Dynamic systems modeling process (فرایندهای مدلسازی سیستم های دینامیکی)

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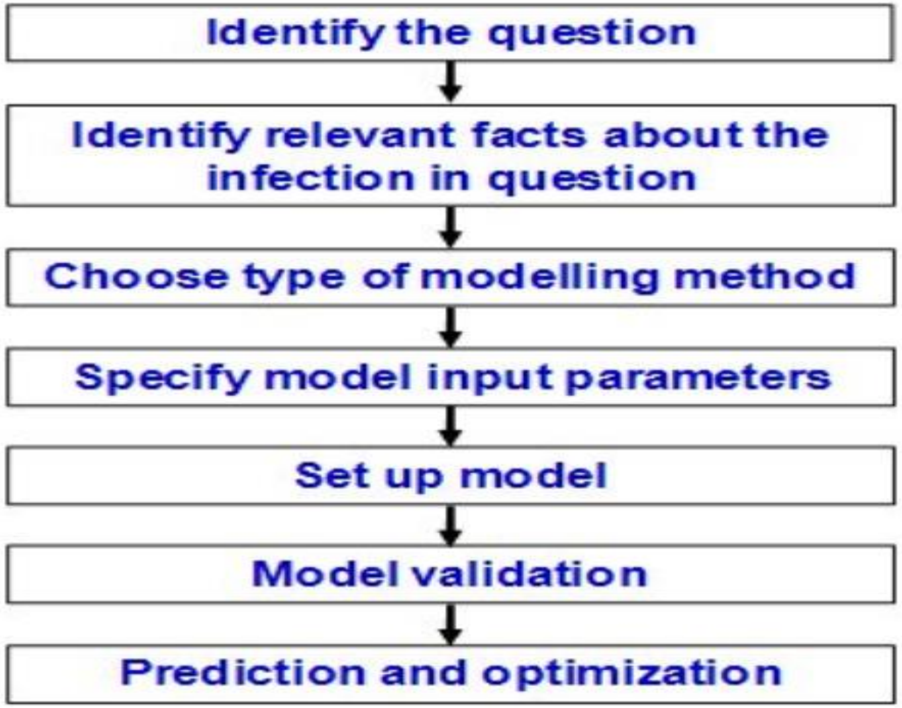
فرایند مدلسازی سیستم های دینامیکی



1-Identifying the question

Some key aspects of why identifying the question or problem is important in dynamic system modeling:

- **1. Clarifies the Purpose**: Defining the question or problem helps clarify the purpose of the modeling
- **2. Guides Model Development:** The question serves as a guide for developing the mathematical model and selecting appropriate variables, parameters, and assumptions
- **3. Determines Scope and Boundaries**: This helps focus on relevant aspects of the system and avoid unnecessary complexity.
- **4. Sets Objectives and Criteria:** It helps establish clear objectives and criteria for evaluating the model's performance
- **5. Facilitates Communication**: A well-defined question facilitates communication among team members, stakeholders, and experts involved in the modeling process.
- **6. Drives Decision-Making:** Identifying the question or problem enables informed decision-making based on the insights and predictions generated by the dynamic system model

Examples:

- Effectiveness of Social Measures against COVID-19 Outbreaks in Selected Japanese Regions Analyzed by System Dynamic Modeling
- System dynamic modelling of healthcare associated influenza -a tool for infection control
- Cost Effectiveness and Budget Impact Analyses of Influenza Vaccination for Prisoners in Thailand: An Application of System Dynamic Modelling

2-Identifying relevant facts about the infection in question

Some important aspects of identifying relevant facts about the infection in dynamic system modeling:

