EPA1121
Requirements for quantitative models and choice of modelling methods

Els van Daalen

Policy Analysis Group
Faculty of Technology, Policy and Management

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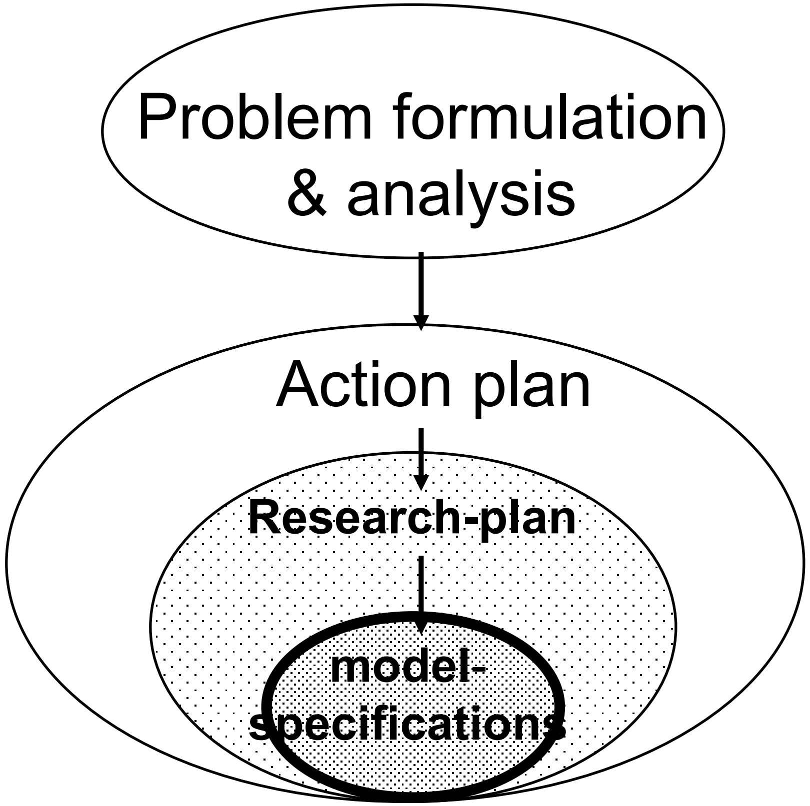
Course theme

1. dimensions of complexity; problem formulation in a multi-actor context
2. problem formulation steps and elementary concepts and tools
3. analysis of objectives, and (re-)determination of scope
4. actor/network analysis and future scenario-analysis
5. adaptation of problem formulation as necessary
6. specification of action plan, research questions and research plan, based on problem analysis
7. **Selection of analytic tools/models to be used to answer (some of the) research questions**

Course theme



Objectives of this lecture

- recognise the role of quantitative models as research methods (i.e. to answer research questions)
- understand the relationship between problem characteristics and model types
- able to select a modelling method based on a problem context
- understand the relationship between a system diagram and a model diagram
- recognise the contribution of a model diagram to specify model requirements and select a modelling method

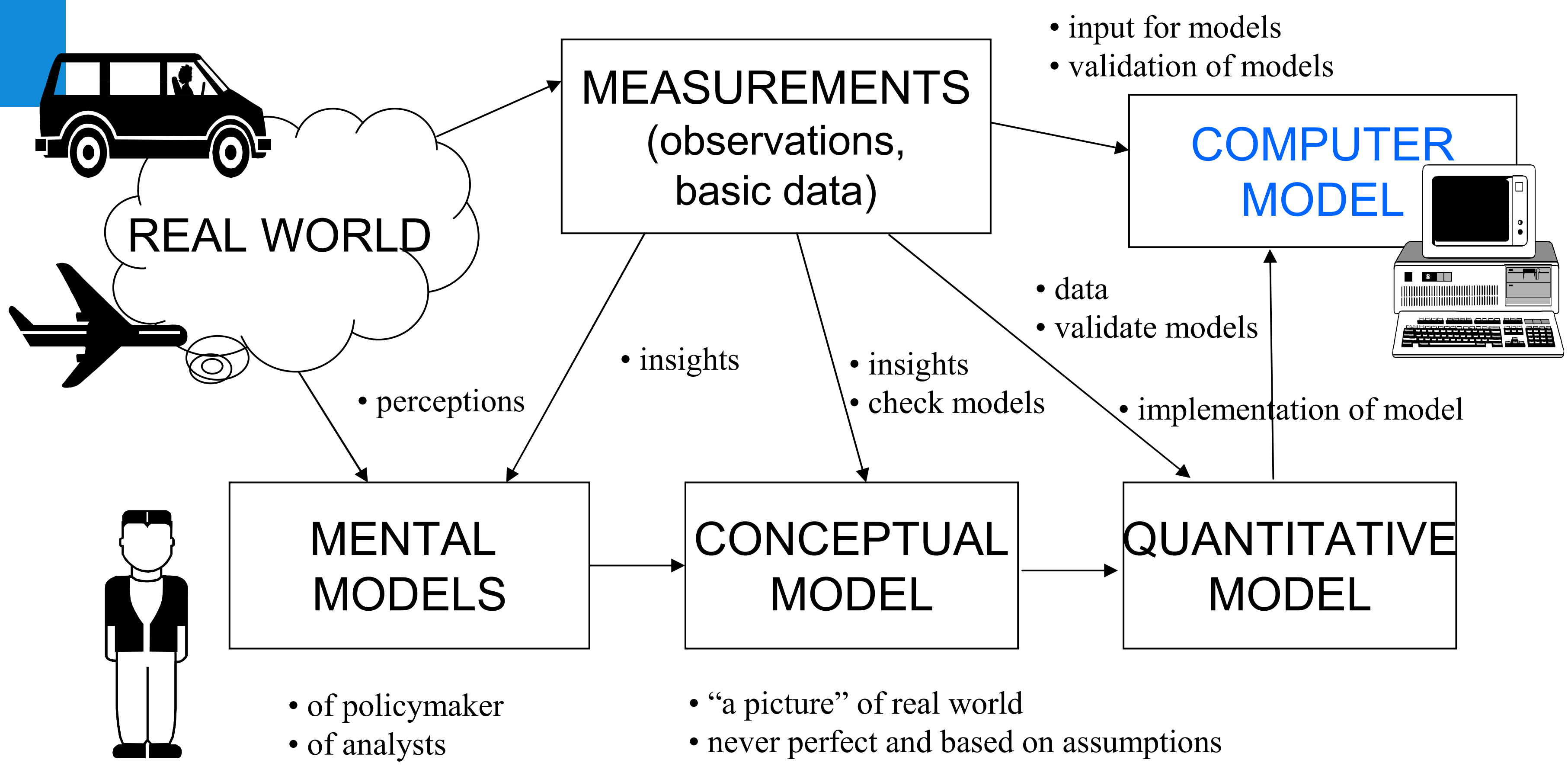
What is a model?

There are many definitions of a model:

a simplified version or representation of reality

- a physical model
- an abstraction
    - conceptual models
    - analytical models
    - simulation models

What do we mean by model?



Strengths of quantitative modelling

- integration of (many) data and theories; make complexity manageable without denying it
- consistency, ‘objectivity’
- transferable, controllable
- makes experiments (with model) possible

Weaknesses, risks

- data and theory may not be available or be inadequate, e.g.
  - many aspects of human interaction cannot well be described mathematically
  - there is high uncertainty about what the key mechanisms are (e.g. technological transitions)
- appearance of objectivity may be misleading; danger of believing reality is equal to model
- tendency to extrapolation of present/past, ‘fixation’
- sometimes lack of transparency, hard to communicate
- building, validating and using models may be costly, time consuming process

When to use mathematical models?

- sufficient quality data and theory available (for parts to be modelled)
- need to take complexity, dynamic interactions into account
- many assumptions, options for action possible
- experimenting in real world not feasible

For what purposes?

