COMP4038 (Spring 2026)

Simulation and Optimisation for Decision Support

Lecture 01A

Introduction to Simulation and Optimisation

Peer-Olaf Siebers

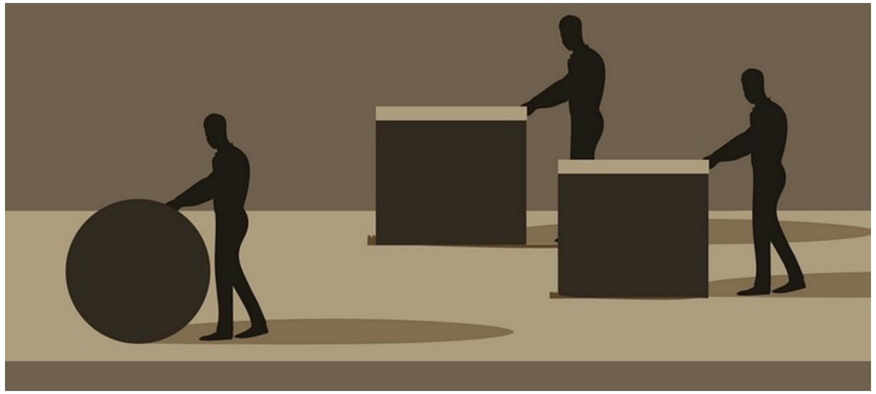
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Introduction to Decision Support

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Decision Support

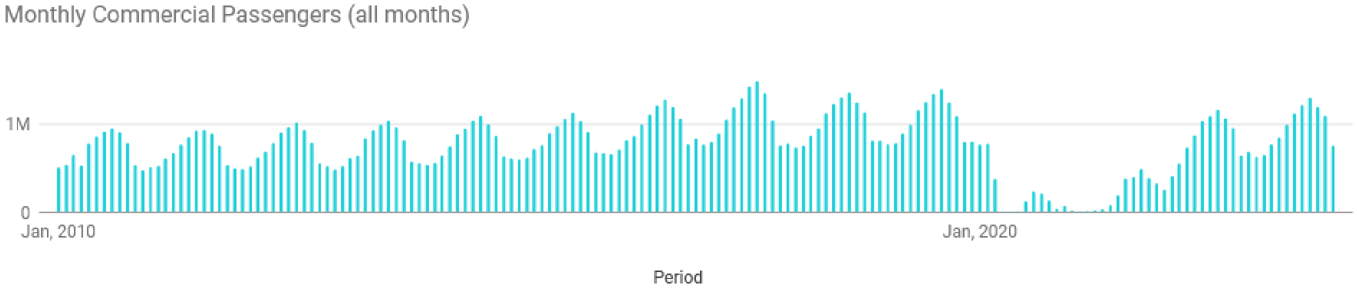
- Decision support
  - Refers to the use of tools, systems, and processes that assist individuals or organisations in making informed, data-driven decisions
  - Encompasses a wide range of techniques, from data analysis and visualisation to predictive modelling and scenario planning, aimed at improving the quality and effectiveness of decision-making



Example: Airport Expansion Planning

- Scenario:
  - You have been hired as a consultant by the Birmingham Airport Management Board, to help them work out an investment strategy for the next 10 years.

How would you approach such a project?
What methods could you use?

