrimaryProgression`

Default (is taken if all other conditions are false)

Action:

Transition Type: Message Triggered

The image shows a statechart editor interface for a TB progression model. The main workspace displays a statechart with the following states and transitions:

- States:** TBSusceptible, LTBI, UnDiagnosedActiveTB, DiagnosedActiveTB, and a final state (represented by a bullseye).
- Transitions:** TBProgressionStatechart (initial), WhetherInfected, WhetherPrimaryProgression, and Death.
- Parameters:** Age, Sex, Ethnicity, and getDegree.

The configuration panel for the transition "ForcedInitialTBInfection" is open, showing the following settings:

- Name:** ForcedInitialTBInfection
- Triggered by:** Message
- Message type:** int (selected), boolean, double, String, Other
- Class Name:** (empty)
- Fire transition:** If message equals (selected), Unconditionally, If expression is true (use msg for message)
- Message:** MsgForceInitialTBInfection

The bottom of the interface shows a console with several error messages, including "Engine.log cannot be resolved" and "Type: statechart cannot be resolved". The status bar at the bottom indicates "Selection" and "Cursor: X=339, Y=320".

Transition Type: Fixed Rate

The screenshot displays the AnyLogic Advanced software interface, specifically the Statechart Editor. The main workspace shows a statechart for TB progression. The states are represented by yellow rounded rectangles: **TBSusceptible**, **LTBI**, **UnDiagnosedActiveTB**, and **DiagnosedActiveTB**. Transitions are shown as arrows between these states. A transition from **TBSusceptible** to **LTBI** is triggered by a **Rate** type event, with the rate expression $\text{MeanDaysToNaturallyClearInfection} / \text{DaysPerTimeUnit}$. The action for this transition is `traceIn("Naturally recovering to LTBI...")`. Other transitions include **WhetherInfected** (diamond), **WhetherPrimaryProgression** (diamond), and **Death** (circle).

The left sidebar shows the project structure for **TBv1***, including **Main** (Parameters, Functions, Environments, Embedded Objects, Presentation) and **Person** (Parameters, Plain Variables, Dynamic Variables, Statecharts). The **Statecharts** section is expanded to show **TBProgressionStatechart** with its sub-elements: **TBProgressionStatechart**, **TBSusceptible**, **TBInfectiousContact**, **WhetherInfected**, **TBTransmission**, **WhetherPrimaryProgression**, **PrimaryProgression**, and **UnDiagnosedActiveTB**.

The bottom panel shows the **Properties** window for the selected transition, **NaturalTBRecovery - Transition**. The **General** tab is active, showing the transition name, **Triggered by: Rate**, and the **Rate** expression. The **Action** field contains `traceIn("Naturally recovering to LTBI...")`. The **Guard** field is empty.

The bottom status bar indicates the cursor position: **Cursor: X=455, Y=420**.

Transition Type: Variable Rate

The screenshot displays the AnyLogic Advanced software interface, titled "AnyLogic Advanced [EDUCATIONAL USE ONLY]". The main workspace shows a statechart for a TB progression model. The states are represented by yellow rounded rectangles: "TBSusceptible", "LTBI", "UnDiagnosedActiveTB", and "DiagnosedActiveTB". Transitions are shown as arrows between these states, with decision diamonds for "WhetherInfected" and "WhetherPrimaryProgression". A transition from "UnDiagnosedActiveTB" to "UnDiagnosedActiveTB" is highlighted with a blue arrow, indicating it is the selected transition. The "Reactivation - Transition" properties window is open, showing the transition name "Reactivation", triggered by "Rate", and the rate expression "ReactivationRateForCKDStage()". The action is "println(\"Reactivated\");".

The left sidebar shows the project structure for "TBv1*" under "Main". The "Person" statechart is selected, showing its parameters, functions, environments, embedded objects, presentation, and plain variables. The "TBProgressionStatechart" is also visible in the statecharts section.

The bottom left shows the "Problems" window with several error messages, including "Engine.log cannot be resolved" and "Cannot make a static reference to the non-static method getCurrentState()".

The bottom right shows the "More Libraries..." window with various library options.

Transition Type: Fixed Residence Time (Timeout)

The screenshot displays the AnyLogic Advanced software interface, titled "AnyLogic Advanced [EDUCATIONAL USE ONLY]". The main workspace shows a statechart for TB progression. The states are represented by yellow rounded rectangles: "TBSusceptible", "LTBI", "UnDiagnosedActiveTB", and "DiagnosedActiveTB". Transitions are shown as arrows between these states, with decision diamonds for "WhetherInfected" and "WhetherPrimaryProgression". A "Diagnosis" transition is shown as a blue arrow from "UnDiagnosedActiveTB" to "DiagnosedActiveTB".

The "Diagnosis" transition is configured in the "Properties" window at the bottom. The "General" tab is active, showing the following settings:

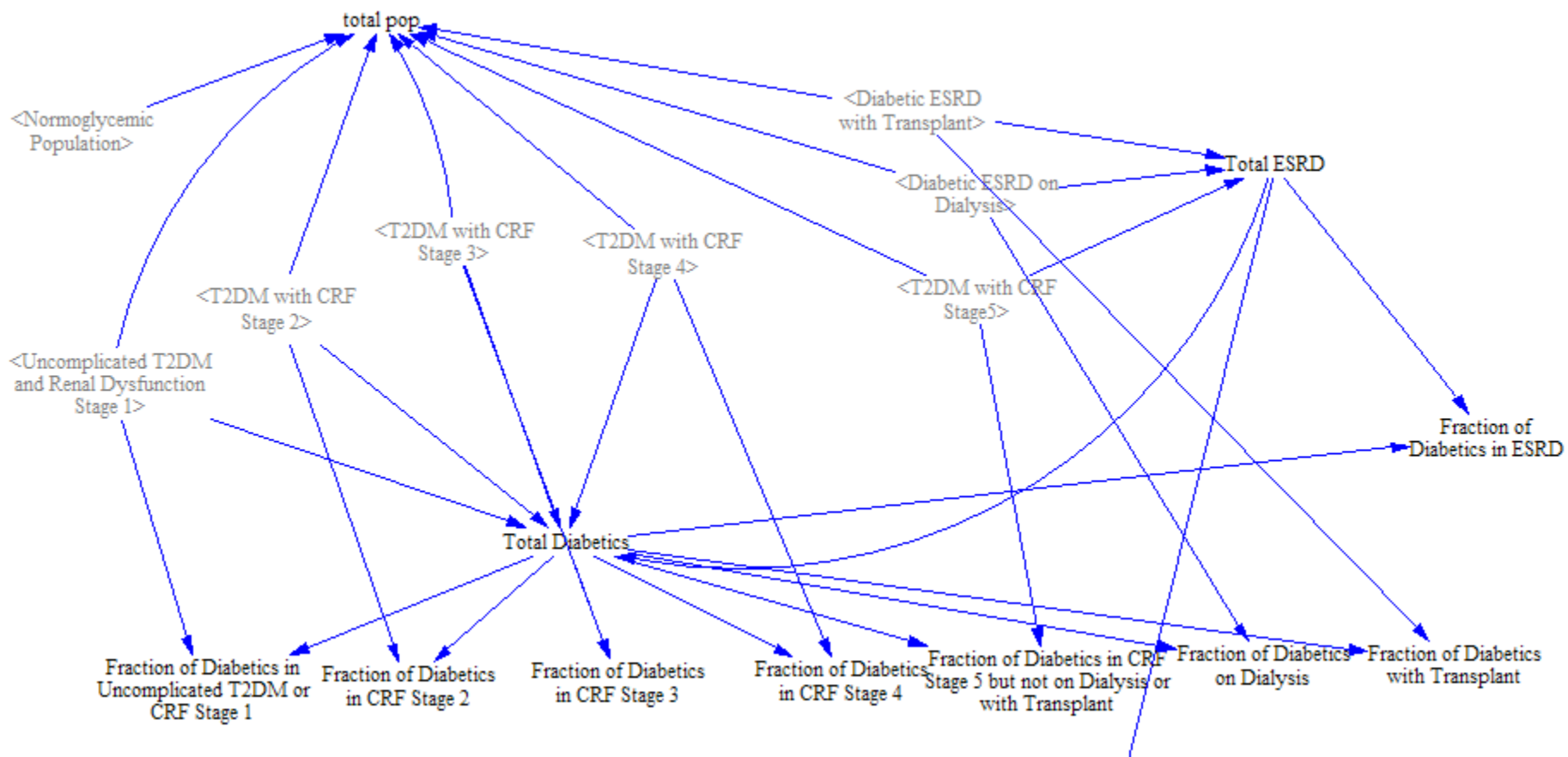
- Name: Diagnosis
- Show Name:
- Ignore:
- Public:
- Show:

The "Description" tab is also visible, showing the following configuration:

- Triggered by: Timeout
- Timeout: `get_Main().DaysUntilDiagnosis/DaysPerTimeUnit`
- Action: `traceln("Diagnosis performed");`
- Guard: (empty)

The left sidebar shows the project structure, including "Main" and "Person" objects. The "Person" object has several parameters and functions listed. The bottom-left corner shows a "Problems" window with several error messages related to "Engine.log" and "get_CurrentState()".

Simple Intermediate Variable



Simple Intermediate Variable

Editing equation for - Fraction of Diabetics in CRF Stage 2

Fraction of Diabetics in CRF Stage 2 Add Eq

= T2DM with CRF Stage 2/Total Diabetics

Type: Auxiliary Undo {()} 7 8 9 + Variables Functions More Choose Variable... Inputs

Normal 1 2 3 * T2DM with CRF Stage 2

Supplementary 0 E . / Total Diabetics

Help () . ^

Units: ▼

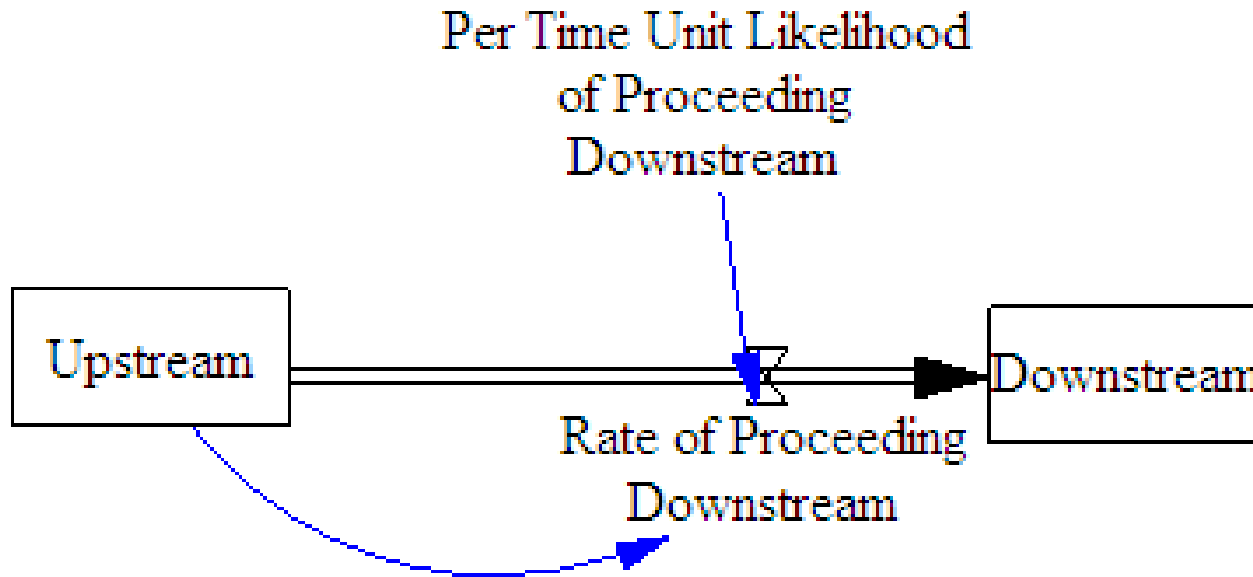
Comment:

