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INDUSTRIAL PLANTS 2

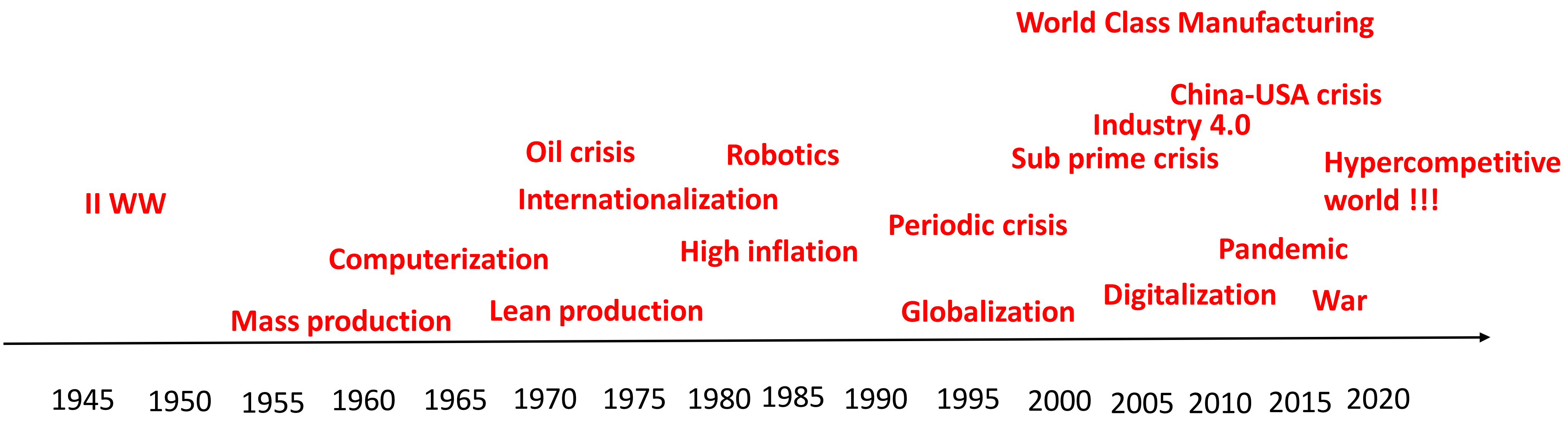
Chapter three ï part 1
Numerical simulation
as a tool for optimizing industrial processes

DOUBLE DEGREE MASTER IN
ñPRODUCTION ENGINEERING AND MANAGEMENTò

CAMPUS OF PORDENONE
UNIVERSITY OF TRIESTE

Why is it so important the change for the companiesô success?

Because the business environment changes !



World Class Manufacturing

China-USA crisis

Industry 4.0

Oil crisis

Robotics

Sub prime crisis

Hypercompetitive world !!!

II WW

Internationalization

Periodic crisis

Computerization

High inflation

Pandemic

Digitalization

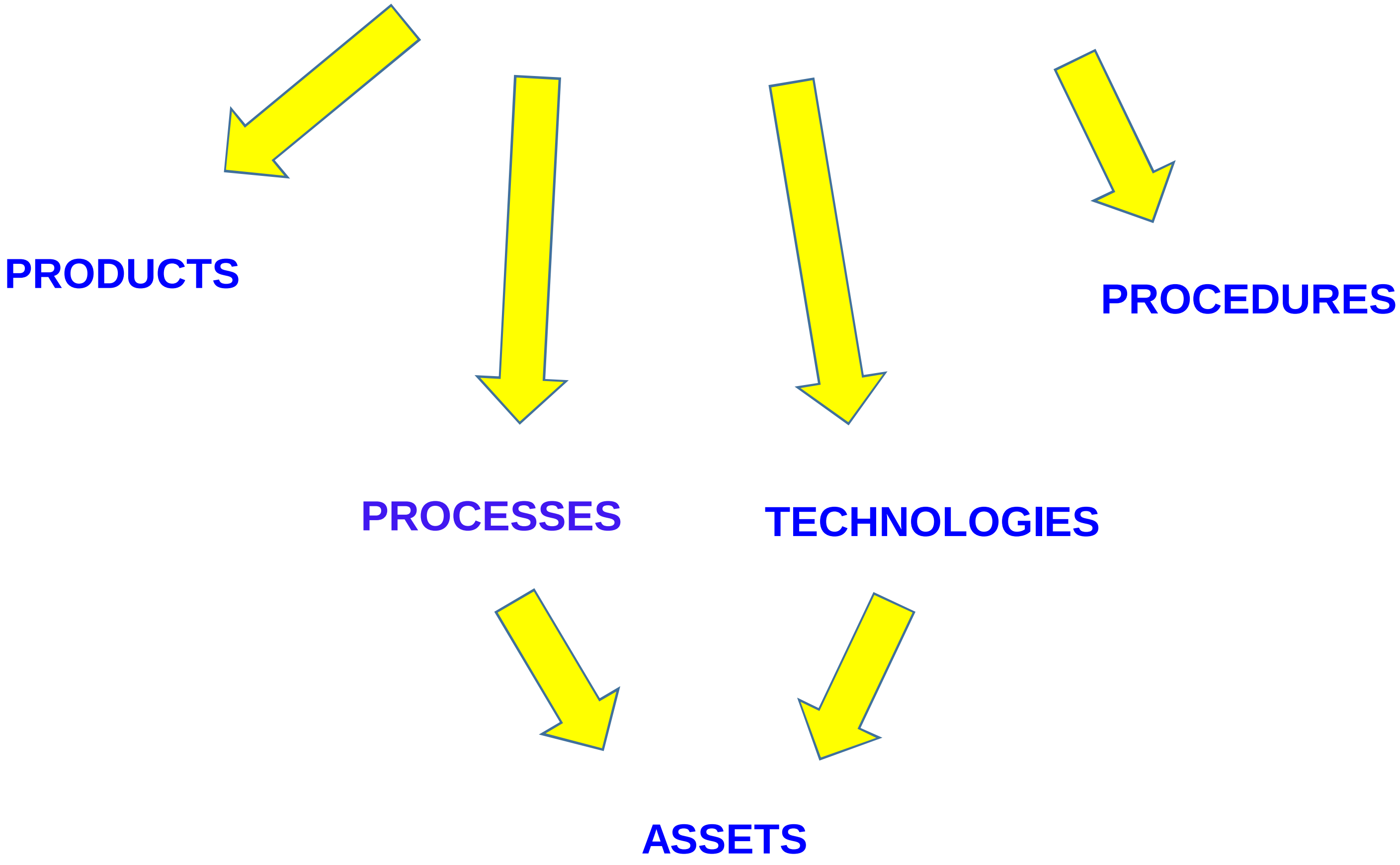
War

Mass production

Lean production

Globalization

What is important to change in a company?



PRODUCTS

PROCEDURES

PROCESSES

TECHNOLOGIES

ASSETS

NUMERICAL SIMULATION

Introduction

Simulation is intended to replicate, by means of appropriate models, an already existing reality to study the effects of possible interventions or events in some foreseeable way, or to plan to evaluate in advance the various possible choices.

Since ancient times, **models** have been used **to support decision-making processes**: typical examples are scale models, used in particular during the design phase, which faithfully replicate on a reduced scale the reality that you want to represent.