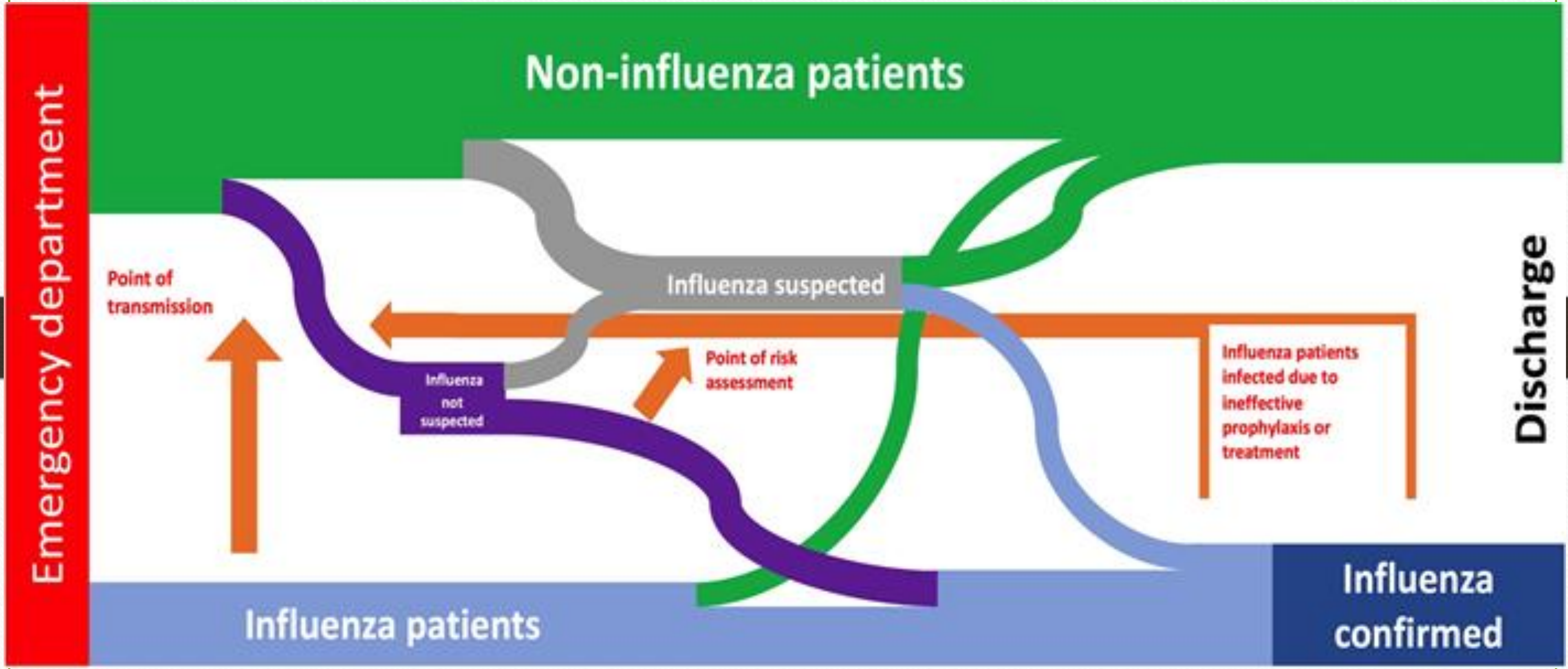
1. Understanding the Pathogen: transmission modes, incubation period, infectious period, and virulence.

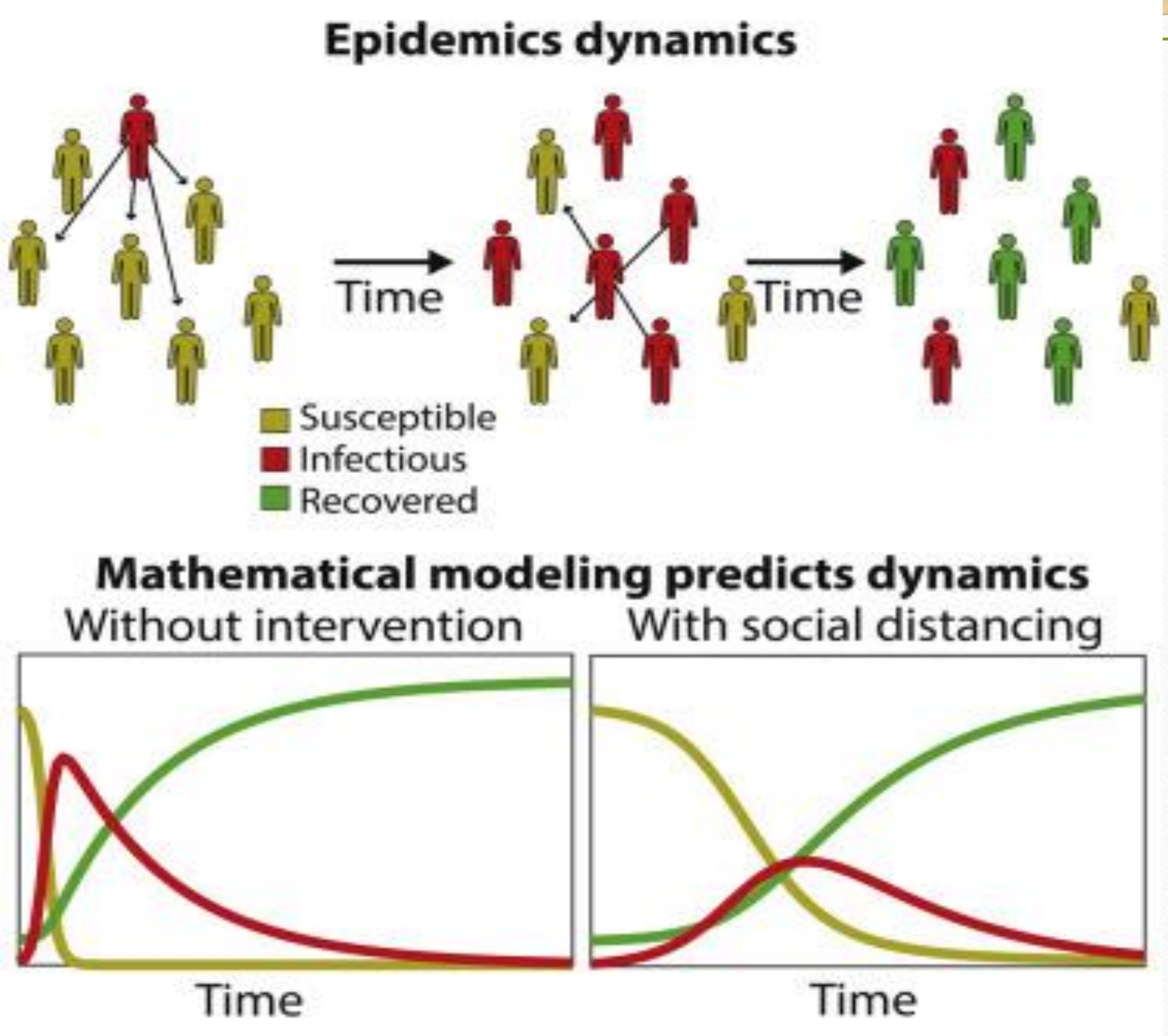
- **Natural history of infection**
- **Accuracy and time period over which the model forecast is required**
- **Research questions**