Group: .v15 ▼ Range: Go To: Prev Next << Hilite Sel... New

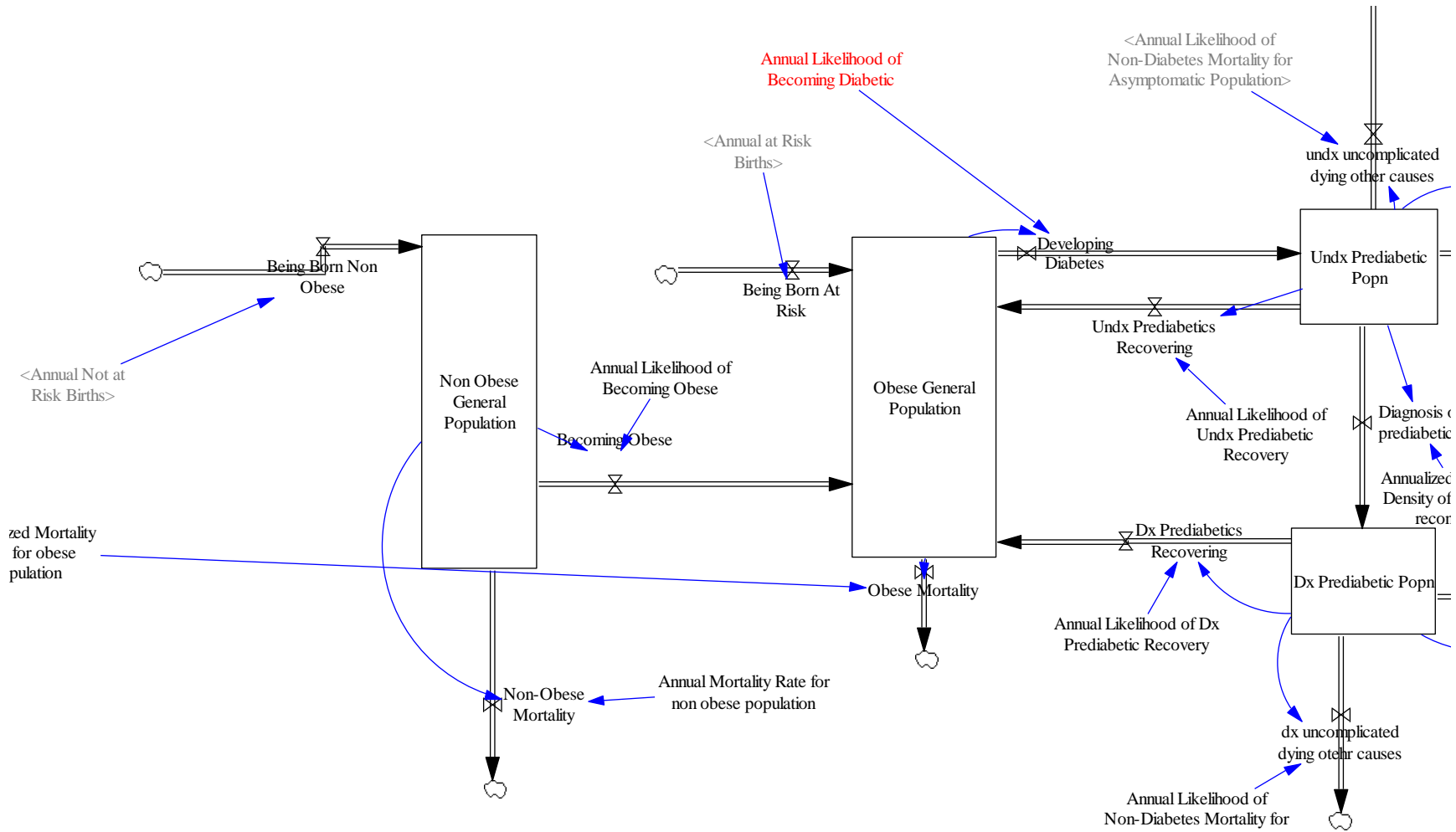
Errors: Equation Modified ▼

OK Check Syntax Check Model Delete Variable Cancel

Simple Basis for Formula: 1st Order Delay



Model Stock & Flow Structure



More Sophisticated Formula: Contact Rates and Transmission Probs.

- Contacts per susceptible: c
- Fraction of contacts that are infective: Y/N
- Per-contact transmission probability: β
- “Force of infection”: Likelihood each susceptible will be infected per unit time
 - Common formulation
 - $c(Y/N)\beta$
- Flow: Total # infections per unit time
 - $X^*(\text{Force of Infection}) = X(c(Y/N)\beta)$
 - Note that this = $Y(c(X/N)\beta)$

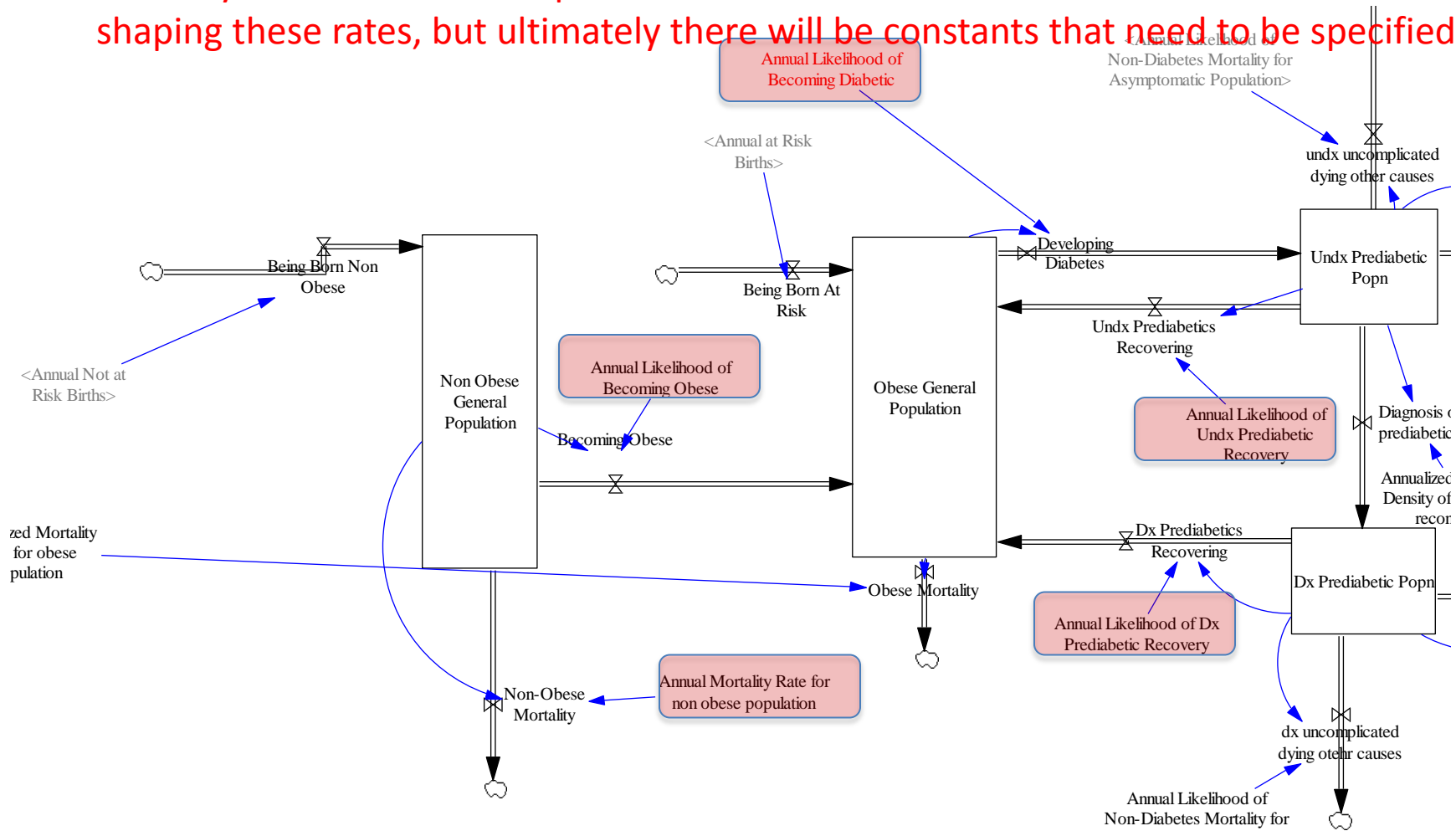
Sources for Parameter Estimates

- Surveillance data
- Controlled trials
- Outbreak data
- Clinical reports data
- Intervention outcomes studies
- Calibration to historic data
- Expert judgement
- Systematic reviews

Parameter*	Description	Baseline value (units)	Reference
μ	Entry/exit of sexual activity	0.0056 (years ⁻¹)	Garnett and Bowden, 2000
c	Partner change rate per Susceptible	16.08 (years ⁻¹)	Approximated from Garnett and Bowden, 2000
β	Probability of infection per sexual contact	0.70	Garnett and Bowden, 2000
ϕ	Fraction of Infectives who are symptomatic	0.20	Garnett and Bowden, 2000
$1/\gamma$	Latent period	0.038 (years)	Brunham et. al., 2005
$1/\sigma$	Duration of infection	0.25 (years)	Brunham et. al., 2005
θ	Asymptomatic recovery coefficient	1.5	Garnett and Bowden, 2000
$1/\pi$	Duration of naturally-acquired immunity	1 (year)	Approximated from Brunham et. al., 2005

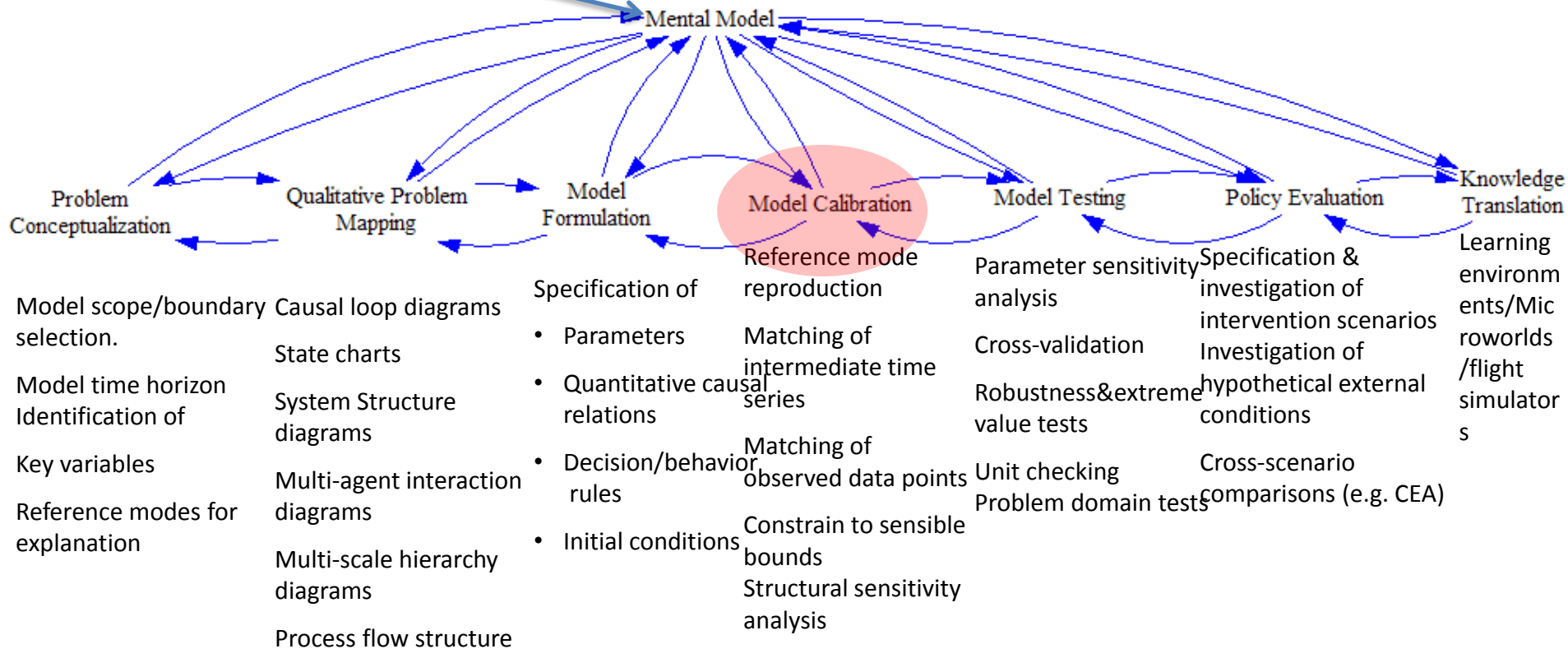
Introduction of Parameter Estimates

Some dynamics models will provide much more detail on networks of factors shaping these rates, but ultimately there will be constants that need to be specified



Modeling Process Overview

A Key Deliverable!