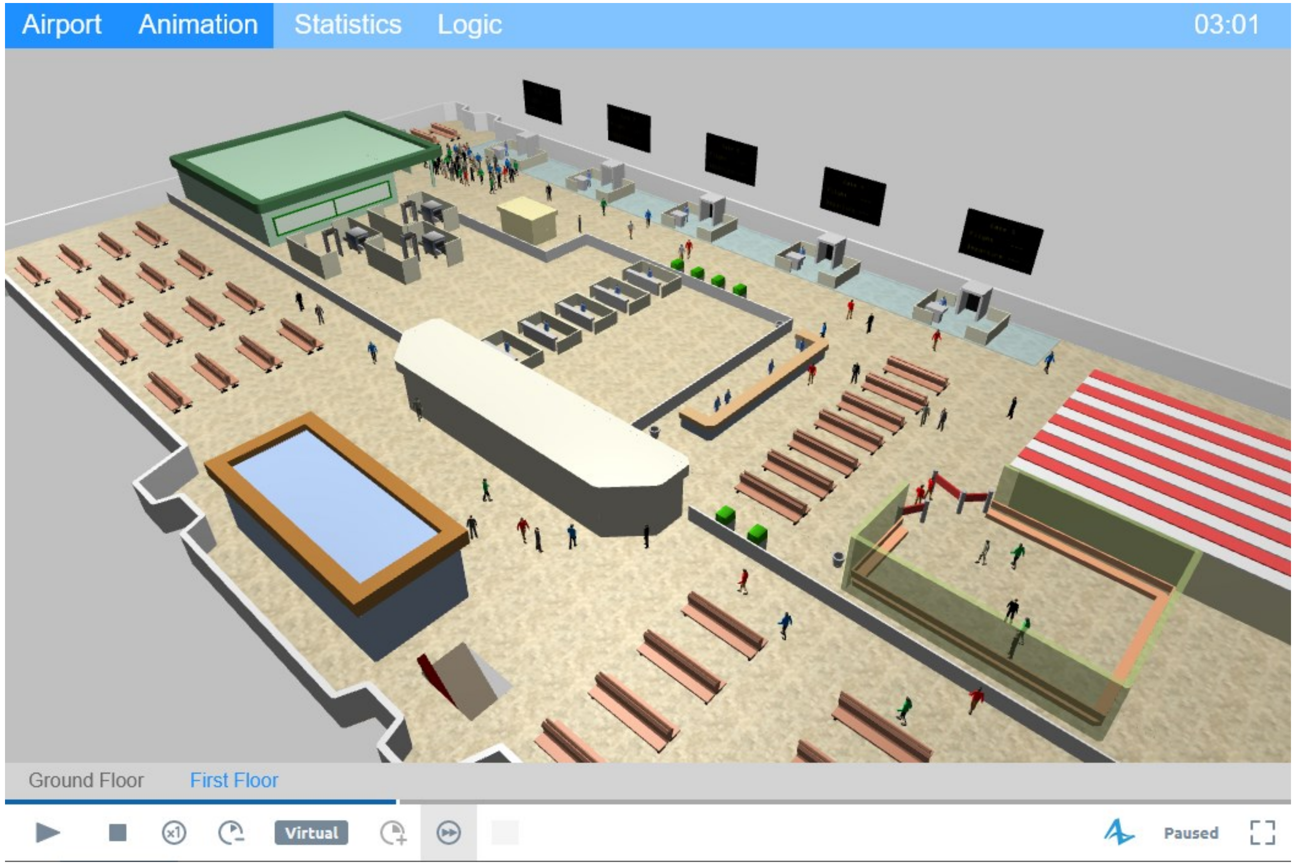


https://birminghamairportguide.com/statistics/

Example: Airport Expansion Planning

- Qualitative methods (capture opinions, attitudes, perceptions)
  - **Focus groups**: To gather input and actively engage key stakeholders
  - **Surveys**: To collect data from a larger group
- Quantitative methods (analyse data, test scenarios, optimise decisions)
  - **Statistical models**: To project future growth
  - **Cost-Benefit Analysis**: To compare expenses versus potential revenue gains
  - **Simulation**: To conduct what-if analysis of operations
  - **Optimisation**: To identify optimal or optimised solutions for operations
- Holistic decision-making
  - Combines **qualitative insights** (e.g. stakeholder preferences) with **quantitative analysis** (e.g. financial and operational projections)

Example: Airport Expansion Planning



https://cloud.anylogic.com/model/7be27b45-0a74-47f9-a78b-9bce22a6faa8

Decision Support: Recap

- What is the purpose of using Simulation and Optimisation?
  - **Simulation**: Mimic real-world systems to test scenarios without real-world consequences
  - **Optimisation**: Identify the best solutions within given constraints

- Why combine Simulation and Optimisation?
  - **Holistic decision-making**: Gaining insight into system dynamics over time through simulation whilst systematically identifying optimal configurations through optimisation

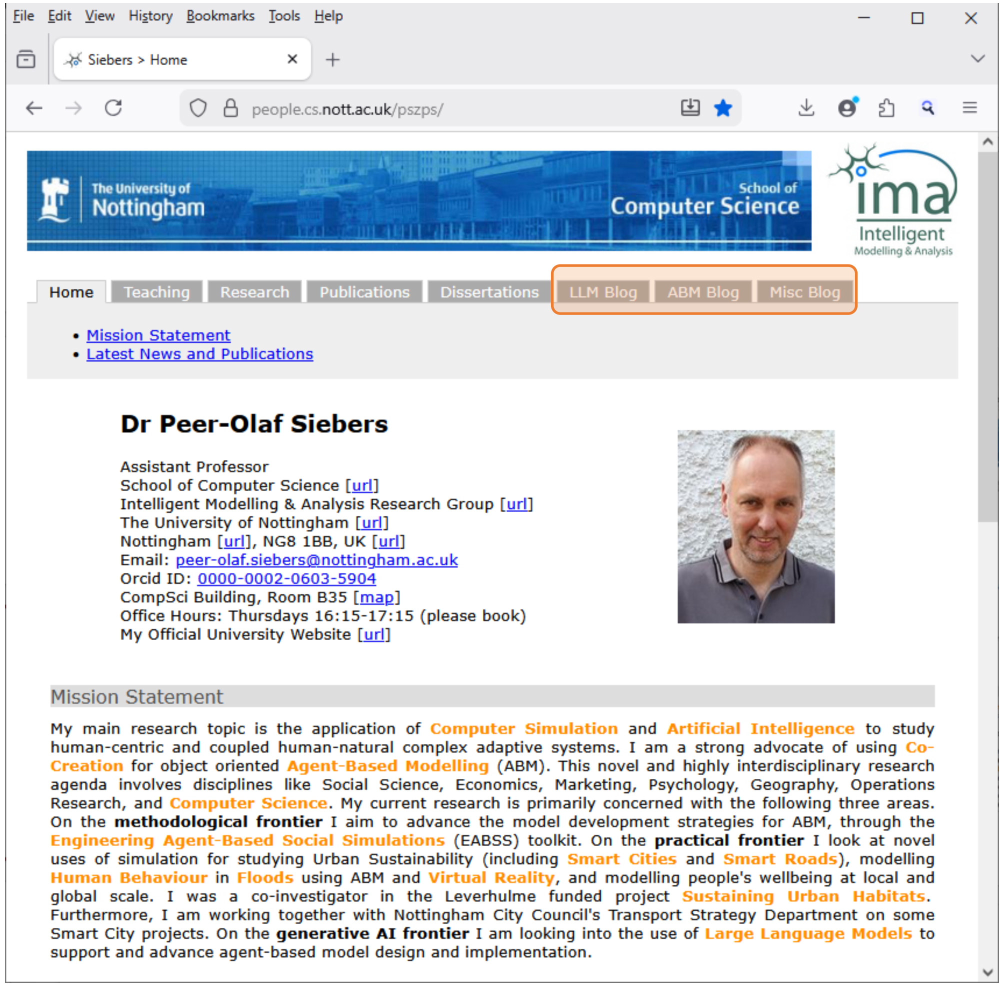
Module Details (Truncated)

What is this module about?

- This module offers insight into the applications of selected methods of decision support related to simulation and optimisation
  - With contributions from Operations Research Simulation, Social Simulation, Data Science, Automated Scheduling, and Decision Analysis
  - You will become more competent in choosing and implementing the appropriate method for the problem at hand and running simulation and optimisation experiments
- Note that we will use some basic Java programming

Module Convenor

- Peer-Olaf Siebers
  - Homepage
    - https://people.cs.nott.ac.uk/pszps/
  - Email
    - peer-olaf.siebers@nottingham.ac.uk



Module Assessment

- CW1 (70%)
  - You will go through the complete life cycle of a simulation-optimisation study and write a consultancy report for this study
- CW2 (30%)
  - Answering a set of questions about optimisation topics discussed in the optimisation lectures and labs.