These **physical models** have as limit a high manufacturing cost and a remarkable rigidity of use; for this reason they are less used in practice in favor of **virtual models**, in which the reality under examination is represented by means of variables and relationships of a logical-mathematical-statistical type.

NUMERICAL SIMULATION

Introduction

Numerical simulation is a very **powerful experimental analysis** tool that allows to dynamically analyze a system, a plant or a machine and **compare** the implications of the different design or operational choices, all in a completely virtual way, without the need to develop expensive prototypes.

Therefore it allows you to:

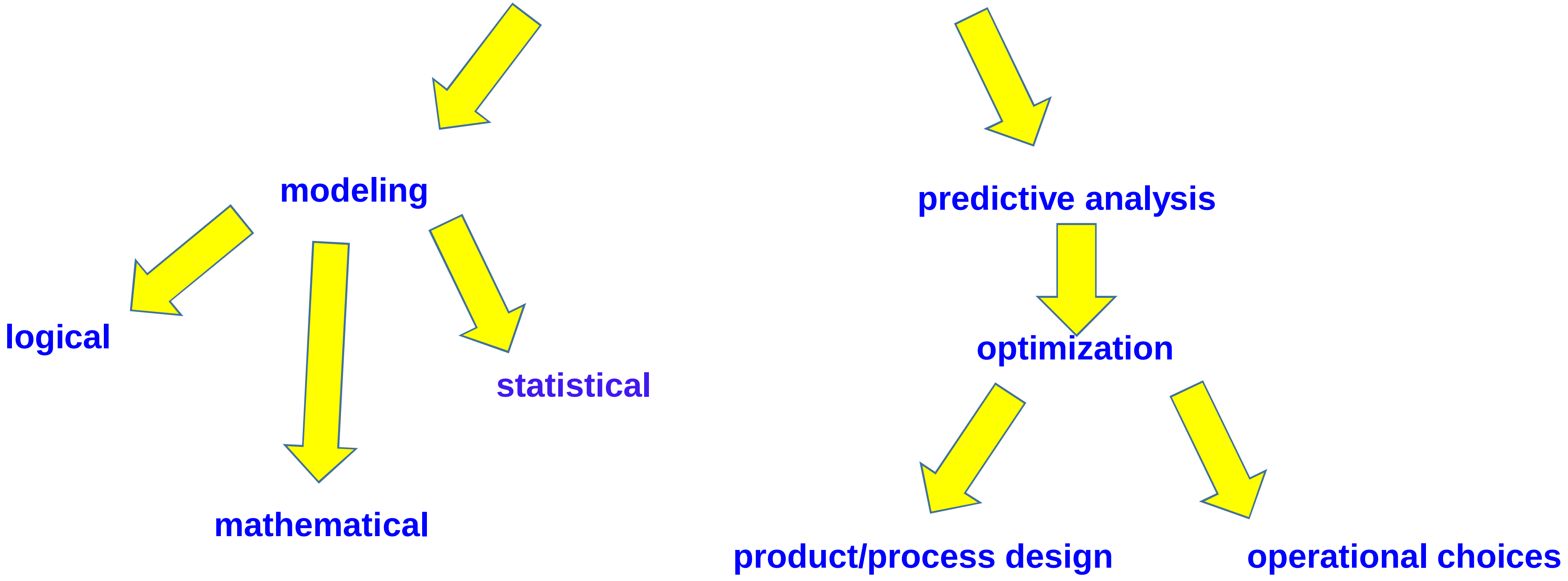
- Drastically reduce the risks related to innovation (**risk management**),
- Provide valuable help in the decision-making process
- Reduce design times and costs.

GENERAL PRINCIPLES OF SIMULATION

NUMERICAL SIMULATION

Introduction

GENERAL PRINCIPLES OF SIMULATION OF COMPLEX SYSTEMS



modeling

logical

mathematical

statistical

predictive analysis

optimization

product/process design

operational choices

Computer-assisted numerical simulation is one of the most used experimental techniques to predict the evolution of economic and industrial systems over extended periods of time.

NUMERICAL SIMULATION

Introduction

The idea of dealing with the **random sampling technique** problems whose direct resolution presents too many mathematical complications dates back to the **mid-1800s** when Kelvin used these techniques to calculate the Boltzmann equation.

During the **Second World War** the need arose to solve mathematical complex problems of diffusion of particles for the realization of the atomic bomb. This original idea underwent a considerable impulse and was perfected by Fermi, Ulam and Von Neumann.

Subsequently, these applications find their place in a methodology born under the name of the **Monte Carlo Method** (1944). After this date the efforts in this direction multiplied up to the **simulation**.

NUMERICAL SIMULATION

Introduction

As the complexity and size of the problems grow, **the computer is the indispensable tool** for calculating and representing the elements that make up the reality under study and the relationships between them.

The correspondence between **reality** and the **model** is no longer based on a proportional reduction of the size, but is functional: **each element of the real system corresponds to an IT object that performs the function in the model**.

Conducting a **simulation project** means first building a **logical-mathematical model** that represents the real system under examination over time and, subsequently, carrying out **experiments on the model** making it generate different possible configurations to deduce the behavior of the system under certain conditions.

Finally, the results must be analyzed, evaluating the various decision-making policies and obtaining information on the links between the alternatives studied and the performance of the system.

In addition to helping in solving multiple problems by identifying potential errors in decisions (expansions, layout, choice of production technologies, etc.), **simulation** provides the intangible benefit of a better understanding of the system, forcing the user to observe and understand his behavior by identifying the most relevant aspects.

NUMERICAL SIMULATION

Introduction

The **applications of a simulation** in a production organization can refer to a wide range of problems, including:

a) **design, sizing and regular verification of products, production systems and various plant components**, such as warehouses, interoperational buffers, handling systems, work stations, etc.;

b) **study of the behavior of the system** when the production mix changes, production volume, labor performance, work cycles, scheduling strategies, etc.;

c) **checks between the various maintenance policies of the plants and relations with distribution and commercial subsidiaries**, such as the solution of flows between the finished product warehouses, collection warehouse, consortium member warehouse and end user;

NUMERICAL SIMULATION

Introduction

d) Support of internal logistic as:

- verification of procurement policies and their effects on production and financial assets within the plant;
- just in time deliveries from suppliers and incoming materials, the effect of direct access to the supplies to the assembly lines;
- effect of standardization and reduction of the number of components of the product;
- verification, control and evaluation of the global flexible production management policy;
- control of lead time, WIP, buffer and financial assets, reduction of the programming cycle, etc.;
- comparison between flow production and job shop (production by departments);
- comparison between small batch and large batch production;
- comparison between pull management and push management.

NUMERICAL SIMULATION

Introduction

The **use of simulation** requires much more experience and attention than that dedicated to software selection and model coding.

