Business Process Modeling and Reengineering

Module 2
Introduction to simulation

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Lecture Objectives

- What is simulation
- Which are the main phases of a simulation project
- What is Discrete Event Simulation (DES)
- How to simulate with Arena

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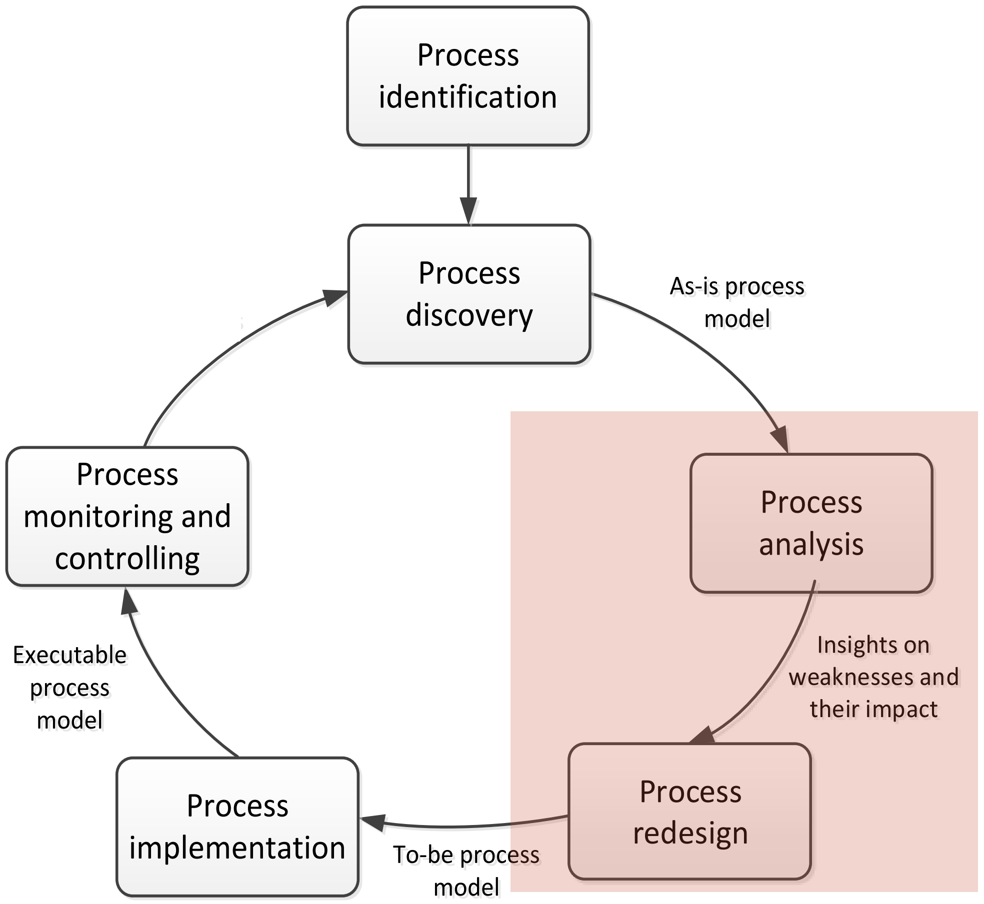
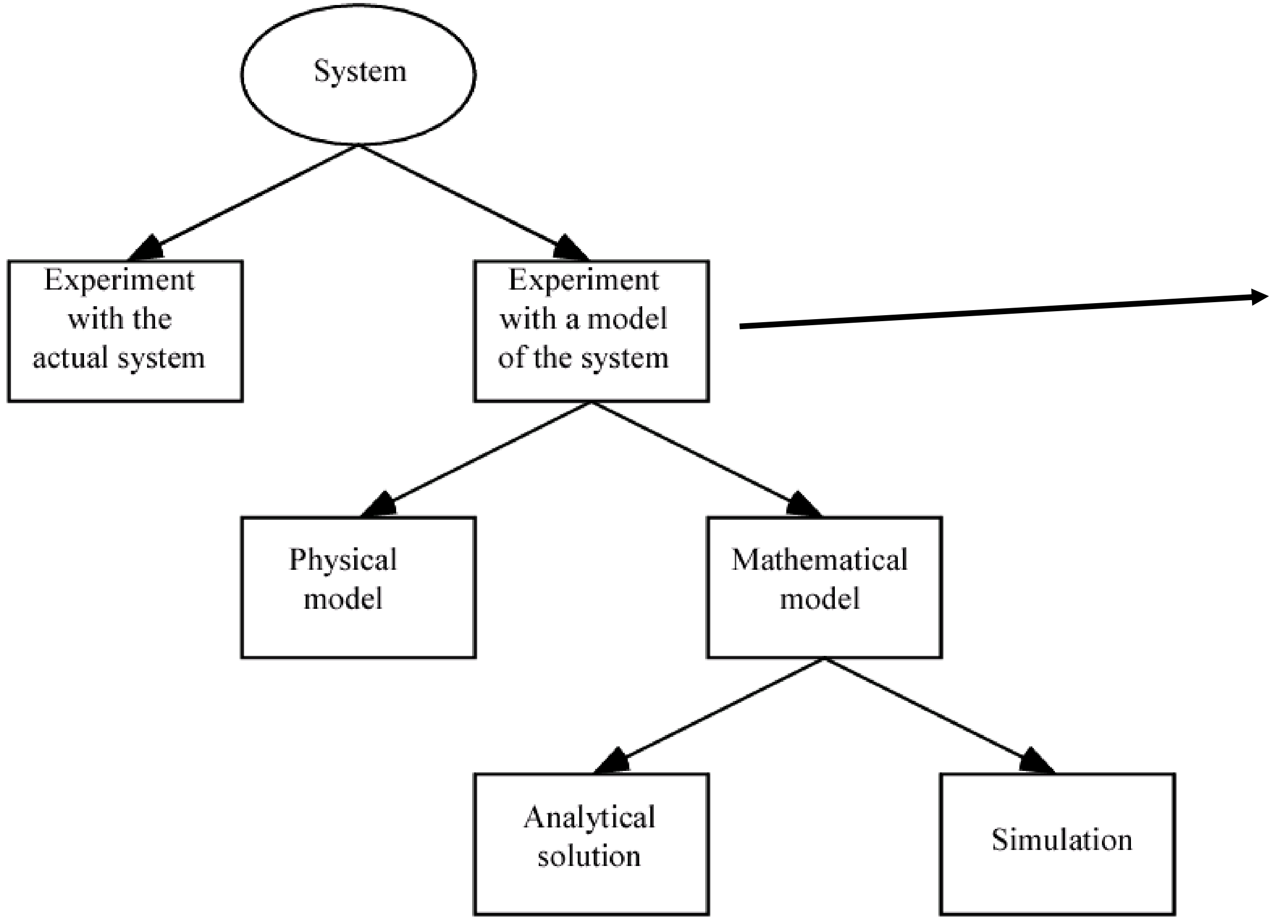
Process improvement



1. Identify a system's owner
2. Ensure that the correct problem is being addressed
3. Model the process
4. Measure the process
5. Improve the process

How to make experiment in a system



- An **abstract** and **simplified** representation of a system
- Not an exact re-creation of the original system!

Mathematical model

ACTUAL SYSTEM

Input Parameters

- N° of resources
- Inter-arrival Time Distribution
- Process Time Distributions
- Process Cost
- …

(X) → **Business process MODEL** → (Y)

$$Y = f(X)$$

Output Parameters

- Waiting Times & Entities
- Queuing
- System Size
- Resources Utilizations
- Process LT and TH

What is Simulation?

- *Simulation* is an imitation of a real-world process or system over a period of time.
  - Most widely used tool for decision making
  - Usually on a computer with appropriate software
  - An analysis (descriptive) tool – can answer what if questions
  - A synthesis (prescriptive) tool – if complemented by other tools

- Applied to complex systems that are impossible to solve mathematically

Purpose of simulation

- Simulation is proposed as a **support tool** within any decision-making process.

- Its generic use (e.g., production, logistics, services) is evidenced by its several applications in the:
  - Design of new systems;
  - Improvement of current production situation;
  - Verification of dynamic performance (e.g., productivity, bottlenecks, resource utilization and saturation, etc.);
  - WHAT-IF Analysis: how outputs respond to the change of the parameters affecting the process;
  - In-depth knowledge of current reality and further understanding of the logic that governs the production process; which is concretized as a training tool for professionals.

Goals and challenges of simulation

- **Goals:**
  - Statistical Analysis of process models over time
  - Pre-execution and post-execution optimization
  - Reducing risk of change
  - Predict business process performance
  - Continuous improvement
    - Performance
    - Quality
    - Resource utilization
- **Challenges:**
  - Increase process complexity
  - Result presentation / interpretation
  - Standard / Interoperability

Applications

Systems – facility or process, actual or planned

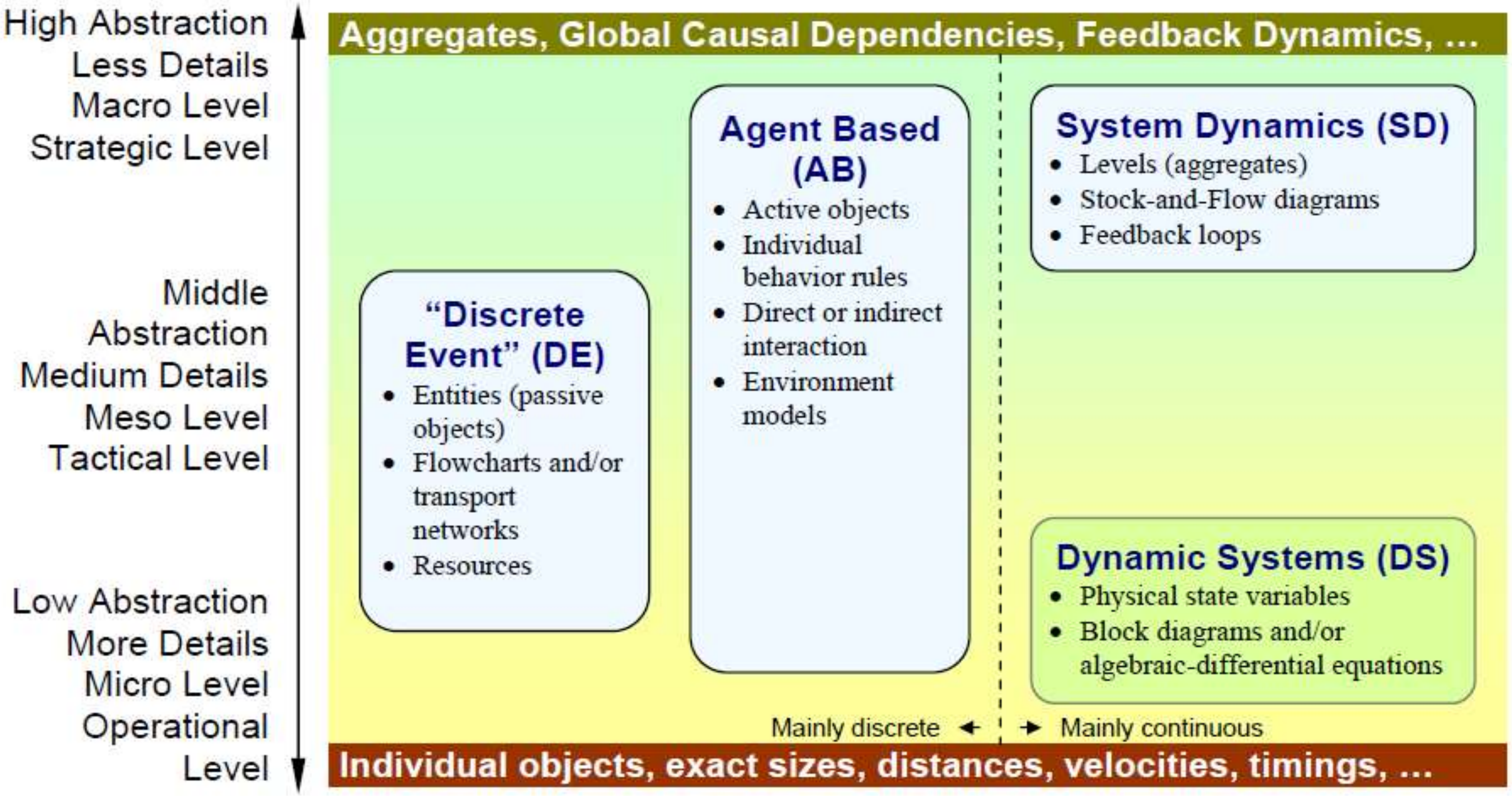
Examples:

- Manufacturing facility
- Bank operation
- Airport operations (passengers, security, planes, crews, baggage)
- Transportation/logistics/distribution operation
- Hospital facilities (emergency room, operating room, admissions)
- Computer network
- Freeway system
- Business process (insurance office)
- Criminal justice system
- Chemical plant
- Fast-food restaurant
- Supermarket
- Theme park
- Emergency-response system