- gain insight in system properties, critical factors, developments in system surroundings, causes of problems/undesired outcomes (empirical, descriptive model)
- gain insight in impacts of alternative actions ('what, if....' questions; **impact assessment** or forecasting model)
- find 'best' alternative, design (**decision** or **optimisation** model)

A host of different modelling approaches

System Dynamics

Regression analysis

Cost-benefit analysis

Decision-Event trees

Agent-based modelling

Transport models

Analytical models

Physical systems modelling

Discrete modelling

Computer Models

Expert systems

Spreadsheet modelling

Statistical models

PowerSim models

GIS-based models

Linear optimisation

A host of different modelling approaches

Discrete event modelling

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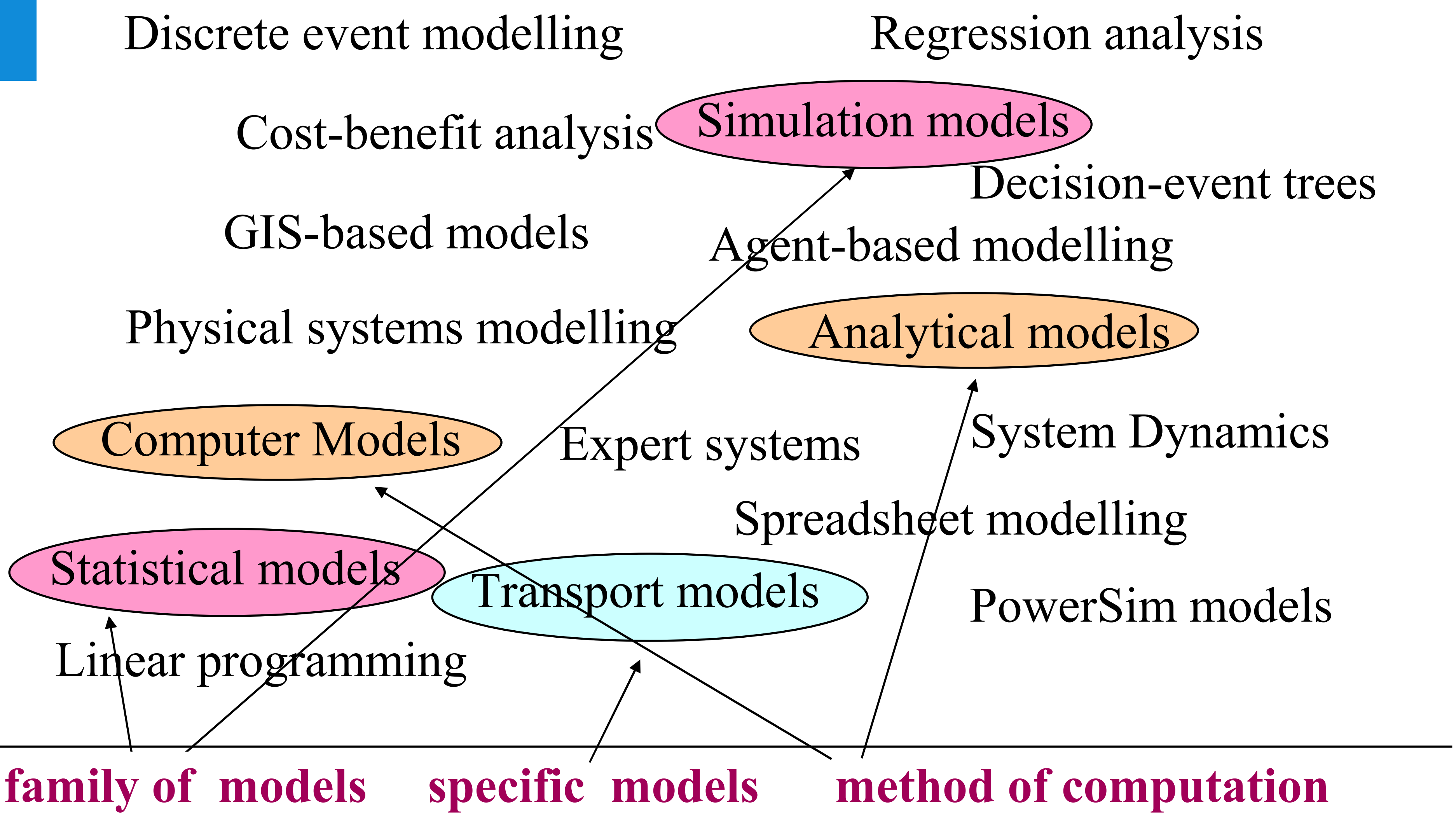
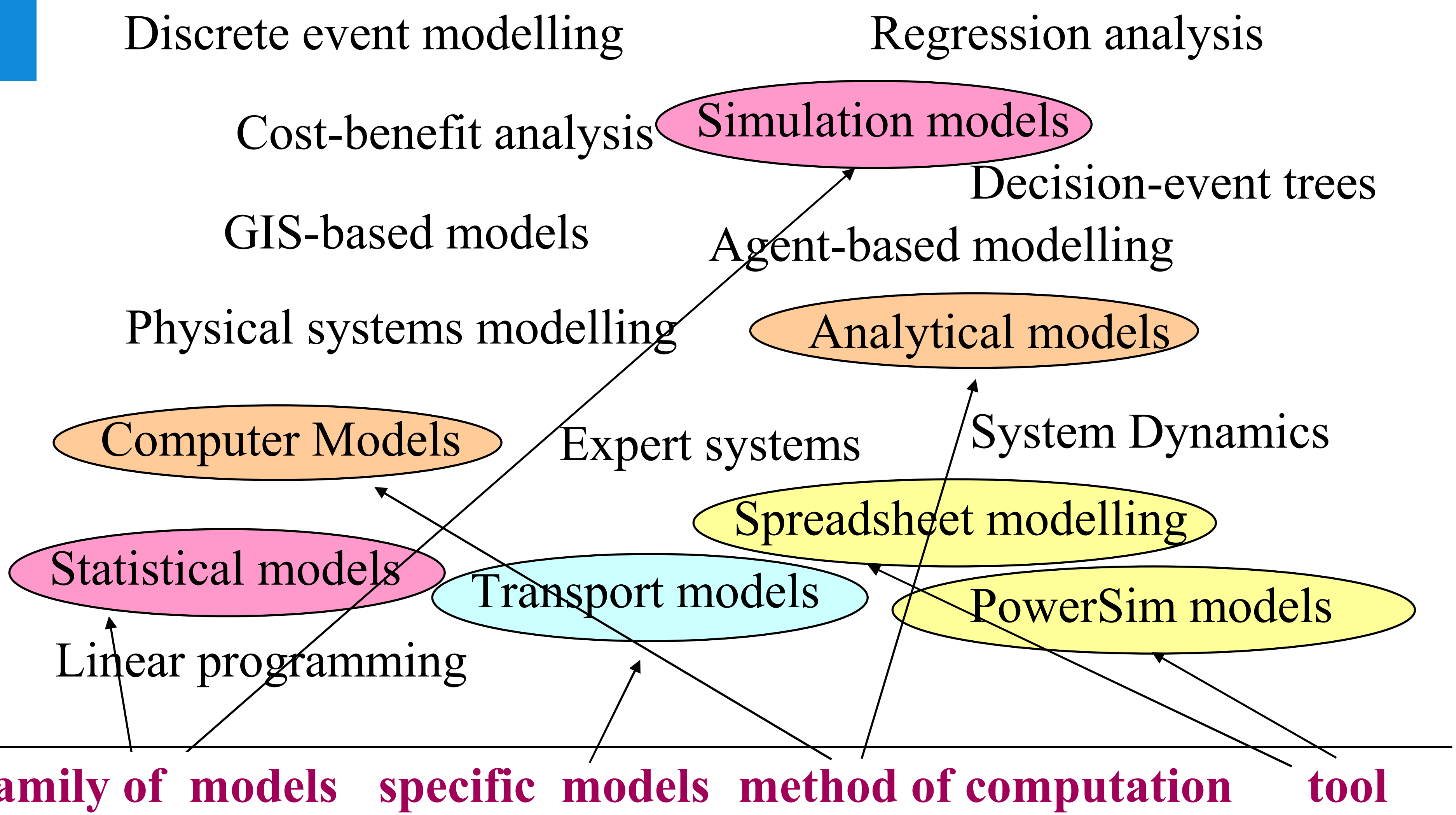
Linear programming

family of models **specific models**

A host of different modelling approaches



A host of different modelling approaches



Modelling paradigm

(paradigm: from greek: ‘pattern’; ‘example’)

- coherent combination of:
  - worldview
  - view on what models are for
  - view on process of model building, model validity and model quality criteria
  - mathematical form, piece of software used to support

Modelling paradigm

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  - view on what models are for
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Question
Can you name some of the modelling paradigms we have seen in EPA?