- **2. Epidemiological Data:** Collecting epidemiological data such as the number of cases, mortality rates, demographics of affected individuals, geographic distribution, and time trends is crucial for calibrating the model and validating its predictions
- **3. Population Dynamics:** population dynamics related to the infection, such as population size, density, mobility patterns, social interactions, and healthcare infrastructure

2-Identifying relevant facts about the infection in question

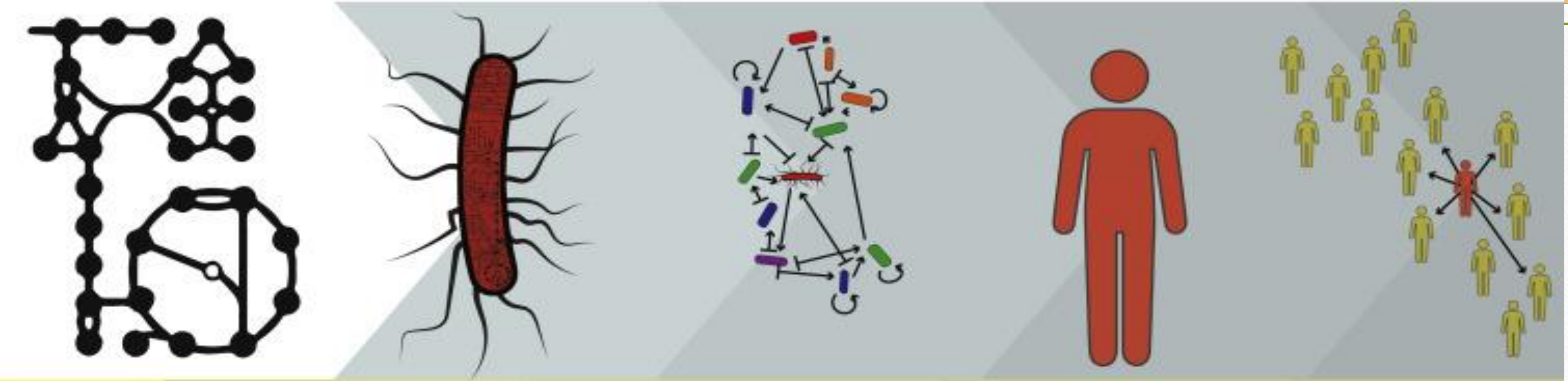
- **4. Intervention** Strategies: available intervention strategies, such as vaccination programs, treatment options, public health measures, and behavioral changes,
- **5. Data Sources and Quality:** It is important to critically evaluate the data sources and consider potential biases or limitations that may affect the model's outcomes**.**
- **6. Model Assumptions: :** Clearly defining the assumptions made about the infection and its dynamics in the model is important for transparency and reproducibility