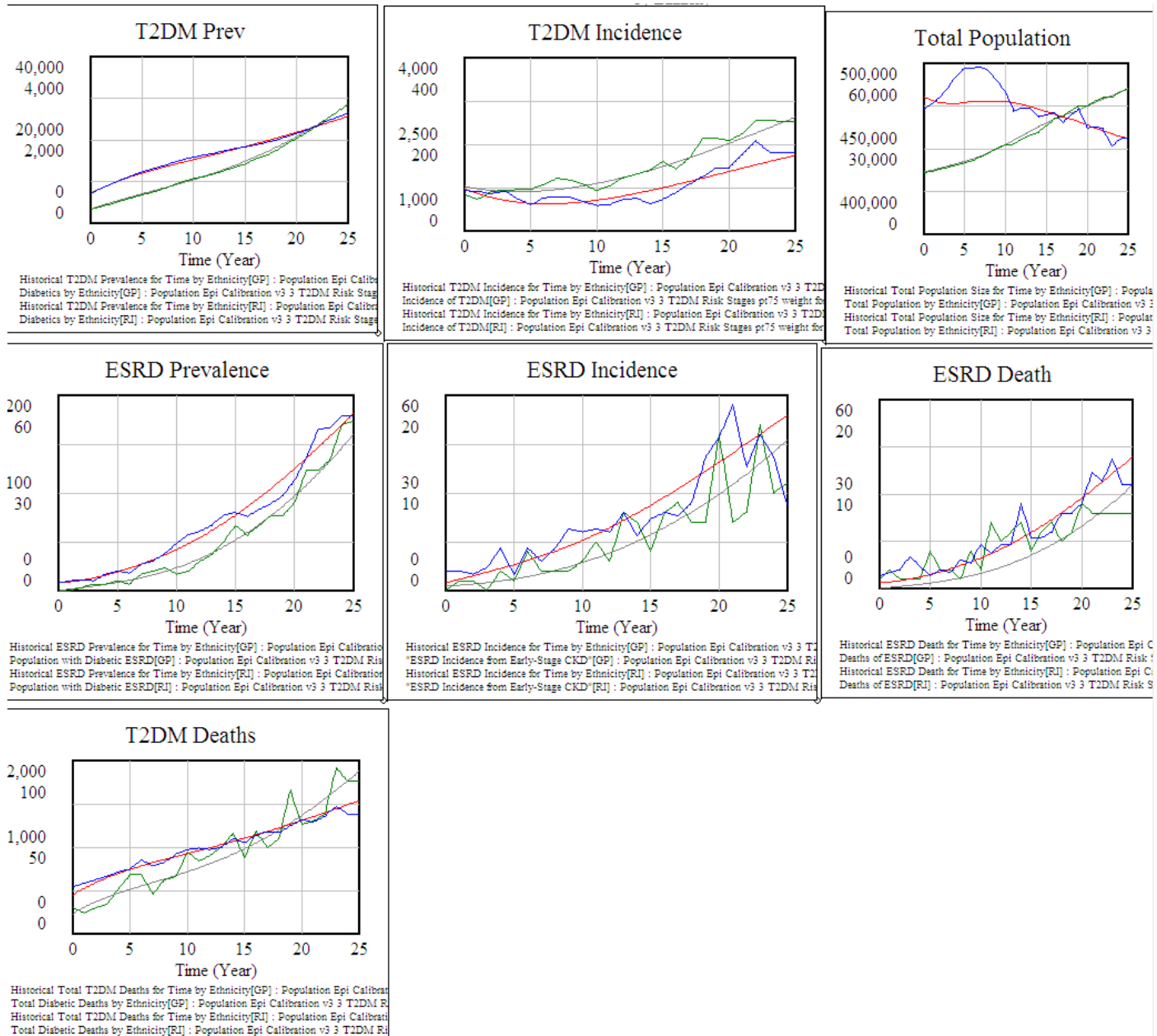


Group model building

Calibration

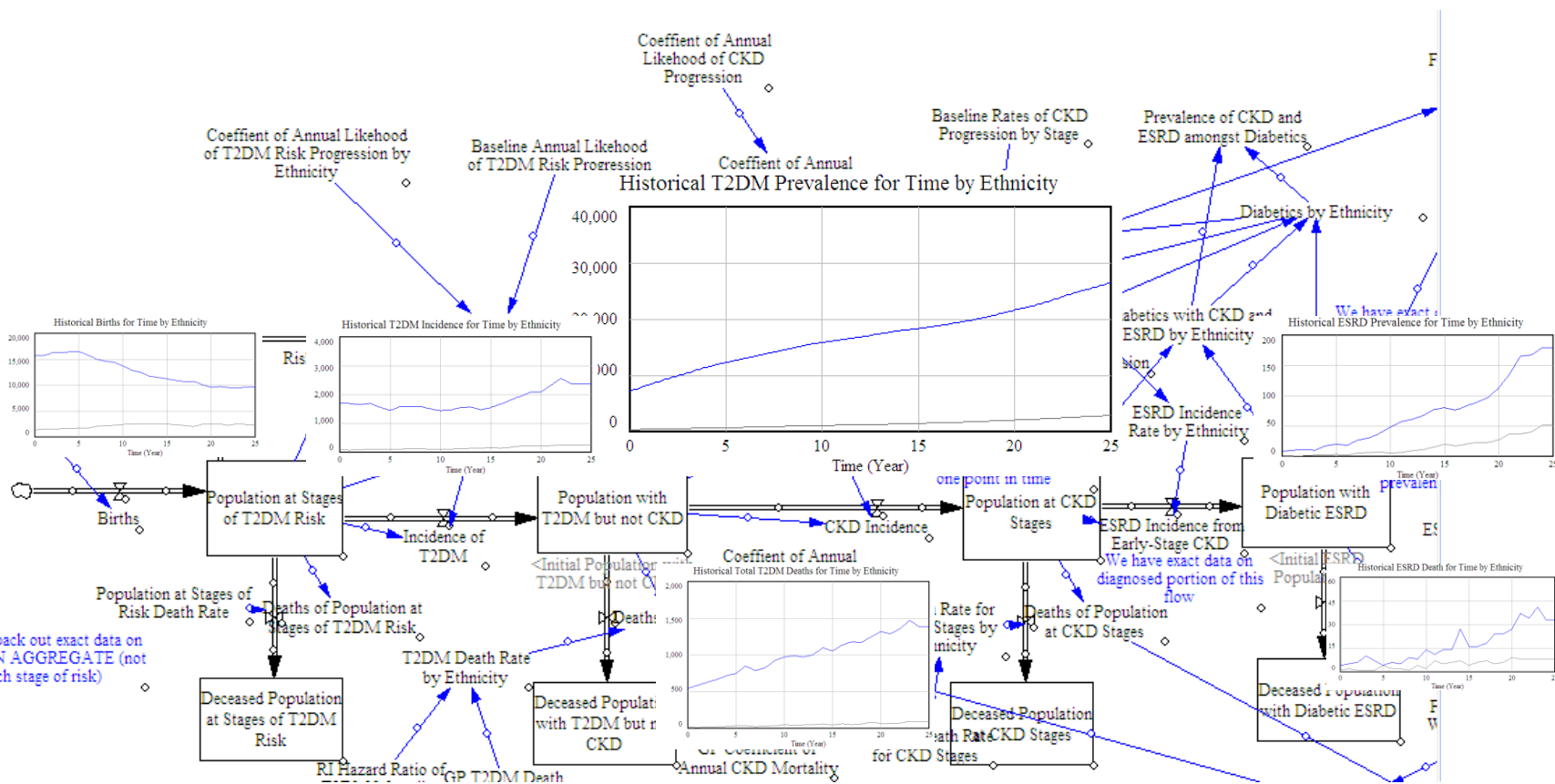
- Often we don't have reliable information on *some* parameters
 - Some parameters may not even be observable!
- Some parameters may implicitly capture a large set of factors not explicitly represented in model
- Often we will calibrate less well known parameters to match observed data
 - “Analytic triangulation”: Often try to match against *many* time series or pieces of data at once
- Sometimes we learn from this that our model structure just can't produce the patterns!