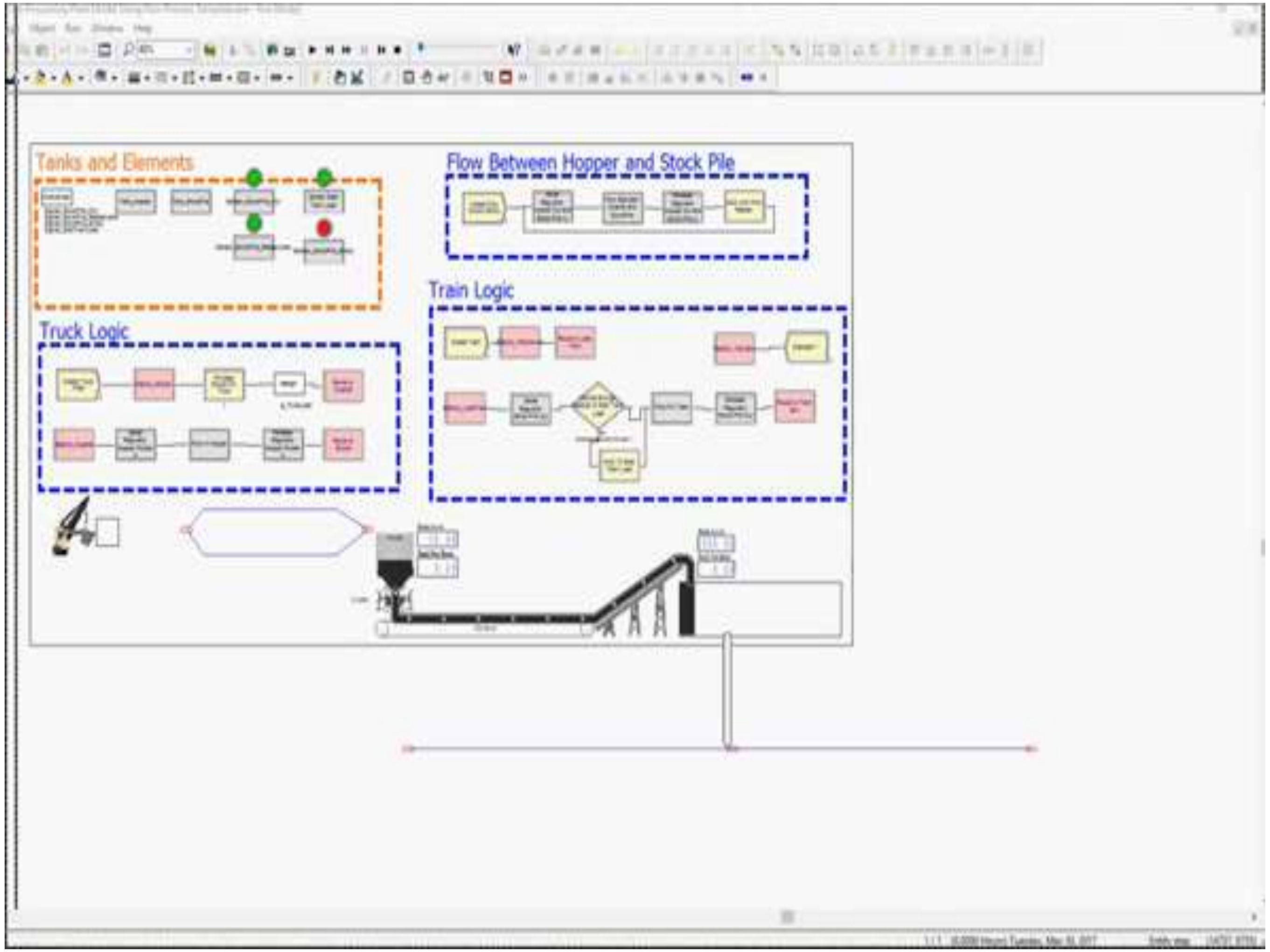
How To Simulate

- By hand
  - Buffon Needle and Cross Experiments (see Kelton et al.)
- Spreadsheets
- Programming in General Purpose Languages
  - Java
- Simulation Languages
  - SIMAN
- Simulation Packages
  - Arena

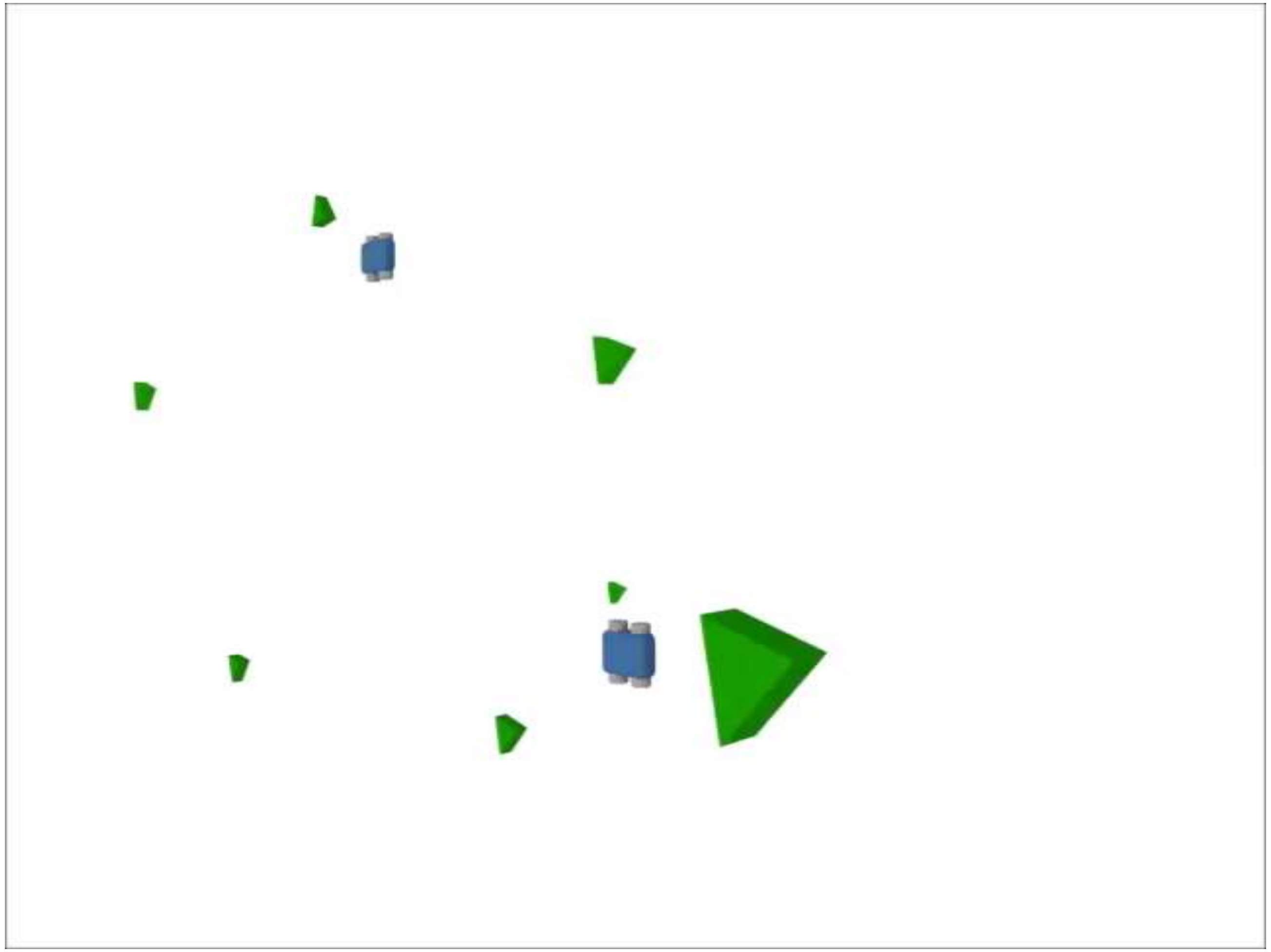
Simulation paradigms



Discrete event simulation

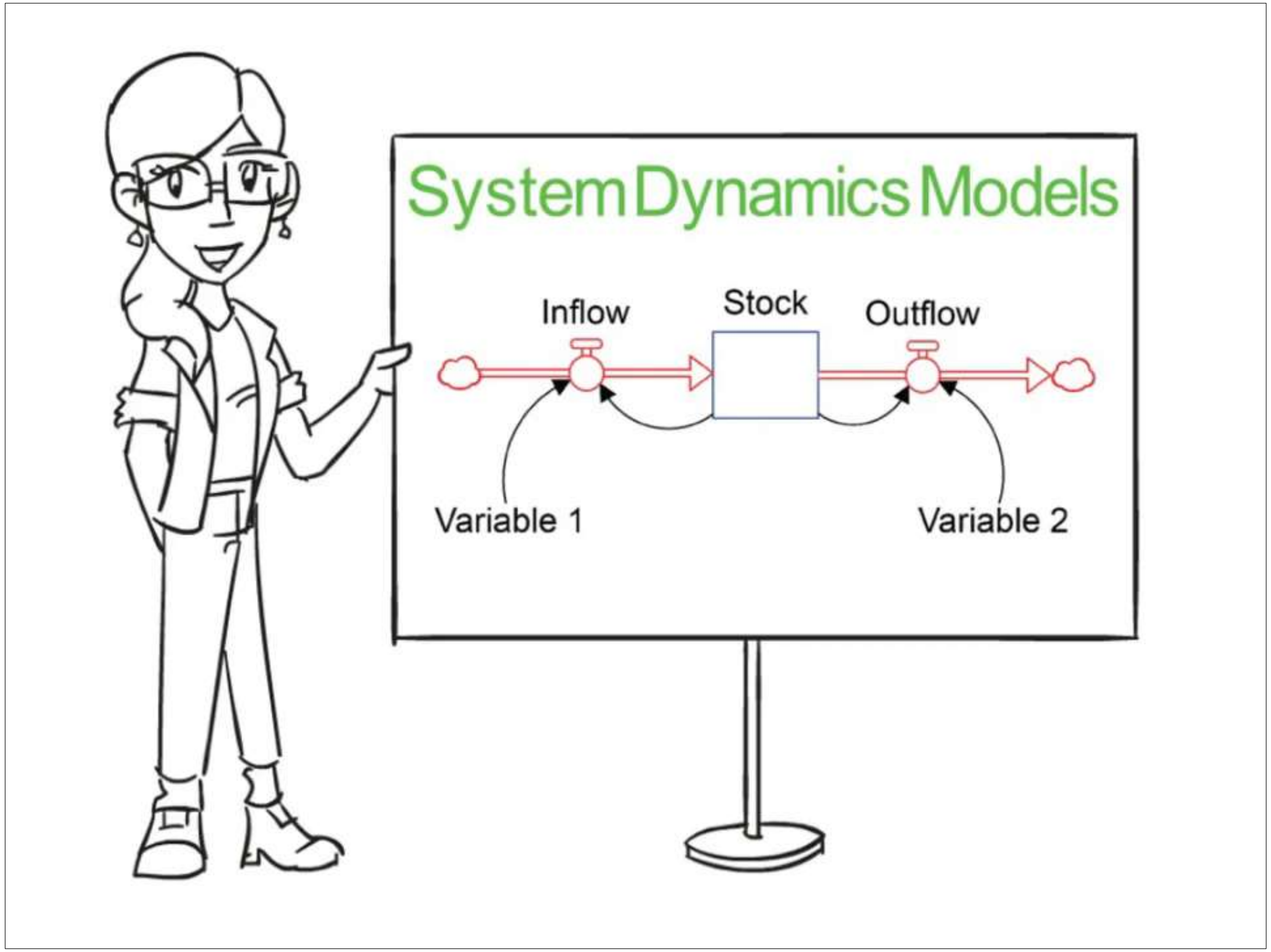


Discrete event simulation



Agent-based modeling

System dynamics



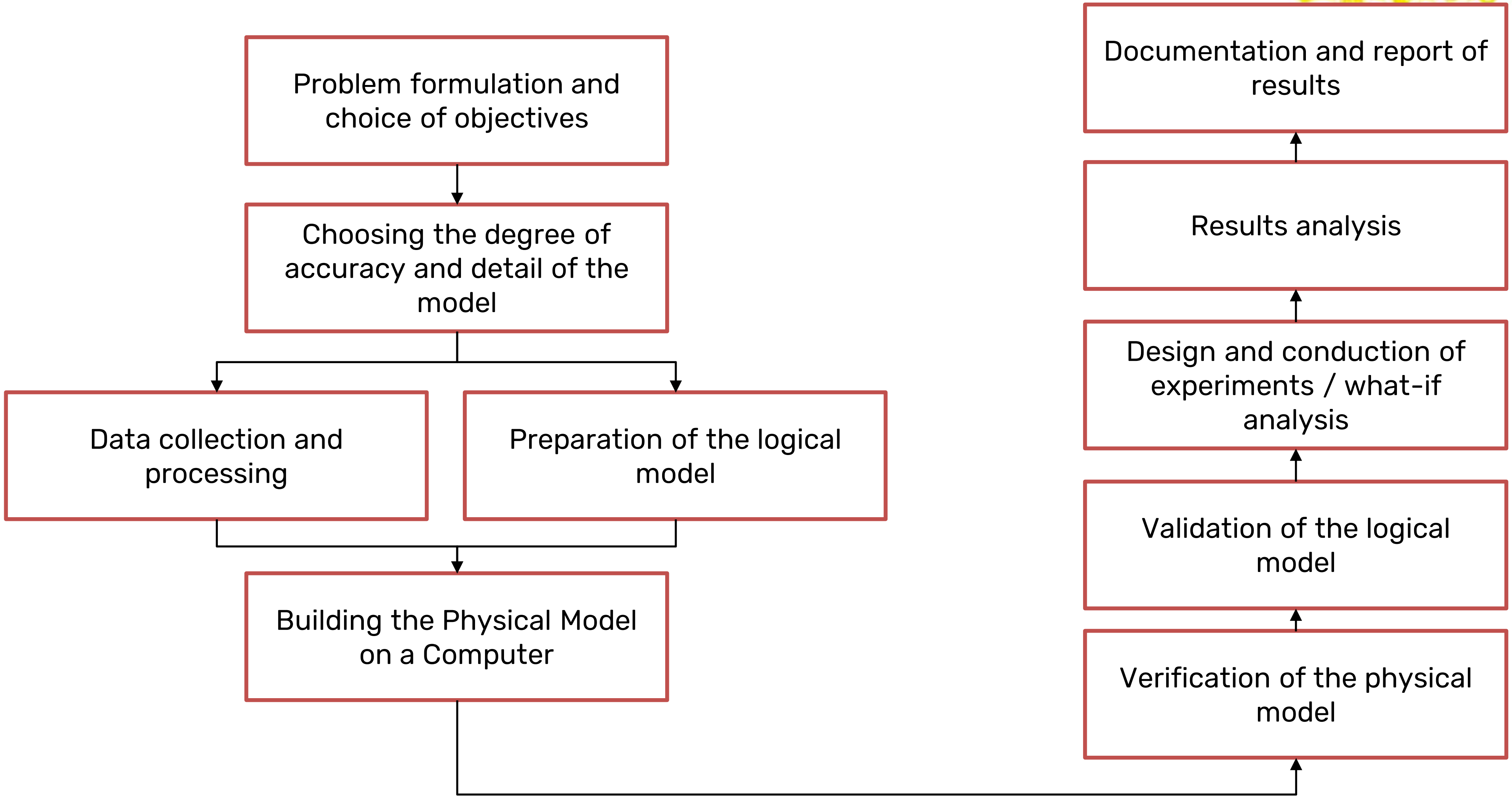
Types of simulation

Discrete Event Simulation	Agent Based Simulation	System Dynamics
Process-oriented: focus is on modeling the system in detail	**Individual-oriented**: the focus is on modeling the entities and interaction between them	**System-oriented**: the focus is on modeling the system observable
Based on entity flows through blocks	Based on the single agents interacting with each others	Based on stocks and flows between stocks
Entities are passive	Agents are active	Continuous systems, no entities
Global system behavior	Global behavior results as the interaction of many agents	Global system behavior as a number of interacting feedback loops
Adopted in business process, manufacturing, logistics and service delivery processes	Mainly applied in social sciences including marketing, social processes, and healthcare/epidemic models	Adopted in urban, social, ecological types of systems.