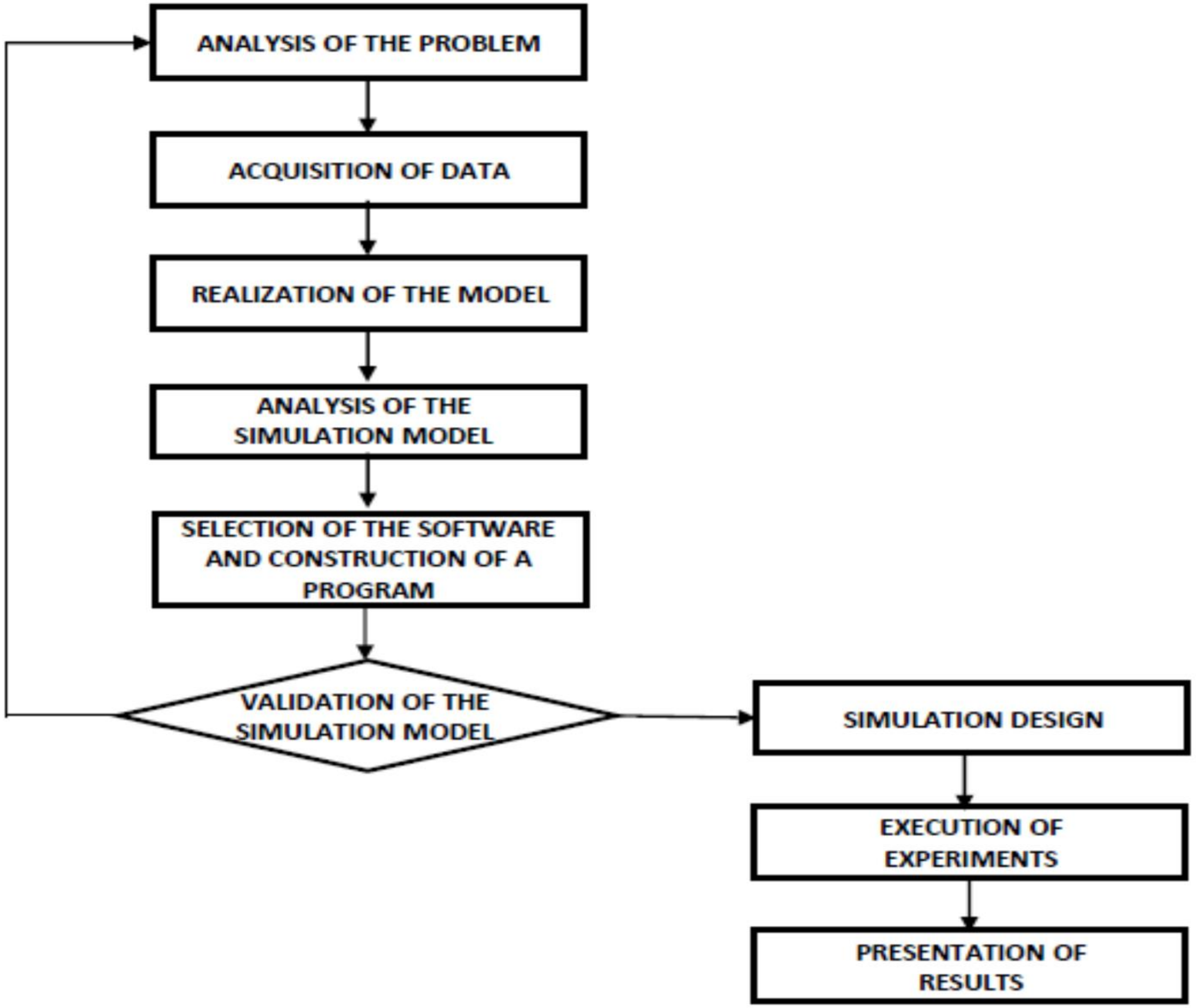
Particular attention must be paid to activities such as the **collection of data and information**, the stochastic modeling of system variability, the development of a valid and credible model, the design and statistical analysis of the campaign of experiments.

Although **simulation** is a very important **technique of operational research,** it is the most used, in an absolute sense, to **support business decisions**.

The **main strength of this technique** is the **extreme flexibility of the simulation models against the structural limitations imposed by an analytical treatment**; in the latter, simulation is sometimes used to clarify the practical implications of the assumptions underlying the mathematical model.

NUMERICAL SIMULATION

Flow chart of the different phases of the simulation



NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Phases

a) problem analysis

Å It consists in **understanding the problem** by trying to understand what the aims and objectives of the study are and to identify which are the essential components and the performance measures that affect the system, determining the **degree of detail** of the model.

Å The **choice of objectives** defines the way to model the system; the model extracts and describes the needs of the investigation, neglecting those components that are not of sufficient importance.

Å The **definition of the problem** is also fundamental for the choice of the degree of detail to pursue the objectives set.

Å In addition to the **organizational aspect**, the **economic aspect** must also be taken into account, so it will be necessary to formulate an **estimate of the development costs** (people, programming languages and processors).

Å From the **balance of these four points**, **objectives and related benefits** on the one hand, **times and costs** on the other, it can be defined whether the simulation approach is advantageous;

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

b) data acquisition

It includes the **collection and processing of the data** necessary for the realization of the model. The **collection of data** must follow the **definition of the problem** to avoid redundancy in the surveys. Often the data are not enough so that you are forced to detect them with **field surveys**. When you want to simulate complex and extensive systems, the data must be collected by several competent people in the various business sectors. From the various observations and forecasts on **similar machines for systems not yet existing**, the fundamental parameters and statistical distributions to which they obey must be collected.

Among the attributes that need to be known there are those relating to resources, work calendars and malfunctions that arise;

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

c) **realization of the model**

It consists in **reproducing the system in question** with a set of logical propositions and mathematical and statistical relationships. Formulating the simulation model is a complex process.

This phase is characterized by the **description of the system**, its **schematization in a model and the realization of a program**.