Single Model Matches Many Data Sources

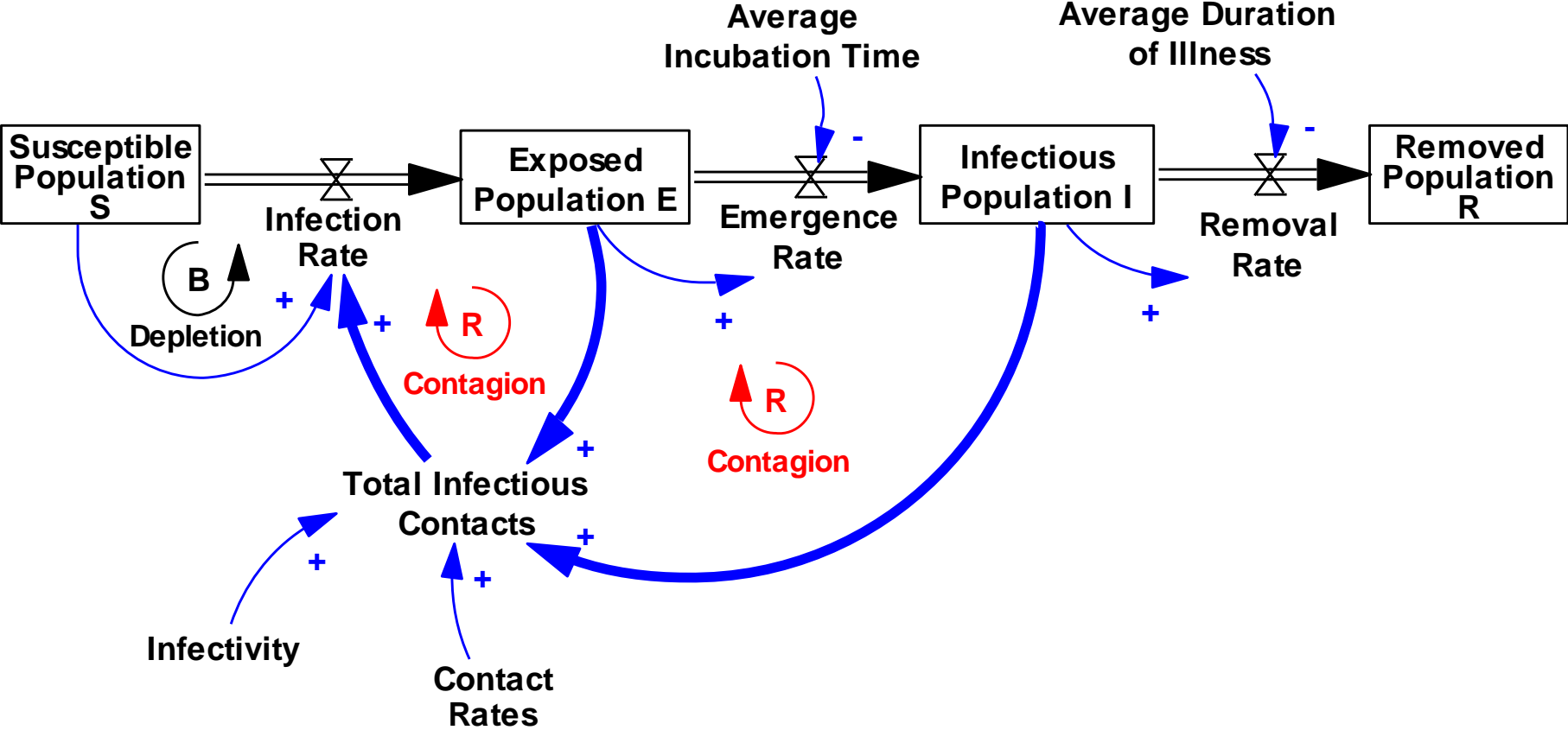


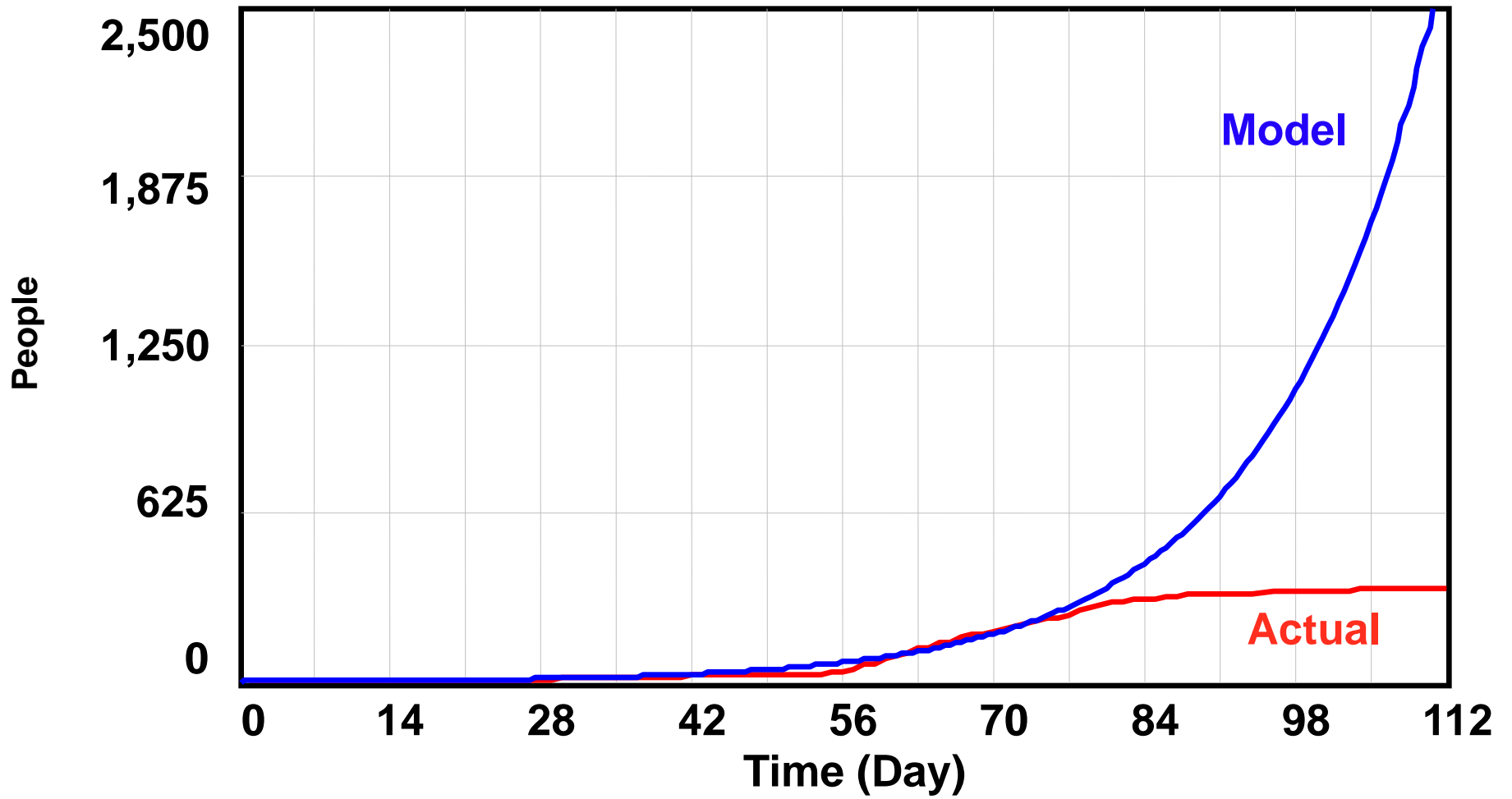
The Pieces of the Elephant

Example Model of Underlying Process & Time Series It Must Match



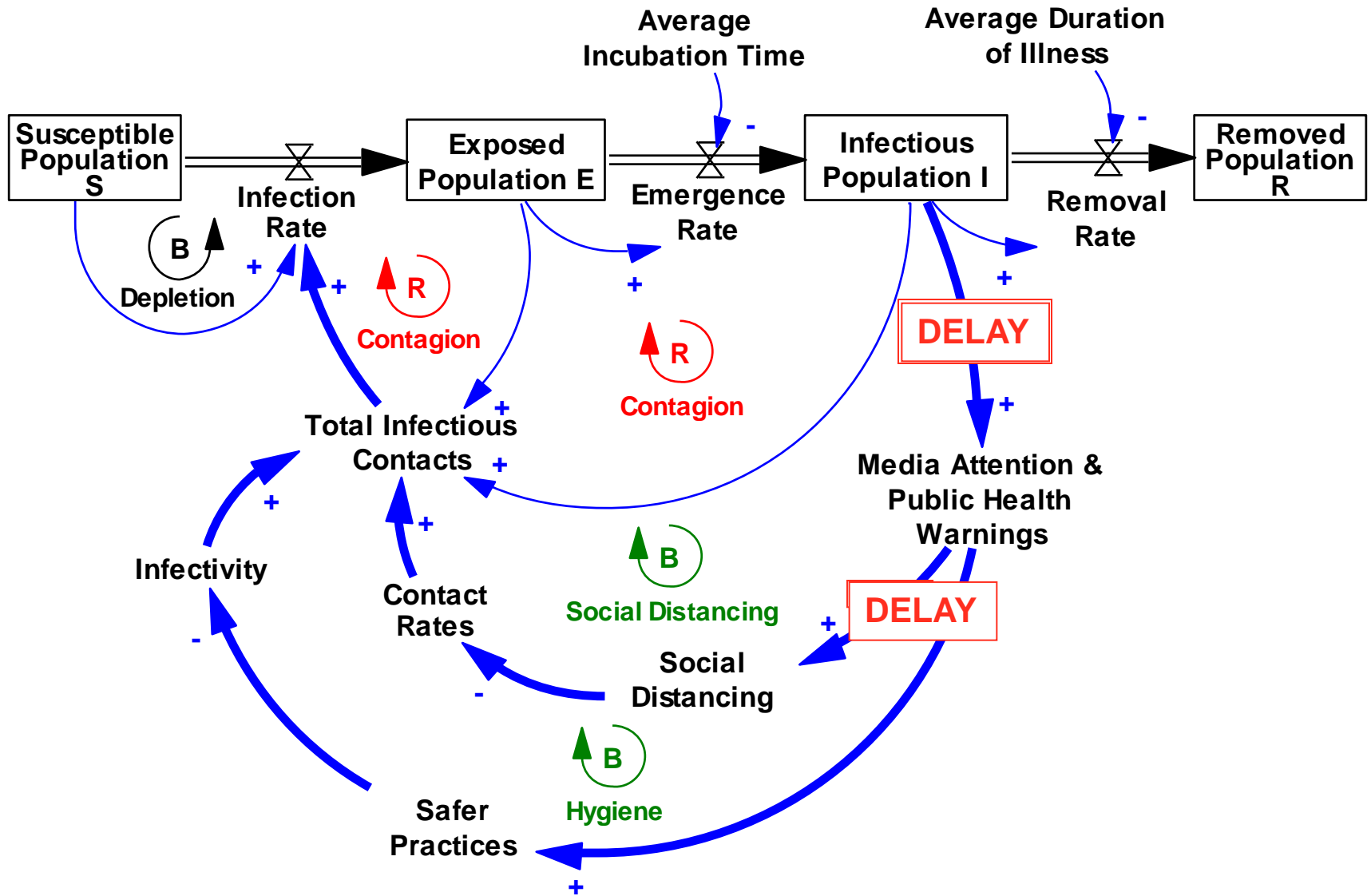
Example: Iteration & Calibration





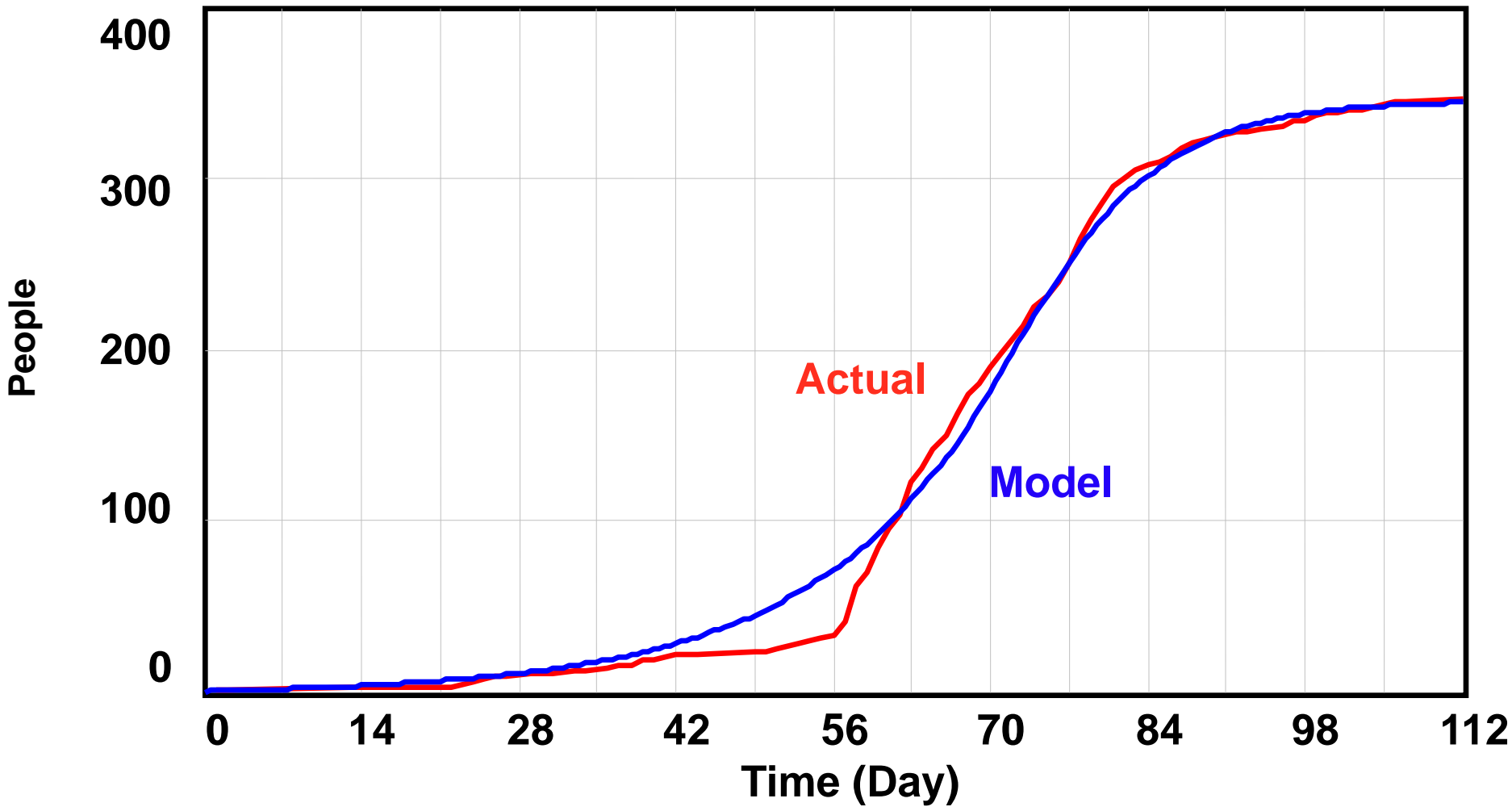
From Sterman

Expanding the Boundary: Behavioral Feedbacks



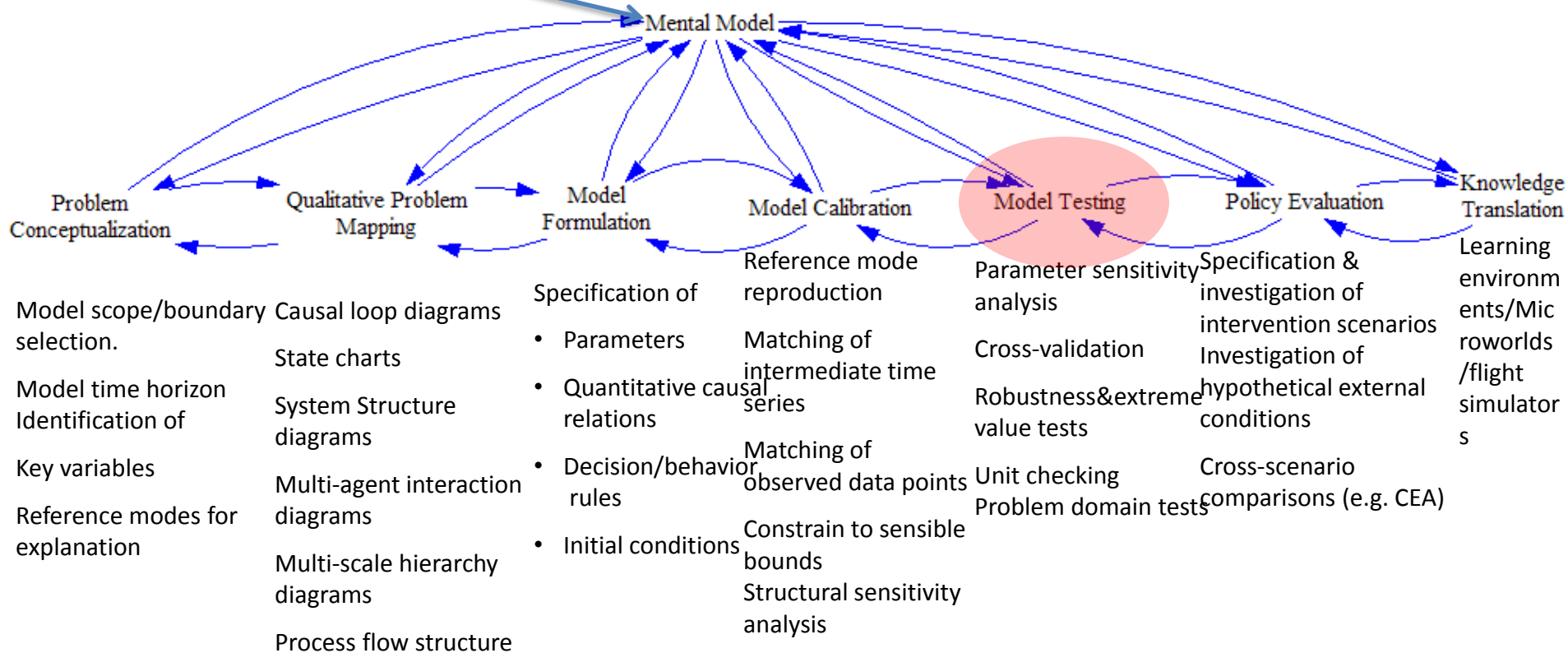
From Sterman

Cumulative Cases



Modeling Process Overview

A Key Deliverable!



Group model building

Units & Dimensions

- Distance
 - Dimension: Length
 - Units: Meters/Fathoms/Li/Parsecs
- Frequency (Growth Rate, etc.)
 - Dimension: $1/\text{Time}$
 - Units: 1/Year, 1/sec, etc.
- Fractions
 - Dimension: “Dimensionless” (“Unit”, 1)
 - Units: 1

Dimensional Analysis

- DA exploits structure of dimensional quantities to facilitate insight into the external world
- Uses
 - Cross-checking dimensional homogeneity of model
 - Deducing form of conjectured relationship
(including showing independence of particular factors)
 - Sanity check on validation of closed-form model analysis
 - Checks on simulation results
 - Derivation of scaling laws
 - * Construction of scale models
 - Reducing dimensionality of model calibration, parameter estimation

Sensitivity Analyses

- Same relative or absolute uncertainty in different parameters may have hugely different effect on outcomes or decisions
- Help identify parameters that strongly affect
 - Key model results
 - Choice between policies
- We place more emphasis in parameter estimation into parameters exhibiting high sensitivity

Sensitivity in Initial Value

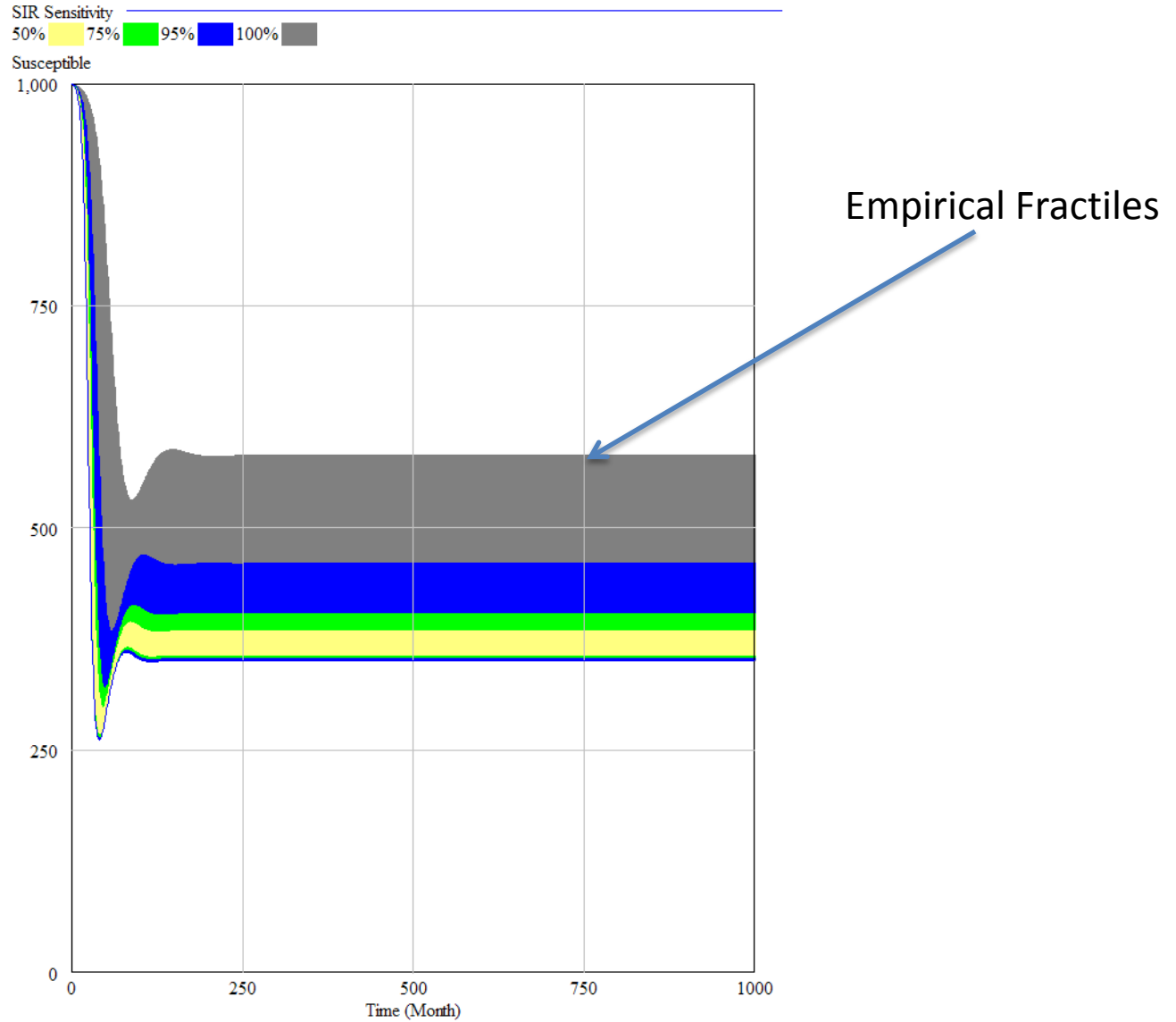
- Frequently we don't know the exact state of the system at a certain point in time
- A very useful type of sensitivity analysis is to vary the initial value of model stocks
- In Vensim, this can be accomplished by
 - Indicating a parameter name within the “initial value” area for a stock
 - Varying the parameter value