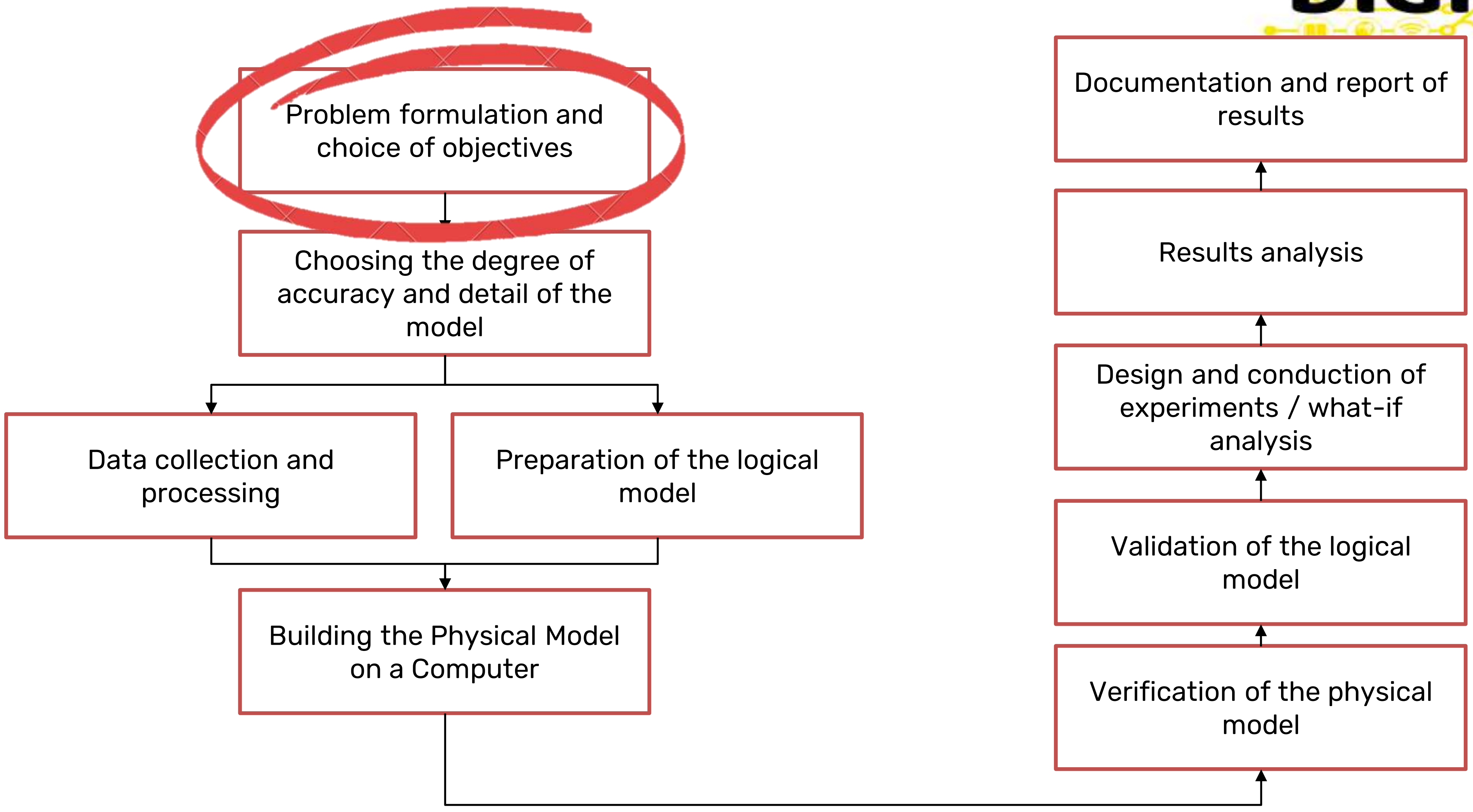
Objectives

- What is simulation
- Which are the main phases of a simulation project
- What is Discrete Event Simulation (DES)
- How to simulate with Arena

The main phases



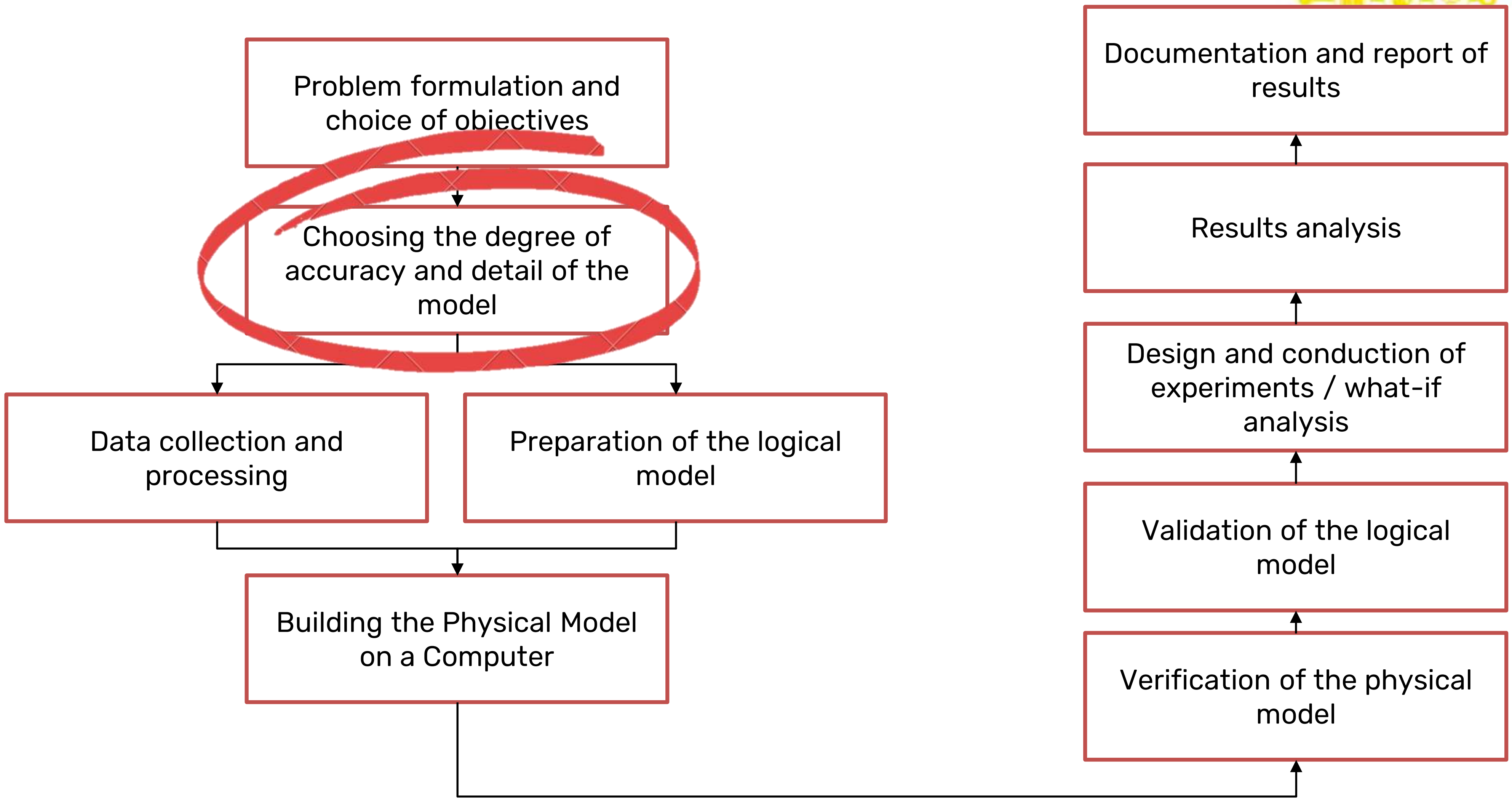
The main phases



Problem formulation

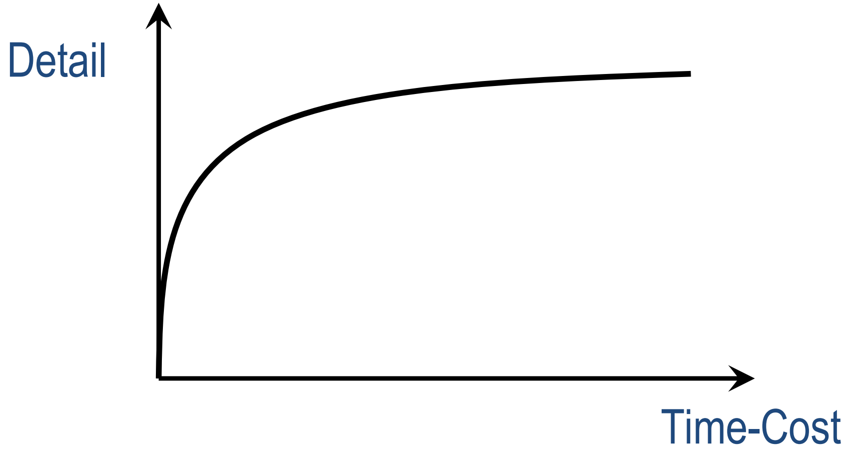
- Requires precise problem definition
- Requires to identify objectives and constraints
- Requires to write down a project plan including:
  - the simulation scenarios to be analysed
  - the timing of the project
  - the team people and their role
  - intermediate meetings for sharing or reviewing the project
  - the deliverables of each phase
  - and, of course, the costs and invoicing procedures

The main phases

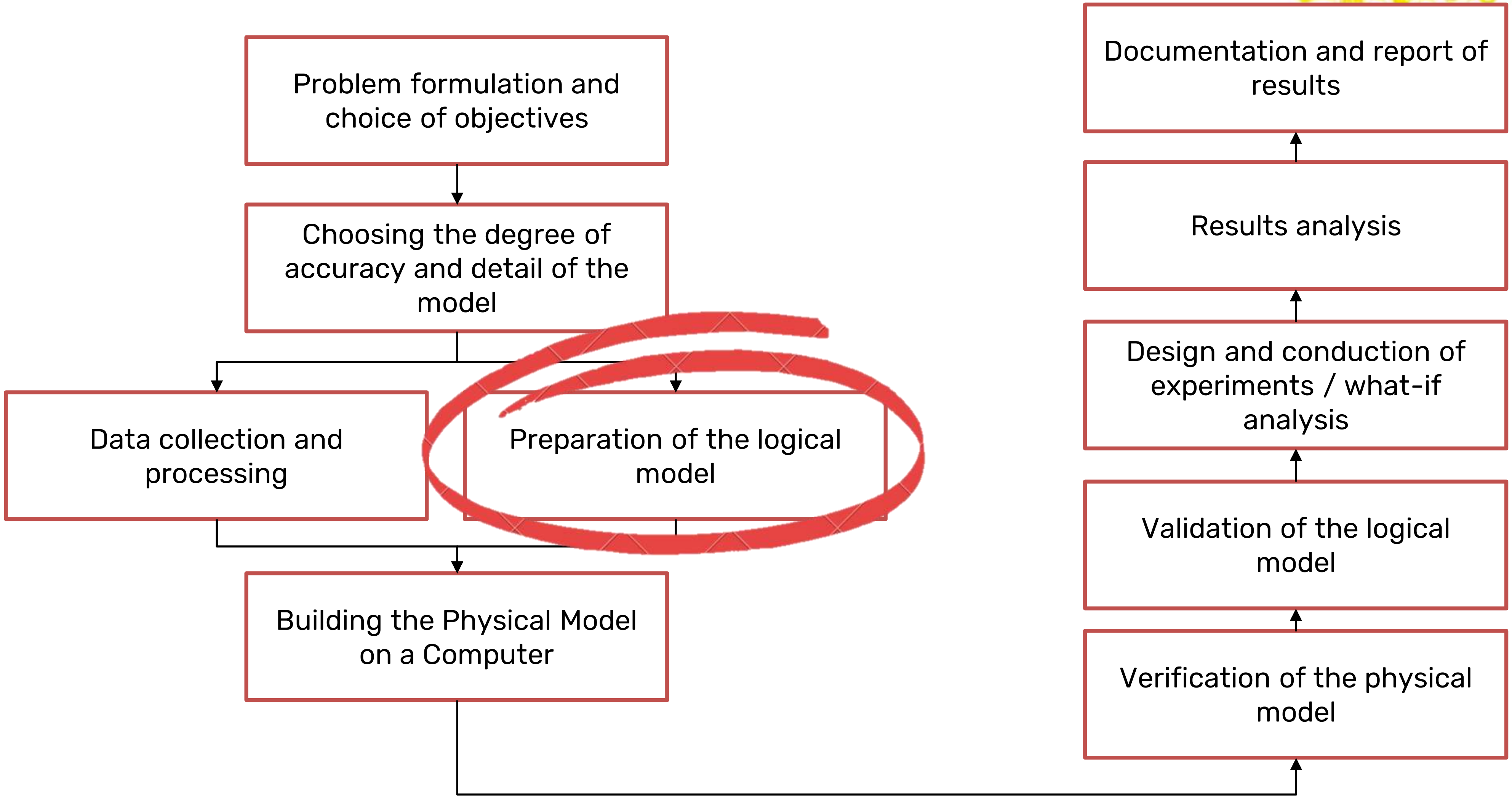


Choosing the model´s degree of accuracy

- **Variables** - distinction between:
  - exogenous variables (e.g.: machining times)
  - decision variables (e.g. number of machines)
  - endogenous variables (e.g. saturation rate)
- **Constraints**
- **Performance** measures
  - derive from endogenous variables
  - choice of objective function (risk of the trade-off between several performance measures)