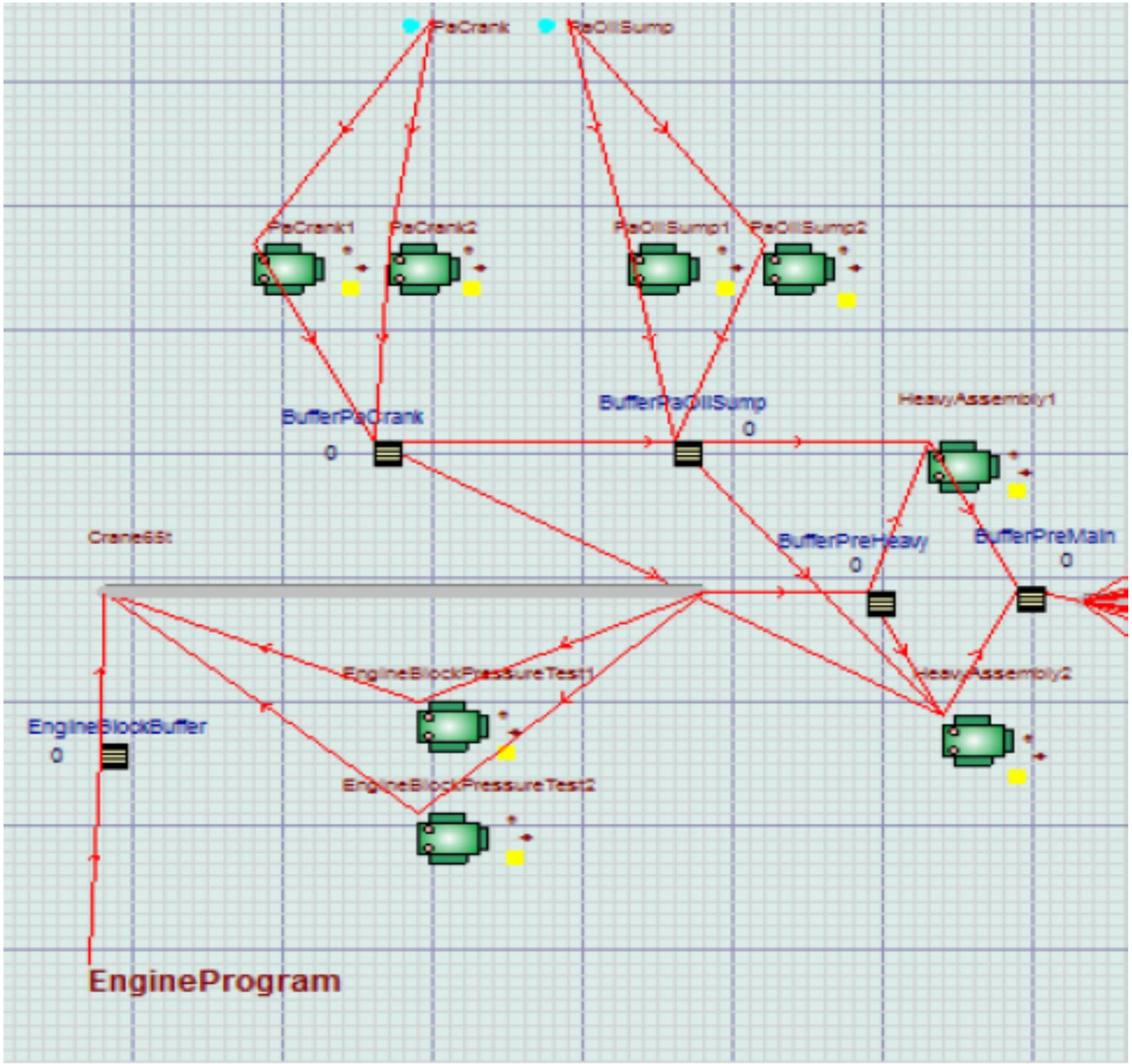
The functioning of the system consists in the description of the organization of the process, identified by the operations that follow one another in carrying out a specific production, together with the behavior of the entity and resources that participate in it.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

c) realization of the model

The system lends itself very well to being schematized with **graphic methods**, to understand the relationships between its various components, and with production diagrams, which list the activities in which actions and durations are summarized.



NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

c) **realization of the model**

These methods play a very important role in the subsequent realization of the model since they synthesize reality, describing the part of the system (processes and parameters) most significant for the chosen objectives.

The **model** generally has a shape that is very close to that of the code used to make it to the computer, so sometimes these are confused at the expense of simplicity of understanding.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

c) **realization of the model**

We are faced with a set of relationships, parameters and variables, completed by a certain number of interactions that produce different actions from language to programming language.

The **logical-mathematical model** is represented by a **pseudocode** that allows you to easily switch to coding.

The code must possess the qualities of readability and comprehensibility and to be modified in those parts that do not satisfy it.

You must start with valid and very simple models, complicating them as soon as their validity has been verified: this allows you to follow the evolution of the model without neglecting its precision.

If the model takes into account the approach to simulation with which the programming language used is conceived, the **coding** will be easier since it will consist of replacing the actions provided in the pseudocode with the instructions of any language, which relies on that philosophy: the effect is the extreme versatility of the model;

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

d) analysis of the simulation model

The **accuracy of the model** created must be verified.

Usually this is done through a **conceptual analysis** of the model that can be carried out together with the experts of the application sector in order to highlight any errors and/or omissions.

In fact, it is essential that the **model faithfully reproduces the system** in question to avoid conducting excellent experiments on an incorrect model;

e) choice of software and construction of a program

Once the model is built, it must be translated into a program. For this purpose it is possible to use different tools: "**general purpose**[1]" **languages**, **general simulation languages** and **simulators**;

[1] Identifies languages characterized by a certain versatility, suitable for many uses and not specialized for particular needs

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

f) **validation of the simulation model**

Model validation refers to the **process of confirming that the model actually achieves its intended purpose**. In most situations, this will involve confirmation that the model is predictive under the conditions of its intended use.

It is necessary to check whether the model that has been created provides **valid results** for the system in question; more specifically it must be checked whether the **performance measures** of the real system are well approximated by the measures generated by the simulation model. This is very difficult to do, especially in the design phase when the real system does not exist.

The **model verification phase** is a process that establishes whether the program faithfully represents the system to be simulated.

By memorizing the history of each individual process and rereading it subsequently, it can be verified that the logic of the model is correct.

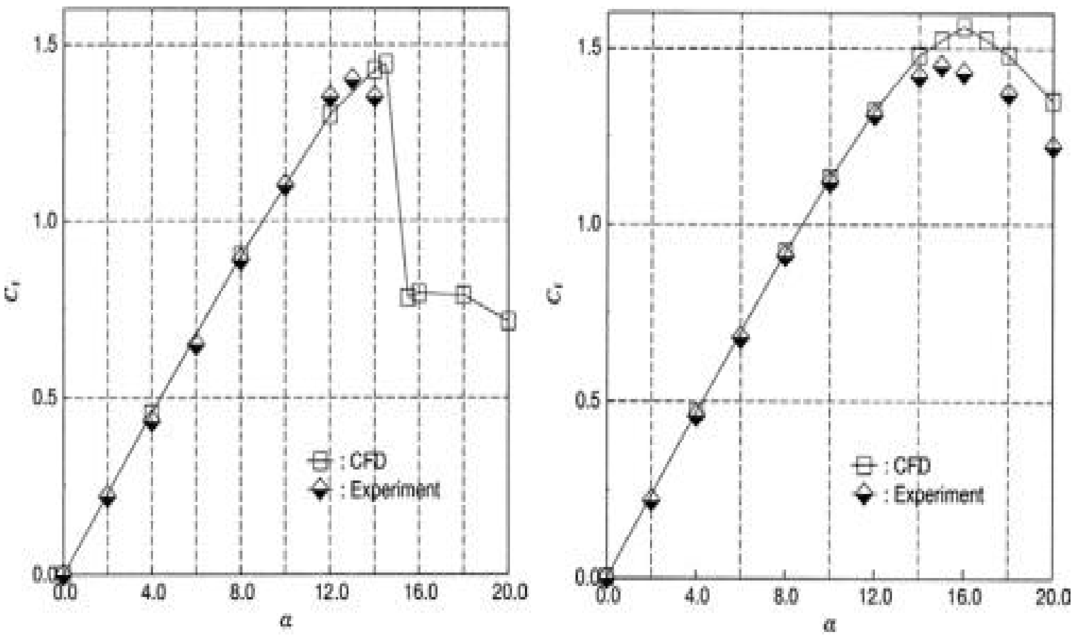
NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

f) validation of the simulation model

The use of **graphic animation functions** allows to observe the flow of entities within the system, helping to understand if the program is executed according to the intentions.