School of Computer Science – Module Assessment Sheet for 2025-2026

Module Convenor(s)	Peer-Olaf Siebers
Module Code	COMP4038
Module Credits	20

Term-time Assessment (TTA)

Assessment Name	**TTA1** --- Coursework 1
Assessment Type	Coursework
Description and Deliverable(s)	Description: You will go through the complete life cycle of a simulation-optimisation study and write a consultancy report for this study. Deliverables: AnyLogic simulation-optimisation model; report, including description of conceptual model, implemented model, simulation-optimisation experiments, and final recommendations; video, demonstrating the model and explaining the work done. Full details will be provided in the related coursework brief.
Frequency, dates & workload	☒ Individual ☐ Weekly ☐ Fortnightly ☐ Custom Release date: 12/02/2026 Submission date: 08/05/2026 Weight (%): 70 Workload (h): 70
Late Policy	☒ UoN Default late policy. ☐ Custom: Enter details of custom late policy (if applicable)
Feedback Mechanism & Date	*Feedback date:* ☒ Within 15 working days of submission ☐ The expected date for feedback is Please enter date here. *Feedback mechanism:* Written individual feedback in Moodle.
Assessment Criteria	The marks are given by assessing quality and completeness of the submitted components. Full details will be provided in the related coursework brief.

https://moodle.nottingham.ac.uk/pluginfile.php/11851976/mod_label/intro/COMP4038_assessment_sheet_2025-2026.pdf

Use of "Generative AI" in the light of Academic Integrity

- Detailed guidance will be provided in the coursework task descriptions.
- My general advice
  - Use it for quick advice
  - Use it to brainstorm
  - Use it to improve your understanding
  - Use it to improve grammar etc. (but keep your original draft)
  - Don't use it to generate solutions to your coursework
  - Don't use it to write up your coursework
- You need to be the intellectual lead and be able to defend your work

https://www.nottingham.ac.uk/currentstudents/news/our-approach-to-ai-in-assessments-is-changing

Module Assessment: Coursework 1

COMP4038 Individual Coursework Demo - Spring 2025 v2025-02-27

Management Decision Support for Parkway Fuels (Petrol Station Chain)

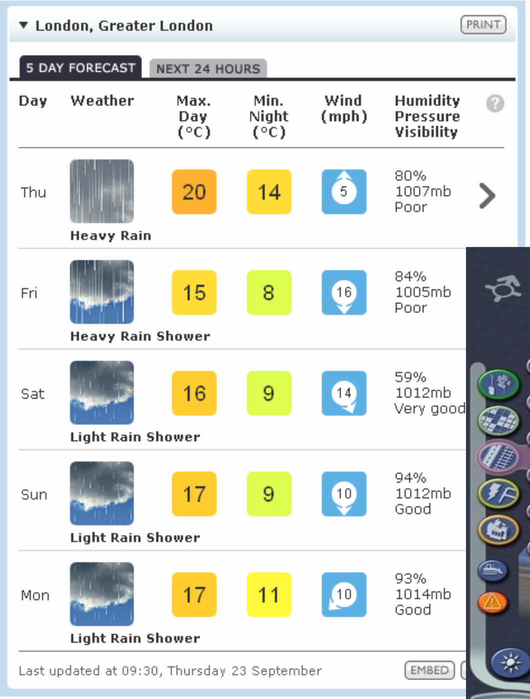
Scenario:
Parkway Fuels is a regional petrol station chain operating four busy petrol stations and a central distribution depot across different locations in Nottingham. Although each station operates in a similar manner, each has its own features related to size, location, traffic patterns, and customer demographics. Parkway Fuels wants to modernise all these facilities and improve operational efficiency. They have employed you as a planning support consultant to explore opportunities for improving system operability and making visiting one of the stations a pleasant experience.

Generated with Nano Banana (Gemini) on 25/01/2026

A first look at Simulation

Simulation Examples

- Provide some applications where simulation is used?



▼ London, Greater London PRINT

5 DAY FORECAST | NEXT 24 HOURS

Day	Weather	Max. Day (°C)	Min. Night (°C)	Wind (mph)	Humidity Pressure Visibility
Thu	Heavy Rain	20	14	5	80% 1007mb Poor
Fri	Heavy Rain Shower	15	8	16	84% 1005mb Poor
Sat	Light Rain Shower	16	9	14	59% 1012mb Very good
Sun	Light Rain Shower	17	9	10	94% 1012mb Good
Mon	Light Rain Shower	17	11	10	93% 1014mb Good

Last updated at 09:30, Thursday 23 September EMBED

Core Terminology

- System
  - A collection of parts organised for a purpose
- Modelling
  - Creating a simplified representation of a system
- Simulating
  - Using a model to explore system behaviour under various conditions

Types of Systems

- **Operations Systems**:
  - Examples: Manufacturing Systems; Service Systems; Supply Chains
- **Social Systems**:
  - Examples: Educational Systems; Health Systems; Communication Systems
- **Political Systems**:
  - Examples: Democracy; Autocracy; Oligarchy
- **Economic Systems**:
  - Examples: Capitalism; Socialism; Mixed Economies
- **Ecological Systems**:
  - Examples: Forest Ecosystems; Fresh Water Ecosystem; Urban Ecosystems

Types of Systems we look at in this Module

- **Operations Systems**:
  - Examples: Manufacturing Systems; Service Systems; Supply Chains
- **Social Systems**:
  - Examples: Educational Systems; Health Systems; Communication Systems

Characteristics of Operational and Social Systems

- Variability
  - Predictable (e.g. flight schedules)
  - Unpredictable (e.g. passenger arrivals)

- Interconnectedness
  - Changes in one part affect others (knock on effects and feedback loops)

- Complexity
  - High interconnectedness leads to challenging cause-effect analysis

Modelling

- What is a model?
    - Abstract representation of a real system to promote understanding of the system it represents
    - A static representation of a system
    - Can have many forms
        - Mathematical equations; diagrams; physical mock-ups

- Purpose?
    - Models give us a comprehensible representations of a systems
        - Something to think about
        - Something to communicate about

Simulation

- What is simulation?
  - Conducting experiments with a model for the purpose of understanding the behaviour of the system and /or evaluating various strategies for the operation of the system [Shannon 1975]
  - Dynamic exploration of system behaviour over time

- Purpose?
  - Predict the performance of a system (what-if analysis)
  - Gaining insight into system dynamics
  - Understanding complex interactions
  - Understand impact of different policies

Analysing Systems with Simulations

- **Operations Systems**:
  - Manufacturing Systems: Assembly line operations; batch production scheduling
  - Service Systems: Shop floor operations; allocation of staff and resources
  - Supply Chains: Inventory management; distribution network design

- **Social Systems**:
  - Education: Impact of assessment policy changes; classroom interaction dynamics
  - Health: Spread of infectious diseases;
  - Communication: Opinion dynamics during elections; uptake and diffusion of new products