Modelling paradigm

(paradigm: from greek: ‘pattern’; ‘example’)

- Coherent combination of:
  - worldview
  - view on what models are for
  - view on process of model building, model validity and model quality criteria
  - mathematical form, piece of software used to support

- Examples of different modelling paradigms:
  - System dynamics
  - Discrete-event simulation

Question
What are the characteristics of these modelling paradigms (world view, purpose etc.)?

System Dynamics

- dynamic behavior is the result of interaction of positive and negative **feedbacks** in a system
- modeling should enhance **insight** in and **understanding** of behaviour **patterns** and identification of points of leverage through which system behaviour may be changed
- a good model is **transparent**, helps understand behavioural **patterns and mechanisms**, and does not have to be numerically precise or detailed
- level of aggregation: fairly high
- mathematical form : continuous differential equations, often deterministic, software e.g. Powersim, Vensim

Discrete-event simulation

- system behaviour results from the interaction of **discrete objects** the state of which **changes in a discrete way**
- modeling should help in the analysis of **operational processes** and in system (re)design to improve system performance
- a model is good if it mimics/describes relevant **elementary interactions** and the resulting system performance indicators in a **precise and statistically accurate** way
- level of aggregation: low
- mathematical form: discrete description, stochastic, software e.g. ARENA, SIMSCRIPT

Other modelling methods

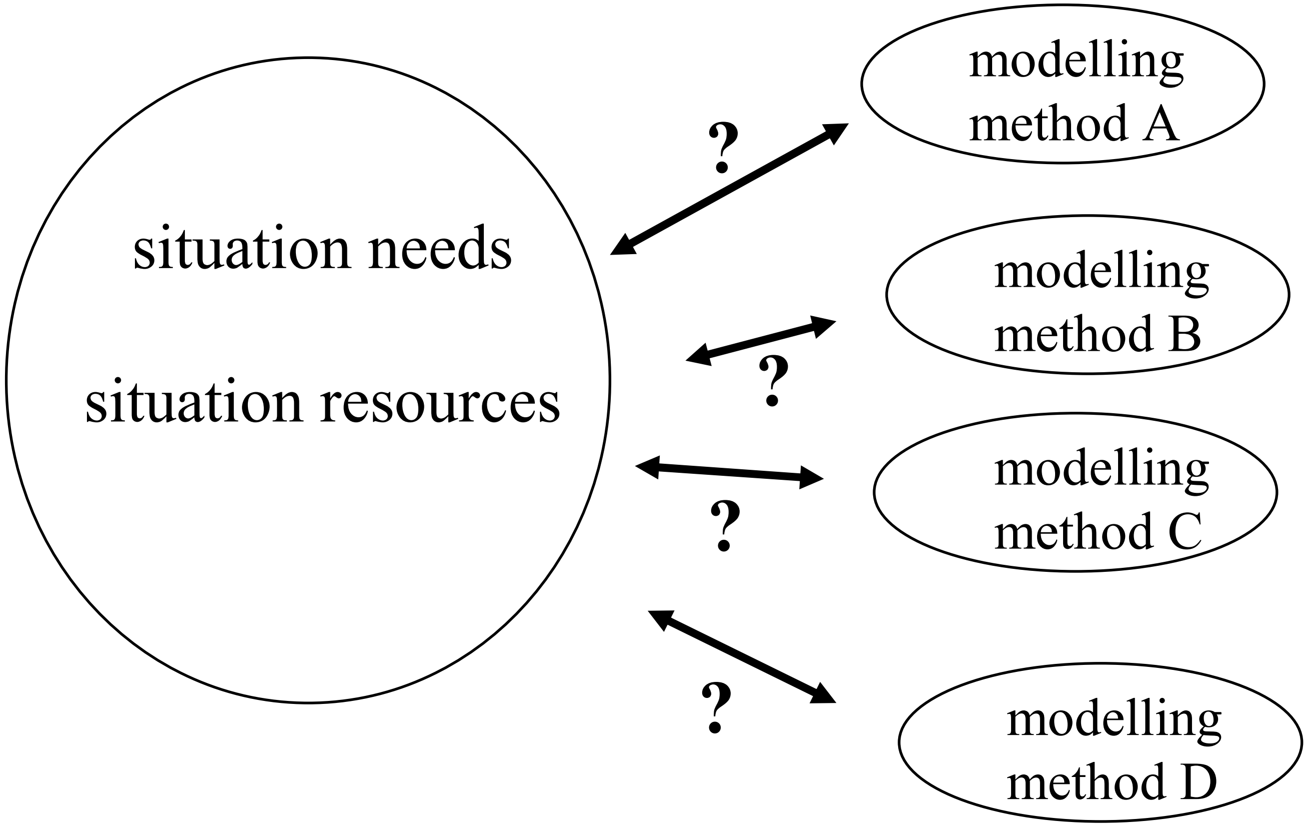
- agent-based models (simulation of complex adaptive systems)
- decision models (often optimisation)
- econometric models (statistical models)
- technical/natural-science based models (often dynamic, continuous, different aggregation levels)
- domain-specific modeling methods/models
  - traffic models
  - risk models
  - etc.
- etc. etc.

Choosing modelling methods

- Leading:
  - what question is to be answered using quantitative models?
  - what are the characteristics of the key mechanisms to be modeled?

- Generally, different questions require different models, analysis of different system parts or aspects may require different types of model! (or: making a single model/using a single modeling method for 'the' system will usually not lead to adequate answers to the different questions!)