Non-influenza patients
Emergency department
Point of transmission
Influenza suspected
Influenza not suspected
Point of risk assessment
Influenza patients infected due to ineffective prophylaxis or treatment
Discharge
Influenza patients
Influenza confirmed



Xavier JB, Monk JM, Poudel S, Norsigian CJ, Sastry AV, Liao C, Bento J, Suchard MA, Arrieta-Ortiz ML, Peterson EJR, Baliga NS, Stoeger T, Ruffin F, Richardson RAK, Gao CA, Horvath TD, Haag AM, Wu Q, Savidge T, Yeaman MR. Mathematical models to study the biology of pathogens and the infectious diseases they cause. iScience. 2022 Mar 15;25(4):104079. doi: 10.1016/j.isci.2022.104079. PMID: 35359802; PMCID: PMC8961237.

Mathematical modeling is used in the study of infectious disease to study processes at wide range of scales



	Intracellular biology	Microbiome ecology	Drug action	Epidemiology
Model	Genome-scale metabolic networks and gene regulation networks	Lotka-Volterra models of species-species interaction	Models of the physical chemistry of drugs, their interaction with the pathogen and the host	The SIR model
Elements	Metabolic flux; gene expression	Species of microbes in the gut microbiome, such as commensal and pathogenic bacteria and fungi	Factors such as anti-microbial susceptibility in vitro, host state, and clinical metadata	The individuals spreading the disease in a population
Examples of uses	Design perturbations to impact pathogen physiology and hinder its virulence; predict drug targets; study mechanism of drug resistance	Identify gut bacteria that may combat pathogens; design mixtures of bacteria to use as probiotics and restore gut health	Understand why a drug that works in vitro fails to treat a patient; design new treatment strategies	Predict the duration of an epidemic; compare measures to stop the spread

3-Choose type of modelling method

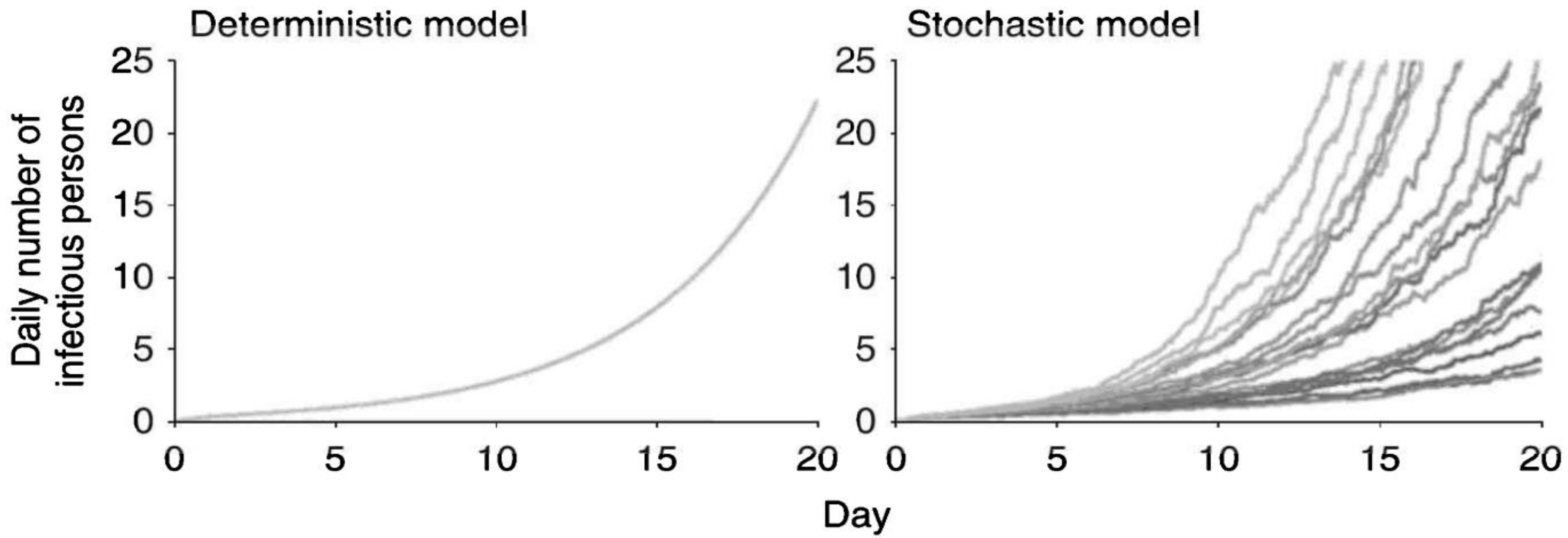
- **a) Statistical and probabilistic models (stochastic models):** Stochastic models allow the number of people who move between compartments to be completely random, for example, the rate of people contracting an infectious disease may randomly recover from the disease.
- **b) Deterministic models:** Deterministic models describe what happens on average in a population. In these models, the input parameters (e.g., the disease onset rate or the rate at which individuals recover) are fixed, and therefore the model's predictions, such as the number of cases observed over time, are predetermined.