Benefits of using Simulation

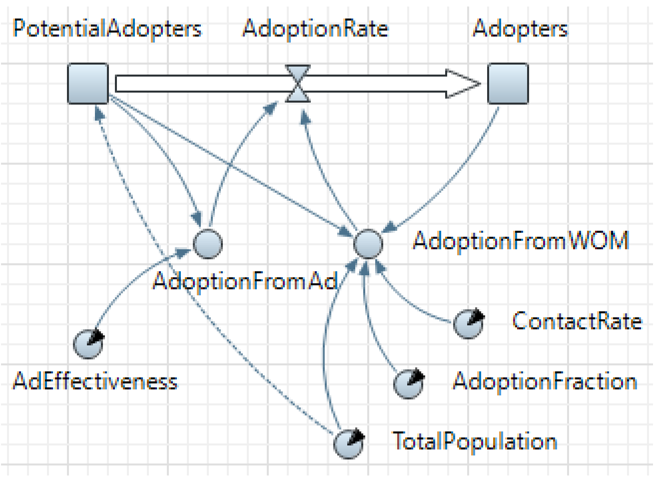
- Why Use Simulation?
  - **Safe experimentation** without disrupting the real system
  - **Cost and risk reduction** compared to real-world trials
  - **What-if analysis** for testing alternative policies and designs
  - **Insight into complex dynamics** that are hard to analyse analytically
  - Ability to **include randomness and uncertainty**
  - …

Simulation Modelling Paradigms

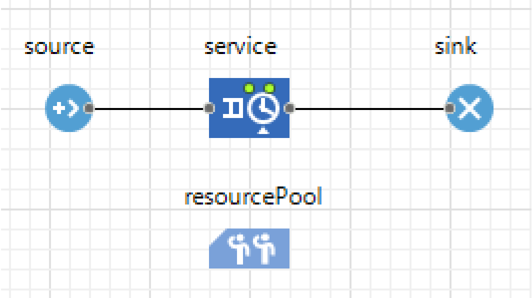
- Discrete Event Simulation (DES) Resource efficient
  - Top-down process centric approach: Focuses on events and processes
  - Modelling: Process flow charts
  - Simulation: Stochastic and discrete (using event-scheduling algorithm)
- Agent-Based Modelling (ABM) Captures emergent phenomena
  - Bottom-up individual based approach: Focuses on individual agents and their interactions
  - Modelling: Agent-level rules, decision logic, or state machines
  - Simulation: Stochastic and discrete (using rule-based state update algorithms)
- System Dynamics (SD) Reveals structural feedback and long-term trends
  - Top-down system centric approach: Focuses on system structure and feedback loops
  - Modelling: Causal loop diagrams (qual) or stock & flow diagrams
  - Simulation: Deterministic and continuous (using differential equations)