Imposing a Probability Distribution

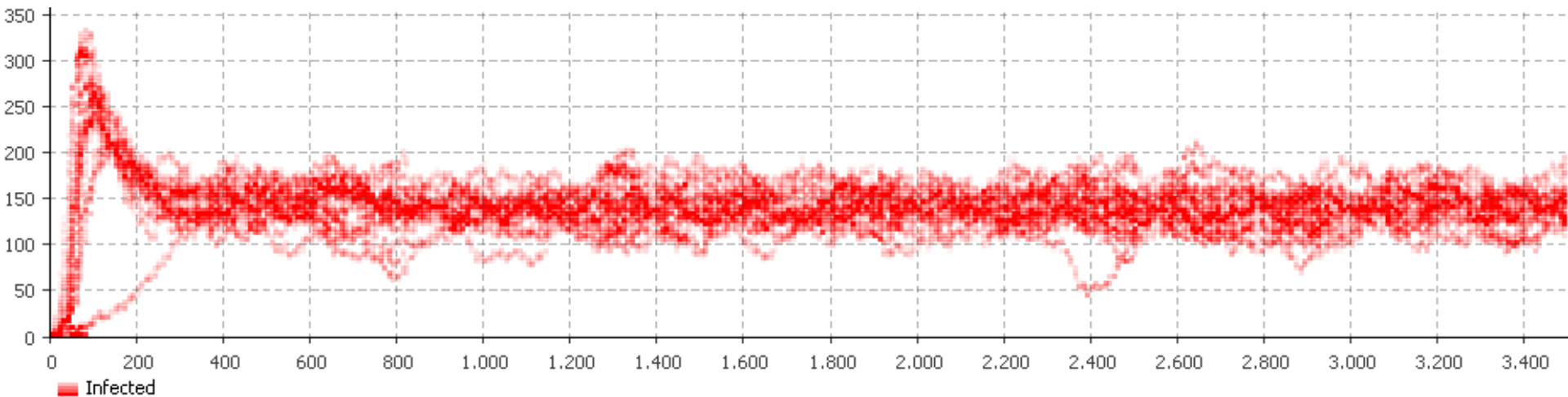
Monte Carlo Analysis

- We feed in probability distributions to reflect our uncertainty about one or more parameters
- The model is run many, many times (realizations)
 - For each realization, the model uses a different draw from those probability distribution
- What emerges is resulting probability distribution for model outputs

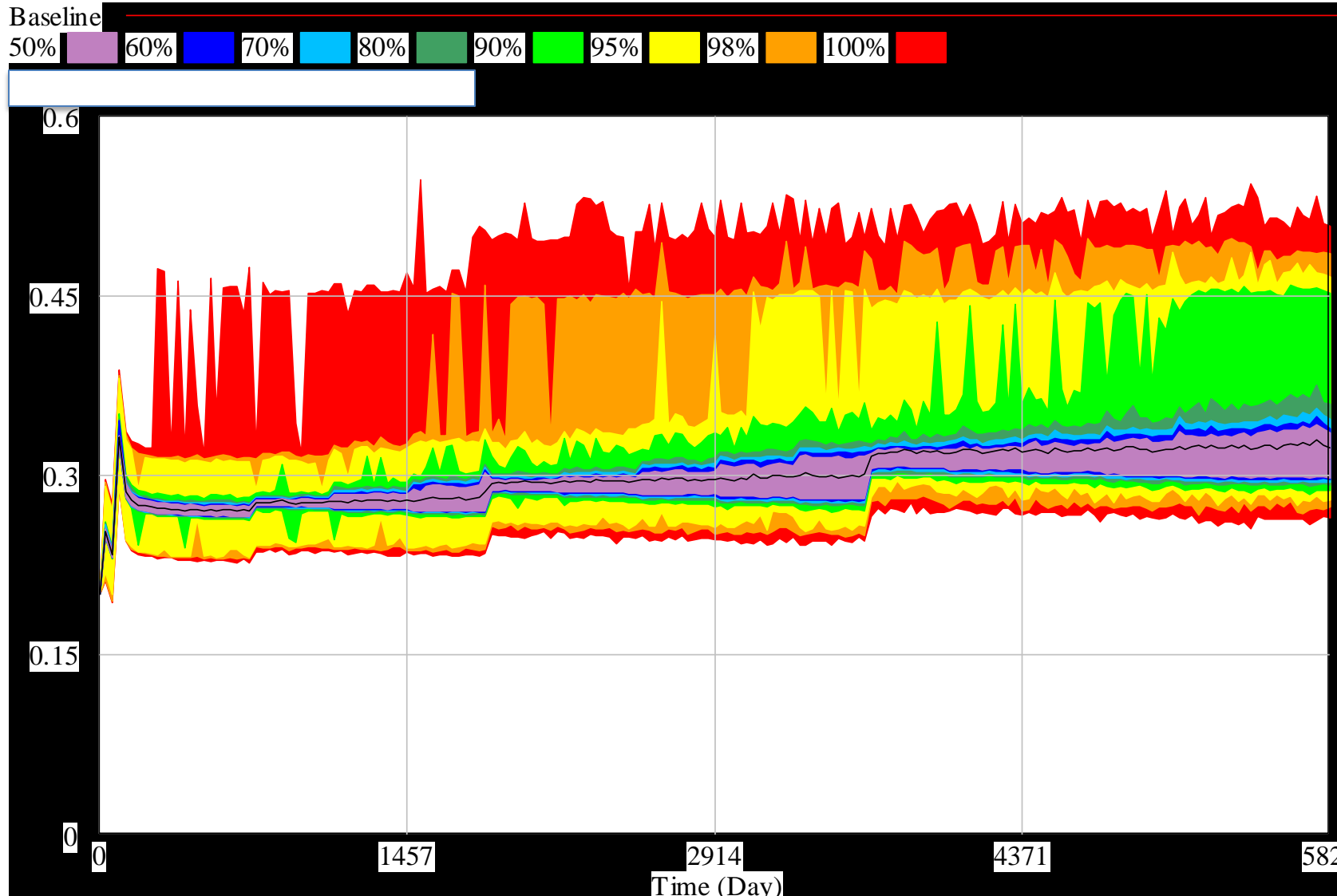
Example Resulting Distribution



Dynamic Uncertainty: Stochastic Processes



Dynamic Uncertainty: Stochastic Processes



Mathematical Analysis of Models

System Linearization (Jacobian)

$$\begin{bmatrix} -\beta \text{ Infectives} - \delta & & -\beta S - \delta \\ \beta \text{ Infectives} & \beta S - \frac{1}{\mu + \frac{\tau \text{ Infectives}}{h}} + \frac{\text{Infectives} \tau}{\left(\mu + \frac{\tau \text{ Infectives}}{h}\right)^2 h} & \end{bmatrix}$$

Fixed-Point Criteria $\dot{S} = -c \left(\frac{I}{N} \right) \hat{\beta} S + R\delta = 0$

$$\dot{I} = c \left(\frac{I}{N} \right) \hat{\beta} S - \frac{I}{\mu + \tau \frac{I}{h}} = 0$$

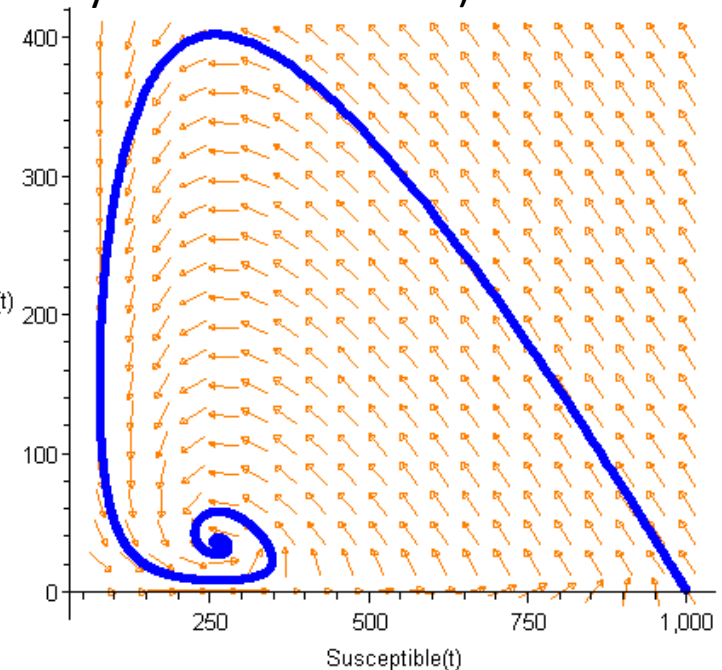
$$\dot{R} = \frac{I}{\mu + \tau \frac{I}{h}} - R\delta = 0$$

Eigenvalues (e.g. for stability analysis around fixed-point)

$$\frac{1}{2} \beta S - \frac{1}{2} \frac{1}{\mu + \frac{\tau \text{ Infectives}}{h}} + \frac{1}{2} \frac{\text{Infectives} \tau}{\left(\mu + \frac{\tau \text{ Infectives}}{h}\right)^2 h} - \frac{1}{2} \beta \text{ Infectives} - \frac{1}{2} \delta$$

$$+ \frac{1}{2} \left(\left(\beta S - \frac{1}{\mu + \frac{\tau \text{ Infectives}}{h}} + \frac{\text{Infectives} \tau}{\left(\mu + \frac{\tau \text{ Infectives}}{h}\right)^2 h} \right)^2 - 2 \left(\beta S - \frac{1}{\mu + \frac{\tau \text{ Infectives}}{h}} \right) \right. \\ \left. + \frac{\text{Infectives} \tau}{\left(\mu + \frac{\tau \text{ Infectives}}{h}\right)^2 h} \right) \left(-\beta \text{ Infectives} - \delta \right) + \left(-\beta \text{ Infectives} - \delta \right)^2 + 4 \beta \text{ Infectives} \left(-\beta S - \delta \right) \right)^{\frac{1}{2}}$$

State space diagram (reasoning about many scenarios at once)



Applied Math & Dynamic Modeling

- Although you may not use it, the dynamic modeling presented rests on the tremendous deep & rich foundation of applied mathematics
 - Linear algebra
 - Calculus (Differentia/Integral, Uni& Multivariate)
 - Differential equations
 - Numerical analysis (including numerical integration, parameter estimation)
 - Control theory
- For the mathematically inclined, the tools of these areas of applied math are available