Types of mathematical models

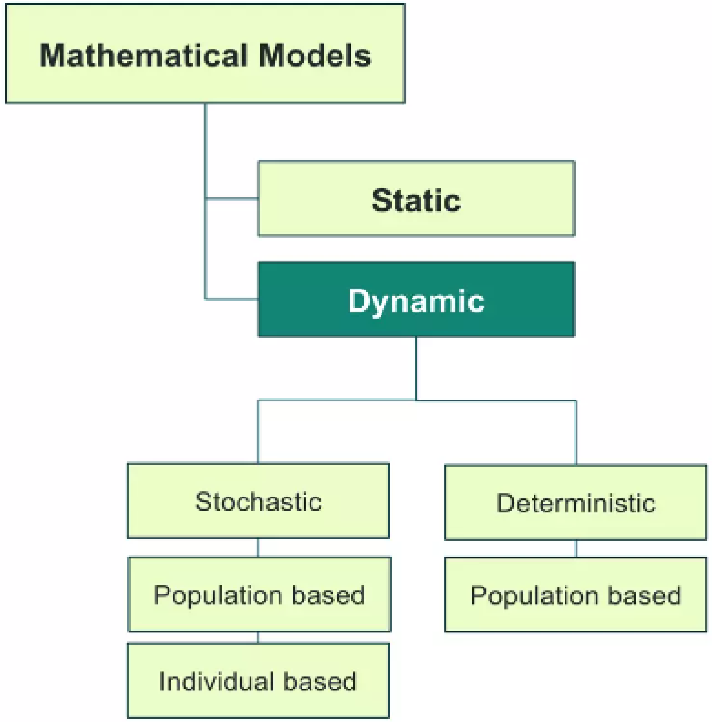
- **Deterministic**
- A same set of model parameters will **always** produce the same results
- The results are strictly determined by the parameter values given a system
- E.g., an infected individual will always develop symptoms at an average rate θ.
- We will focus on these !!

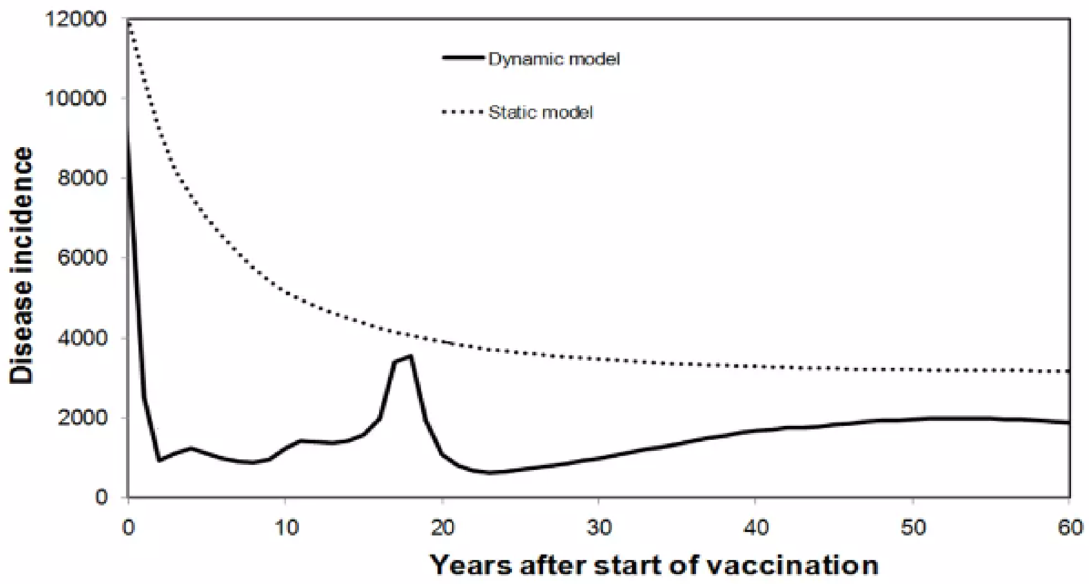
- **Stochastic**
- A same set of model parameters can produce **different** results
- The results combine the input and randomness in the events of transition
- E.g., an infected individual can or cannot develop symptoms out of chance.

The majority of deterministic models are so-called "compartmental" models.