Simulation Modelling Paradigms

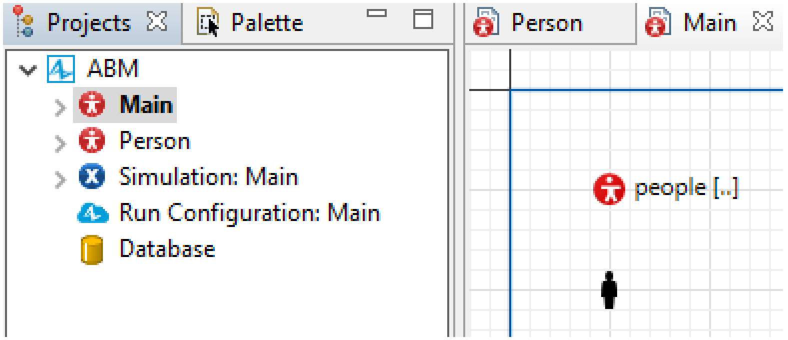
- SDM

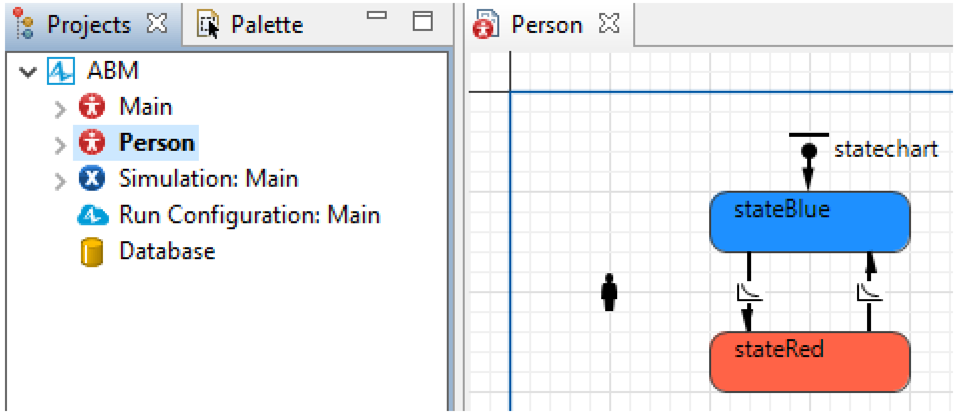


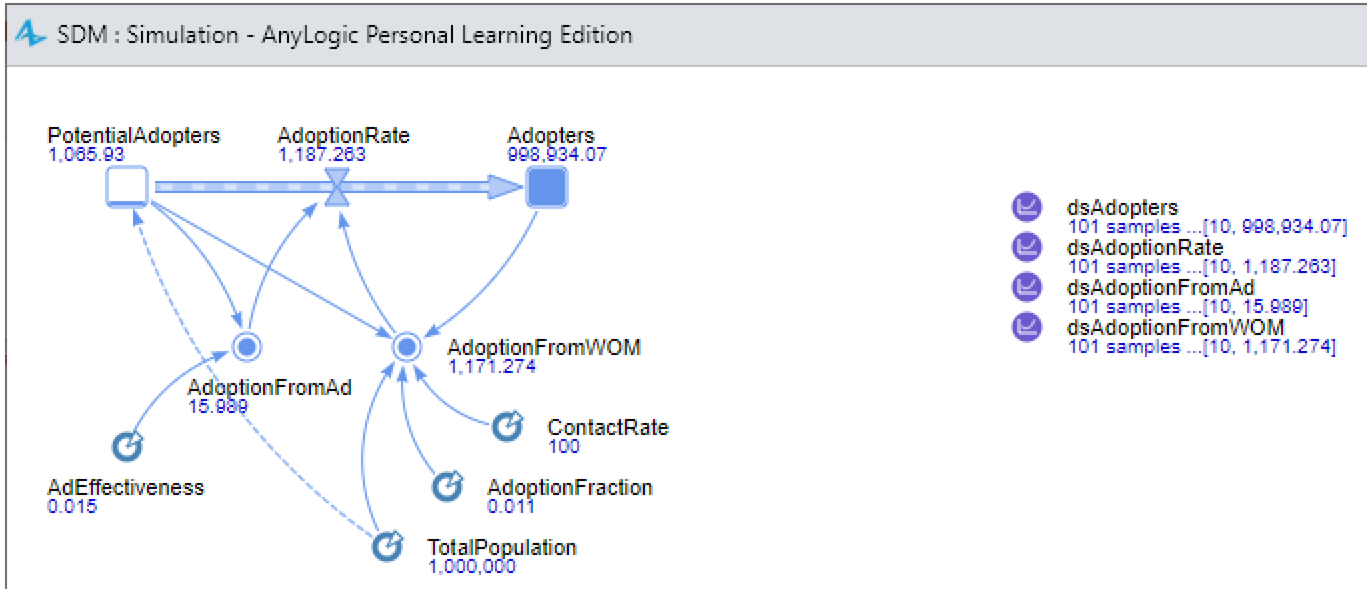
- DEM



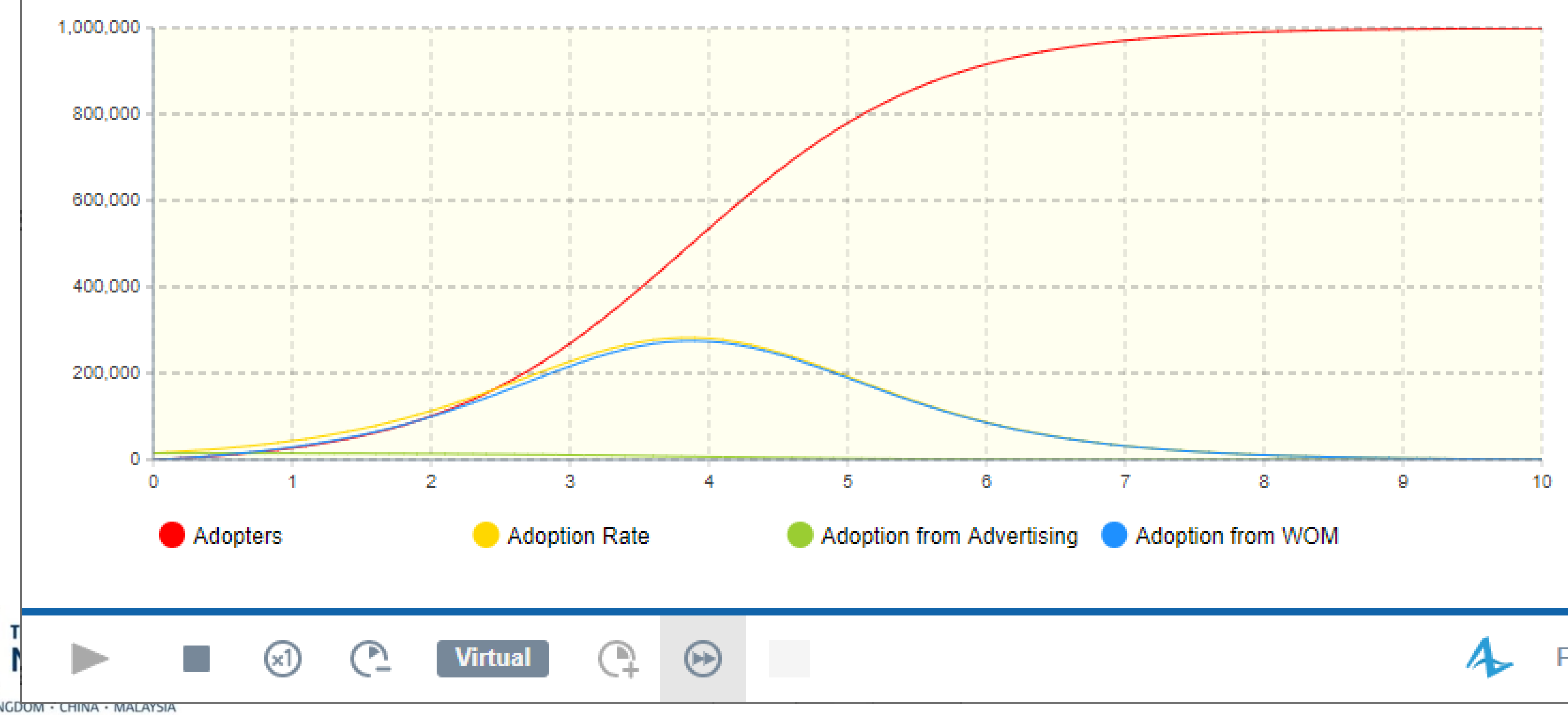
- ABM







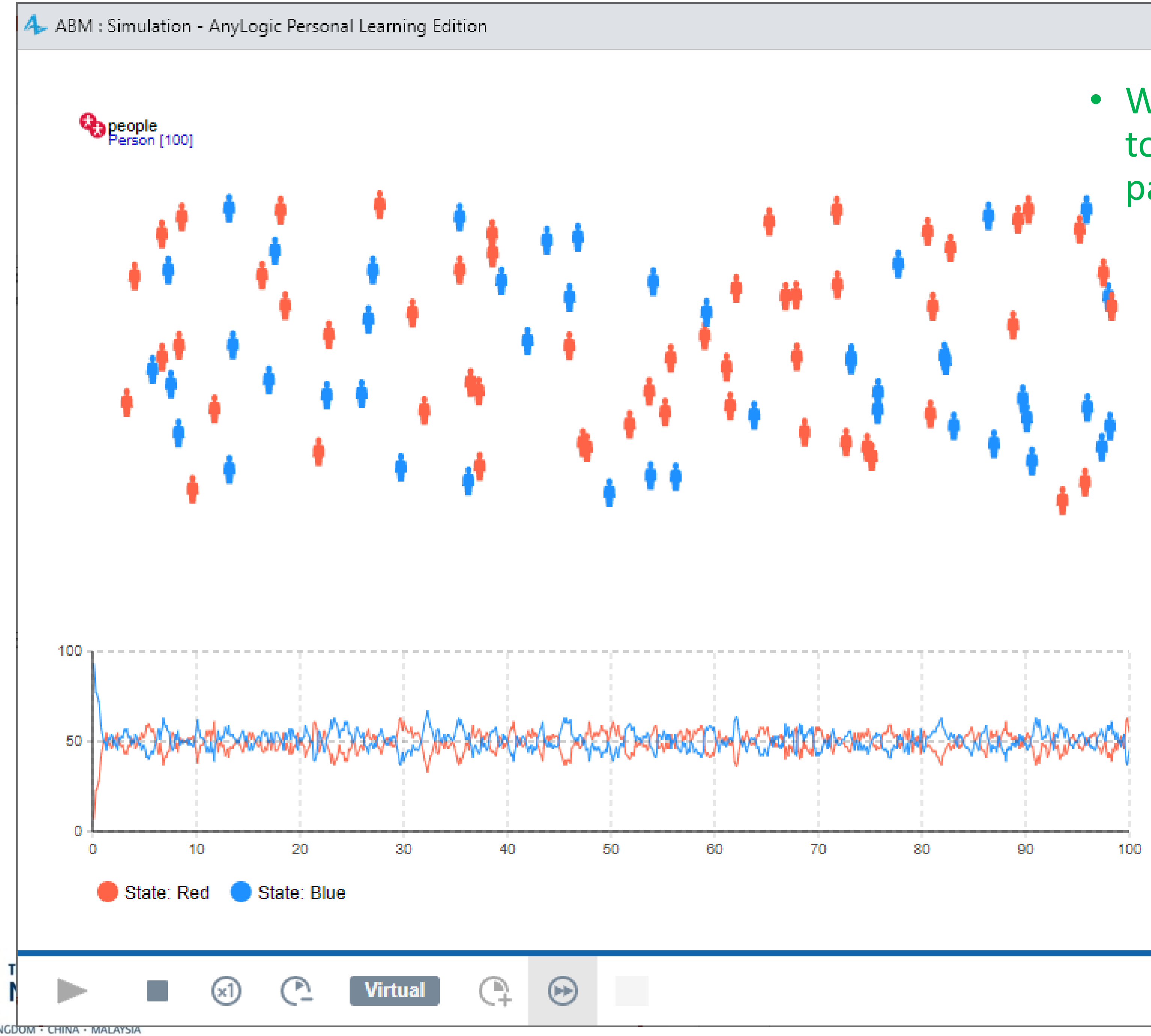
- How should we invest our budget?
  - Stop advertising
  - Increase spending on WOM nudges



- What could we consider to improve the situation?

  - Define a target utilisation
    - Employ one more staff?
    - Employ two more staff?

  - Define service standards
    - Average waiting time
    - Proportion of customers served below a time limit
    - Maximum waiting time



- What could we model to influence this pattern?
  - Add archetypes with specific attributes
  - Add more states and transitions
  - Add communication channels

Factors to Consider for the **Choice of your Simulation Study Approach** (1/3): **Purpose of Study**

- Exploratory
  - Investigates a topic or problem with an open-ended approach
  - Gathers initial insights and identifies key questions
  - Essential for guiding explanatory and predictive modelling
- Explanatory
  - Seeks to explain the causes and effects behind a phenomenon
