Systems Dynamics Modeling

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Outline

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- Key properties
- Main uses
- Strengths and limitations
- Case examples
- Lab

Definition

Definition

- The founding of SDM has been attributed to Jay Wright Forrester in the later 1950s when it was first used in industrial dynamics.
- Also known as compartmental models, SDM is the representation of the real-world made by dividing the population up into categories or compartments, with accompanying mathematical representations of how these categories interact with each other and how members from one category move to the other.
- It incorporates non-linear behaviors and feedback.

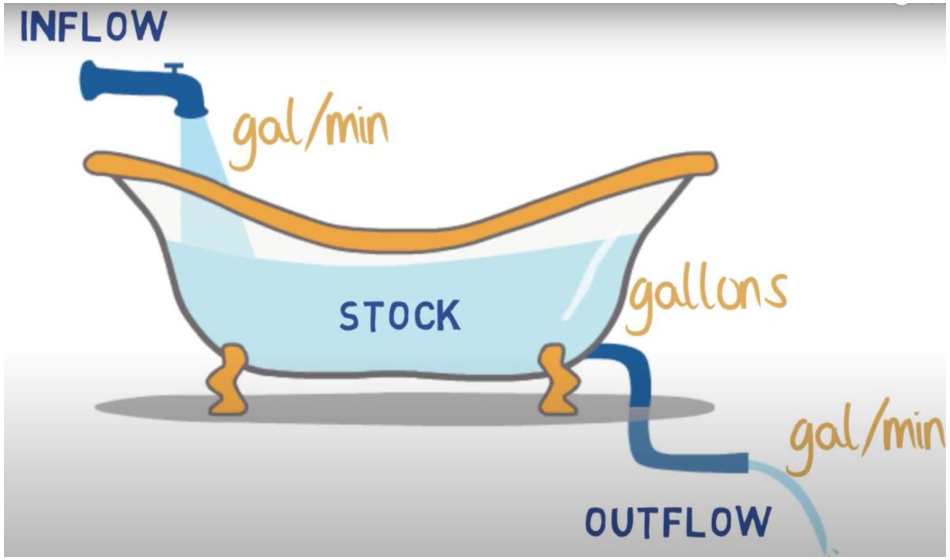
Key properties

Key properties

- Stocks and flows.
  - The stocks are accumulation while the flows represent the rate of change.
  - Stocks are solved using integration. In fact, the volume of the stock is computed as the area under the net flow curve between initial and final times.
  - E.g. *stocks (people, gallons)* and the *flows (people/day gallons/day)*.

Key properties

- Net flow =∑Inflows – ∑Outflows
- If net flow (+) → Stock will ↑
- If net flow (-) → Stock will ↓
- If net flow = 0 → Stock will remain unchanged → Dynamic equilibrium



Key properties

- Feedback. A feedback loop is a closed chain of causal links from a stock, through a flow, and back to the original stock again.
- It can be reinforcing (R, positive feedback loop) and amplifies change and drives exponential growth
- It can be balancing (B, negative feedback loop) and limits unconstrained growth.

Key properties

- Aggregate vs individual. SDM are *aggregate (population-level)* simulation models—generally assuming a homogenous population.
- Dynamic/Time. As the name implies, SDM are dynamic models and time is generally modeled continuously.
- Decision rule: Differential equation

Main uses

Main uses

- SDM are mainly used when the system as a whole is more of interest (rather than just processes) and when there is extensive feedback and time is continuous (rather than discrete).
- A classic example is the Kermack-McKendrick Model—also known as the Susceptible-Infected-Recovered (SIR) model or its variant, the Susceptible-Exposed-Infected-Recovered (SEIR)

Strengths and limitations

Strengths

- A key strength is its relative simplicity since it assumes the population is homogenous.
- It is, however, possible to have disaggregated SDMs, but in general, this disaggregation only includes one or two variables (e.g. age groups, sex, etc…). Including more variables may result in an overly complex SDM—at which point, an individual-based model might be better suited.

Limitations

- One limitation of this model is its inability to incorporate individual characteristics and heterogeneity.
- Another limitation is that SDMs are less suited for modelling discrete changes in systems.