Classification of mathematical models



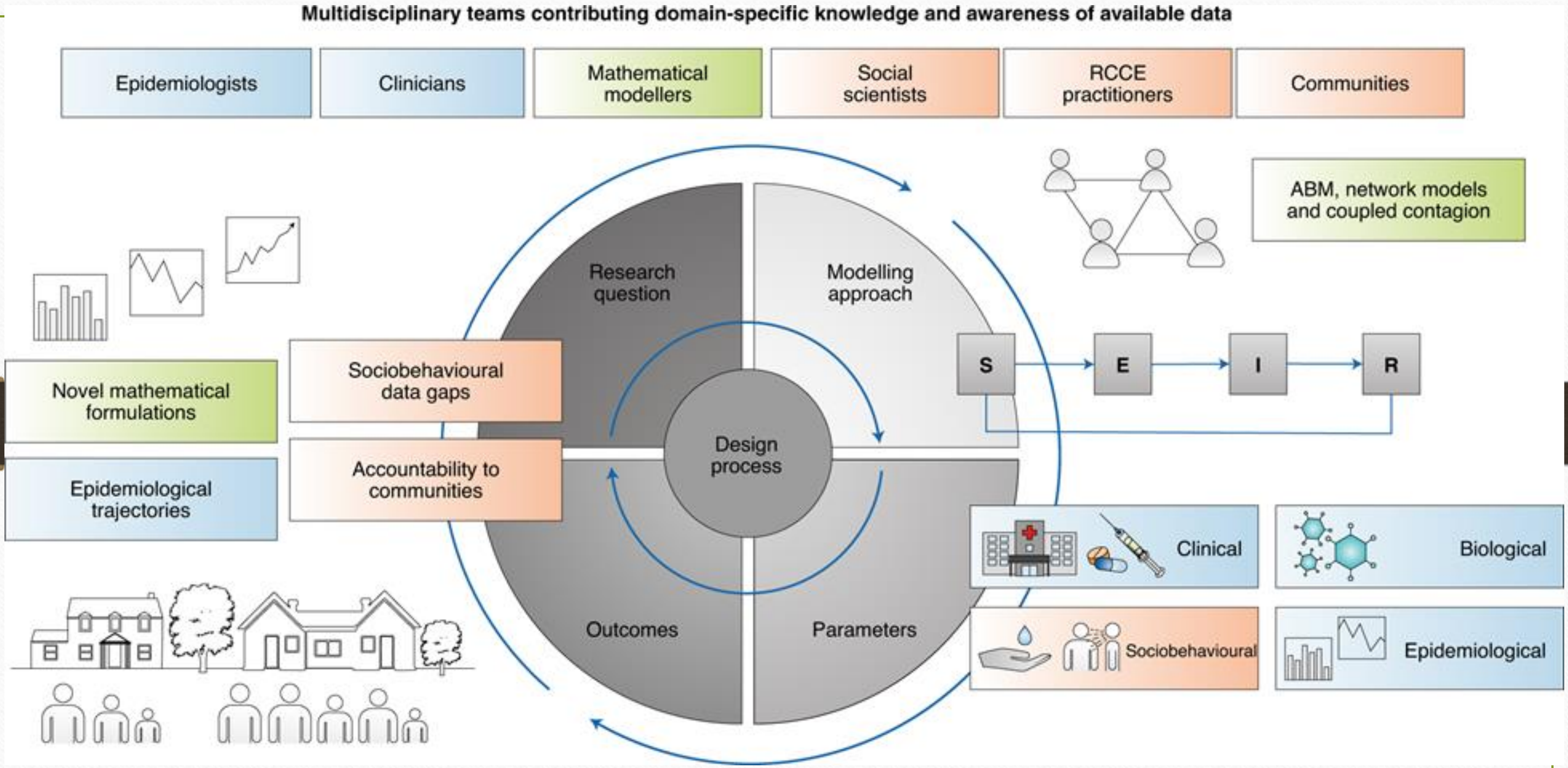


Brisson and Edmunds. (2003) Med Decis Making 23: 76.

4-Specify model input parameters

- **1. Identify Relevant Variables:** Determine the key variables that affect the behavior of the system and need to be included in the model. These variables could represent physical quantities, environmental conditions, policy decisions, economic factors, or other relevant aspects of the system.

- **2. Define Parameter Values:** Assign specific values or ranges to each input parameter based on available data, expert knowledge, experimental results, or assumptions. The values of input parameters can be constant, time-varying, stochastic, or dependent on other variables.