  - Tests hypotheses about relationships between variables
  - Emphasises understanding why something happens
- Predictive
  - Seeks to make empirical predictions regarding future events of interest
  - Uses calibrated models to forecast the outcomes of different policy or operational choices
  - Employs what-if scenarios to understand system behaviour and identify critical decision points

Factors to Consider for the **Choice of your Simulation Study Approach** (2/3): **Drivers of Model Formulation**

- Theory driven
  - Theory for model formulation
  - Data (or expert opinion) for model calibration/validation
- Data driven
  - Data for model formulation (qualitative or quantitative)
  - Data (or expert opinion) for model calibration/validation
- Logic driven
  - Logic for model formulation
  - Data (or expert opinion) for model calibration/validation

Model calibration refers to the process of adjusting the parameters or inputs of a simulation to ensure that its outputs align with observed or known real-world data.

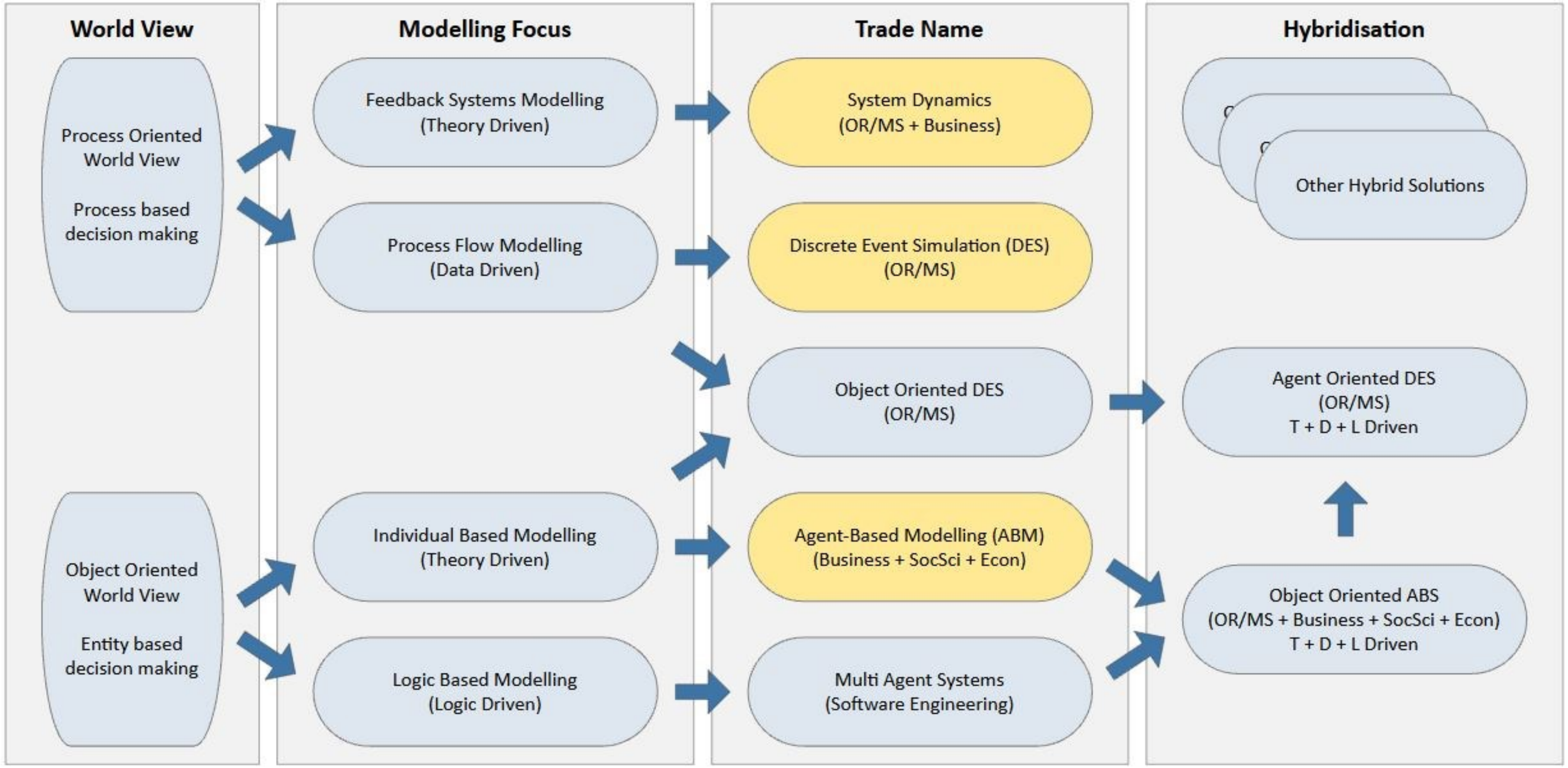
Factors to Consider for the **Choice of your Simulation Study Approach** (3/3): **Domain**