The **validation of the model** is a process that establishes the existence of an adequate level of accuracy to guarantee the correspondence between the model and the real system. It must always be kept in mind that a simulation model is still an approximation. Increasing the validity of a model beyond a certain level could be useful, but not economic, due to the excessive research and acquisition of data that would be necessary, and the heaviness in the development of the related software.



a) $NACA63_1 - 012$ b) $NACA63_3 - 018$

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

g) simulation design

The design phase is normally divided into three phases:

determination of the transient length of the system before it reaches stationary conditions (**warm-up period**), the moment from which you start to collect data if you want system performance measures in steady state

determination of the simulation length (duration) after the system has reached equilibrium.

It should always be borne in mind that simulation does not produce exact values of the performance measures of a system as each individual simulation can be seen as a "**statistical experiment**" that generates statistical observations on system performance.

These observations are then useful for producing estimates of performance measures and of course increasing the duration of the simulation can increase the precision of these estimates

determining the number of iterations to perform for each of the decision variable values

The greater the number of iterations, the greater the estimate of the expected values. The **experiment** that allows to obtain a set of values of the performance variables of a simulation model is defined, given a value of the set of decision variables. The **duration of the iterations** can be determined strictly according to statistics. In the case of presence of **uncertainty,** the determination of the number of iterations depends on the maximum limit of the **acceptable error**, which defines the **sample size** necessary for the estimates of the performance parameters to be affected, with a determined probability, by a smaller or equal error to the predetermined one. For each alternative, it is necessary to conduct various identical iterations up to having a significant sample for statistical purposes.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

h) execution of simulation experiments and analysis of results

The simulation output provides statistical estimates of **system performance measures.** Each measure is associated with a **confidence interval**, that is a range of values within which the measurement falls with "**high**" **probability.**

The analysis of the results is important for how it interacts with that of planning new experiments on the basis of the results obtained from the previous tests. It is essential to have available output data whose meaning is immediately clear and easy to interpret.

Some languages statistically process the data collected during the test run; in these cases the user can have indications in the form of average values, standard deviations, number of observations, resource utilization coefficients, diagrams and tables that highlight the relationships between the decision and performance variables. This type of information makes the model optimization phase fast enough, allowing you to immediately identify the critical points of the system;

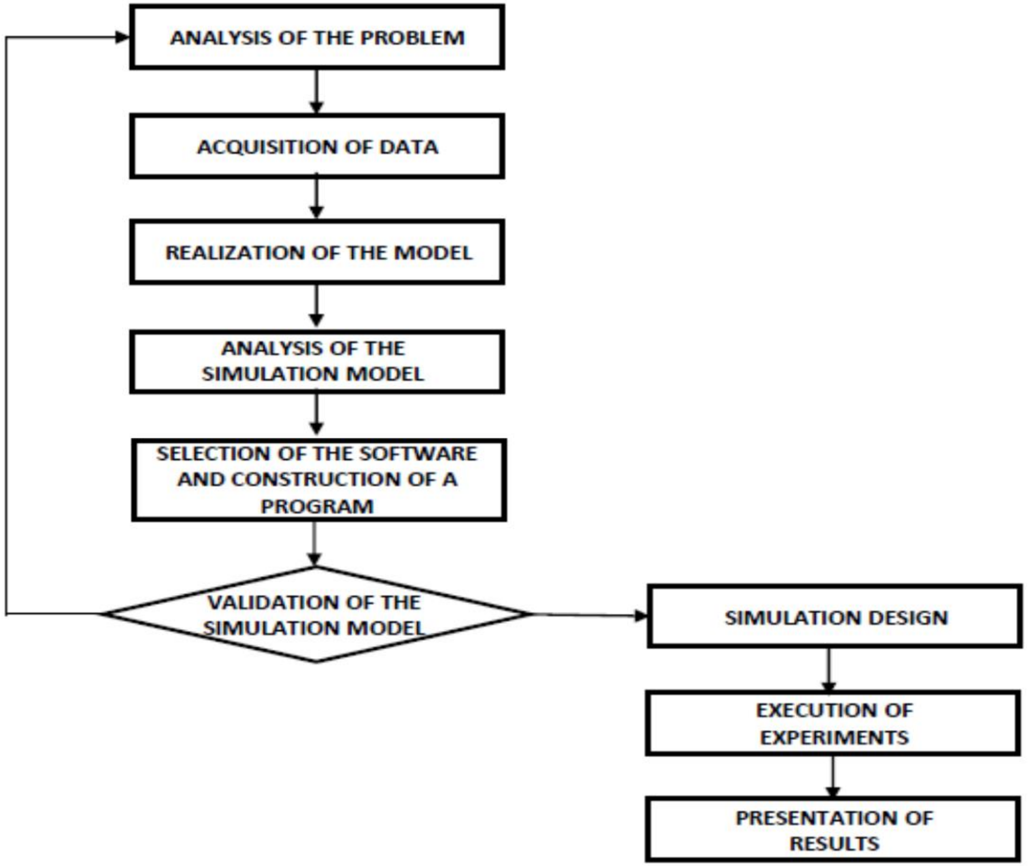
NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

i) **presentation of results**

In conclusion, it is necessary to draw up a report and a presentation summarizing the study carried out.

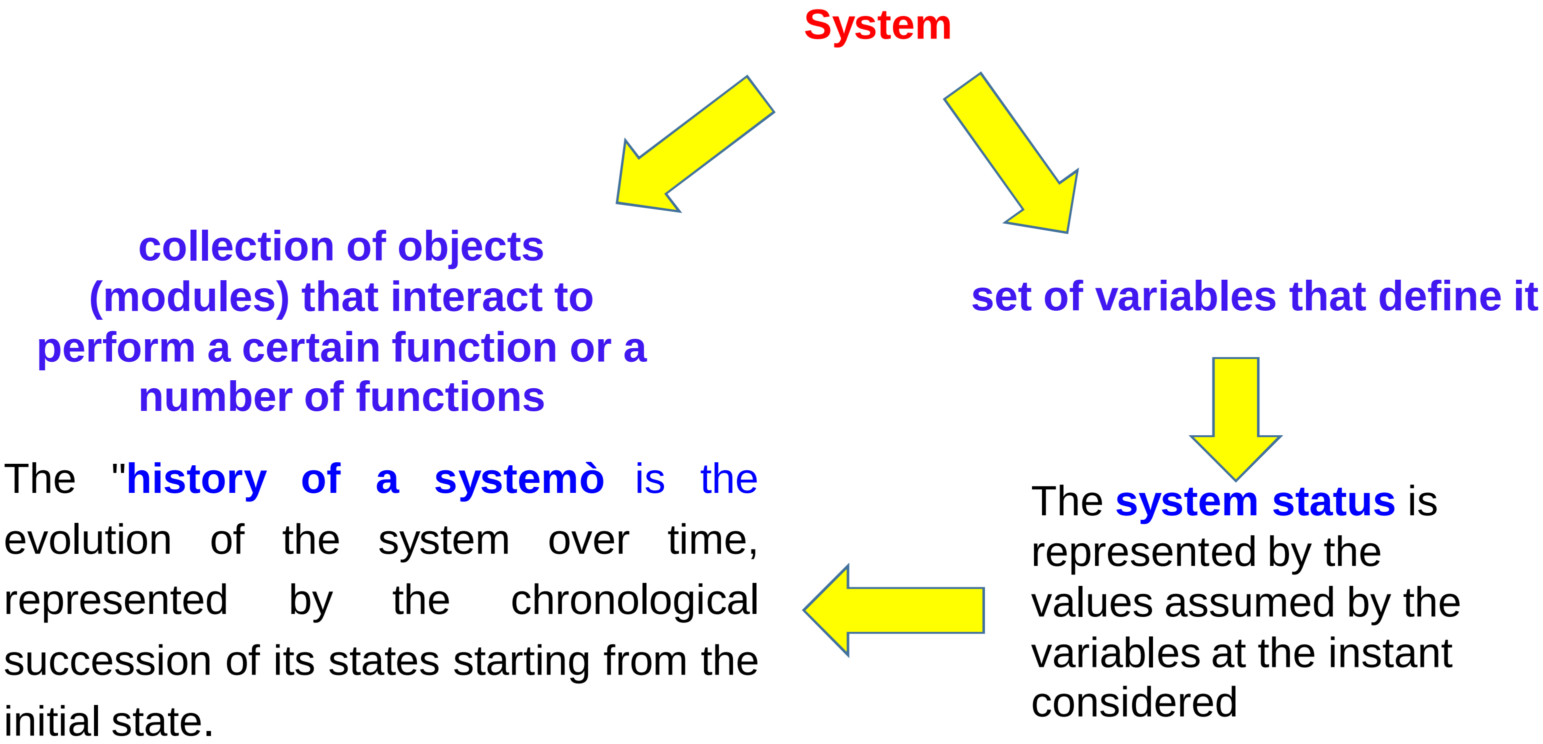
These phases, visualized by the flow diagram aside, are conceptually one after the other, but are allowed also returns to the previous phases, since the fundamental requirement for obtaining a good simulation tool is that they are possibly the most correct. There are stages, such as that of model realization, which must be very precise to avoid conducting excellent experiments on a completely incorrect model.



NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Systems and models



System

collection of objects (modules) that interact to perform a certain function or a number of functions

set of variables that define it

The **system status** is represented by the values assumed by the variables at the instant considered

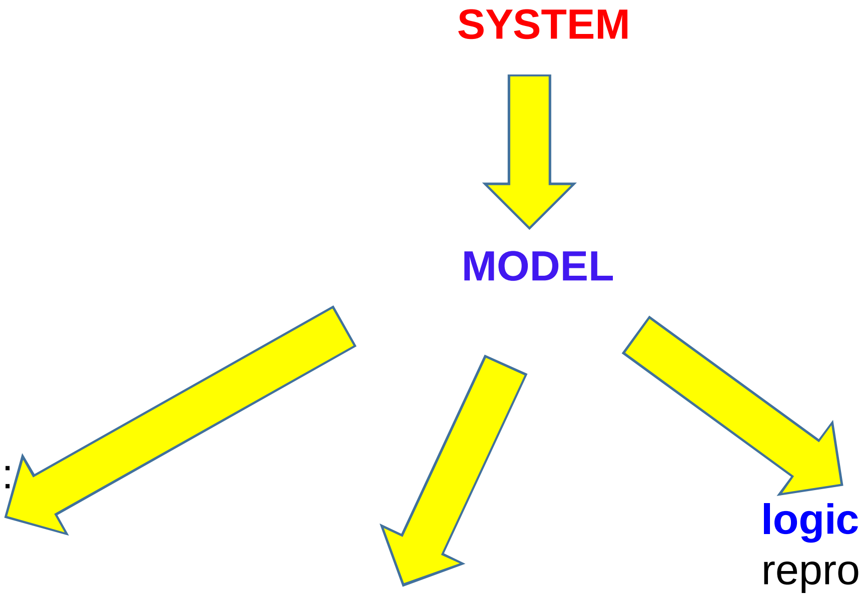
The "**history of a systemò** is the evolution of the system over time, represented by the chronological succession of its states starting from the initial state.

The term **system** is commonly adopted to define the subject of a trial. In engineering technique, the object of study and experimentation can be a fluid dynamic system, but also a production plant, an economic system or a control equipment.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Systems and models



SYSTEM

MODEL

icastic or pictorial models: they are those obtained with scale and functional reconstructions

analogic models: they are physical and are based on principles other than the real system while retaining a formal analogy (for example electrical, hydraulic and thermal analogies)

logical-mathematical models: they reproduce the system with a set of logical-mathematical and statistical relationships where parameters and variables, priority and/or exclusion rules and appointments are assumed in order to faithfully reproduce the functioning of the system over time

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

logical-mathematical models

deterministic models

They do not take into account the element of random variability and **can be solved with exact methods of mathematical analysis or numerical calculation.** In other words, the evolution over time of the built model is univocally determined by its characteristics and initial conditions. The simulation of these models will generate one and only one possible story.

Deterministic models assume that known average rates with no random deviations are applied to large populations. For example if 10,000 individuals each have a 95% chance of surviving 1 year, then we can be reasonably certain that 9500 of them will indeed survive.

stochastic models

They are characterized by the possibility of taking into account **probability distribution of elements, components and variables, considering them as random variables.** In this case, we use the model's ability to generate random numbers. In this type of systems there is no longer a one-to-one correspondence between the data and the system's history, since there are no longer only and exclusively exact relationships, but also some probability density functions. This leads to an **infinite number of possible stories** starting from a certain set of assumptions; the main operating characteristics of the system will be extracted from the sampling of several possible stories.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

logical-mathematical models

Stochastic models approximate reality in a much more effective way than **deterministic ones**, although they are definetely more complicated.

Classification according to the way the system evolves over time into:

static models, which represent the system in a given instant;

dynamic models, which represent the constantly evolving system.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

logical-mathematical models

Classification according to the way the system evolves over time into:

dynamic models

continuous models

State variables vary continuously over time. The model is created using differential equations which can be solved with analytical methods or with numerical integration methods using the computer;

discrete models

Status variables vary only at certain time intervals.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Operations of the simulation model Objects

Let's consider **our shop example** and let's construct and implement a simulation model. At this stage, we can neglect some implementation details. These could be formalized later on.

Assumptions:

- the **queue in the shop is possibly infinite**: whenever a customer arrives she will stay in the queue independent of how many customers are already queuing and he/she will wait until he/she is served.
- customers are served on a **first-come, first-served basis (FIFO)**.
- there are **two employees**. On average they take the same time to serve a customer. Whenever an employee is free, a customer is allocated to that employee. If both employees are free, either of the two starts serving a customer.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Operations of the simulation model Objects

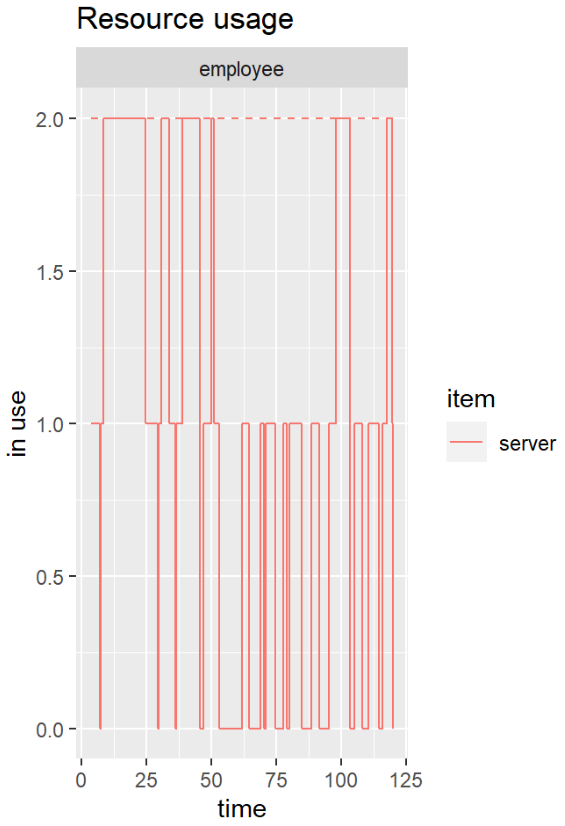
The components of the simulation model are the following:

- **System state:** $N_C(t)$ number of customers waiting to be served at time t, $N_E(t)$ number of employees busy at time t.
- **Resources:** customers and employees;
- **Events**: arrival of a customer; service completion by an employee.
- **Activities:** time between a customer arrival and the next; service time by an employee.
- **Delay:** customers’ waiting time in the queue until an employee is available.