Assumptions

- The system can be represented using stocks and flows
- The population is homogenous
- The system is dynamic
- The relationship between variables often non-linear and the system is mostly governed by feedback

Case examples

Case example

- The Susceptible-Infected-Recovered (SIR) model (Kermack-McKendrick Model)

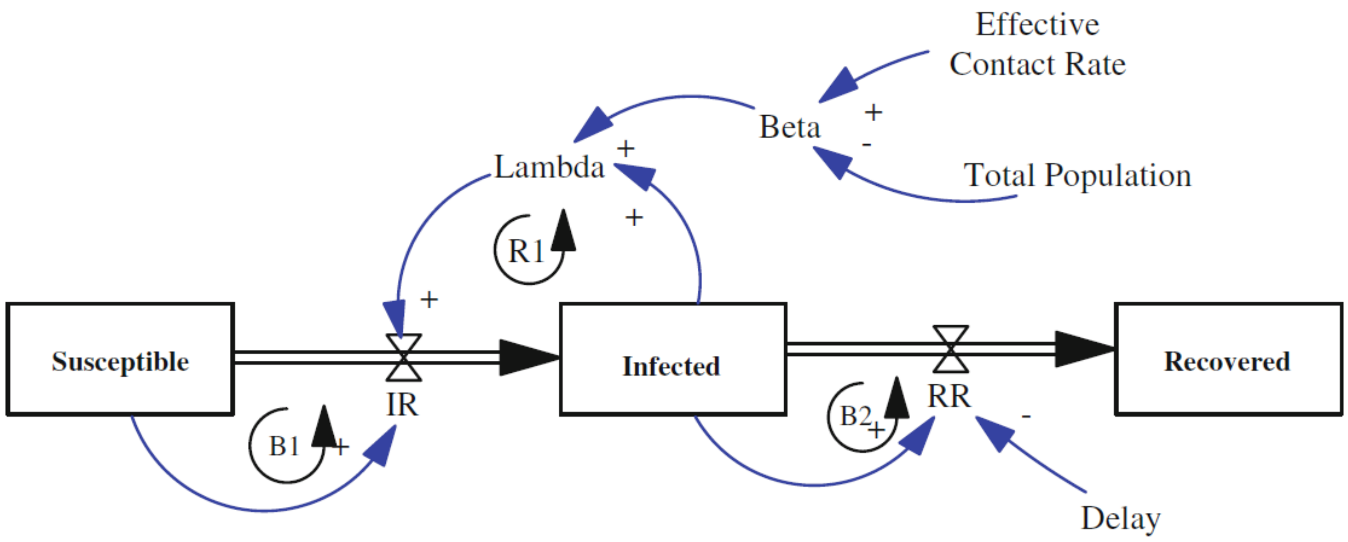


Fig. 5.1 The SIR model of contagion

Case example

- Fowler et al. *Solving Homelessness from a Complex Systems Perspective: Insights for Prevention Responses. Annu Rev Public Health. 2019*

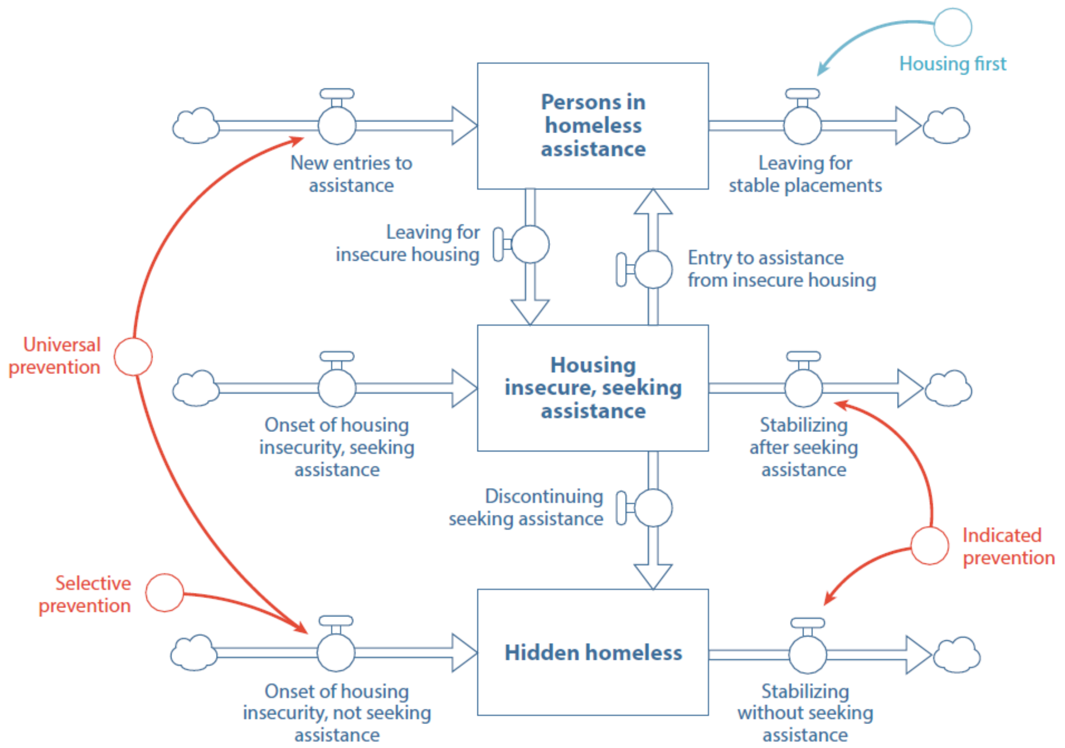


Figure 6

System dynamics model of people receiving homeless assistance and those experiencing housing insecurity and hidden homelessness. Boxes represent accumulations of people, arrows represent transitions in and out of stocks, and clouds represent stable housing.

