System Dynamics Model for Ventilation effect on COVID-19 transmission

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Context

- COVID-19 is transmissible through air
- Transmissibility is dependent upon, among others, viral concentration in air
- Ventilation has an effect on air viral concentration

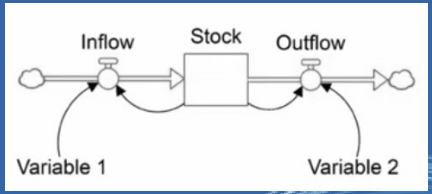
- Principal policy focus so far on:
  - Distance guidelines (density, absolute distance)
  - Personal air filters (masks)
  - Generic ventilation guidelines

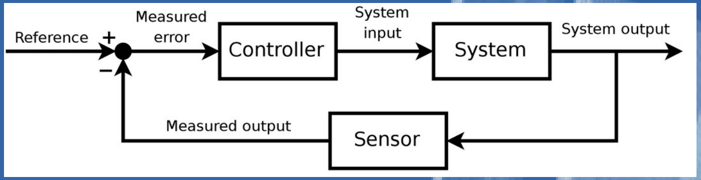
- Opportunity for
  - Testing scenarios for indoor environments
  - Activity-dependent ventilation (e.g., Restaurants, Classrooms)
  - Identify Operational recommendations
    - Ventilation System Characteristics (Q, pf, RH)
    - Activity type and duration (e.g., number and length of school breaks)

Proposal outline

- **<u>Develop a:</u>**
- Simulation model of relationship between Transmission rate and:
  - Ventilation, activity type and level
- Identify policy levers and their sensitivity
- Apply to specific example cases
- **<u>In order to:</u>**
- Provide a learning platform with the explicit representation and simulation of:
  - Accumulations (Sources of Inertia)
  - Causal relationships
  - Feedback Loops
  - Exogenous versus
  - Endogenous variables
- **<u>Through the use of:</u>**
- System Dynamics Method

System Dynamics versus traditional control





- ✓ Stock and Flow representation
- ✓ States as Accumulations
- ✓ Focus on Relationships
- ✓ Important variables not necessarily quantified

System Dynamics

Control Theory

- ✓ Frequency domain analysis
- ✓ Focus on Transfer Function

- ✓ States
- ✓ Dynamic modelling (over time)
- ✓ Polarity (Pos.&Neg.)
- ✓ Feedback (Pos. & Neg.)