Matching supply and demand

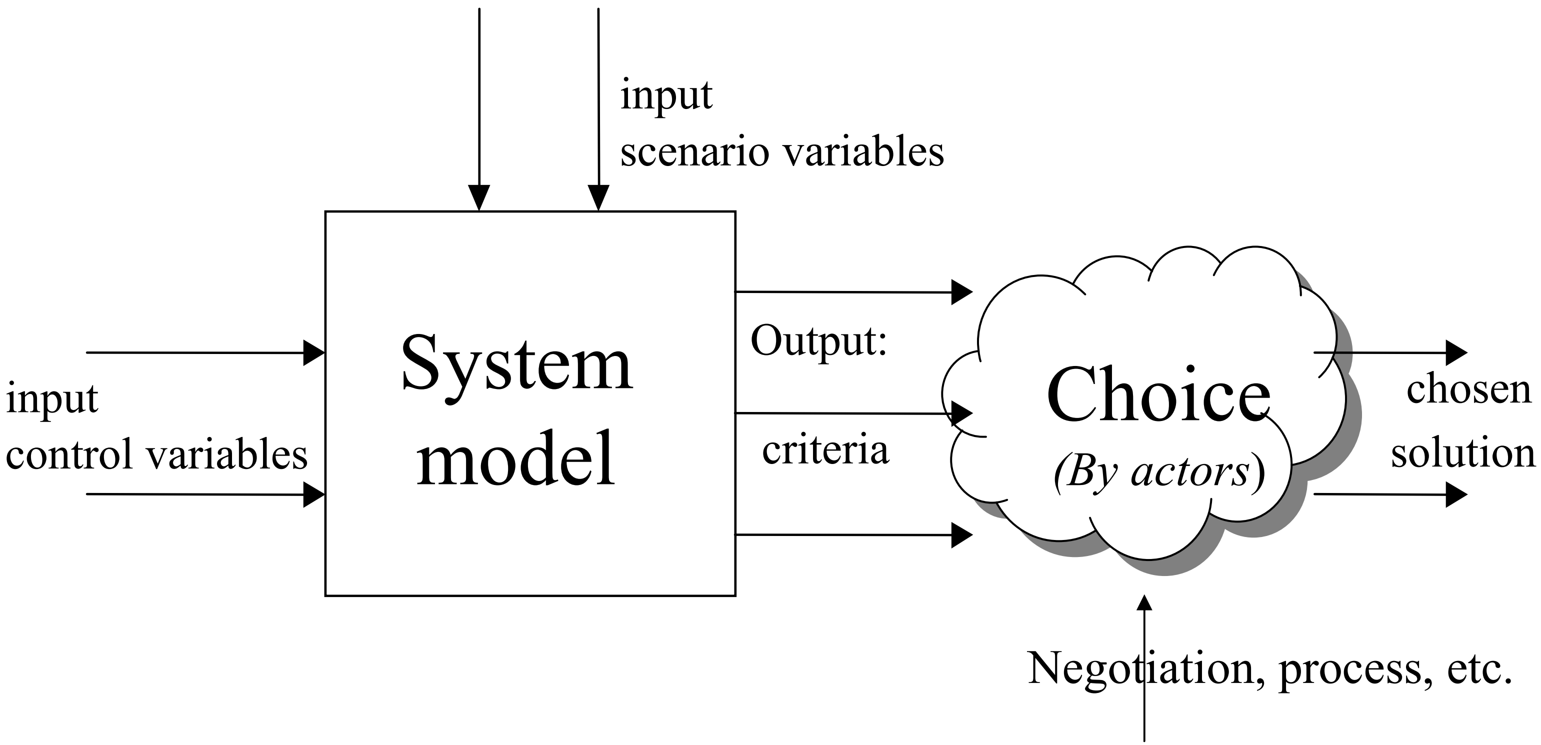


Choice of modelling method depends on

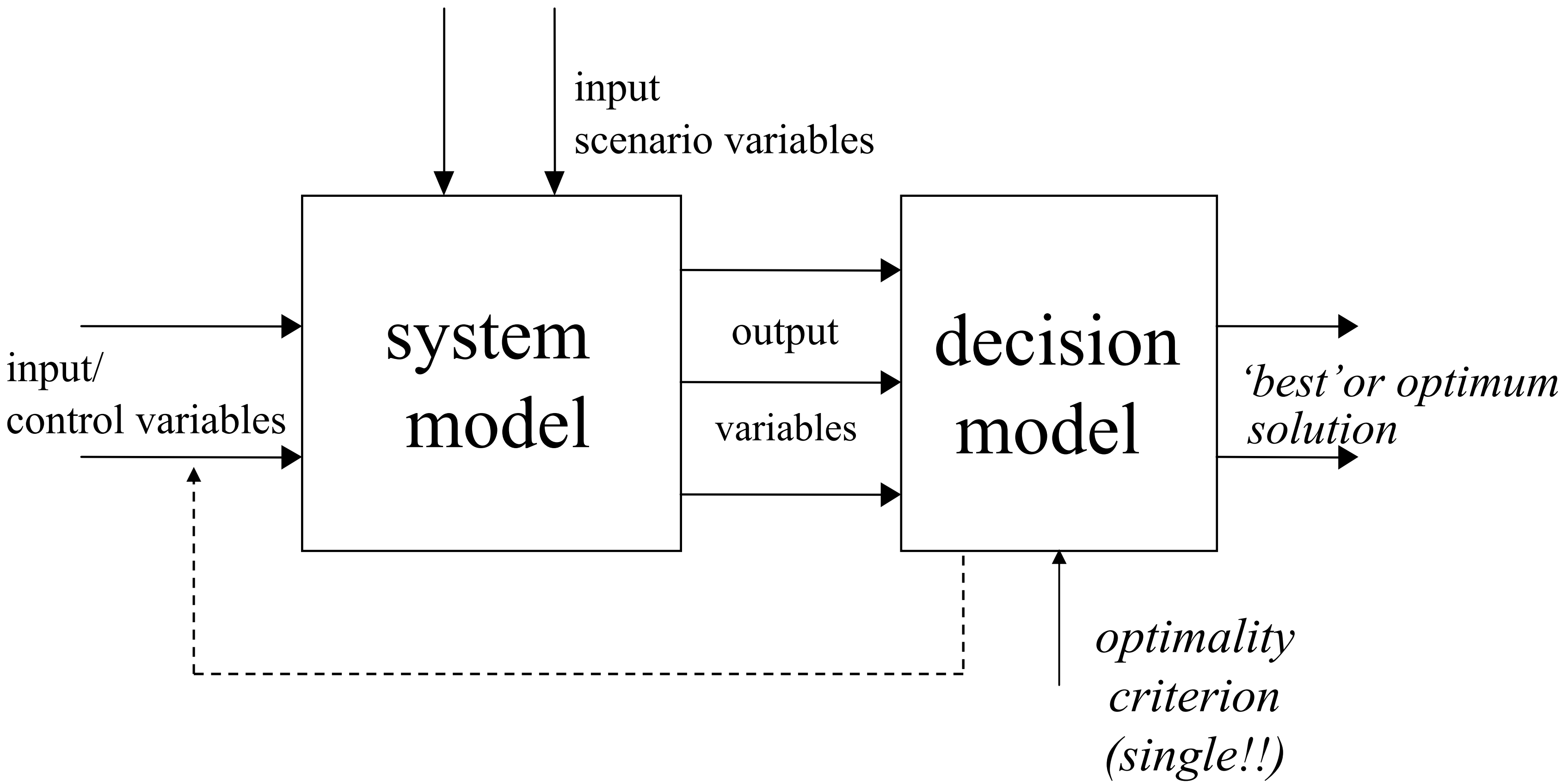
1. purpose of modelling effort (insight – impacts – ‘best’ decision?)
2. attributes of questions to be answered
3. characteristics of key relevant mechanisms of system to be modeled
4. availability of knowledge/theories and data
5. time, money, actors involved

- in complex situations different modelling methods may be used to address different parts or sub-questions