Bedson, J., Skrip, L.A., Pedi, D. *et al.* A review and agenda for integrated disease models including social and behavioural factors. *Nat Hum Behav* **5**, 834–846 (2021). https://doi.org/10.1038/s41562-021-01136-2

5-Set up model

When setting up a model in dynamic system modeling, several key steps are typically involved:

- **1. Define System Components:** This could involve physical entities, processes, decision variables, environmental factors, feedback loops, or other relevant aspects of the system.
  2. Formulate Mathematical Equations: Develop mathematical equations or relationships that describe how the variables in the model interact with each other and evolve over time
- **3. Specify Input Parameters:** Define the input parameters. Input parameters can represent exogenous factors, control variables, external disturbances, or initial conditions that drive the system dynamics.
- **4. Establish Relationships:** Establish causal relationships, dependencies, constraints, and feedback loops between different variables in the model

6-Model validation

Key aspects of model validation in dynamic system modeling include:

- **1. Comparing Model Outputs with Real Data:** Validate the model by comparing its outputs, simulations, or predictions with observed data from the real system
- **2. Testing Under Various Scenarios:** Evaluate the model's performance by testing it under different scenarios, input conditions, parameter values, and boundary conditions to assess its robustness and generalizability.
- **3. Sensitivity Analysis:** Conduct sensitivity analysis to examine how changes in input parameters, initial conditions, or model assumptions affect the model's outputs and predictions

6-Model validation

- **4. Cross-Validation: .** Cross-validation helps assess the model's ability to make accurate predictions on new or unseen data.
- **5. Expert Review and Peer Feedback:** Expert review can provide valuable insights, identify potential biases, and improve the model's accuracy.
- **6. Model Calibration:** Calibrate the model by adjusting parameters, coefficients, or equations to improve its fit with observed data and ensure that it accurately captures the dynamics of the real system.

7-Prediction and Optimization

- Prediction and optimization are fundamental concepts in dynamic system modeling that enable researchers and practitioners to forecast future behavior and identify optimal solutions for complex systems in various domains.
- By integrating predictive modeling and optimization techniques, analysts can make informed decisions, optimize system performance, and address real-world challenges effectively.

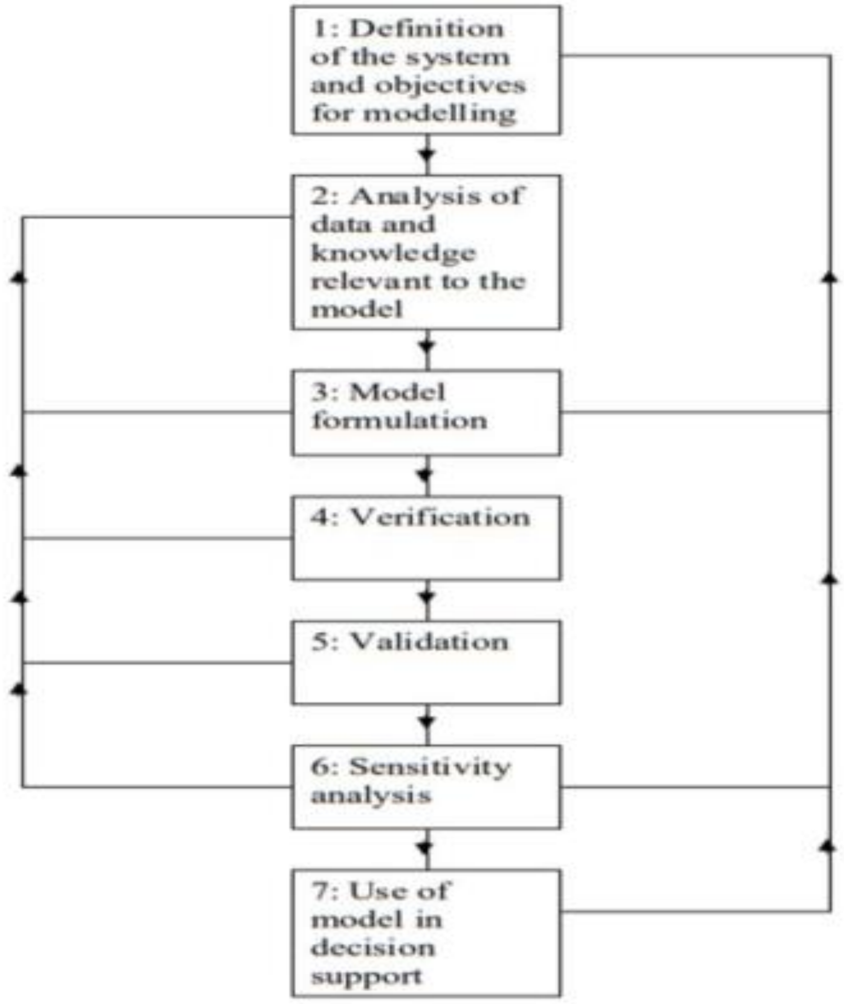


Figure 1. Stages in model building (19).