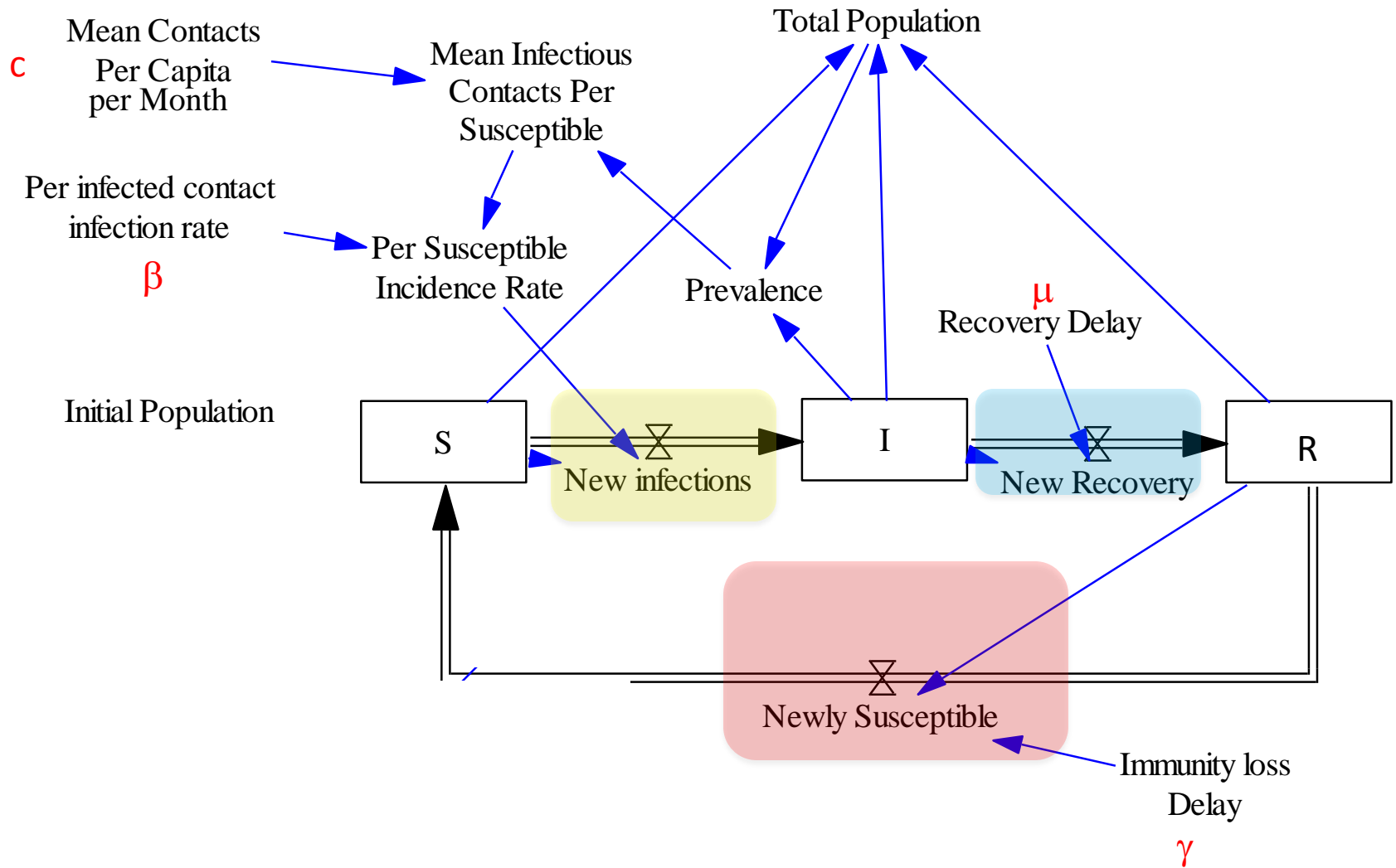
Comments on Mathematics & Dynamic Modeling

- Many accomplished & well-published dynamic modelers have limited mathematical background
 - Can investigate pressing & important issues
 - Software tools are making this easier over time
- Can gain extra insight/flexibility if willing to push to learn some of the associated mathematics
- Achieving highest skill levels in dynamic modeling do require mathematical facility and sophistication
 - To do sophisticated work, often those lacking this background or inclination collaborate with someone with background

Examples of Mathematical Insights from System Dynamics Models

- Identification of long-term behavior
 - Eventual outcome(s)
 - The impact of parameters on outcomes
 - The robustness of these outcomes to disturbance
- Insight into key causal linkages driving the system at each point in time
- Identification of high leverage parameters (interventions)
- Explanation for elements of observed behavior

Example: Simple SITS Model



Associated System of State Equations

$$\dot{S} = -c \left(\frac{I}{S + I + R} \right) \beta S + \frac{R}{\gamma}$$

These represent the same infection flow (flowing out of S, and into I)

$$\dot{I} = c \left(\frac{I}{S + I + R} \right) \beta S - \frac{I}{\mu}$$

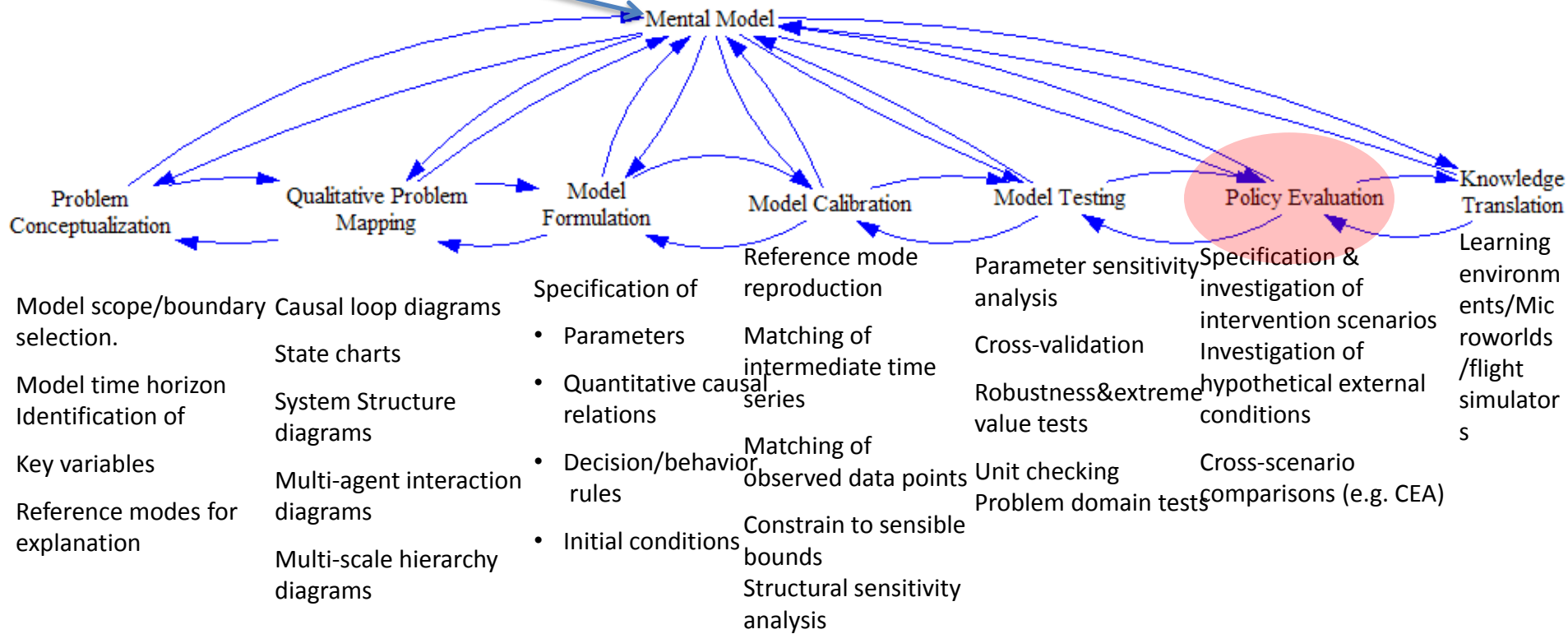
These represent the same recovery flow (flowing out of I, and into R)

$$\dot{R} = \frac{I}{\mu} - \frac{R}{\gamma}$$

These represent the same loss-of-immunity flow (flowing out of R (hence the minus sign), flowing into S)

Modeling Process Overview

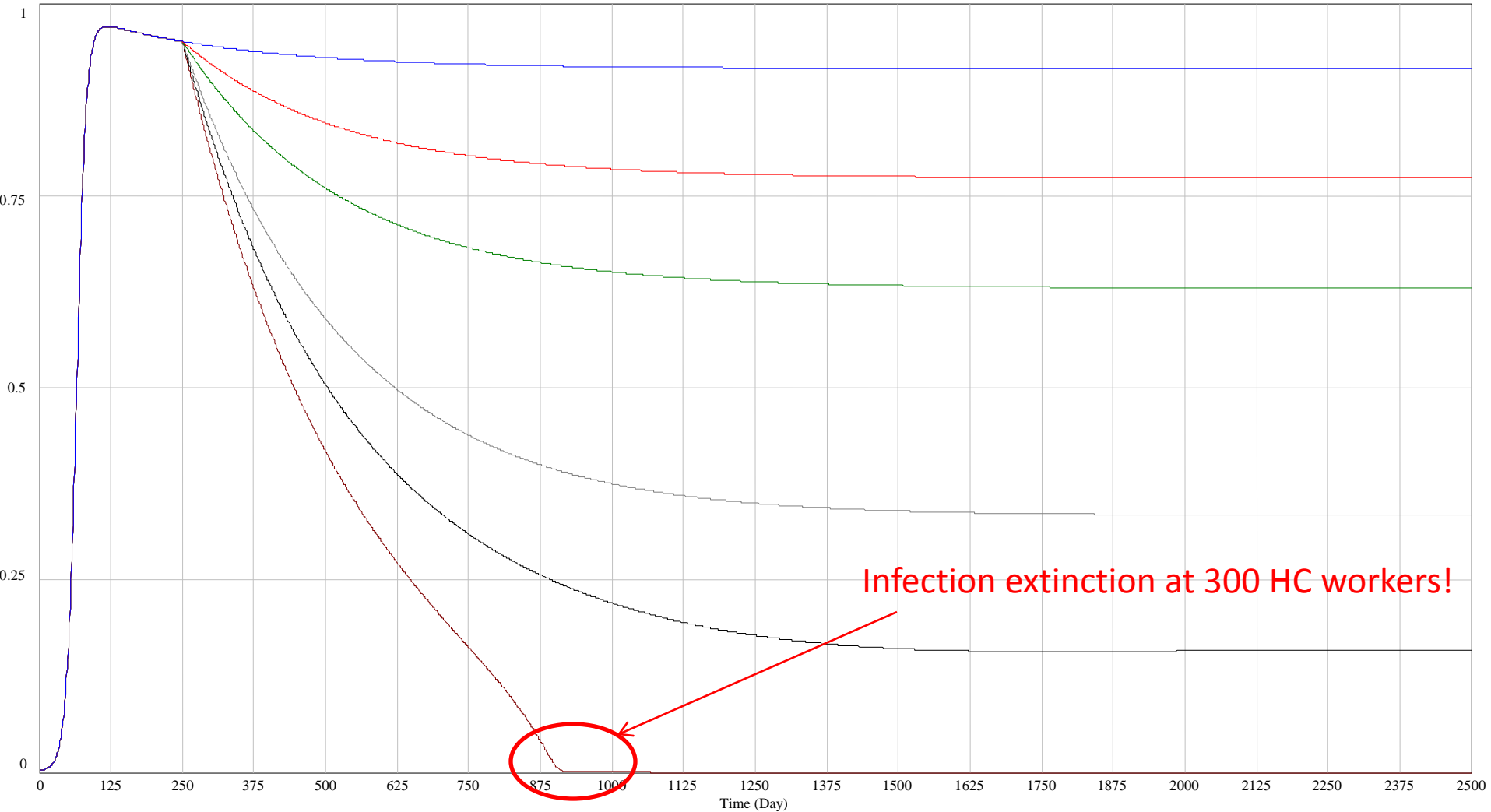
A Key Deliverable!



Group model building

Late Availability of HC Workers

Prevalence

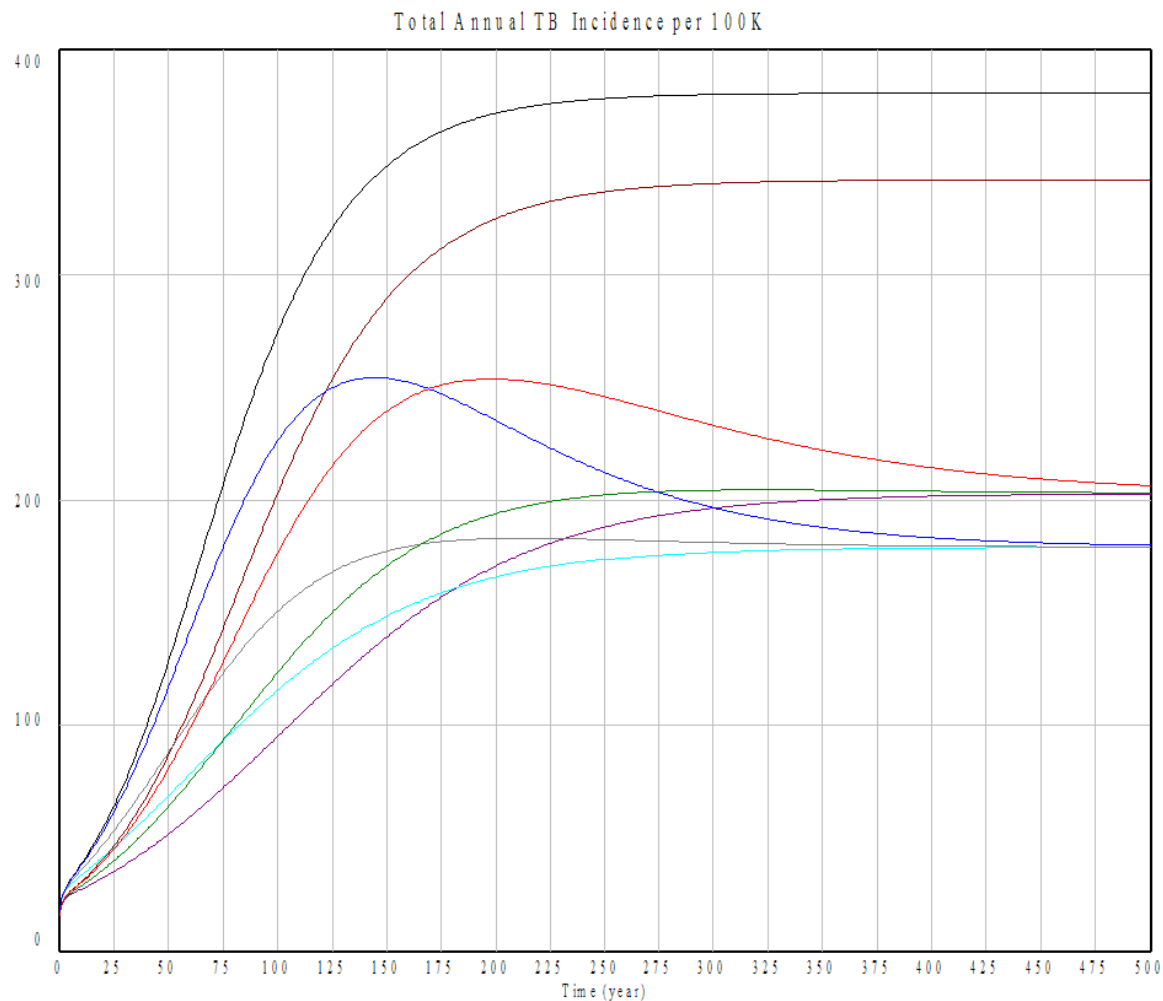


Infection extinction at 300 HC workers!