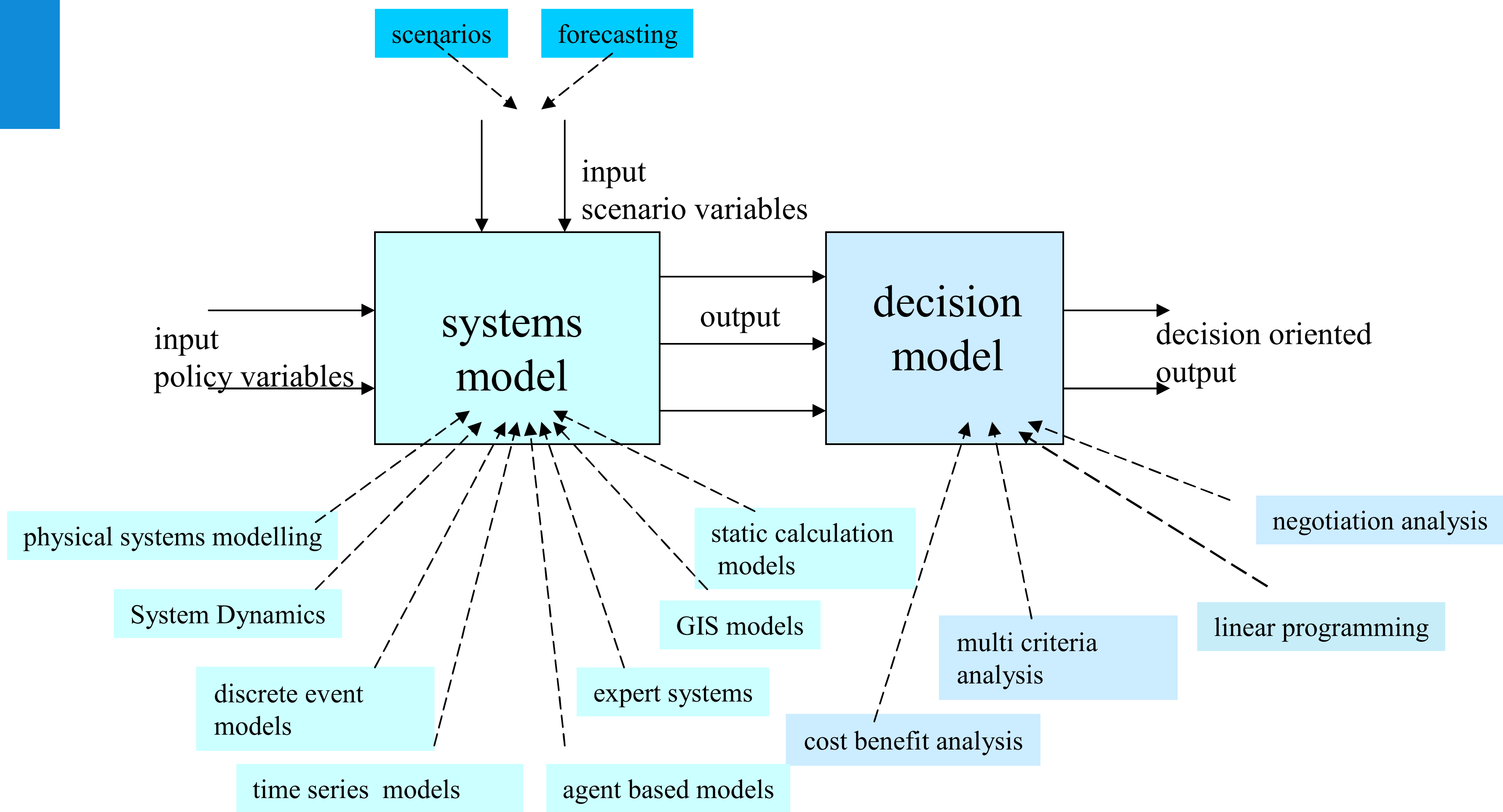
1. Purpose - impact assessment model



1. Purpose - decision model



Different model types for purposes



2. Relevant problem characteristics - attributes of questions to be answered

time	time horizon trajectory or point forecast
space	relevance
quality	level of detail accuracy

Implications for model attributes

time	time horizon trajectory or point forecast	
space	relevance	
quality	level of detail accuracy	

➔

operational (short-term) – strategic (long-term)
temporal – not temporal
spatial – not spatial
micro (low aggregation) - macro (high aggregation)

3. Relevant problem characteristics - related to key mechanisms

endogenous behaviour
type of process
type of uncertainty

Implications for model attributes

endogenous behaviour	➔	dynamic - static
type of process		discrete - continuous
type of uncertainty		stochastic – deterministic

4. Relevant problem characteristics - related to knowledge conditions

availability of knowledge, theories
availability of data

Implications for model attributes

availability of knowledge, theories	➔	White/transparent box - black box
availability of data		data rich - data poor

5. Relevant problem characteristics - related to process conditions

available time
available means
actor characteristics

Implications for model type & modelling process

available time	➔	quick and dirty/simple – more deep/detailed
available means		required expertise, staff
actor characteristics		transparency, method of presentation/communication

Overview

characteristics	**Problem situation (demand)**	**Modelling approach (supply)**
purpose/function	insight, impacts; decision	system model – decision model
questions to be answered	time horizon trajectory or point forecast space level of detail; accuracy	operational – strategic temporal spatial micro (low aggr.) – macro (high aggr.)
key mechanisms to be modelled	endogenous/exogenous behaviour type of process type of uncertainties	dynamic – static discrete – continuous stochastic - deterministic
knowledge conditions	theory data	white box – black box data rich – data poor
process conditions	availability of time availability of means actor characteristics	simple - elaborate/detailed required expertise, staff transparancy, presentation means

Some systems models and their characteristics

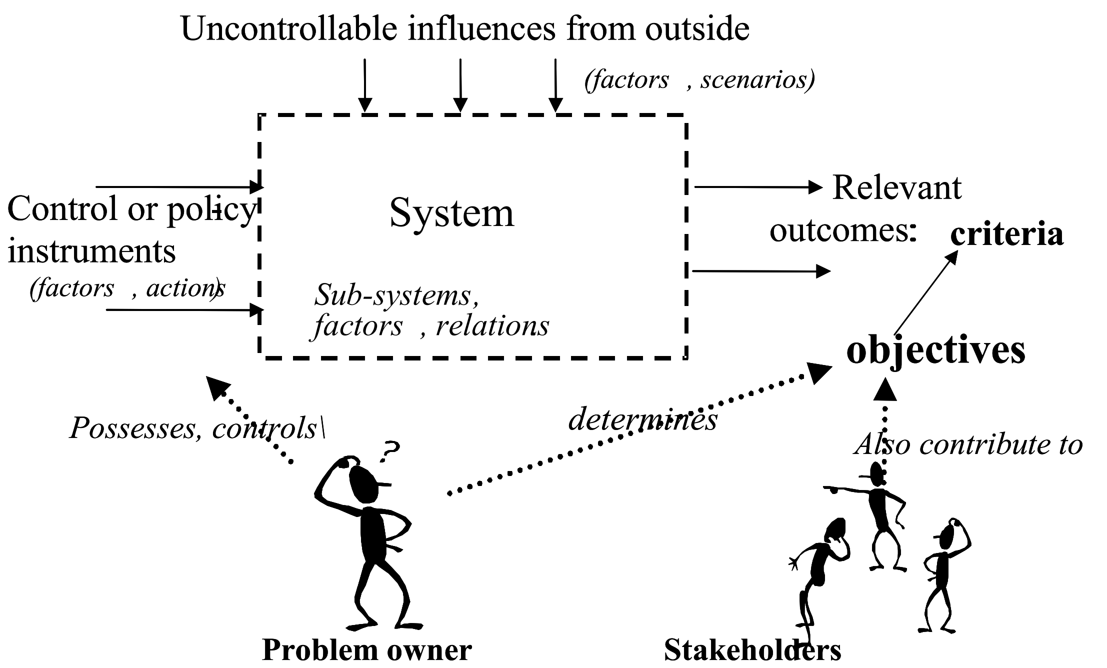
Physical system modelling (e.g. hydrodynamical)
System Dynamics
Discrete event models
Statistical models (e.g. ARIMA models)
GIS models
Spreadsheet models
Optimization models (e.g. graph-theoretic route planning)

Some systems models and characteristics

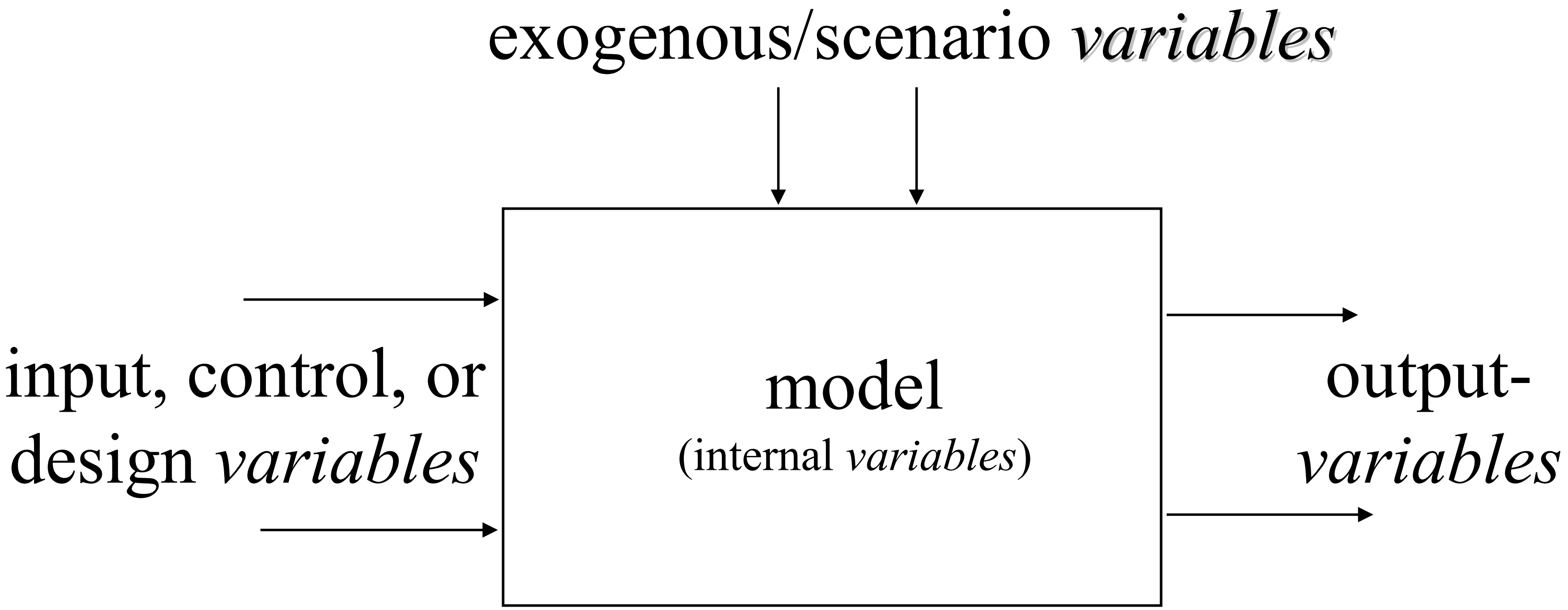
Physical system modelling (e.g. hydrodynamical)	quantitative, white box, dynamic, temporal, operational, system model
System Dynamics	continuous, deterministic, white box, dynamic, temporal, strategic, system model
Discrete event models	discrete, stochastic, dynamic, temporal, operational, system model
Statistical models (e.g. ARIMA models)	quantitative, stochastic, black box, temporal, data rich
GIS models	white box, static, spatial, data rich
Spreadsheet models	quantitative, deterministic, white box, static, temporal
Optimization models (e.g. graph-theoretic route planning)	quantitative, deterministic, static, decision model

How do we actually approach the modelling decisions in the issue paper?