COVID-19 Model Equations

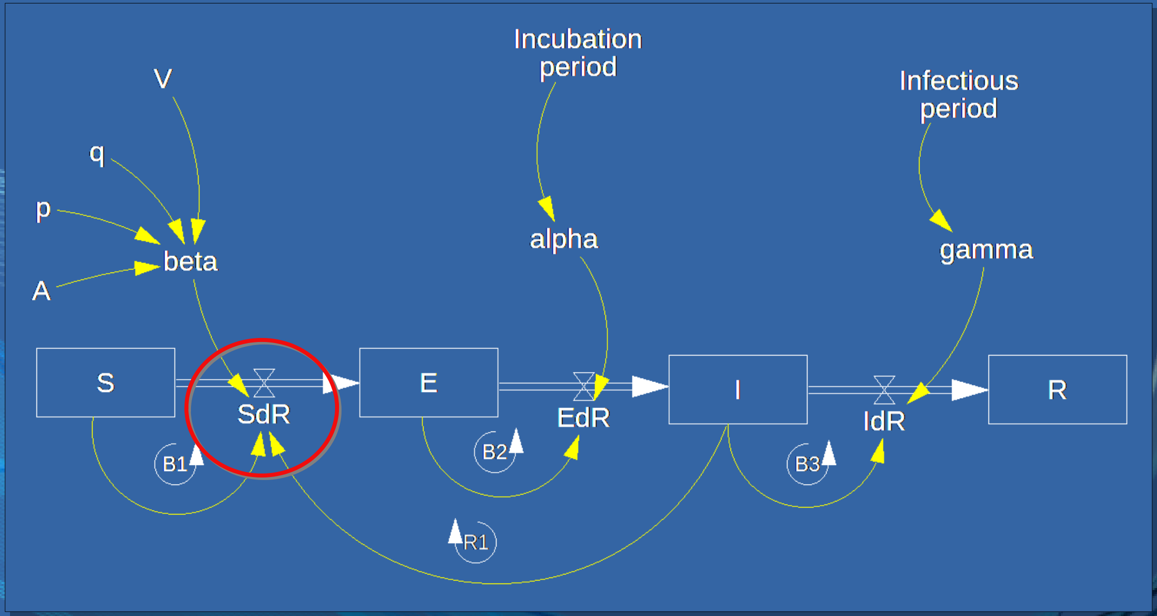
$$\frac{dS}{dt} = -\frac{pq}{VA} IS,$$

$$\frac{dE}{dt} = \frac{pq}{VA} IS - \alpha E,$$

$$\frac{dI}{dt} = \alpha E - \gamma I,$$

$$\frac{dR}{dt} = \gamma I,$$

$$S + I + E + R = N,$$



Model Source: Noakes, C.J., Beggs, C.B., Sleigh, P.A. and Kerr, K.G., 2006. Modelling the transmission of airborne infections in enclosed spaces. Epidemiology & Infection, 134(5), pp.1082-1091.

$$SdR = beta \cdot S \cdot I$$

$$\frac{dS}{dt} = -\beta(t) SI$$

$$\beta(t) = Q_b C(t) c_i p_m$$

$$C(t) = \frac{P}{Q}\left(1 - e^{-\lambda_a t}\right)$$

System Dynamics representation of SEIR Model

- *Differential Equations*

$$\frac{dS}{dt} = -\frac{pq}{VA} IS,$$

$$\frac{dE}{dt} = \frac{pq}{VA} IS - \alpha E,$$

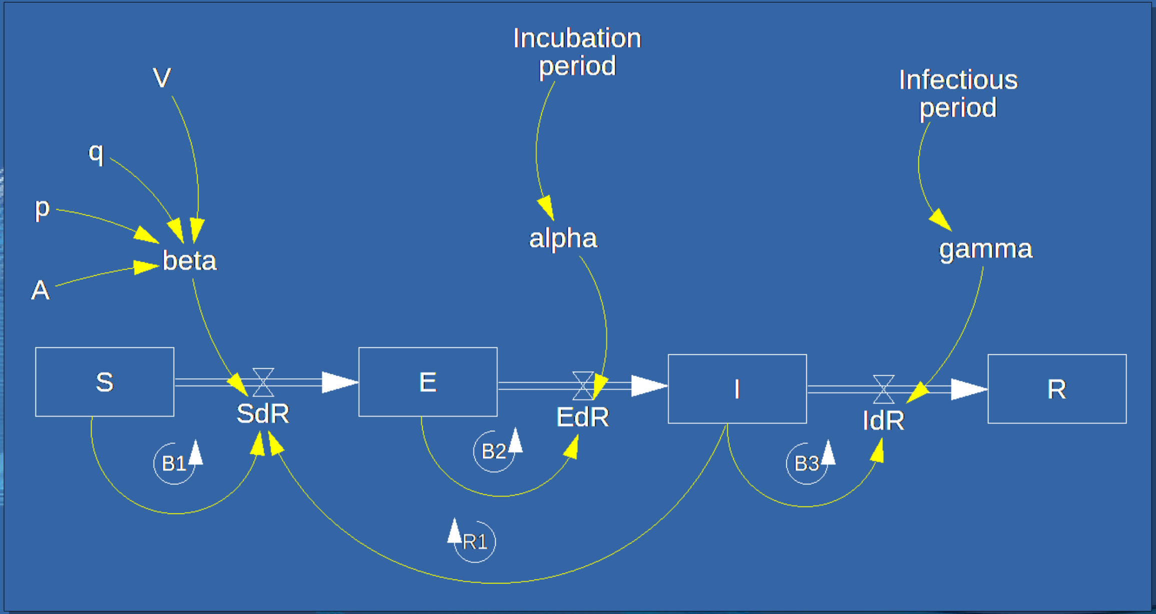
$$\frac{dI}{dt} = \alpha E - \gamma I,$$

$$\frac{dR}{dt} = \gamma I,$$

$$S + I + E + R = N,$$

Variable	Name
S	Suceptible
E	Exposed
I	Infected
R	Recovered
V	Room Volume
A	Ventilation Rate
q	Quanta production
p	Pulmonary Ventilation rate

- *Model Representation*



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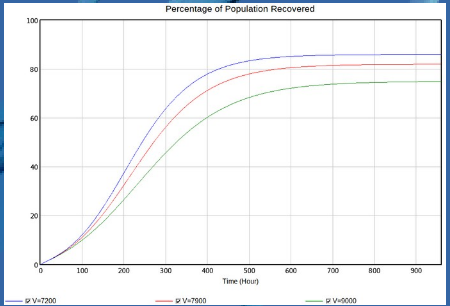
Dynamic Simulation