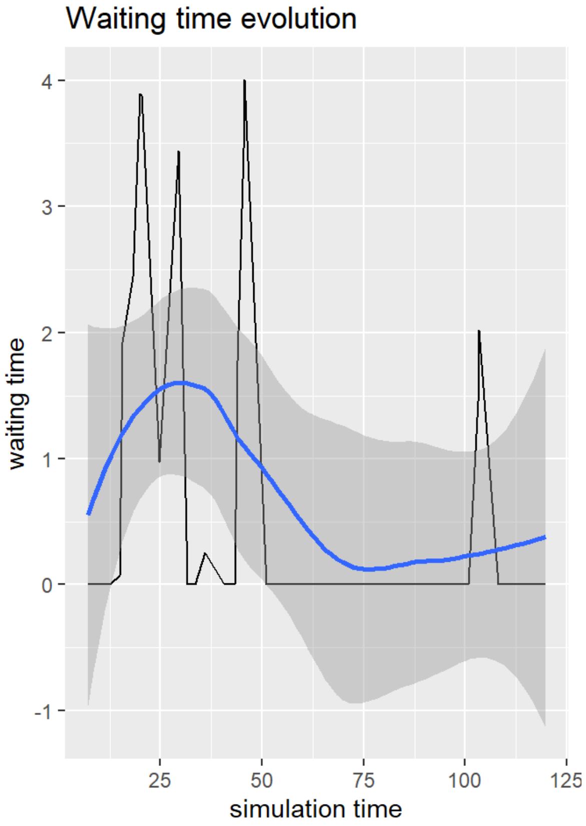
From an abstract point of view we have now defined all components of our simulation model. Before implementing, we need to choose the length of the activities. This is usually done using common sense, intuition or historical data. Suppose for instance that the time between the arrival of customers is modeled as an Exponential distribution with parameter 1/3 (that is on average a customer arrives every three minutes) and the service time is modeled as a continuous Uniform distribution between 1 and 5 (on average a service takes three minutes).

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Operations of the simulation model Objects



(minutes)



(minutes)

The left plot reports the **number of busy employees** busy throughout the simulation. We can observe that often no employees were busy, but sometimes both of them are busy. The right plot reports **the waiting time of customers throughout the simulation**. Most often customers do not wait in our shop and the largest waiting time is of about four minutes.

Some observations:

Åthis is the result of a single simulation where inputs are random and described by a random variable (for instance, Poisson and Uniform). **If we were to run the simulation again we would observe different results**.

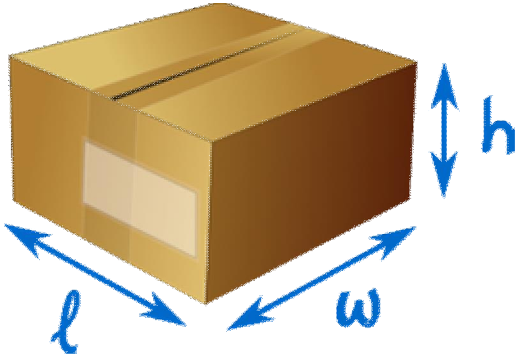
Ågiven that we have built the simulation model, it is easy to change some of the inputs and observe the results under different conditions. For instance, we could investigate what would happen if we had only one employee. We could also investigate the use of different input parameters for the customer arrival times and the service times.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Mathematical model

Space?

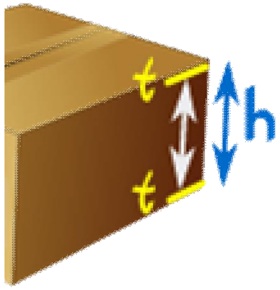
V = l x w x h



Accurate? Useful?

Vi = (l ï 2t) x (w ï 2t) x (h ï 2t)

Ve = l x w x h



Example: Your company uses 200x300x400 mm size boxes, and the cardboard is 5mm thick. Someone suggests using 4mm cardboard … how much better is that?

Vi = (l ï 2t) x (w ï 2t) x (h ï 2t)

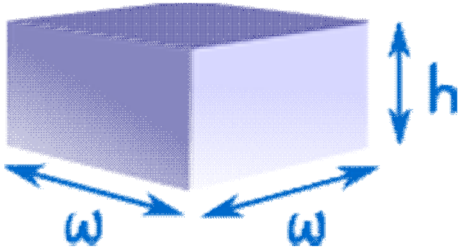
5 mm → 4 mm = -20%

$V_{i5} \rightarrow V_{i4}$ = about -2%

NUMERICAL SIMULATION

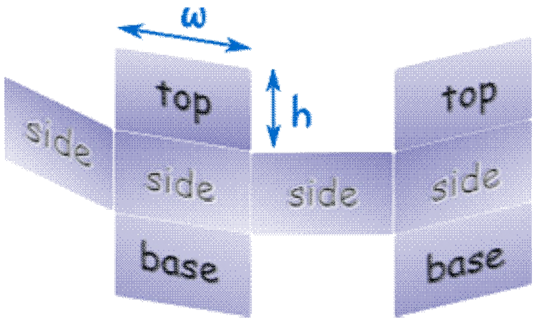
General scheme of the study of a problem based on simulation
Mathematical model

It has been decided the box should hold **$0{,}02 m^3$** (0,02 cubic meters which is equal to 20 liters) of nuts and bolts.
The box should have a square base, and double thickness top and bottom.
Cardboard costs **\$0,30** per square meter.
It is up to you to decide the most economical size



Ignoring thickness for this model:

$$\text{Volume} = w \times w \times h = w^2h = 0{,}02\ m^3$$



Areas:

$$\text{Area of the 4 Sides} = 4 \times w \times h = 4wh$$
$$\text{Area of Double Tops and Bases} = 4 \times w \times w = 4w^2$$

Total cardboard needed:

$$\text{Area of Cardboard} = 4wh + 4w^2$$

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Mathematical model

Cardboard costs **$0,30** per square meter.
What is the most economical size?

We want a single formula for cost:

$$\text{Cost} = \$0{,}30 \times \text{Area of Cardboard} = \$0{,}30 \times (4wh + 4w^2)$$

function with two variables and one parameter.