- System diagram is basic point of departure for research questions, making a model diagram, defining model requirements and choosing a modelling method



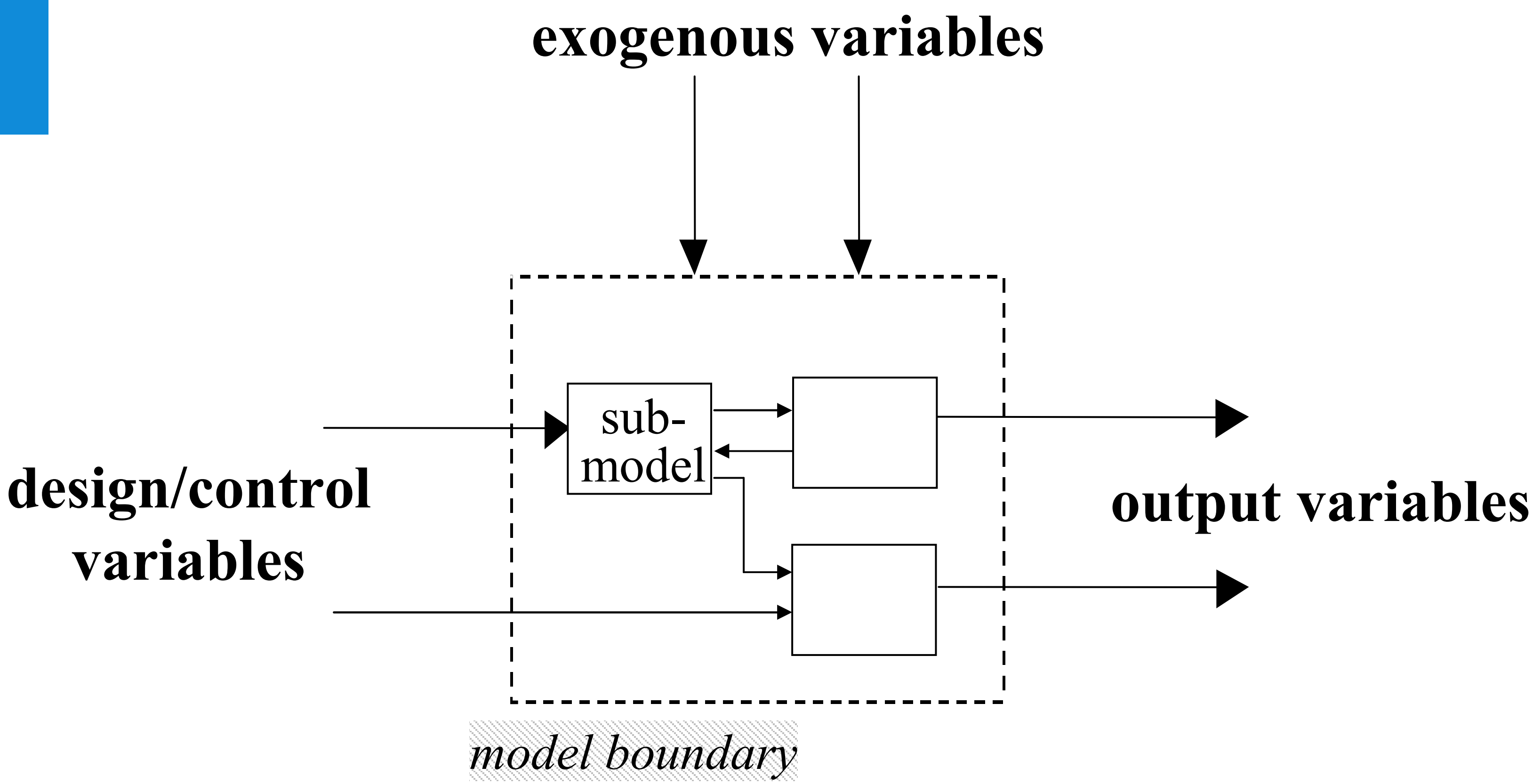
Model diagram



Factors ⟷ ? ⟷ Variables

- Factors are properties of the *system*
  - observable in reality
  - assumed relevant for problem solving
- Variables are properties of the *model*
  - “building blocks” of a model
  - abstractions “made up” by the analyst to describe system properties