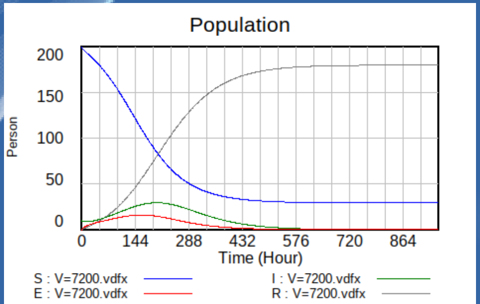
- Sensitivity
- Phase Diagrams



Sensitivity Analysis: Percentage of Population Recovered with different room Volumes, 7200,

7900 and 9000 m3

- *SEIR dynamics*



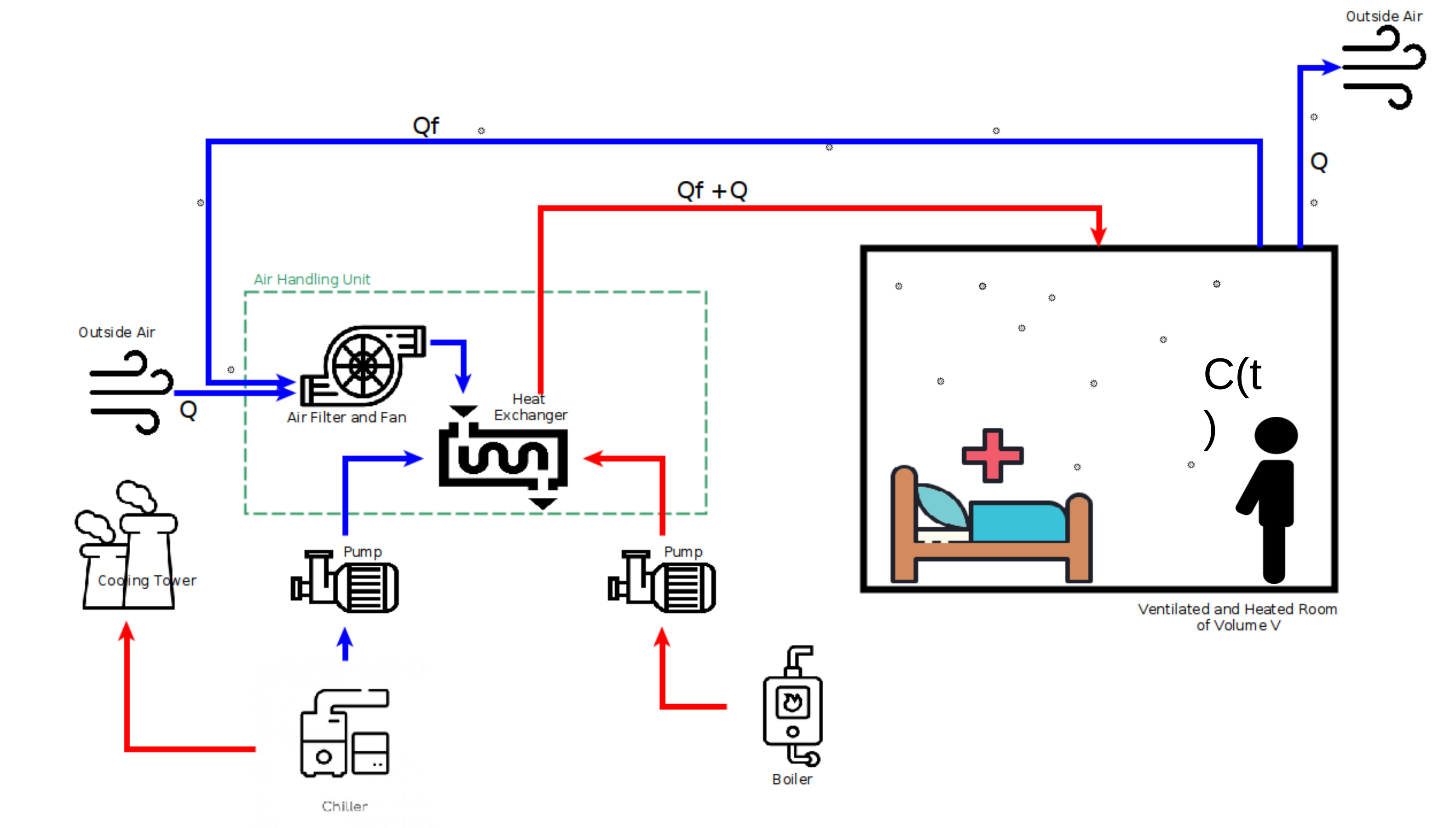
Explicit Representation of

- Accumulations (Inertia)
- Causal Relationships
- Exogenous vs Endogenous Variables
- Feedback Loop visibility (R,B)