- Typical simulation study characteristics in different domains

Operations Research	Business, Economics, Social Science
Empirical basis	Theoretical basis
Improving the real world	Thinking about the real world
Data collection and analysis	Dynamic hypothesis
Validation: Sufficient accuracy for purpose	Plausibility: Seeming reasonable or probable
Implementing findings	Learning + understanding

after Robinson (2011)

Simulation Modelling Paradigm Overview



Theory Driven: Theories for model formulation; data for model validation
Data Driven: Data for model formulation (can be quantitative and qualitative); data for model validation
Logic Driven: Logic for model formulation; data for model validation

A first look at Optimisation

Optimisation: What is it?

- Definition of "Optimisation"
  - Optimisation seeks to find the best solution from all feasible alternatives, typically by maximising or minimising an objective function (a formula representing the goal) subject to constraints.
  - Typical objectives of an optimisation
    - Maximising revenue and/or profits (or more abstract "utility")
    - Minimising costs and/or time and/or resource wastage
- Definition of "Optimisation Algorithm"
  - An optimisation algorithm is a procedure which is executed iteratively by comparing various solutions till an optimum or a satisfactory solution is found

Optimisation: What is it?

- A typical optimisation problem (e.g. Production Planning and Scheduling)
  - A firm wishes to **maximise its profit**, given **constraints on availability of resources** (labour equipment, and raw materials), production costs, and forecast demand

- A typical optimisation problem formulation
  - Utility function:
    - Maximise profit = Revenue − Costs
  - Constraints:
    - Labour, equipment, and raw material limits
    - Production cannot exceed forecast demand

Objective (Utility) Function:

$$\text{Maximise } Z = \sum_{i=1}^{n}(p_i \cdot x_i) - \sum_{i=1}^{n}(c_i \cdot x_i)$$

Where:

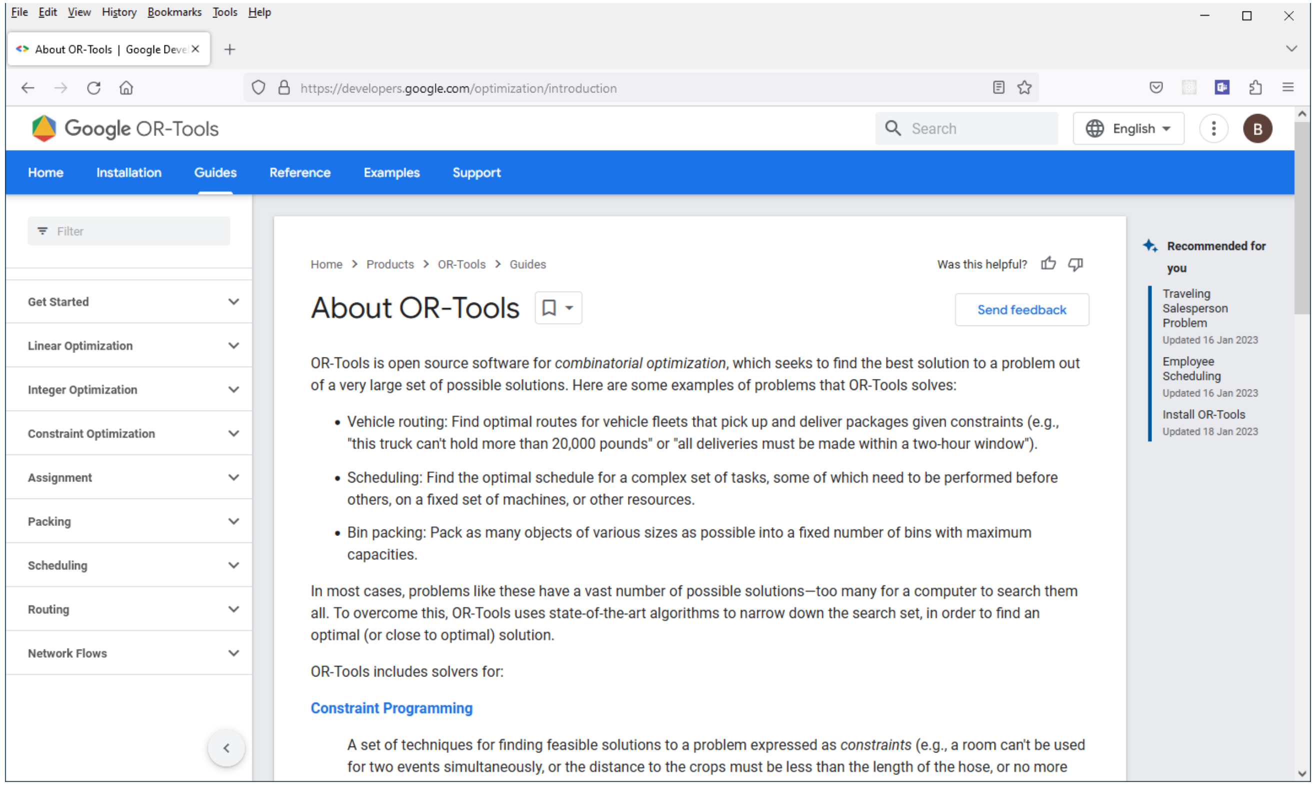
- Z = total profit (utility)
- n = number of products
- p_i = selling price of product i
- x_i = quantity of product i produced
- c_i = production cost per unit of product i