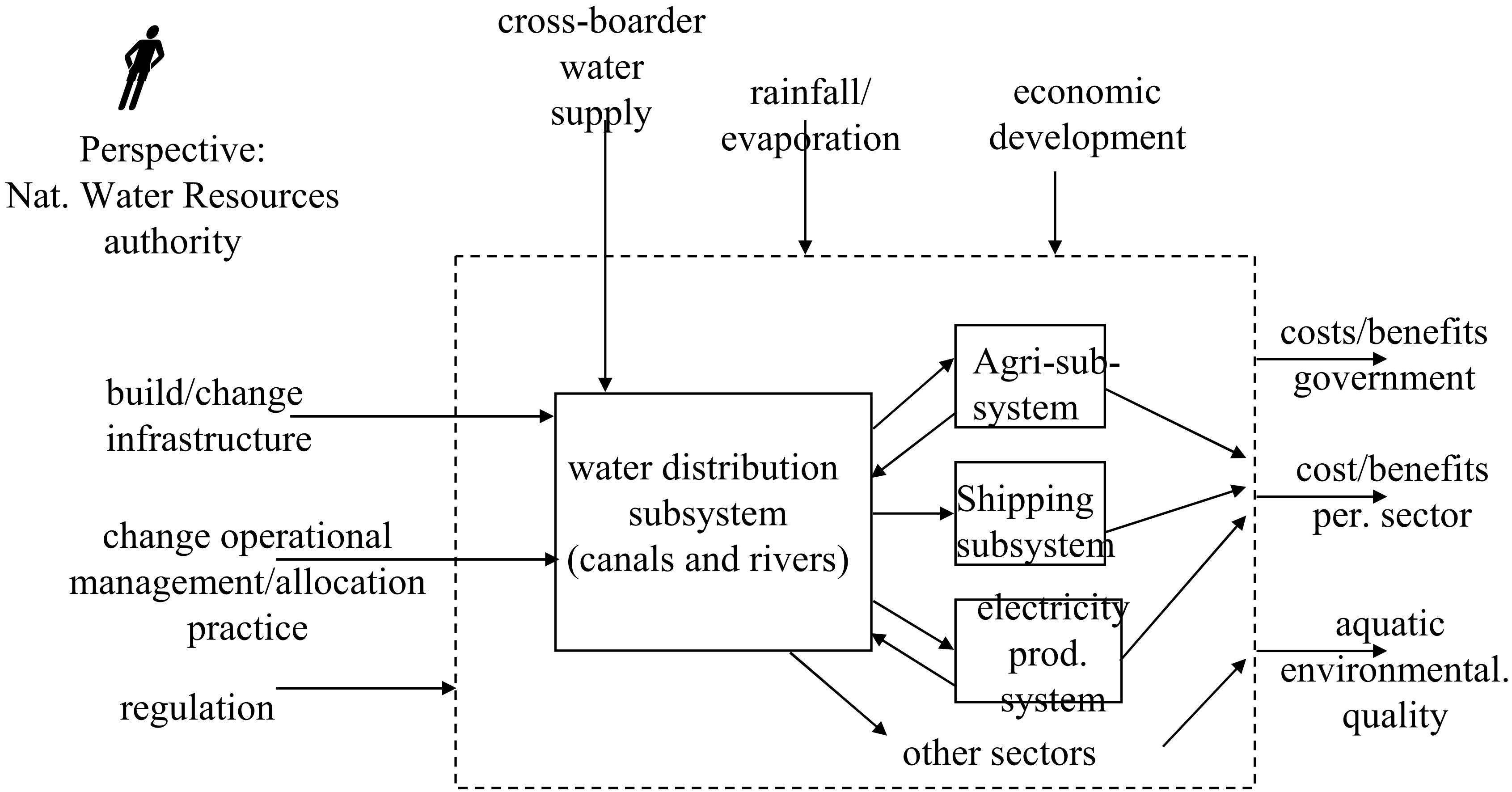
With submodels



Choosing in/output variables

- directly related to questions to be addressed!
- for example, if essentials of full system can be modeled in a single model:
  - Input variables: *operationalisation* of alternative measures, tactics
  - Exogenous variables: key scenario-factors
  - Output variables: criteria or objectives measures , i.e. *measurable* aspects indicating the degree of achievement of the objectives

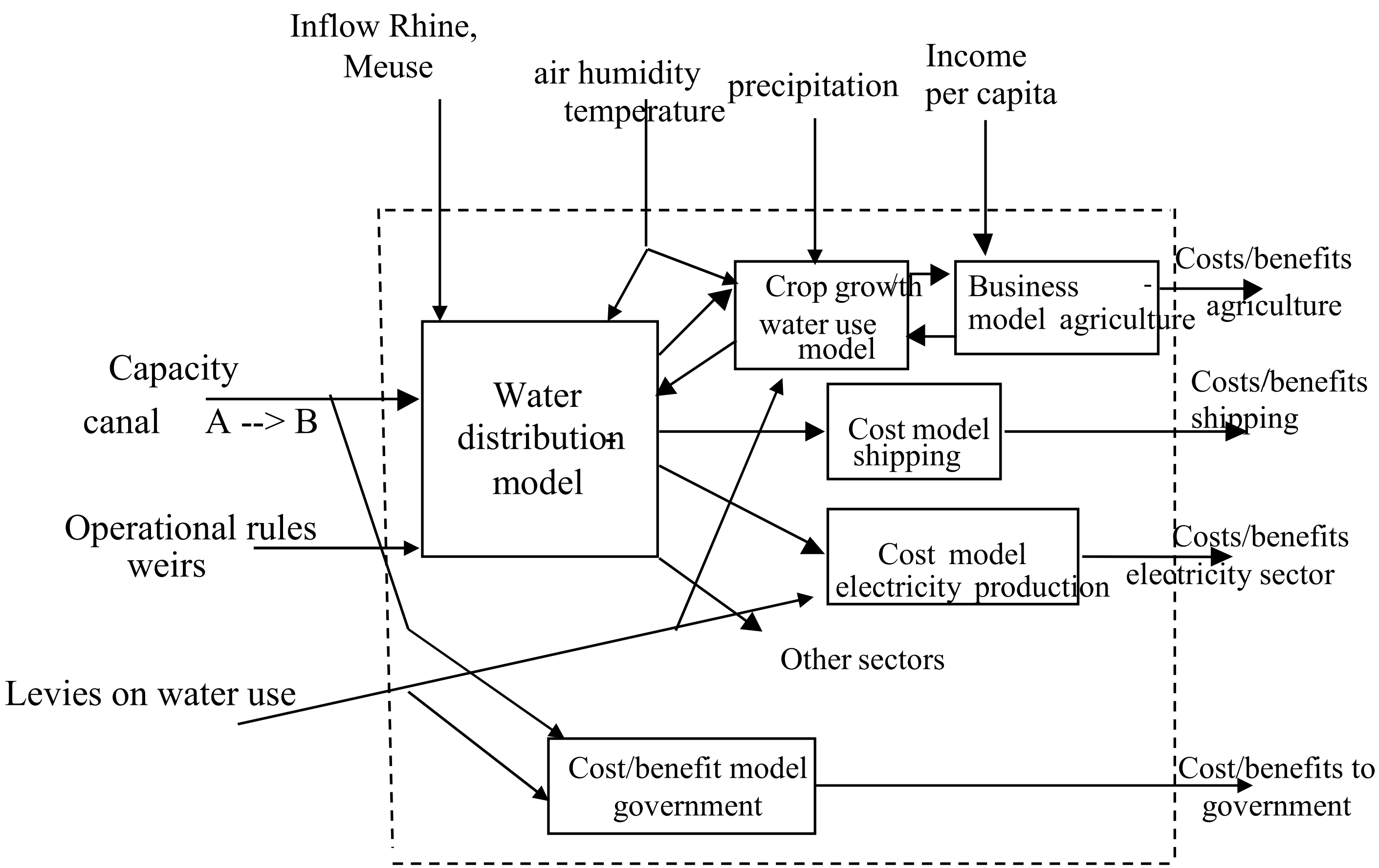
Example: water scarcity (incomplete system diagram)



Relevant research questions (for water scarcity problem)

- Effectiveness of infrastructure options in terms of costs and benefits and for whom?
- What is ‘best’ allocation principle in times of water scarcity?
- How effective are restrictions on surface water use by farmers? What are the costs to farmers?
- What if farmers would grow different mix of crops?
- How do effects depend on different weather conditions?
- Etc.

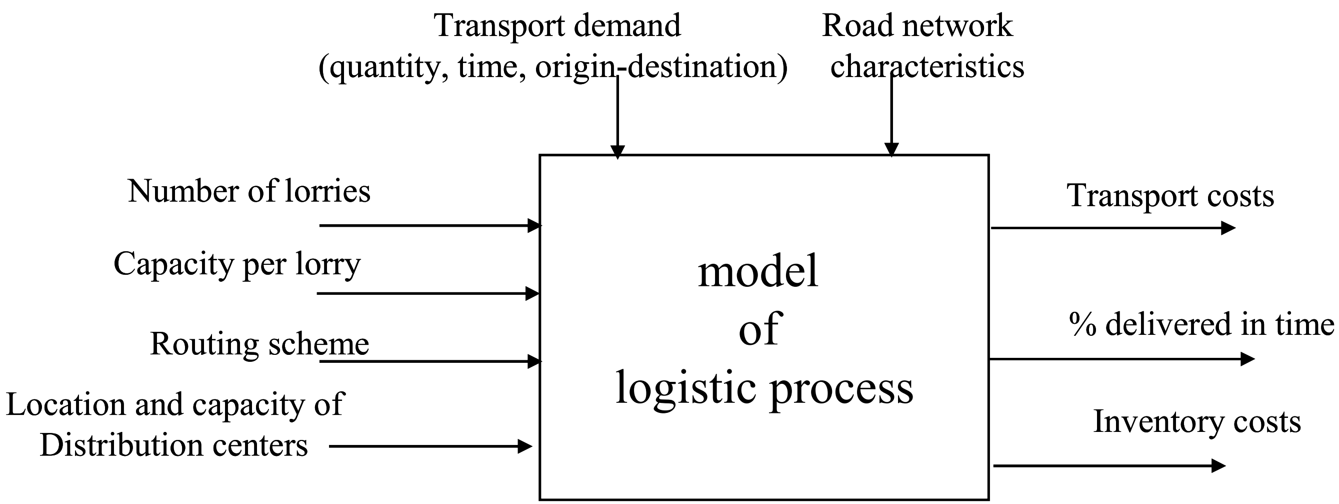
Example of model diagram (incomplete)



Procedure

- Use system diagram as starting point for
  - Identification of research questions
  - Making a model diagram to
    - identify system parts to be modelled
    - make distinctions between subsystems
    - specify inputs/ouputs (sub)models
    - selection of modelling method

Example requirements: analyse a distribution system



Time frame: 1 week
Space: location in Netherlands
Aggregation level: low (individual loads and trucks)
Characteristics: endogenous behaviour, uncertainties
Key variables: location and load lorries, distri centres, roads
Knowledge: available
Required data: speed, travel times, fuel consumption and costs/truck-km,
load-unload times, wages, etc.