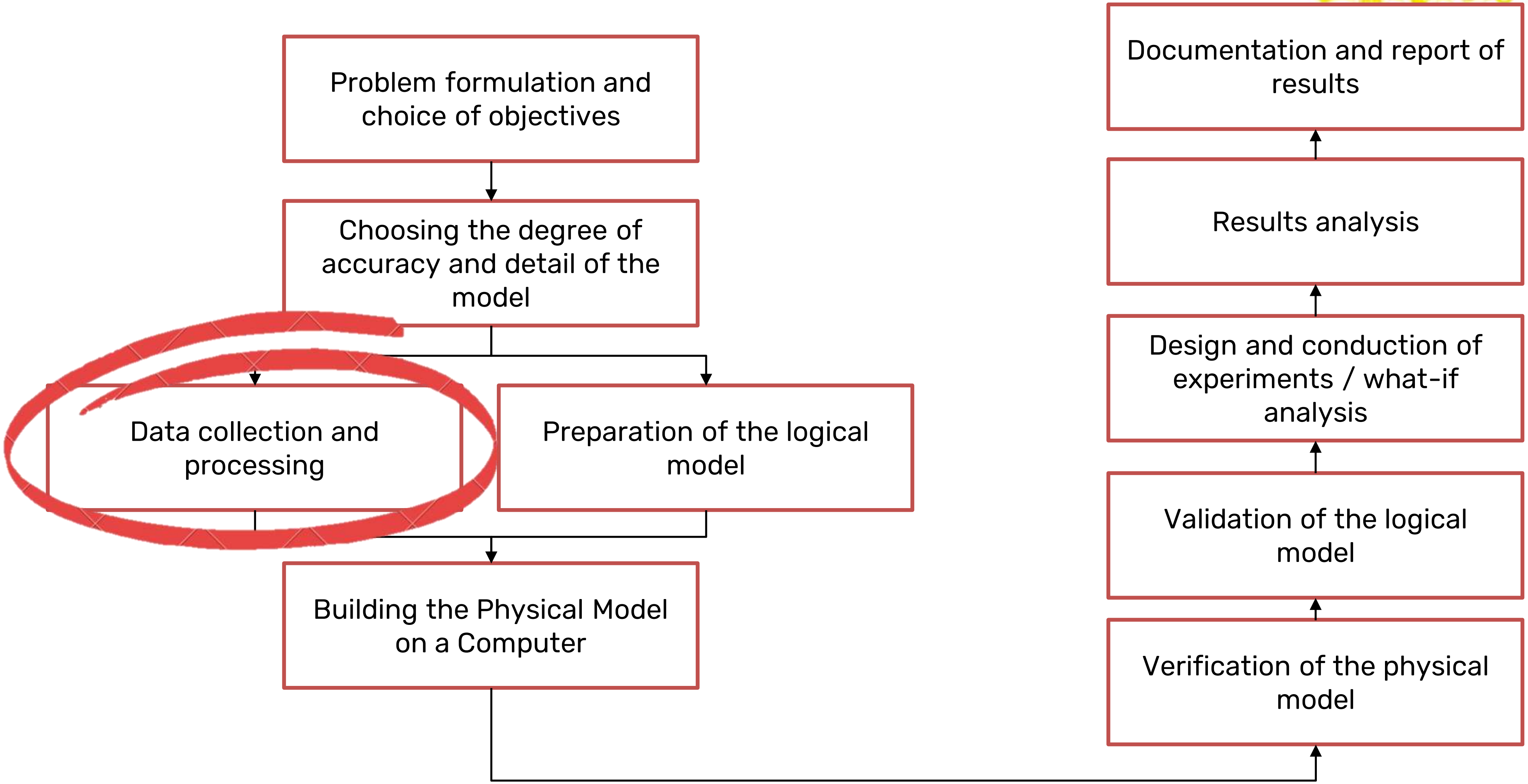
The main phases



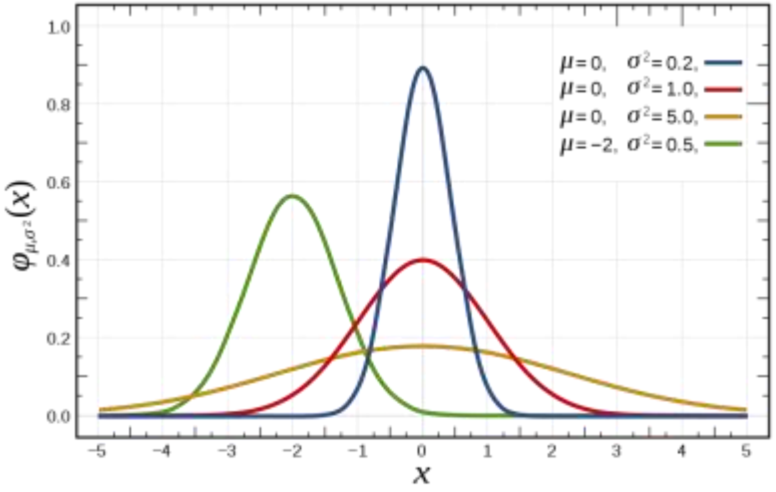
First the model and then the data

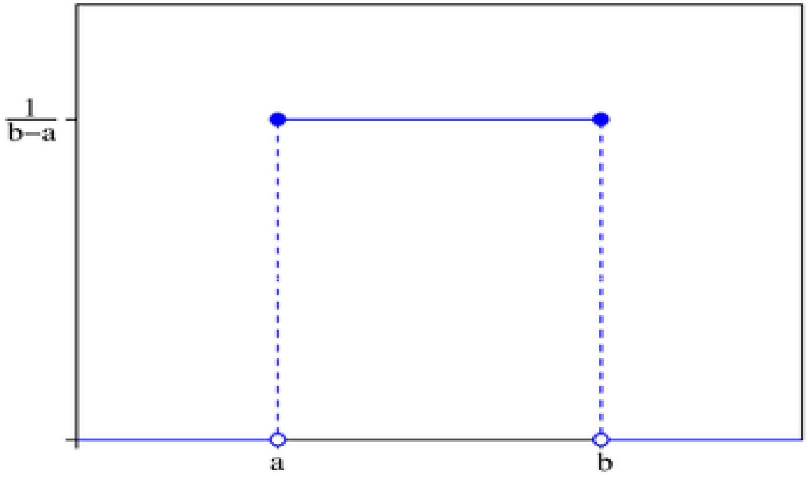
- It is advisable to conceptualize the static model before the data collection phase.
- This allows you to understand which data is needed, and what level of detail is required.
- This reduces the risk of possible recycling in the course of the activities of a simulation project