Subject to constraints:

- Labour availability: $\sum_{i=1}^{n} l_i x_i \leq L_{\text{available}}$
- Equipment capacity: $\sum_{i=1}^{n} e_i x_i \leq E_{\text{available}}$
- Raw material limits: $\sum_{i=1}^{n} m_i x_i \leq M_{\text{available}}$
- Demand limits: $0 \leq x_i \leq D_i$

Optimisation: What is it?

- Problem classification
  - Routing problems
  - Scheduling problems
  - Planning problems
  - Assignment problems
  - Packing problems



https://developers.google.com/optimization/introduction

Optimisation Methods

- Traditional (Mathematical) Methods (direct search vs gradient-based methods vs ...)
  - Exact solving approaches based on geometrical, algebraic or tree search procedures to guarantee finding the optimum result

- Heuristics (constructive vs local search methods)
  - Designed to solve a problem in a faster and more efficient fashion than traditional methods by sacrificing optimality, accuracy, precision, or completeness for speed

- Metaheuristics (trajectory-based vs population-based methods)
  - Methods for controlling and tuning basic heuristics, usually with usage of memory and learning

Optimisation Methods

- Hyperheuristics (selection vs generate-and-select vs move acceptance vs learning)
  - Aim to automate the selection, combination, or generation of metaheuristics to enhance their performance across a diverse range of problem instances
  - Their primary goal is to provide a more adaptive and generalised approach to problem-solving, passing the limitations of individual metaheuristics

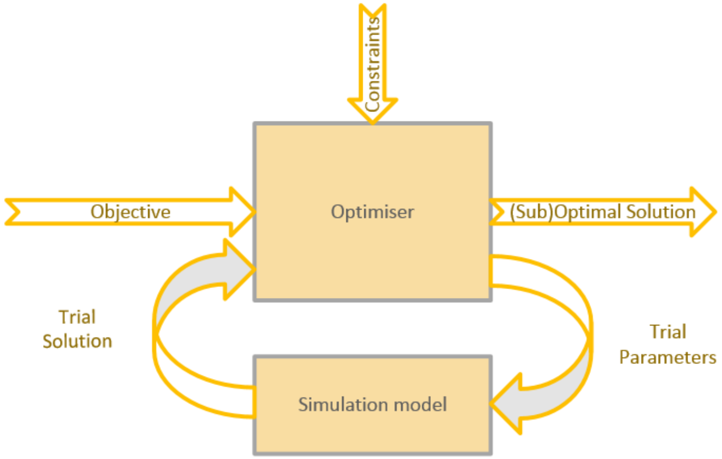
- Optimisation with Uncertainty (stochastic programming vs simulation-based optimisation)
  - Maximise or minimise an objective function while acknowledging and accounting for uncertain or variable factors that may impact the outcomes
  - Explicitly incorporates uncertainty into the decision-making process to ensure solutions are robust, reliable, and not invalidated by realistic variations in data or the environment

A first look at
Simulation-based Optimisation

UNITED KINGDOM · CHINA · MALAYSIA

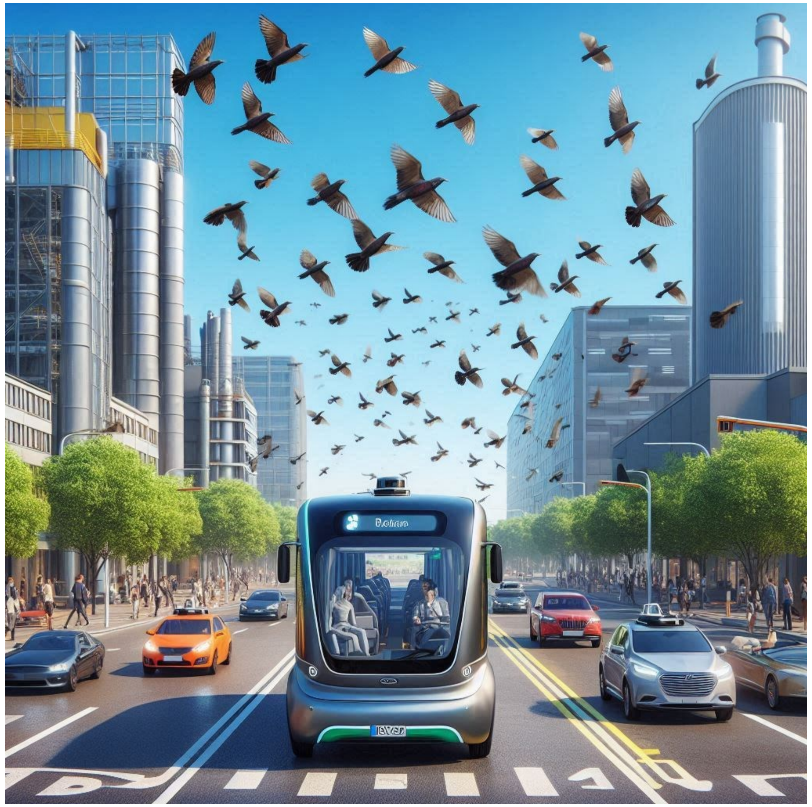
Simulation-based Optimisation

- How does it work?
  - The optimiser runs as a master application that controls the simulation model
    - The optimisation process involves repetitive simulations of a model using different trial parameter (design variable) values
    - Employing sophisticated algorithms, the optimiser varies parameter values within a specified range to identify the optimal parameter value set for solving a given problem
    - The simulation provides a mechanism for taking stochasticity into account during the optimisation process



Classroom Challenge

- What are the simulation opportunities for this scenario, and which methods should we use?



The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Any Questions?

References

- Shannon (1975) Systems Simulation: The Art and Science
- Robinson (2011) SIG presentation by Stewart Robinson