Ö YILMAZ-ÇAĞIRAN, AA ÇAĞIRAN. Epidemiological modelling in infectious diseases: stages and classification. MAE Vet Fak Derg. 2020; 5 (3) :151-158.

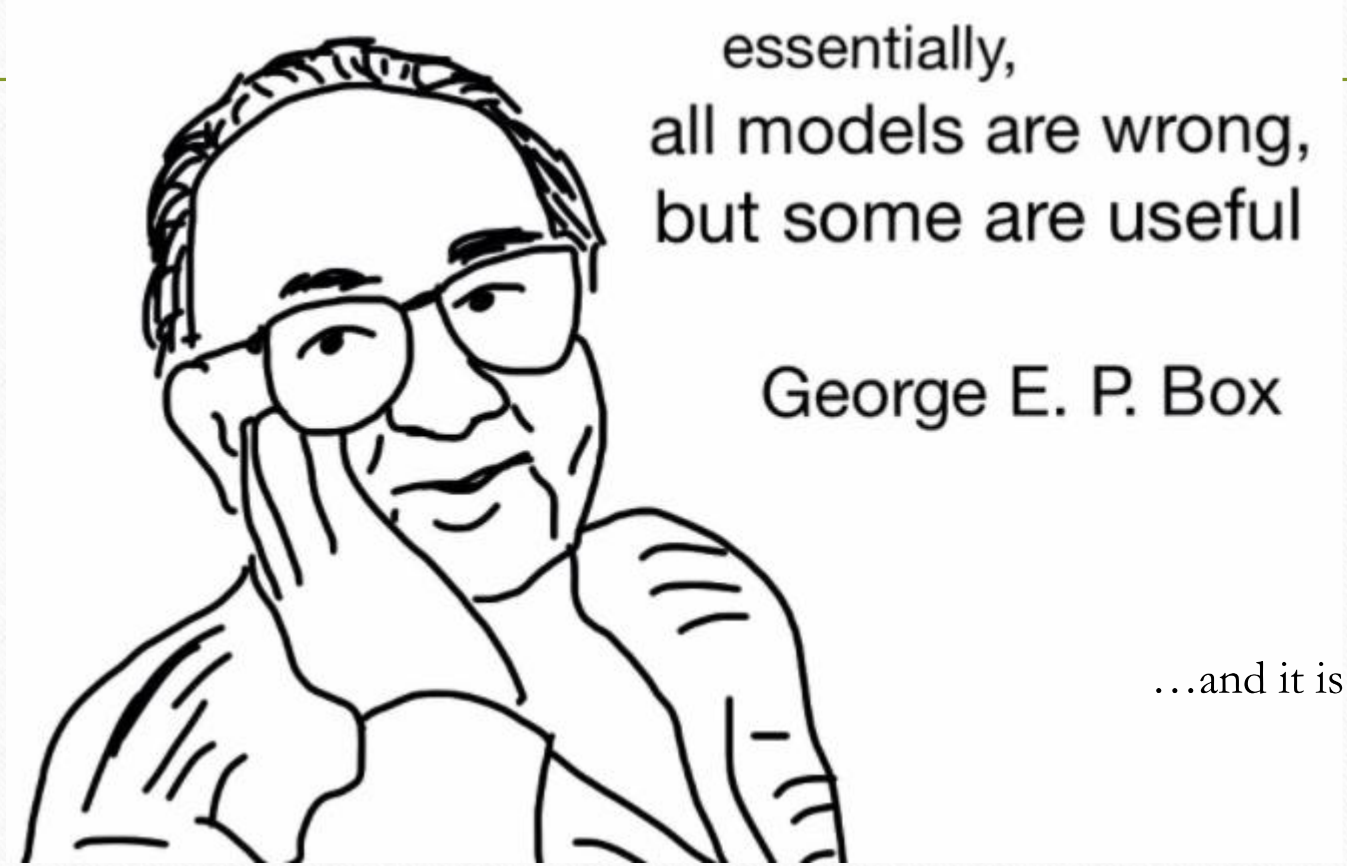
We need to understand the phenomenon

- Weather: very predictable -> laws of physics

- Infectious diseases -> very complex!
  - Biology of the pathogen
  - Clinical characteristics
  - Host behaviour
  - Population dynamics

By definition a multidisciplinary field (all are welcome!)

[Widely repeated quote goes here]



…and it is true!

Iranian Epidemiological Association

Thank you for your attention