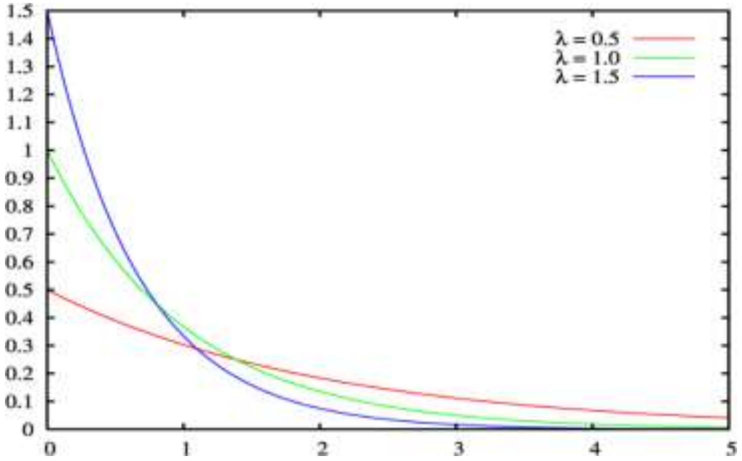
The main phases

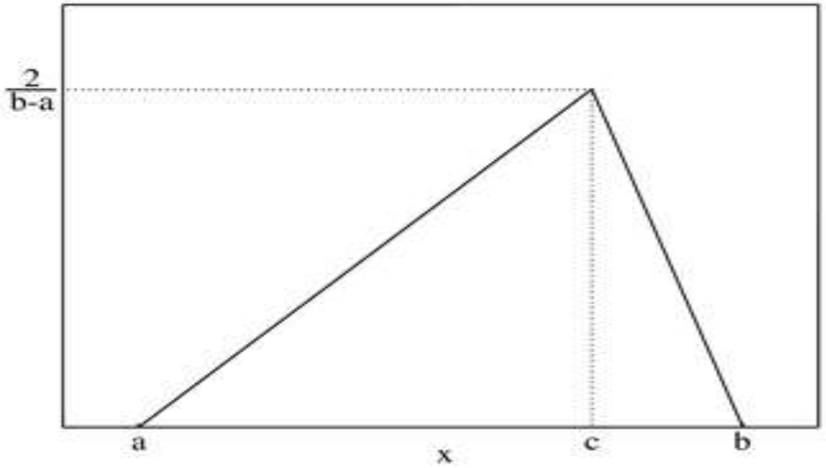


Common probability distributions







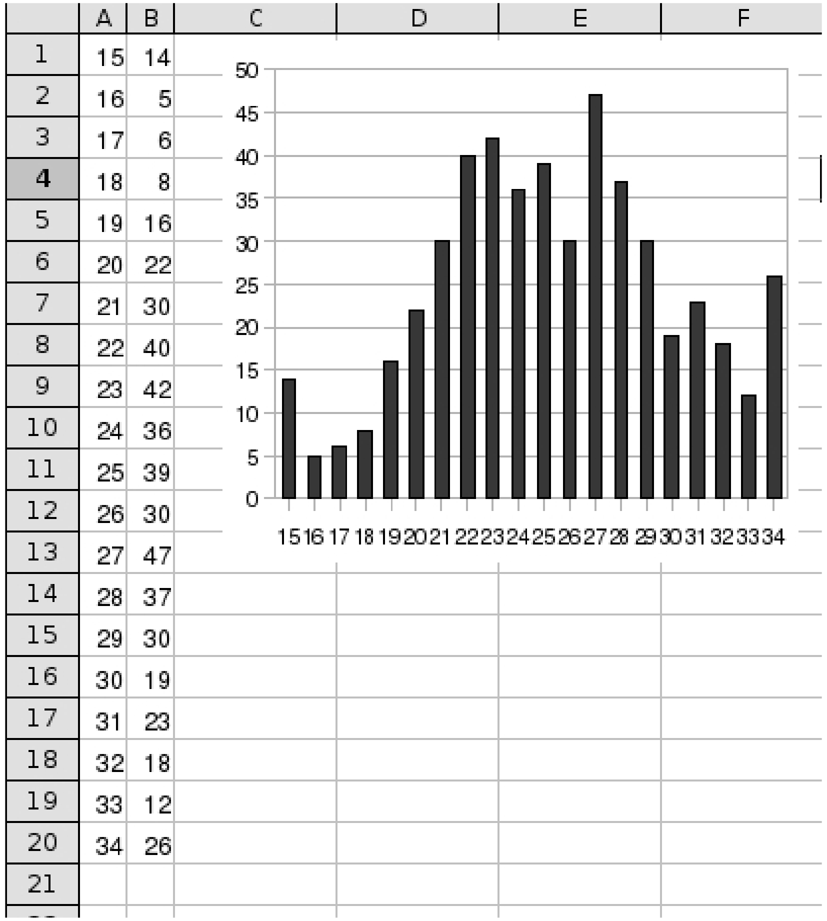


Common probability distributions

- Load the values into a Spreadsheet

- Then graph the result

- Identify the closer distribution

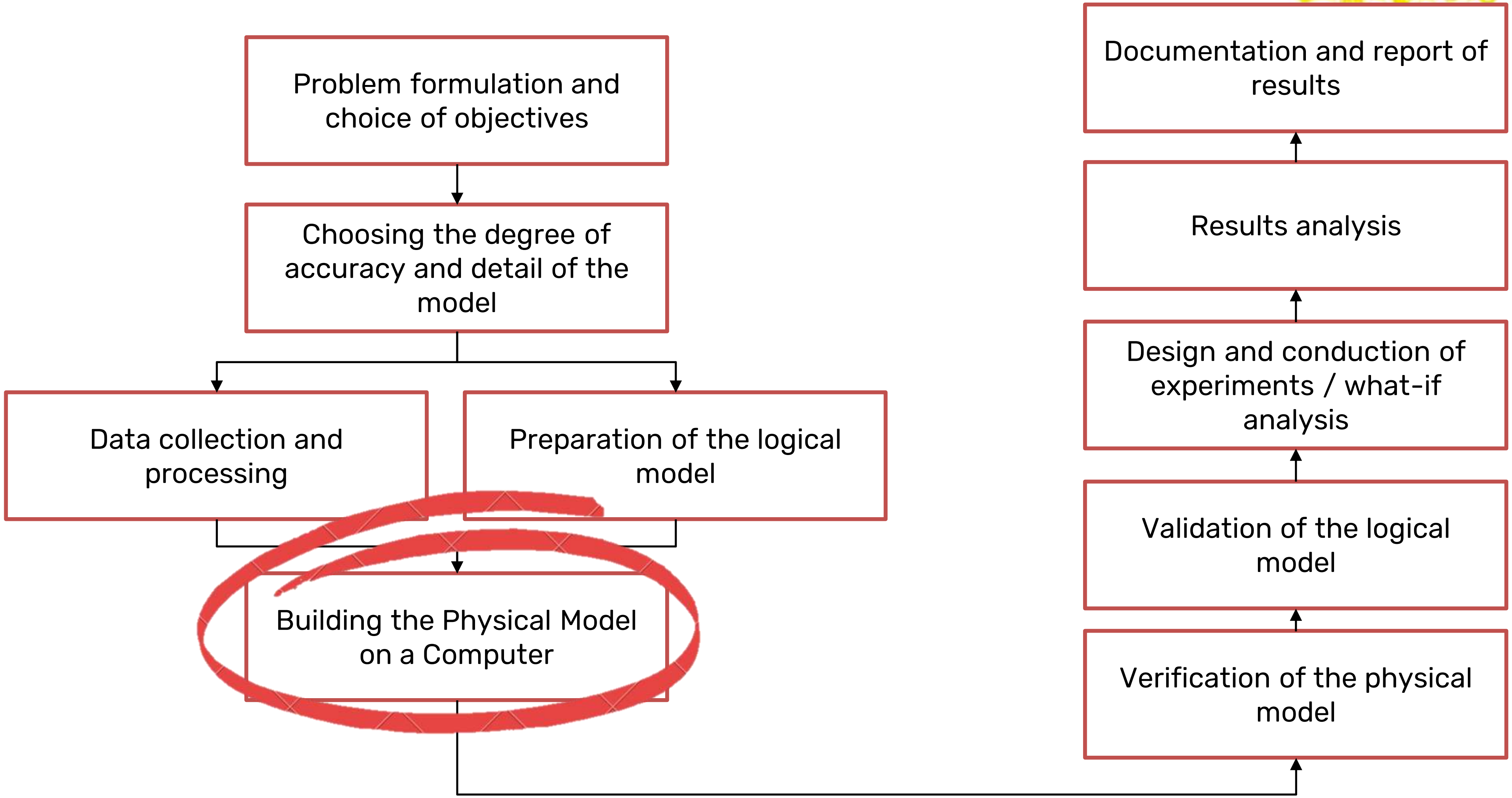


	A	B
1	15	14
2	16	5
3	17	6
4	18	8
5	19	16
6	20	22
7	21	30
8	22	40
9	23	42
10	24	36
11	25	39
12	26	30
13	27	47
14	28	37
15	29	30
16	30	19
17	31	23
18	32	18
19	33	12
20	34	26
21		

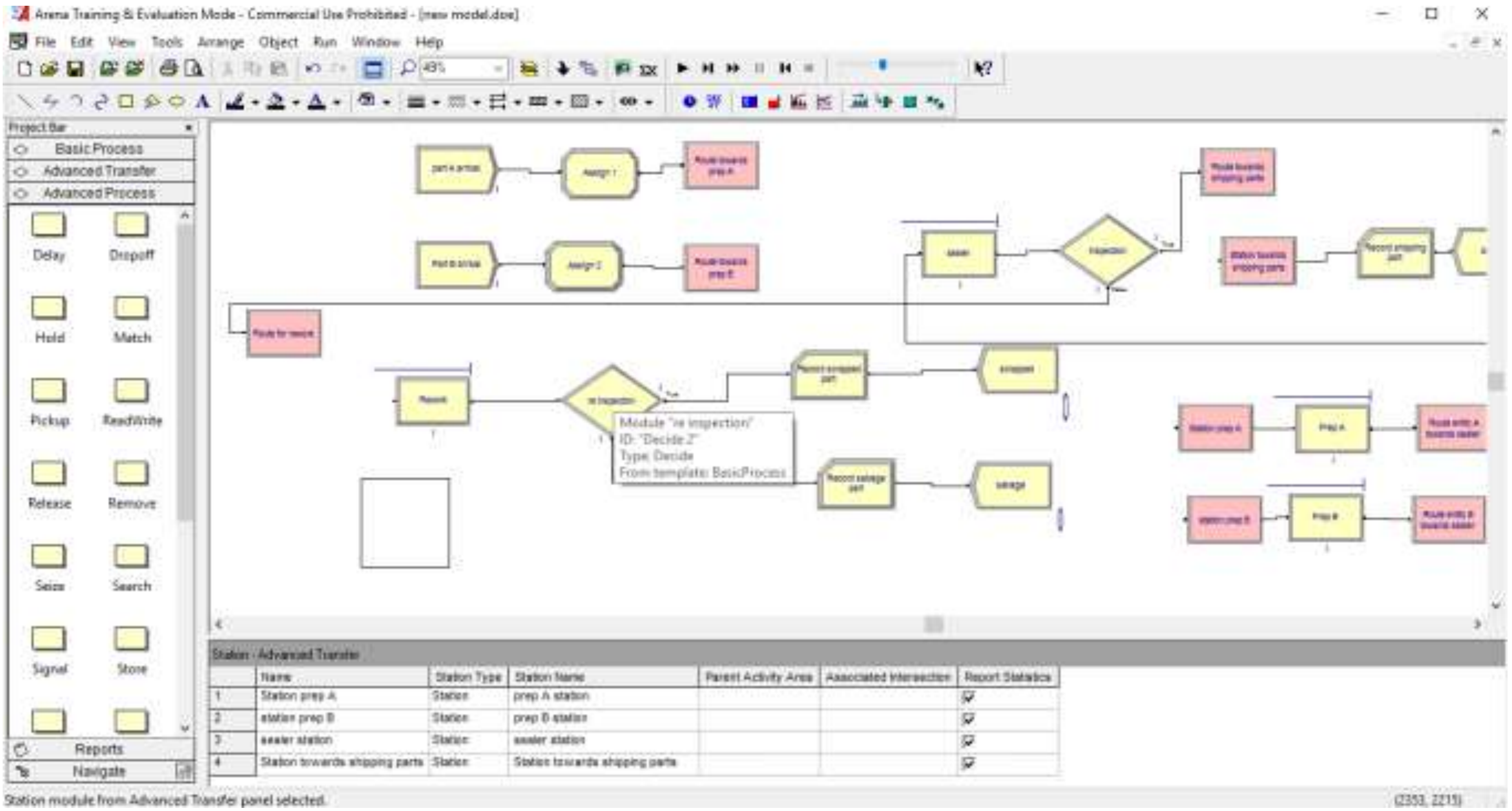
Data collection: problems

- Experience has shown that:
- Data collection is often very laborious and complex and requires a considerable amount of time.
- The outcome of this activity significantly affects the quality of the simulation model generated.
- Often, lack of data or data detail leads to a redefinition of the degree of accuracy of the conceptual model and the domain of investigation of the simulation study.

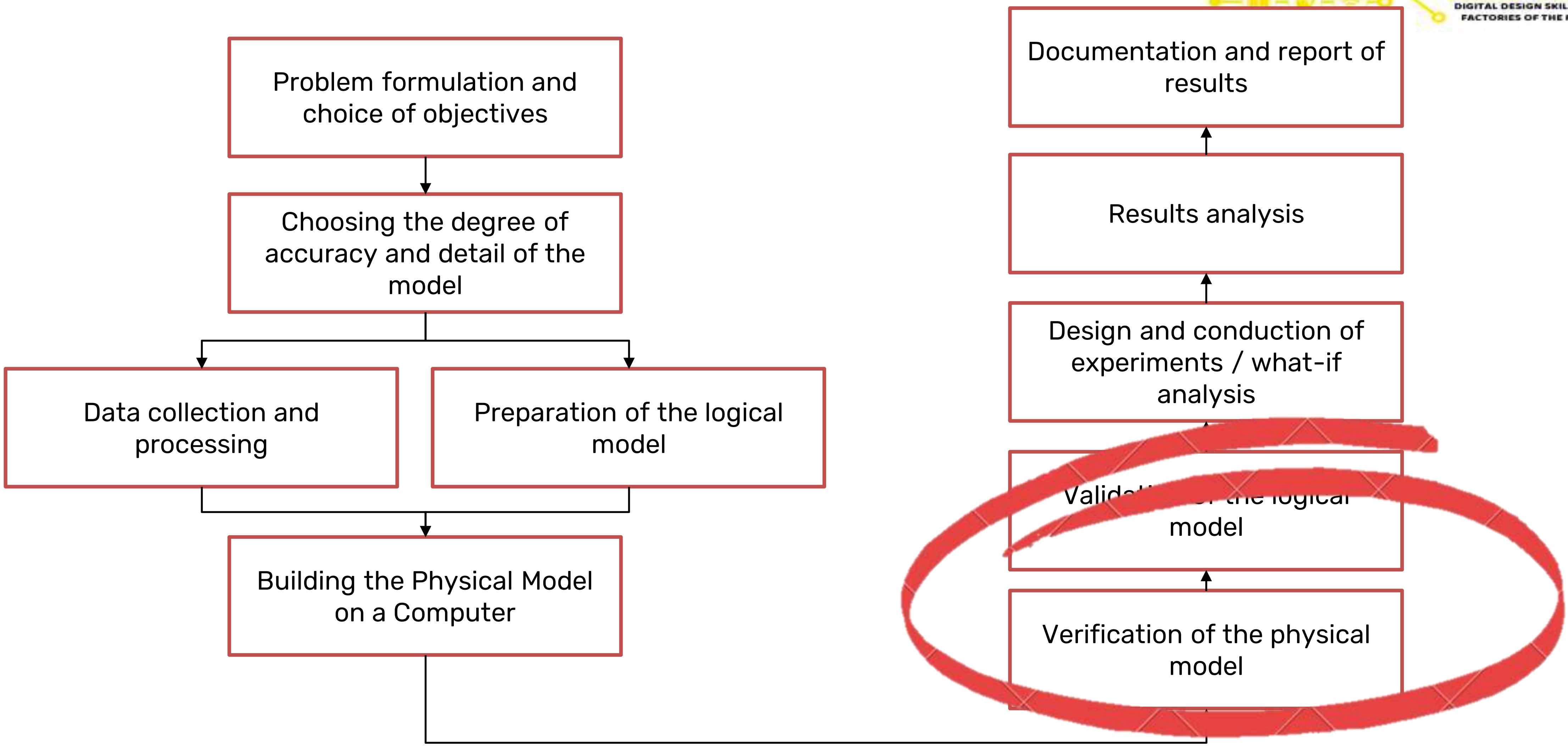
The main phases



Building the physical model - Arena



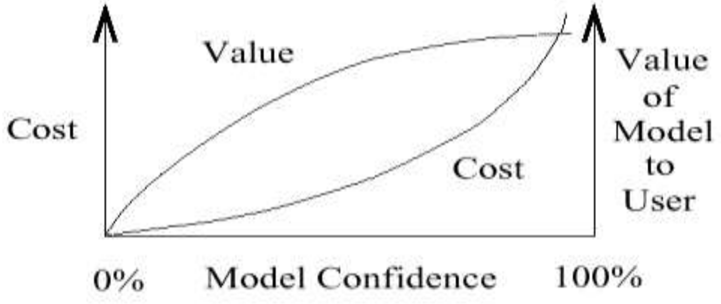
The main phases



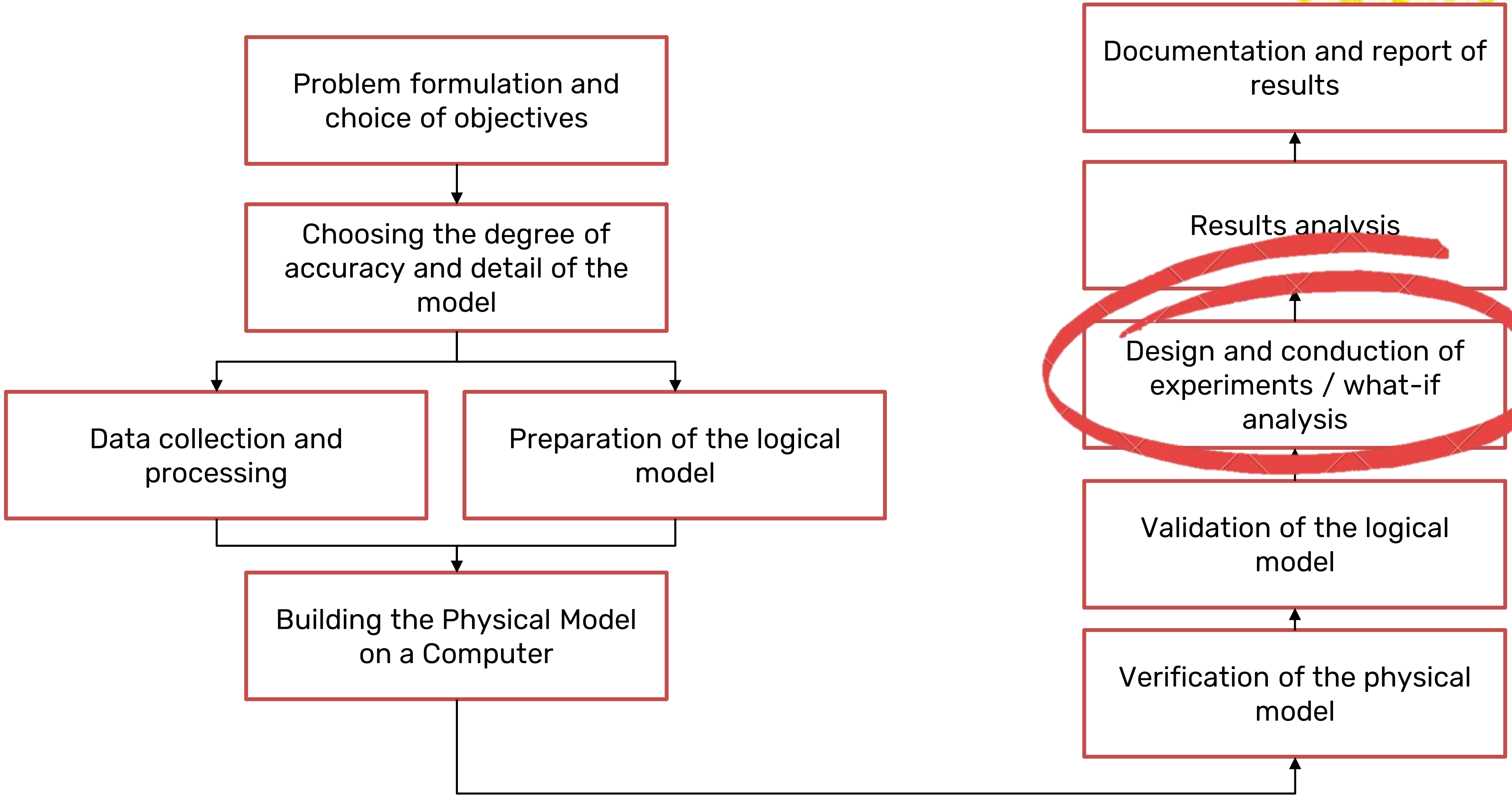
Verification and Validation phase

- The **verification** refers to the correctness, consistency and completeness of the model and the implementation of the model in relation to the project specifications (defined in the conceptual model).
- **Validation** concerns the correctness, consistency and completeness of the model with respect to the real system.