Application Example:

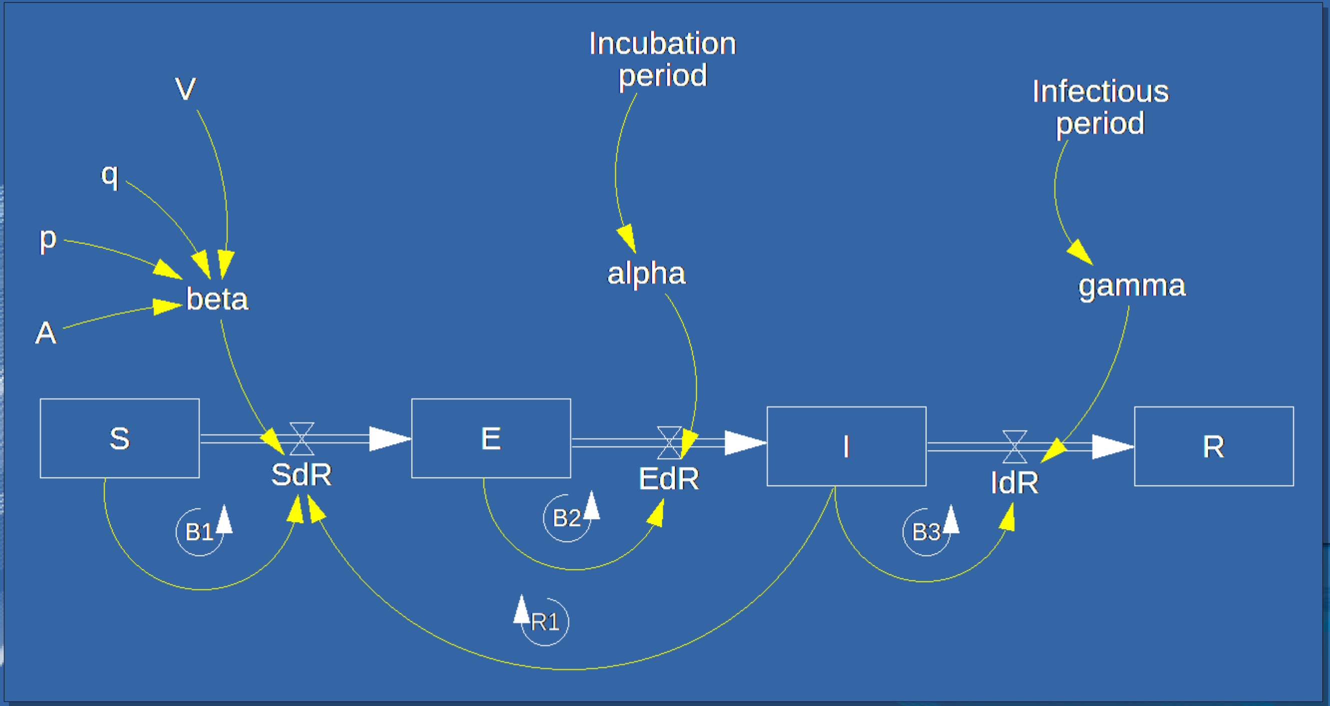
Let’s go to VENSIM

Ventilation : Simple Ventilation System



Thank you

Model with all Variable names



Variable	Name
S	Susceptible
E	Exposed
I	Infected
R	Recovered
V	Room Volume
A	Ventilation Rate
q	Quanta Production
p	Pulmonary Ventilation Rate
SdR	Susceptible decrease Rate
EdR	Exposed decrease Rate
IdR	Infected decrease Rate
Bx	Balancing Loops
Rx	Reinforcing Loops

COMPLETE: Model with all Variable names

Presentation

- **Daniel Sepulveda Estay**
- **PhD, Operations Management, DTU**

- System Dynamics Modelling for:
  - Supply Systems
    - Stock fluctuations
    - Bullwhip effects & Hoarding
    - Cyber-resilience
  - Healthcare
    - Compliance Behaviour of Diabetes patients
    - Return patients to Emergency care

- **Christian Sørup**
- **PhD, Operations Management, DTU**

- System Dynamics Modelling for:
  - Healthcare
    - Return patients to Emergency care
    - Policy analysis for COVID-19 Spread