Case example

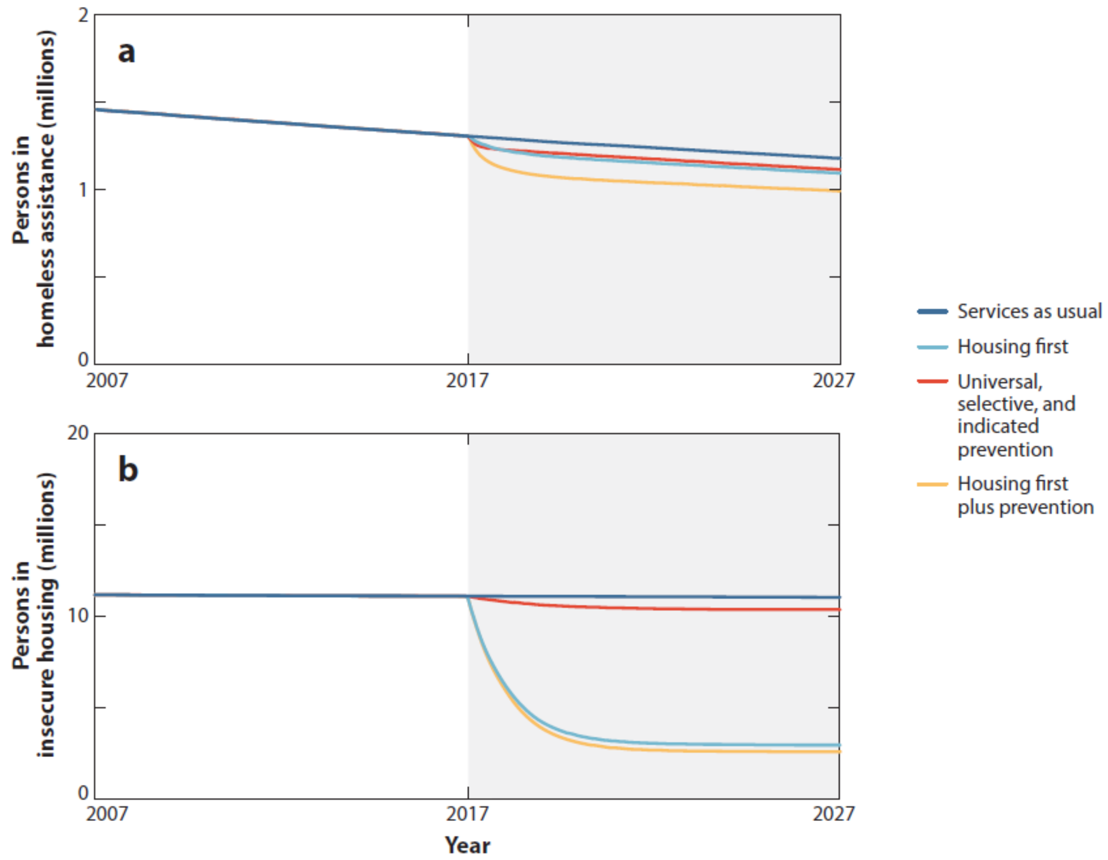


Figure 7

Policy experiments showing the impact of housing first and prevention efforts on the number of people in homeless assistance (*a*) and number of hidden homeless (*b*) with services as usual (*dark blue line*); housing first only (*light blue line*); universal, selective, and indicated prevention (*red line*); and housing first plus universal, selective, and indicated prevention (*yellow line*).

Lab

Lab exercise

- 1) Modify the code to change the effective contact rate to 2 and then 0.5. What do you observe? Could you quantify observed difference?
- 2) Change the time to adoption to 42 days. What do you observe?
- 3) How many people would have reduced their weight by day 100 if you changed the time to adoption to 42?

References

- eBook: Duggan J. System Dynamics Modeling with R. Springer 2016.
  - Chap 1: An Introduction to System Dynamics
  - Chap 2: An Introduction to R for Systems Dynamics
  - Chap 5: Diffusion Model—The SIR Model
- Book: Basu S. Modeling Public Health and Healthcare Systems. Oxford; New York: Oxford University Press, 2018.
  - Chap 9. Modeling large-scale epidemics