Prevalence : Baseline 30 HC Workers
Prevalence : Alternative HC Workers Late 50
Prevalence : Alternative HC Workers Late 100
Prevalence : Alternative HC Workers Late 200
Prevalence : Alternative HC Workers Late 250
Prevalence : Alternative HC Workers Late 300

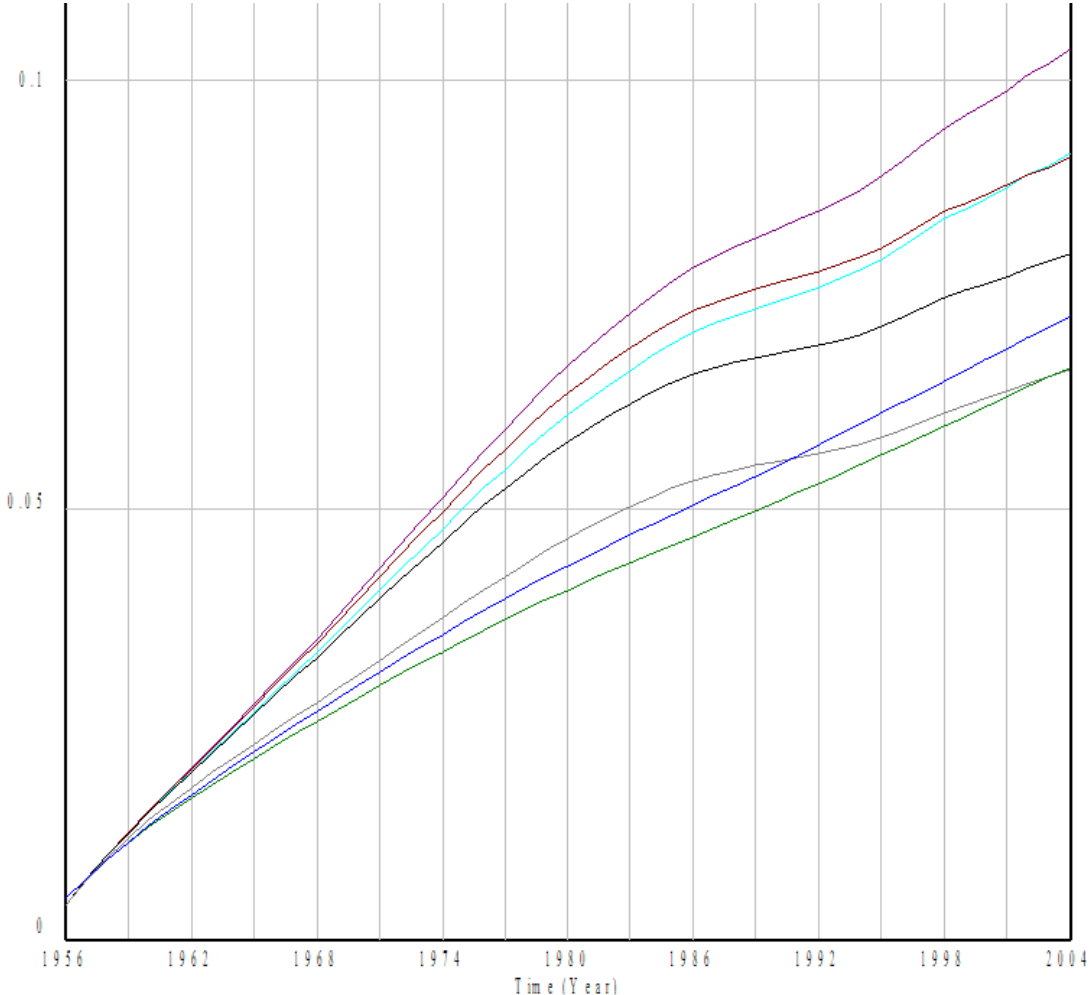


Simulation Analysis: Scenarios for Understanding How X affects System



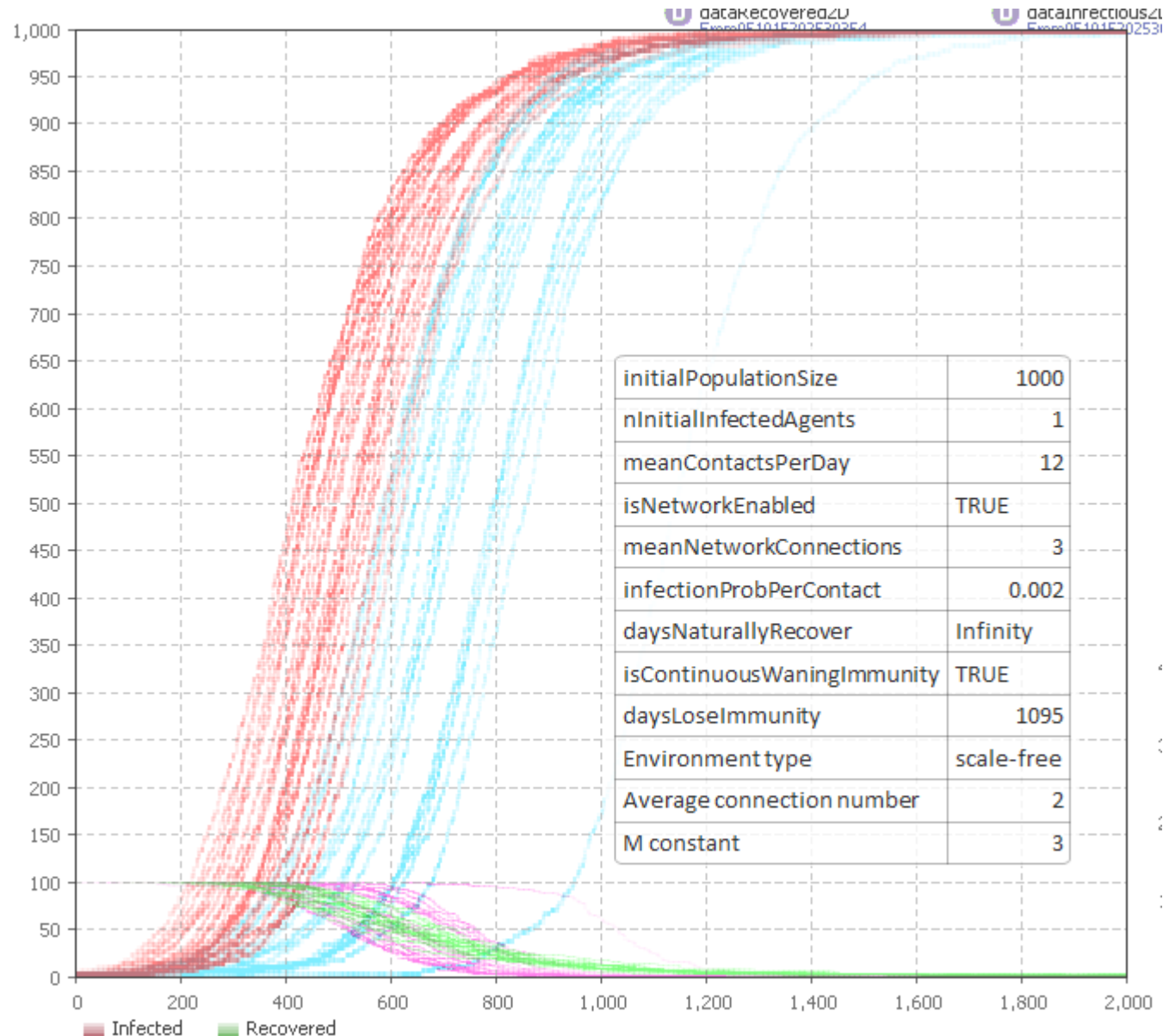
Total Annual TB Incidence per 100K : 1x Standard Immigration T2DM
Total Annual TB Incidence per 100K : 1x Standard Immigration No T2DM
Total Annual TB Incidence per 100K : Half Standard Immigration No T2DM
Total Annual TB Incidence per 100K : Half Standard Immigration T2DM
Total Annual TB Incidence per 100K : No Immigration T2DM
Total Annual TB Incidence per 100K : No Immigration No T2DM
Total Annual TB Incidence per 100K : Standard Immigration T2DM
Total Annual TB Incidence per 100K : Standard Immigration No T2DM

Policy Formulation & Evaluation

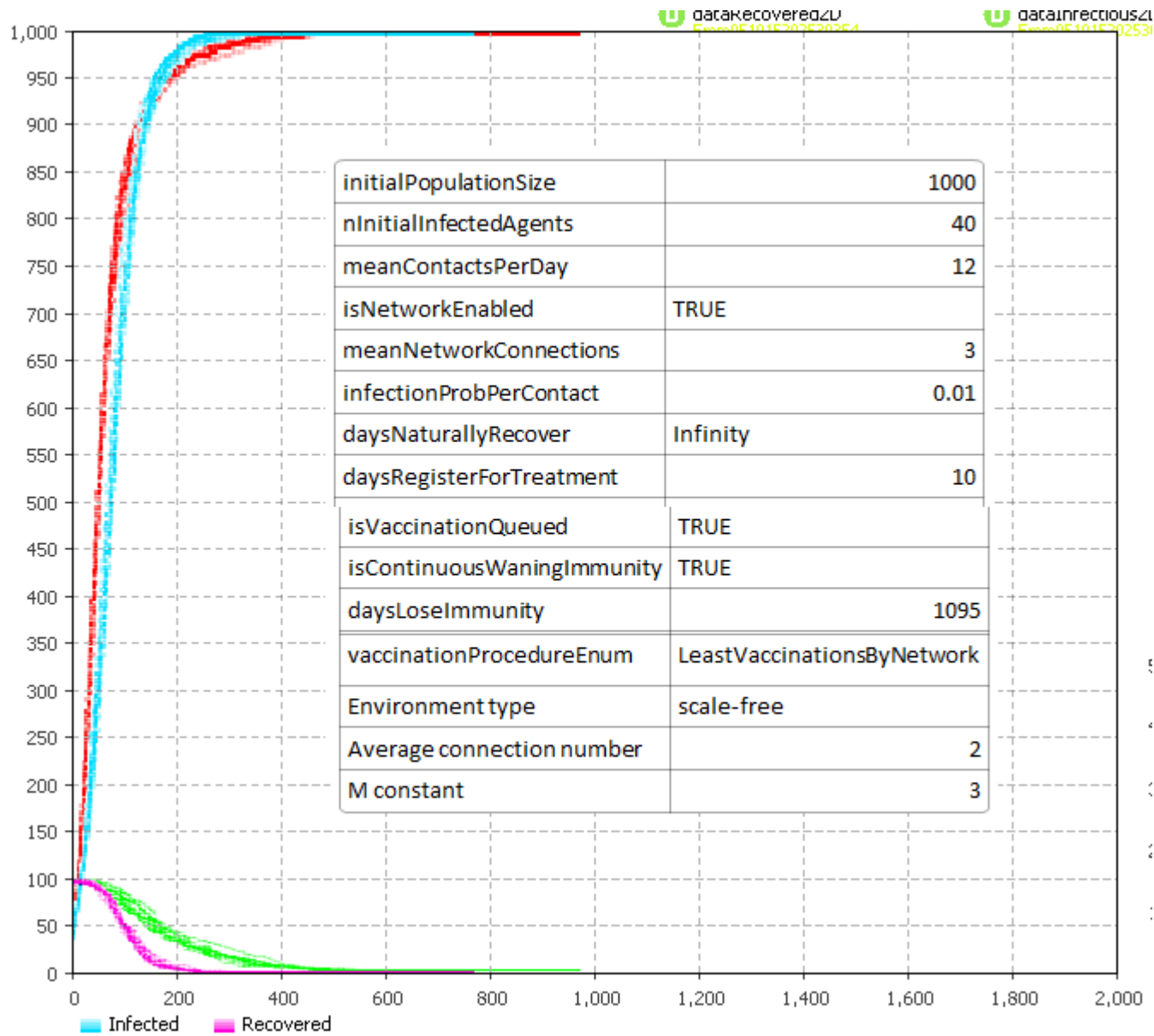


Fractional Prevalence of T1DM [Scenario] : Test 1971 GP 15% Controlled GDM T1DM
 Fractional Prevalence of T1DM [Scenario] : Test 1971 GP with GDM
 Fractional Prevalence of T1DM [Scenario] : Test 1971 GP no GDM
 Fractional Prevalence of T1DM [Scenario] : Test 1971 AB No GDM
 Fractional Prevalence of T1DM [Scenario] : Test 1971 AB No GDM or T1DM Effect on Child
 Fractional Prevalence of T1DM [Scenario] : Test 1971 AB No T1DM Effect on Child
 Fractional Prevalence of T1DM [Scenario] : Test 1971 AB No GDM Effect on Child
 Fractional Prevalence of T1DM [Scenario] : Test 1971 AB 15% Controlled GDM T1DM