- Attention! The mode o be an exact replica of reality!!



The main phases

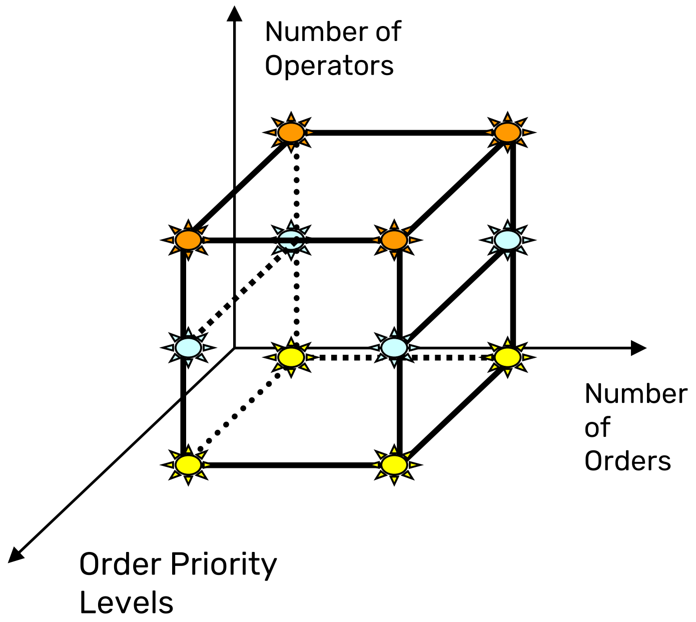


Design and conduction of experiments

- What is the length of the runs?
- How many simulation runs should be carried out?
- What model configurations should be simulated?
- How to analyze outputs?
- What is the most efficient way to carry out runs?

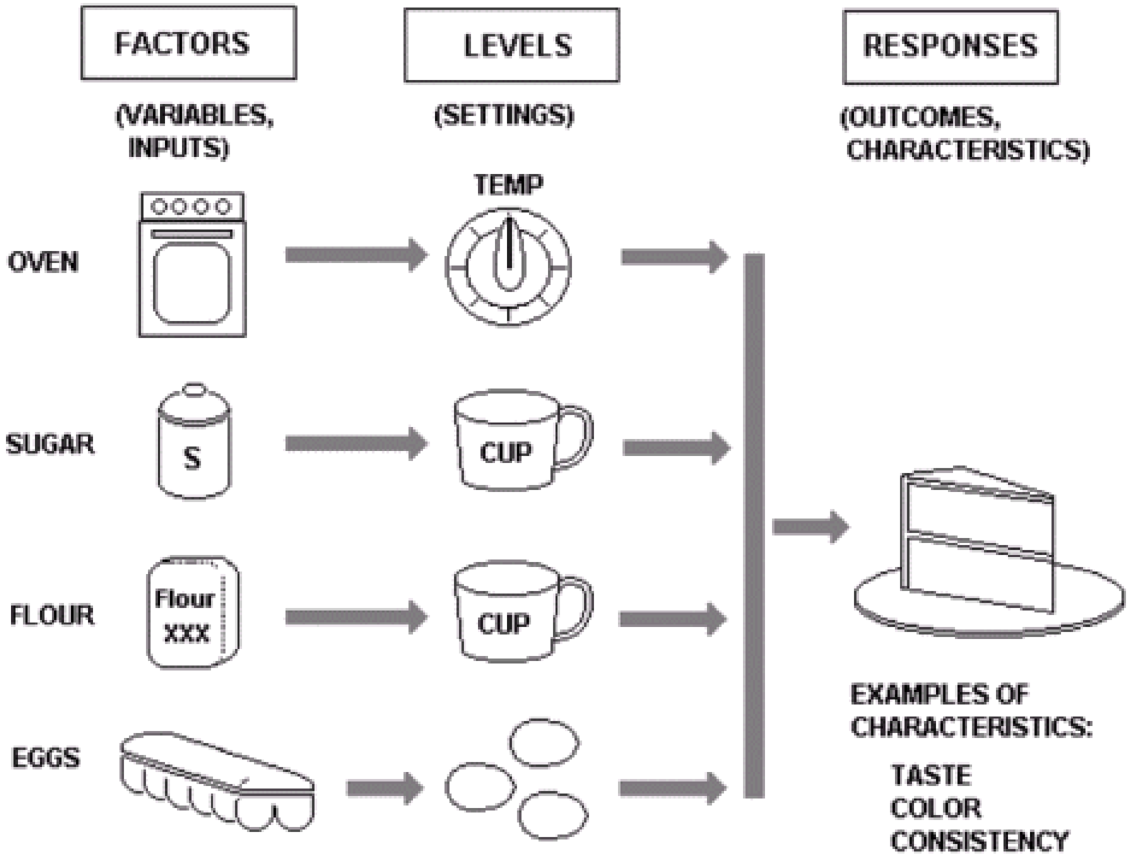
Design and conduction of experiments

- There are generally a **number of alternative configurations** that can be reasonably simulated.
- The different possible system configurations derive from different values that can be given to the model's decision variables.
- **Experiments** are used to evaluate *which process inputs have a significant impact on the process output*, and what the target level of those inputs should be to achieve a desired result (output).

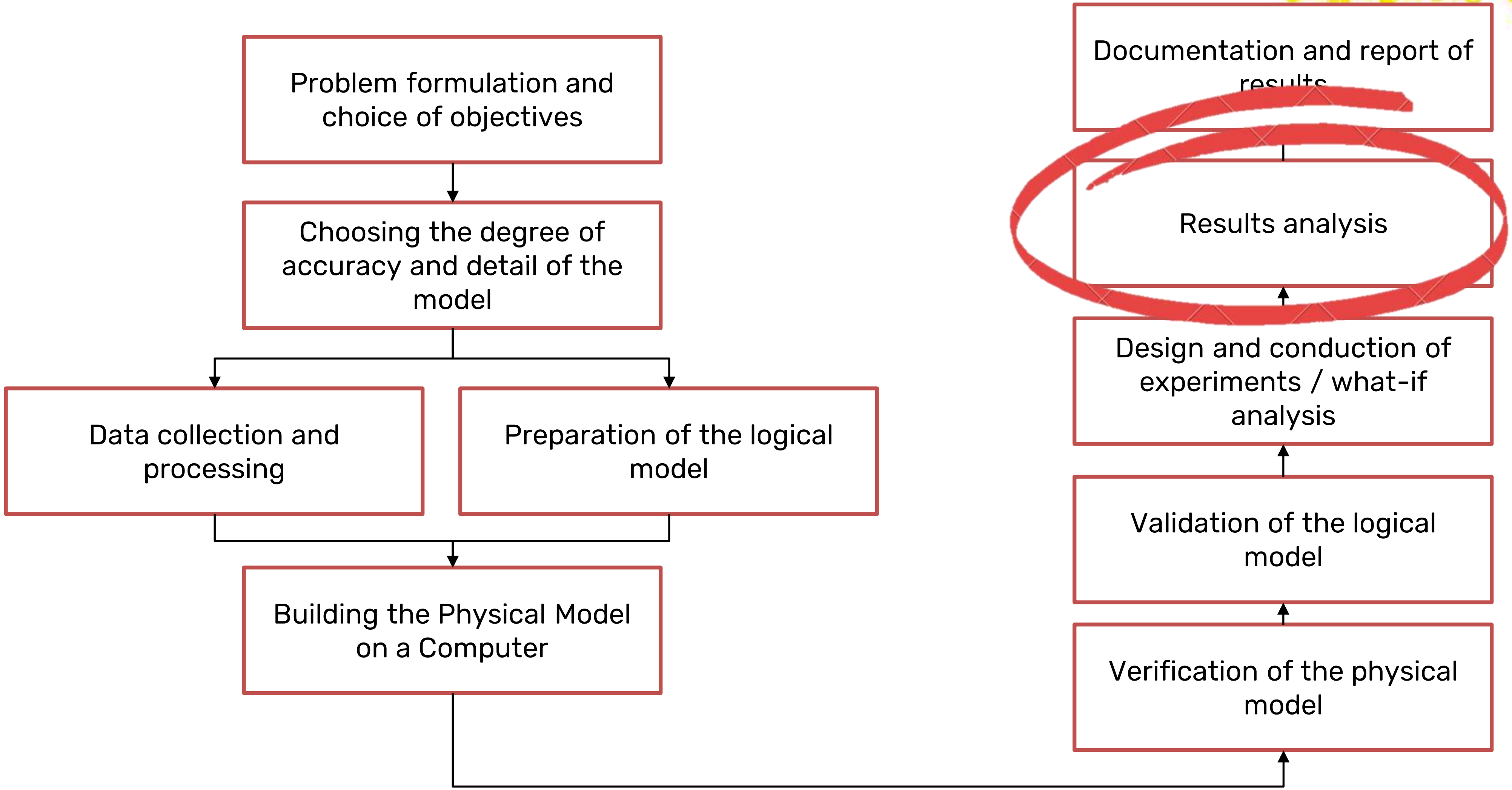


Design of Experiments (DOE)

- DOE is a systematic method to **determine the relationship** between factors affecting a process and the output of that process.
- It is used to find cause-and-effect relationships.



The main phases

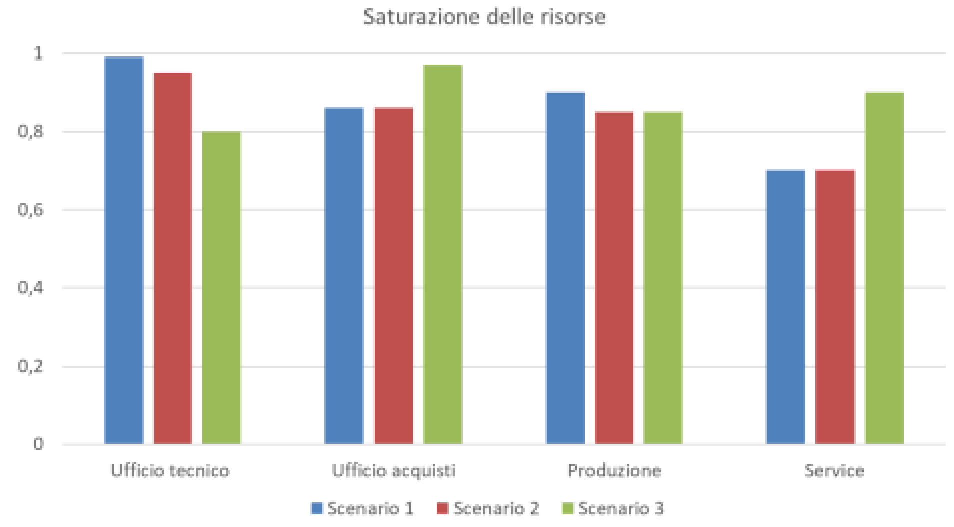


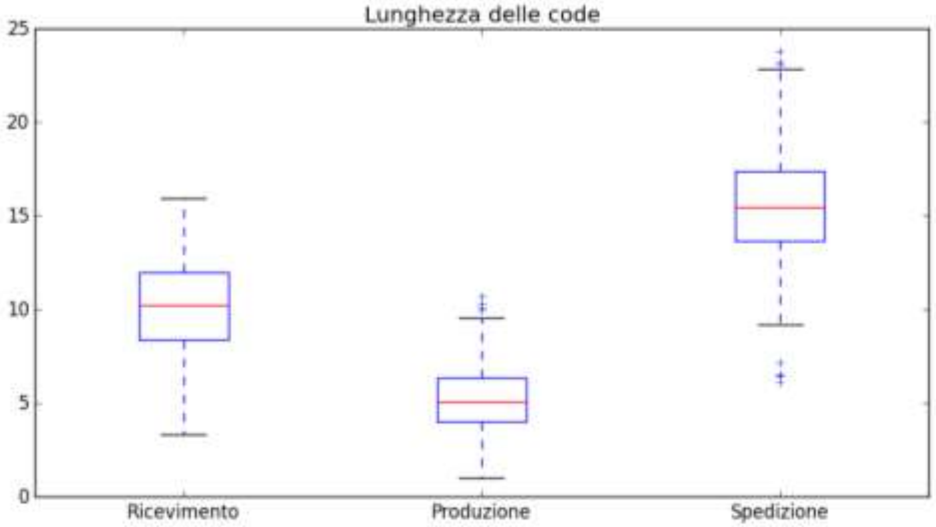
Results Analysis

- The importance of this phase arises from the fact that to model the real systems in the simulation process **stochastic models** are used, in which the inputs and the various parameters are made up of random variables.