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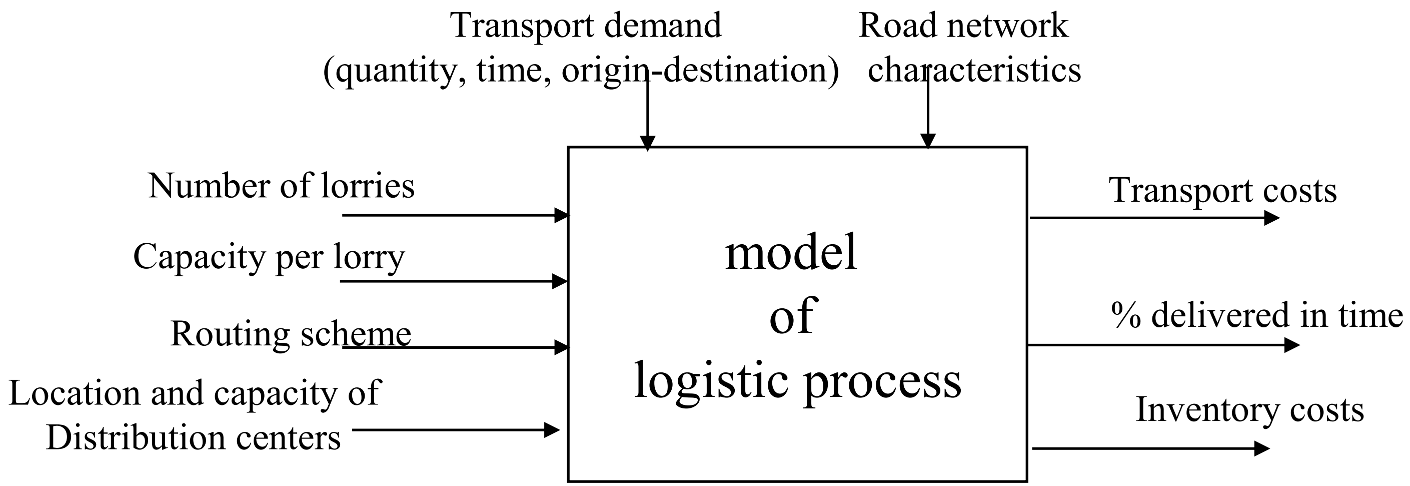
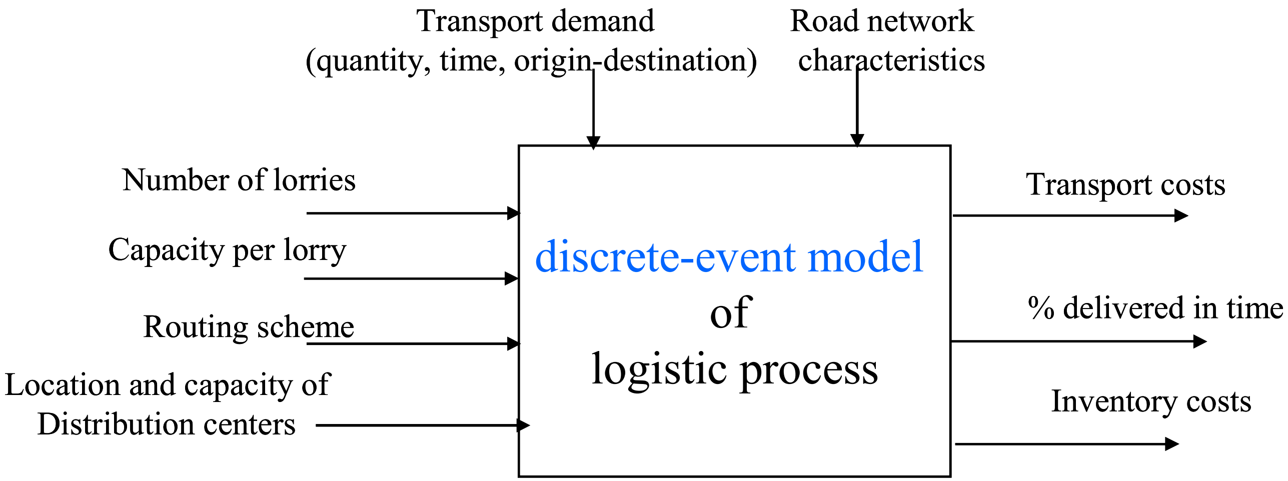


Time frame: 1 week (operational)
Space: location in Netherlands (spatial)
Aggregation level: low (individual loads and trucks) (micro)
Characteristics: endogenous behaviour, uncertainties (dynamic, stochastic)
Key variables: location and load lorries, distri centres, roads (discrete)
Knowledge: available (white box)
Required data: speed, travel times, fuel consumption and costs/truck-km,
load-unload times, wages, etc. (data rich)

Example requirements: analyse a distribution system



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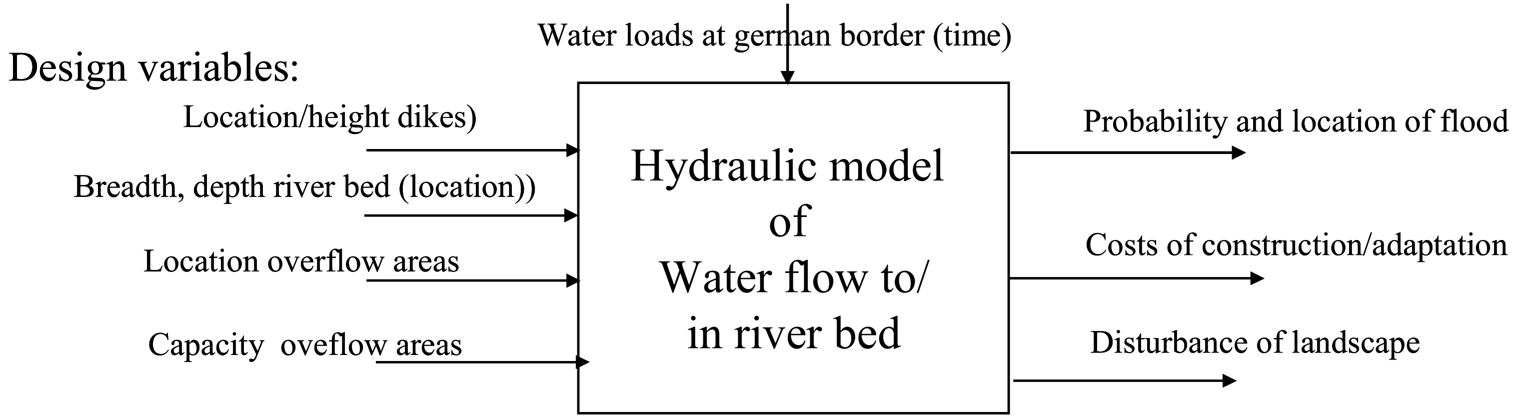
Key variables: location and load lorries, distri centres, roads (discrete)
Knowledge: available (white box)
Required data: speed, travel times, fuel consumption and costs/truck-km, load-unload times, wages, etc. (data rich)

Example: design dikes/river system



Time frame: 1 month (operational/strategic)
Space: mid Netherlands between German border and the sea (spatial)
Aggregation level: mid to high
Characteristics: endogenous behaviour, uncertainties (dynamic, stochastic)
Key variables: water heights en flow speeds (time and location); status of dikes;
implementation status of overflow area (continuous)
Knowledge: theory available (white box)
Data needed: flow resistance, stability data dikes,
evacuation speed, costs of civil engineering projects considered, landscape quality and vulnerability, etc.. (data rich)

Objectives of this lecture

- recognise the role of quantitative models as research methods (i.e. to answer research questions)
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Exercise for issue paper

- Start from research questions identified before
- Select 2 questions for which mathematical modeling appears suitable to you
- For each draw model diagram and specify (and indicate why!):
  - time horizon
  - level of aggregation
  - dynamic or static
  - main input, internal and output variables
  - type of model, paradigm
- Use table overview as support!