Policy Comparison: Stochastic Processes

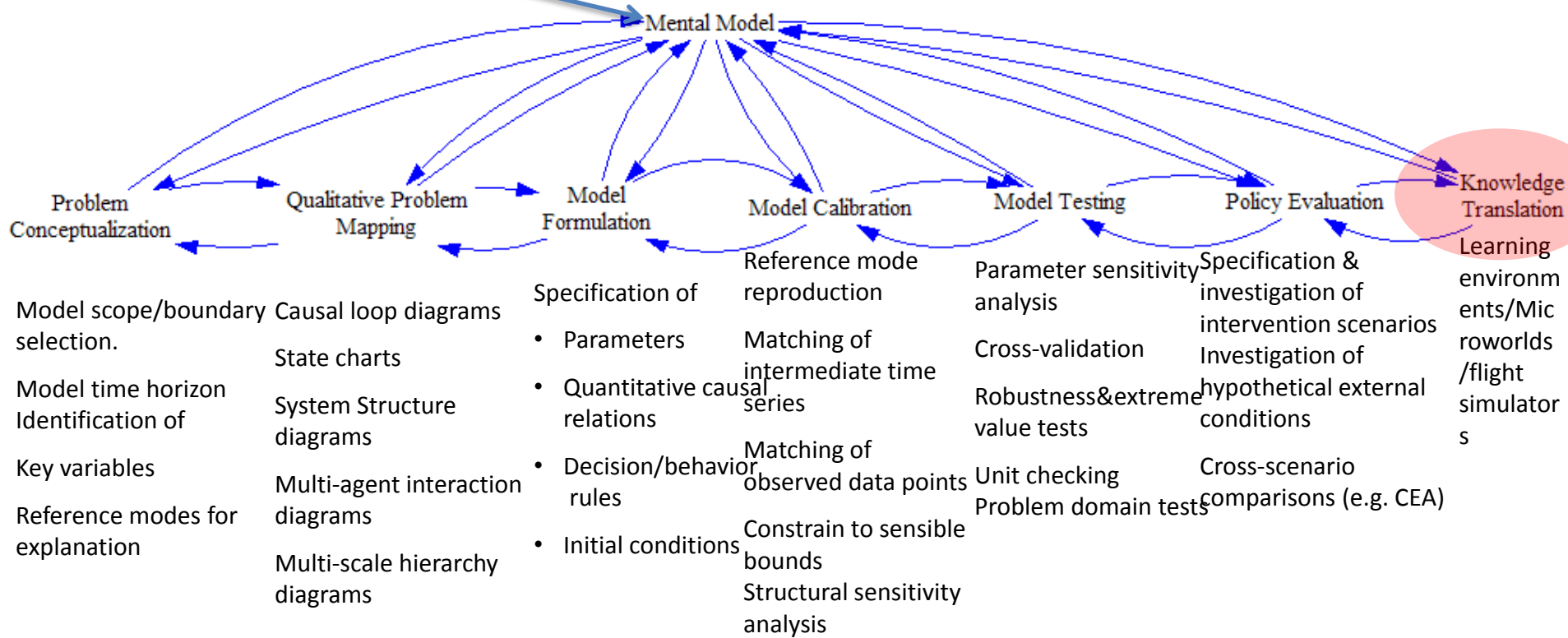


Policy Comparison: Stochastic Processes



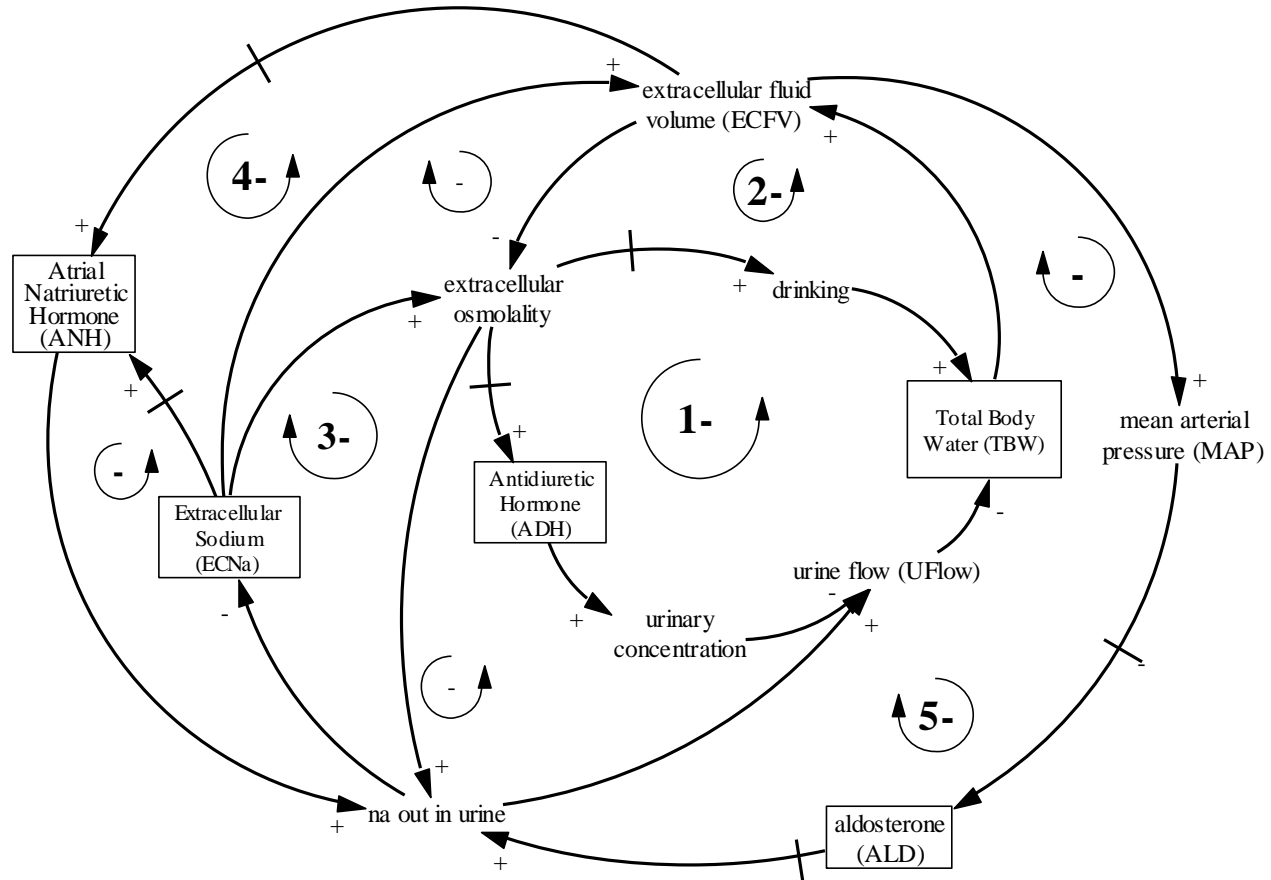
Modeling Process Overview

A Key Deliverable!



Group model building

OVERVIEW OF THE MODEL



Simplified causal loop diagram of the overall model

THE INTERACTIVE DYNAMIC SIMULATOR (BWATERGAME)

Treatment Options

Drug Infusion ?

oral
 intravenous

DOSE DIURETIC

?

DOSE ADH ANTAGONIST

?

Fluid Therapy ?

ISOTONIC SALINE

?

HYPERTONIC 3% SALINE

U ?

HYPOTONIC SALINE

?

Instructions **Control Panel**

8

decision interval

18

hours

2

period

Key Indicators

Body Water **Units:** ?

Total Body Water	45.1	?	[Liter]
Extracellular Fluid Vol	15.7	?	[Liter]
Intracellular Fluid Vol	29.4	?	[Liter]

Units: ?

Mean Arter Press	111	?	[mmHg]
WaterIn current period	0.3	?	[Liter]
UrineOut current period	0.2	?	[Liter]

Graph

Body Sodium **Units:** ?

Extracellular Na	1899	?	[mEq]
ExtracellularNa conc	121	?	[mEq/L]
Urinary Na conc	60	?	[mEq/L]

Units: ?

Glomerular Filtr Rate	131	?	[ml/min]
Na In Current Period	60	?	[mEq]
Na Out Current Period	21	?	[mEq]

Graph

Hormonal Indicators **Units:** ?

Renin ratio	0.2	?	[]
ALD ratio to normal	0.6	?	[]

Units: ?

ADH ratio to normal	3.0	?	[]
ANH ratio to normal	3.6	?	[]

Graph

About Controls

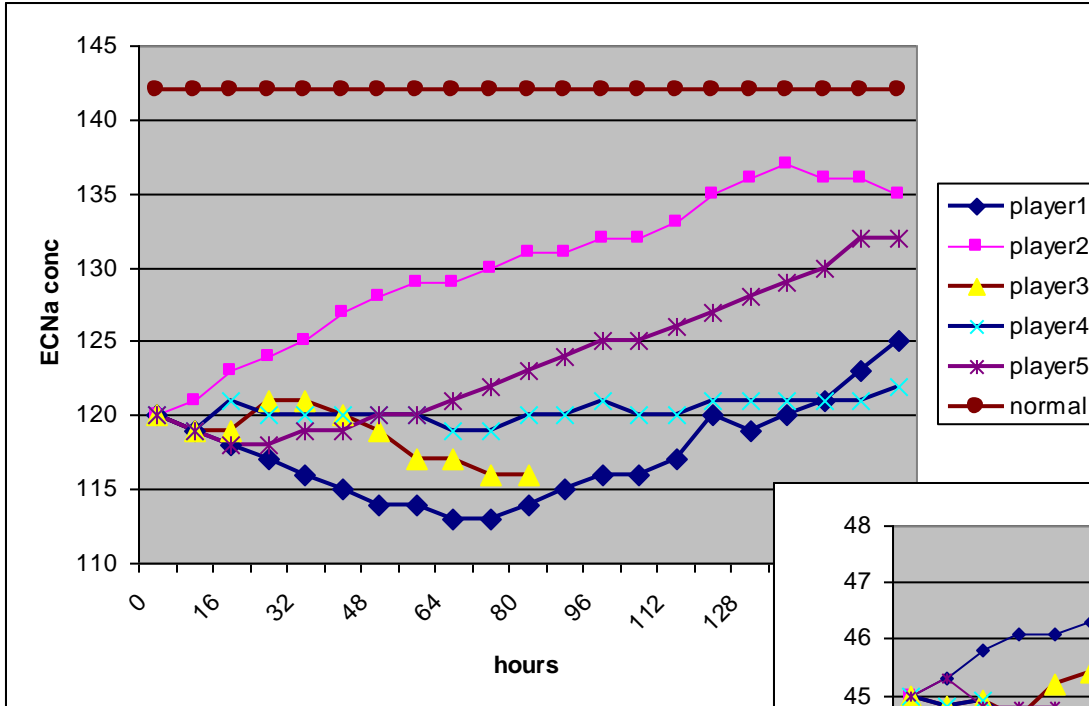
Record of Decisions

Vary Scenario...

New Game
Reset
Start

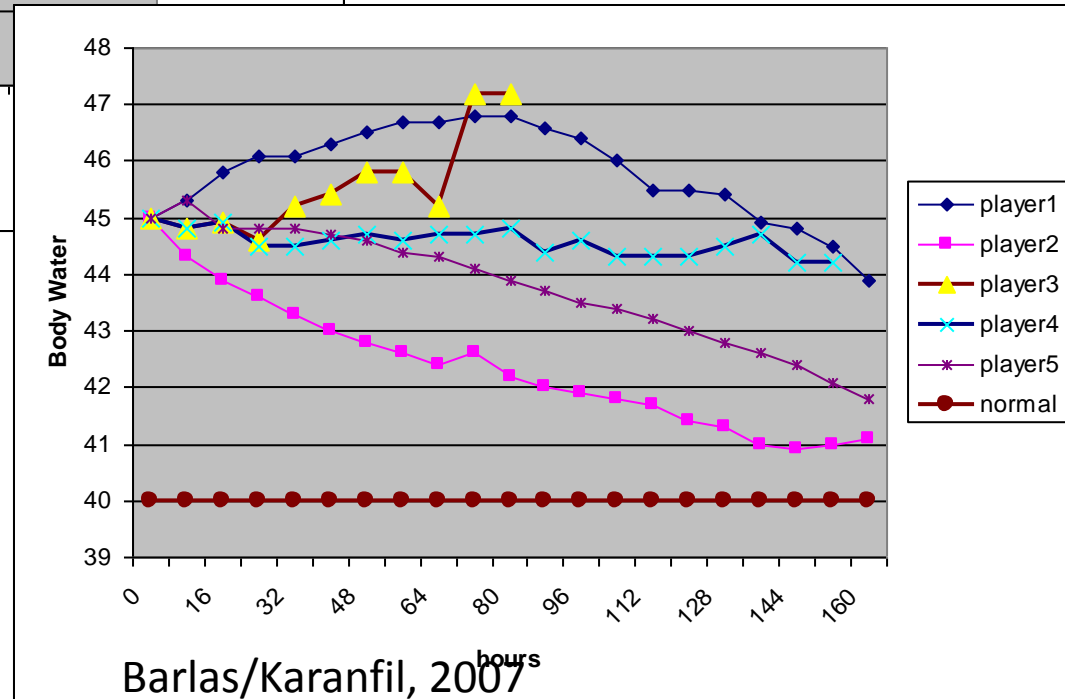
Main Menu
Advance
End Game

Results of the Game Tests by Players



Dynamics of ECNa concentration for five players...

Dynamics of total body water...



Stakeholder Action Labs

- Team Meetings



Mabry, 2009, “**Simulating the Dynamics of Cardiovascular Health and Related Risk Factors**”

Key Take-Home Messages from this Morning

- Models express dynamic hypotheses about processes underlying observed behavior
- Models help understanding how diverse pieces of system work together
- SD focus on feedbacks as the fundamental shapers of dynamics
- Models are specific to purpose
- System dynamics includes both qualitative & quantitative components
- SD models admit to formal reasoning & analysis