- Consequently, the **output variables** of the model, which represent the performance measures, are also **stochastic**.

Data visulization



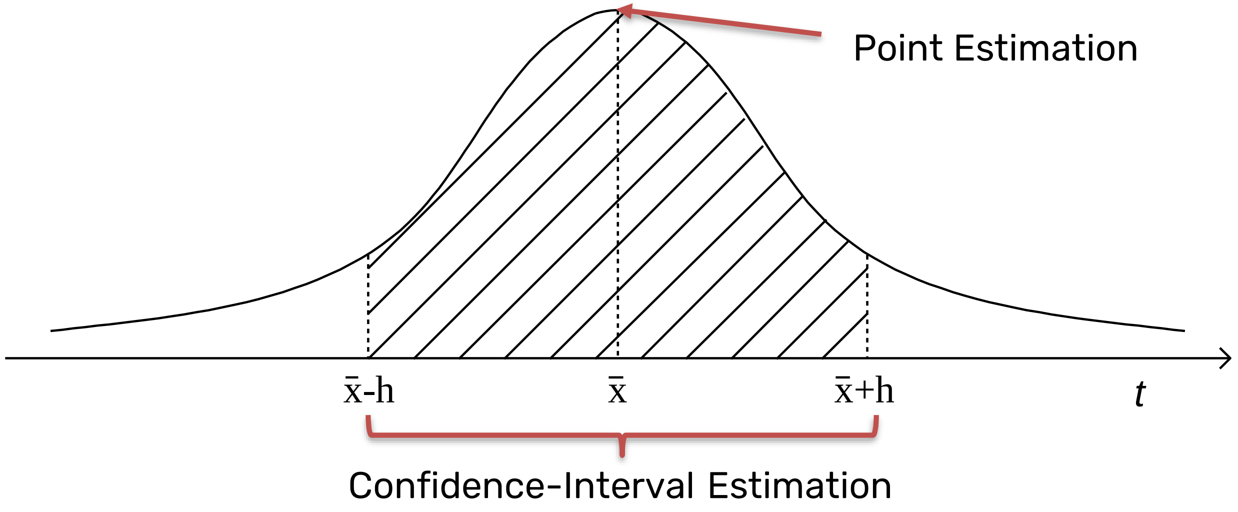


Analysis Output Data

- Efficiency (Utilization, N° of served customers)
- Effectiveness (Service availability)
- Quality (Customer satisfaction)
- Cost
- Timing (Lead Time, Cycle time, Queue)

Analysis Output Data

- Statistical tests for significance and ranking
  - **Point Estimation**: is a single number. How much uncertainty is associated with the point of estimation?
  - **Confidence-Interval Estimation**: it contains a set of possible value of the parameters. It represents the probability that the value of a parameter falls within a specified range of values.
- Interpretation of results
- More runs?



Objectives

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Discrete-Event Simulation

- *Discrete-event simulation*: Modeling of a system as it evolves over time by a representation where the state variables change instantaneously **at separated points in time**

  – More precisely, state can change only at *countable* number of points in time
  – These points in time are when *events* occur

- *Event*: Instantaneous occurrence that <u>may</u> change the state of the system
  – Sometimes get creative about what an “event” is … e.g., end of simulation, make a decision about a system’s operation

Components of a system

- ***Entity***: is an object of interest in the system
  - *Dynamic objects* — get created, move around, change status, affect and are affected by other entities, leave (maybe)
  - Usually have multiple *realizations* floating around
  - Can have different types of entities concurrently

Attribute: is a characteristic of all entities, but with a specific value “local” to the entity that can differ from one entity to another.

Components of a system

- **Activity**: represents a time period of specified length.
- **Resources**: what entities compete for
  - Entity seizes a resource, uses it, releases it
  - Think of a resource being assigned to an entity, rather than an entity “belonging to” a resource
  - “A” resource can have several units of capacity which can be changed during the simulation

Event: An instantaneous occurrence that changes the state of the system

Advantages of Simulation

- When mathematical analysis methods are not available, simulation may be the only investigation tool
- When mathematical analysis methods are available, but are so complex that simulation may provide a simpler solution
- Allows comparisons of alternative designs or alternative operating policies
- Allows time compression or expansion

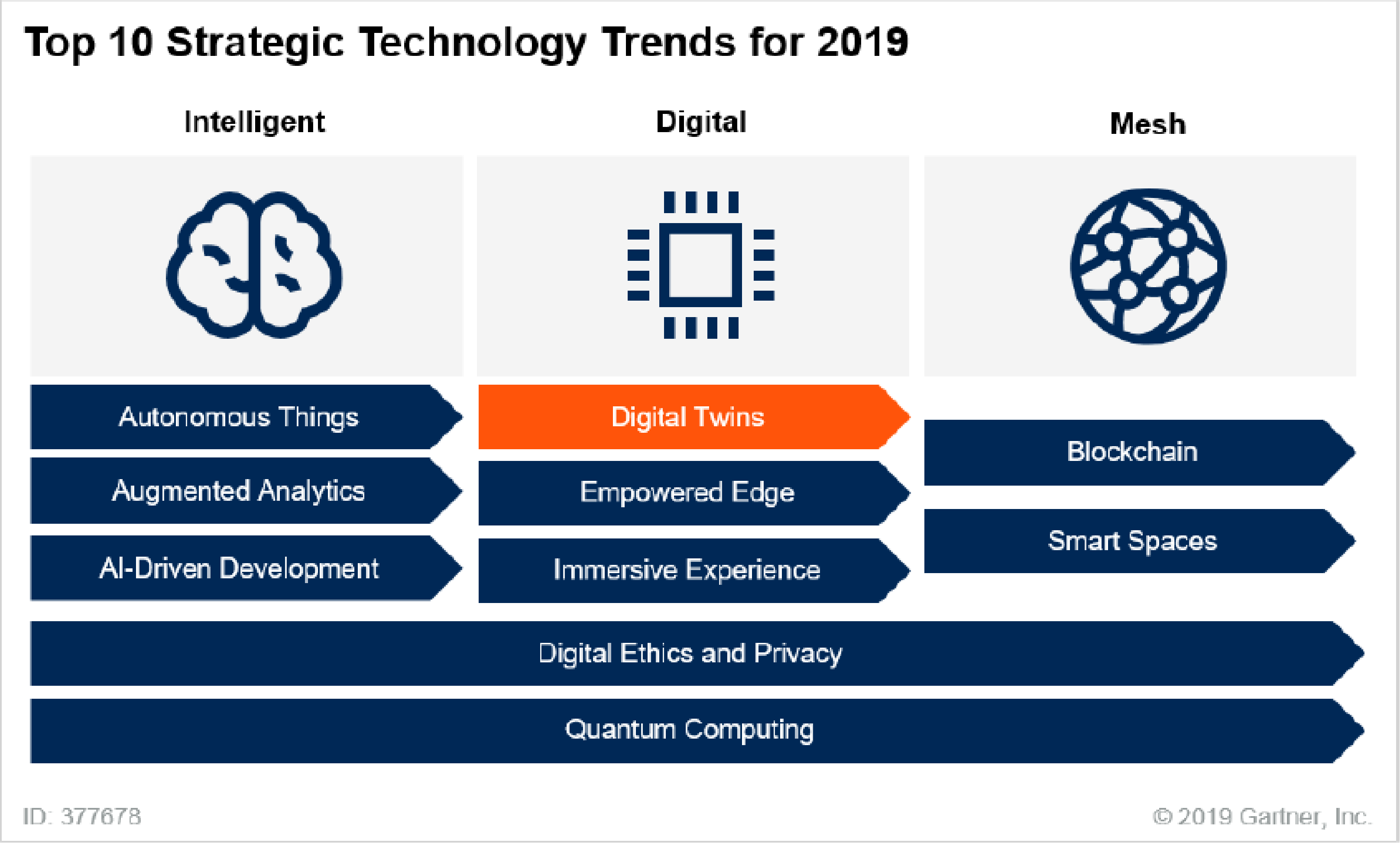
Disadvantages of Simulation

- For a stochastic model, simulation <u>estimates</u> the output while an analytical solution, if available, produces the exact output

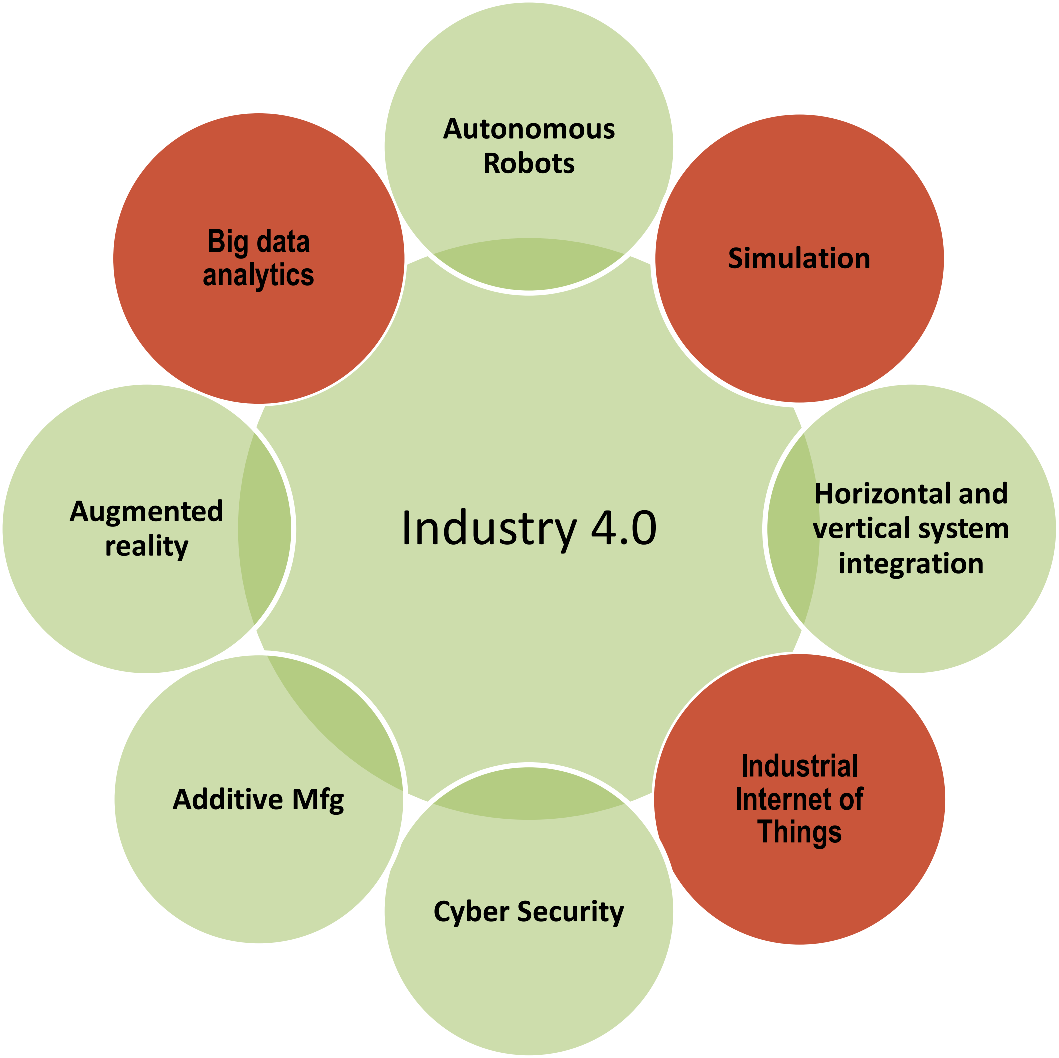
- Often expensive and time consuming to develop

- An invalid model may result with confidence in wrong results.

Evolution of simulation …digital twin



Technologies of Industry 4.0



Some definitions

Simulation: imitation of the real-world process or system over the time

Industrial Internet of Things (IIoT): the use of smart sensors and actuators to enhance manufacturing and industrial processes. IIoT is a network of intelligent devices connected to form systems that monitor, collect, exchange and analyze data.

Big data analytics: complex process of examining large and varied data sets, or big data, to uncover information - such as hidden patterns, unknown correlations, market trends and customer preferences - that can help organizations make informed business decisions.

DIGITAL TWIN: *a virtual representation of an entity such as an asset, person or process and is developed to support new or enhanced business objectives.*

Gartner, 2019

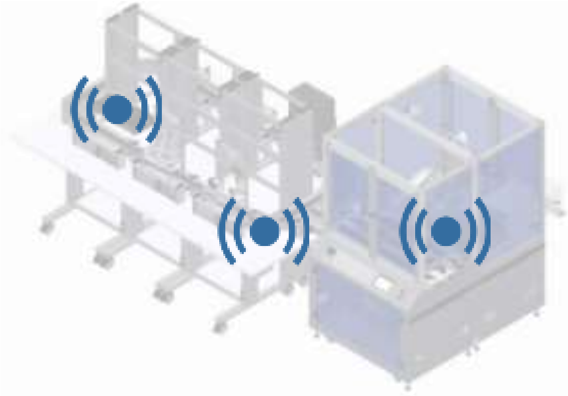
Components of a digital twin

Real world system

Physical Part

Digital Twin

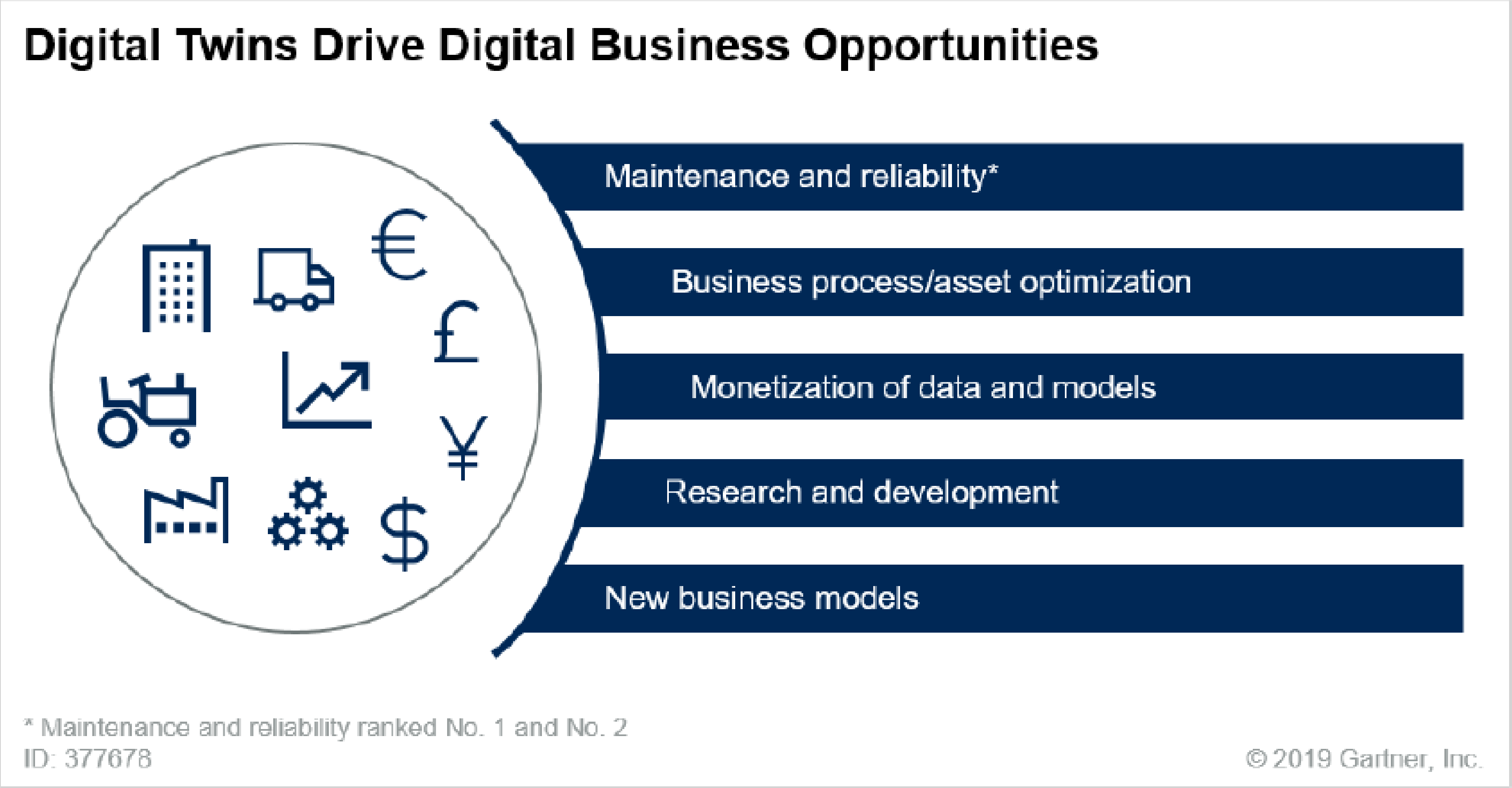
Cyber Part



Sensors/actuators

Communication Network

Digital twin applications



Simulation modeling vs. digital twin

	Simulation model	Digital twin
Simulation To-Be vs As-Is	Enables the decision makers to evaluate if the outcome of their decisions and actions is as they intend.	In addition to that, the objective of a DT is to identify deviations from optimal conditions allowing a correction in the short term.
One-time built vs continuous evolution	Once for a system or process improvement	Has a more holistic approach. Continuous project which evolves in time
Single vs multiple focus	Answer a set of specific questions	Different users at different roles. It covers wider points of view (e.g. maintenance, operation, strategy or sales)
Offline vs Online	Offline	Online
Analysis vs action	Addresses the analytical and decision support requirements by providing detailed and accurate replication of the system or process state in imaginary scenario being either in past or future	In addition to that, it can suggest possible courses of action and execute them depending on the nature of the necessary steps
Logic based vs data intensiveness	It is realized on top of the logics behind how a system or a process is behaving	Besides of these logics, it accounts also for for the huge amount of data they generate while operating.
Stand-alone vs connectivity	Stand-alone	Technologies like cloud, edge and IoT are indispensable for realizing Digital Twins.

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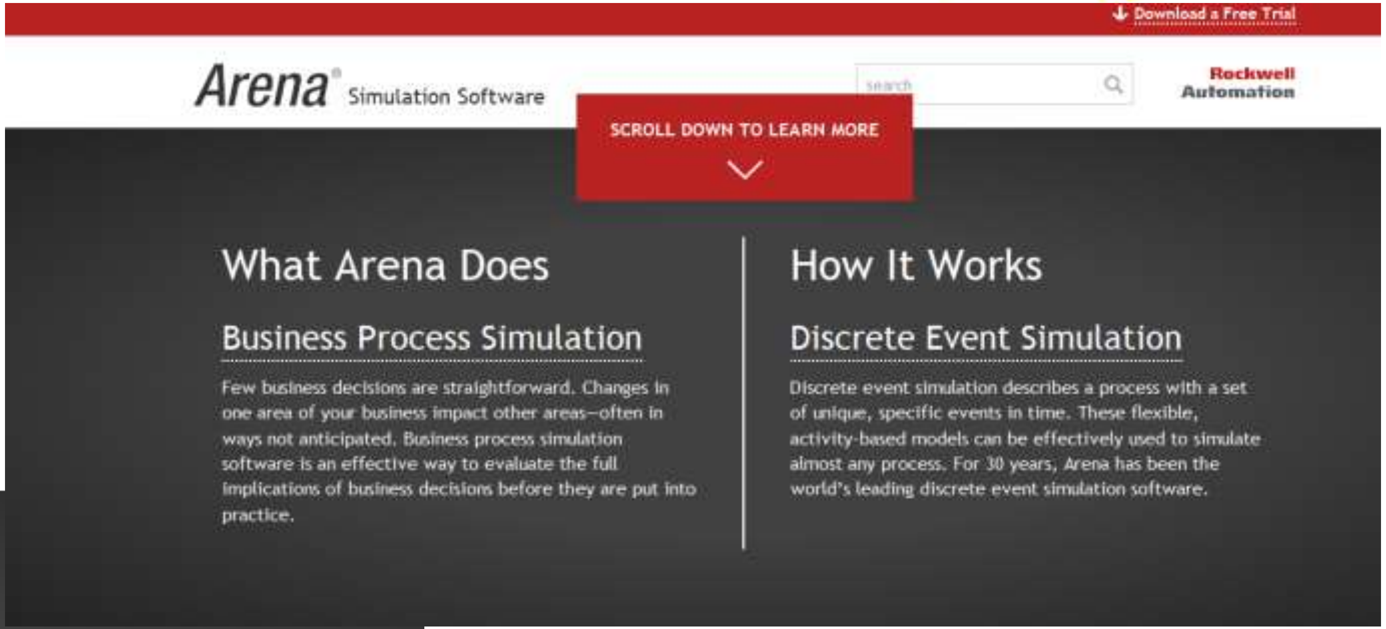
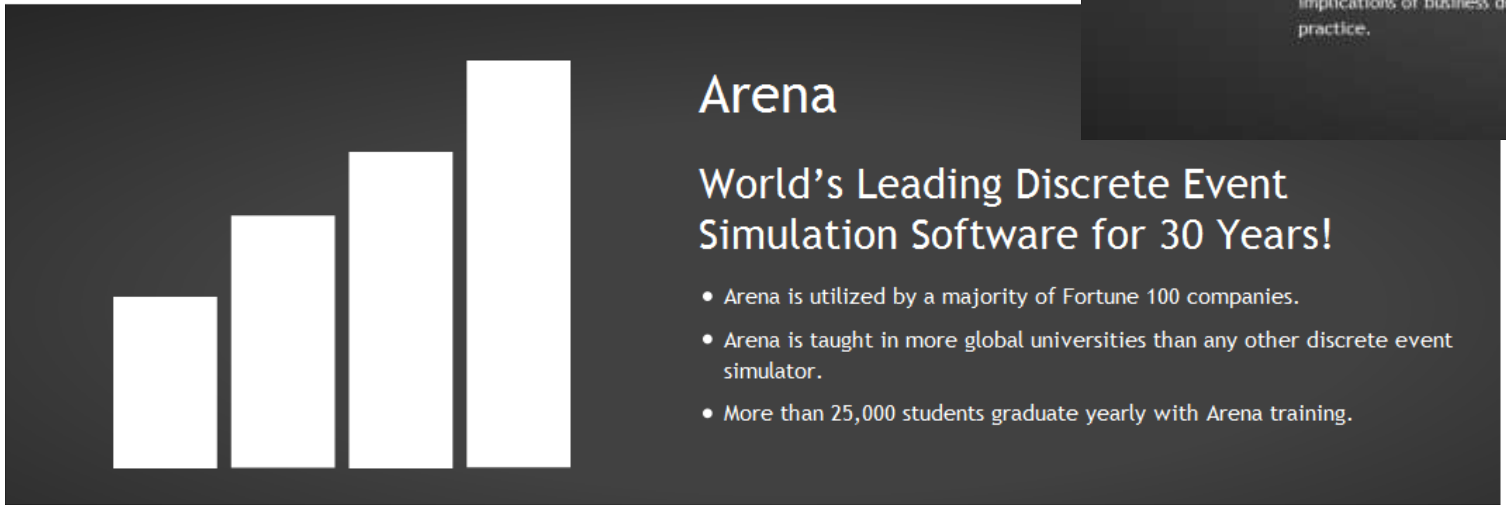
Arena Rockwell simulation software





Arena Discrete Event Simulation Software

- The Arena modeling system is a flexible and powerful tool that allows analysts to create animated simulation models that accurately represent virtually any system.

- Arena employs an object-oriented design for entirely graphical model development. Simulation analysts place graphical objects—called modules—on a layout in order to define system components such as machines, operators, and material handling devices.

Download ARENA

- https://www.arenasimulation.com/simulation-software-download

Flowchart Model Development

- Arena was designed to make creating simulation models an entirely graphical process.
- All system behaviors are represented by using graphical modules.

Entities

- Entities are dynamic elements that pass through the system.
- Entities are distinguished by their attributes.
- Entities must be created to get them into the module and are disposed when they leave.
- Attributes must be numerical values.
- You may have different types of entities in the same model.

Processes

- Entity must be processed.
- This activity is performed by one or more resources and requires some time to complete.

Resources

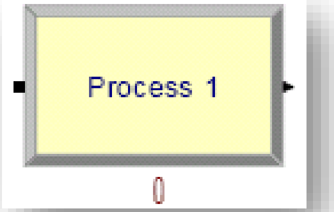
- Resources have a name and a capacity (number of identical units of the resource).
- Resources may have a schedule (how many of them are available and when).
- Resources are automatically defined by some modules (e.g., Process).
- Resources can be defined manually, and the properties of all resources can be edited in the same way.

Queues

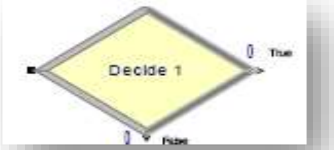
- Entities queue when they need processing
- An entity tries to seize a resource.
- The time the entity uses the resource is the delay.
- If the resource is not available, the entity waits in a queue.
- The entity releases the resource when processing is complete.
- Queues are created automatically by some modules (e.g., Process), and can be defined manually.

The Main Modules

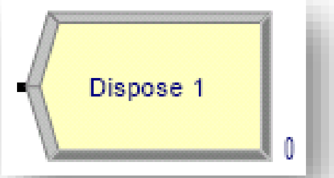
Push (possibly) batches of entities into the model with a (possibly) random time between.



Models Queue-Seize-Delay-Release of Resource, or any part of this (like pure Delay).

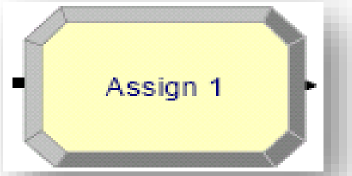


Make decisions about where to go next based on conditions or chance.



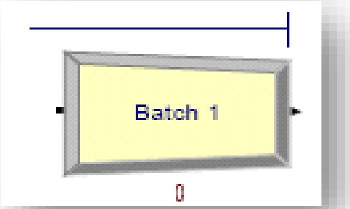
Take entities out of the model and (perhaps) record statistics.

The Main Modules

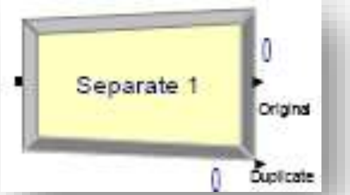


Assign values (especially Attributes) when an entity passes through.

Record information when entities pass through, typically statistics on entities.



Combine multiple entities into a single entity.



Split multiple entities that were combined, or duplicate a single entity.

Example

- Simulation of a production process:
- Assembly: usual duration 1,2 hours, max 1,5 hours, min 0,5 hours. Performed by assemblers
- Test: usual duration 0,5 hours, max 1 hours, min 0,2 hours. . Performed by tester
- Final preparation: usual duration 15 min, max 18 min, min 10 min. Performed by assemblers
- Resources:
- 2 assemblers working from 8.00 to 12.00 and from 13.00 to 17.00
- 1 tester working from 9.00 to 13.00 and from 14.00 to 18.00
- Demand
- Random every 45 minutes 1 arrival
- In the 95% of cases the assembled product passes the test. In it does not pass the test, a new test is done. The probability to pass this new test is 50%. If the assembled product does not pass the second test is it discarded.