$\text{Volume} = w^2h = 0{,}02 \quad \rightarrow \quad h = 0{,}02/w^2$

$$\text{Cost} = \$0{,}30 \times (4w\times\mathbf{0{,}02/w^2} + 4w^2)$$

$$\text{Cost} = \$0{,}30 \times (0{,}08/w + 4w^2)$$

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Mathematical model

If we plot the curve $y= 0,3(0,08/x+4x^2)$ (parabola) taking widths between 0,0 m and 0,55 m

It is evident that **the cost reaches a minimum (ab. 0,17) at about 0,22 of width**

Infact, looking at the graph, the width could be anywhere between 0,20 and 0,24 without affecting the minimum cost very much.

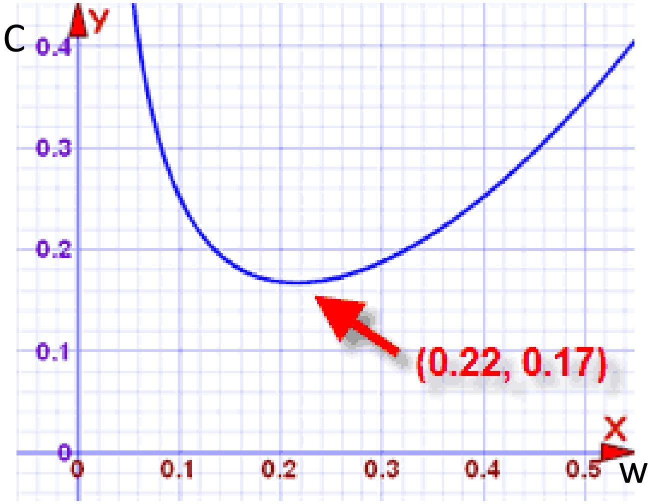
Further considerations

Using this mathematical model you can now recommend:

- Width = 0,22 m
- Height = $0,02/w^2 = 0,02/0,22^2 = 0,413$ m
- Cost = \$0,30 × $(0,08/w+ 4w^2)$ = \$0,30 × $(0,08/0,22+ 4×0,22^2)$ = 0,167 \$/box

But any width between 0,20 m and 0,24 m is fine.
You might also like to suggest improvements to this model:

- Include cost of glue/staples and assembly
- Include wastage when cutting box shape from cardboard.
- Is this box a good shape for packing, handling and storing?



NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Systems and models

All real systems are continuous, while all digital simulations are discrete. This distinction makes sense only if you consider it as an approach to the problem and it is more effective for the analysis to be conducted and for the formulation of the model. This must have such a **degree of detail** that the results extrapolated to the real system can be considered sufficient.

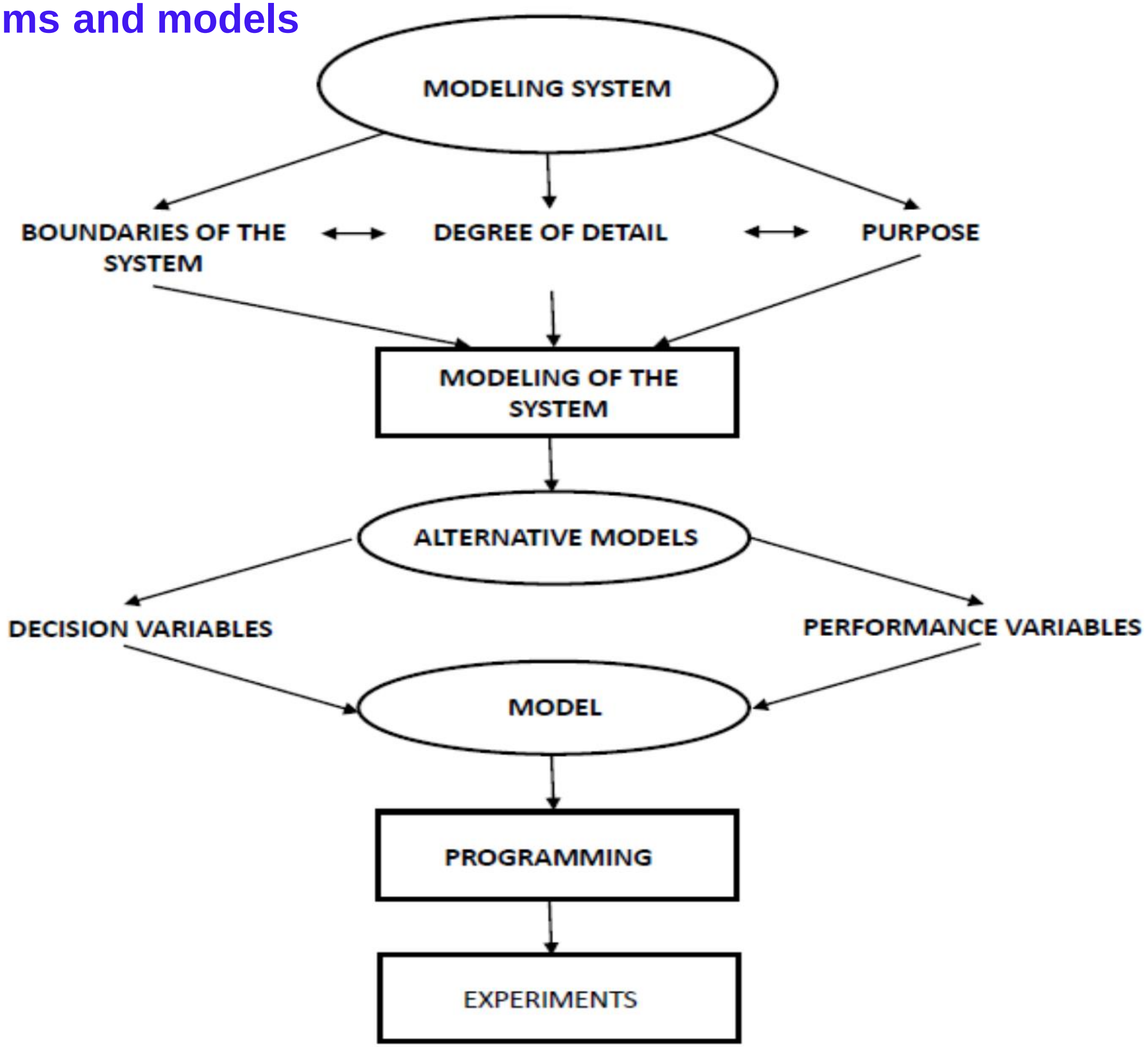
Although **continuous simulation** is carried out using numerical calculation programs that discretize the domain, even if with very fine intervals, this approach is chosen because one is interested in knowing, instant by instant, the evolution of the system; on the contrary, the **simulation for discrete events** is adopted when the state between two consecutive events is considered unimportant.

The models that describe the most complex systems are made up of a combination of these two: some variables will be integrated continuously, while others will evolve discretely in the model.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Systems and models

The modeling of a system is bound by the objectives to be achieved and therefore by which quantities or state variables have the greatest significance for research (figure). **The simulation describes and analyzes only a part of the system,** the one that allows you to respond reliably to the objectives on which the simulation is based, avoiding redundancies.


MODELING SYSTEM
BOUNDARIES OF THE SYSTEM
DEGREE OF DETAIL
PURPOSE
MODELING OF THE SYSTEM
ALTERNATIVE MODELS
DECISION VARIABLES
PERFORMANCE VARIABLES
MODEL
PROGRAMMING
EXPERIMENTS

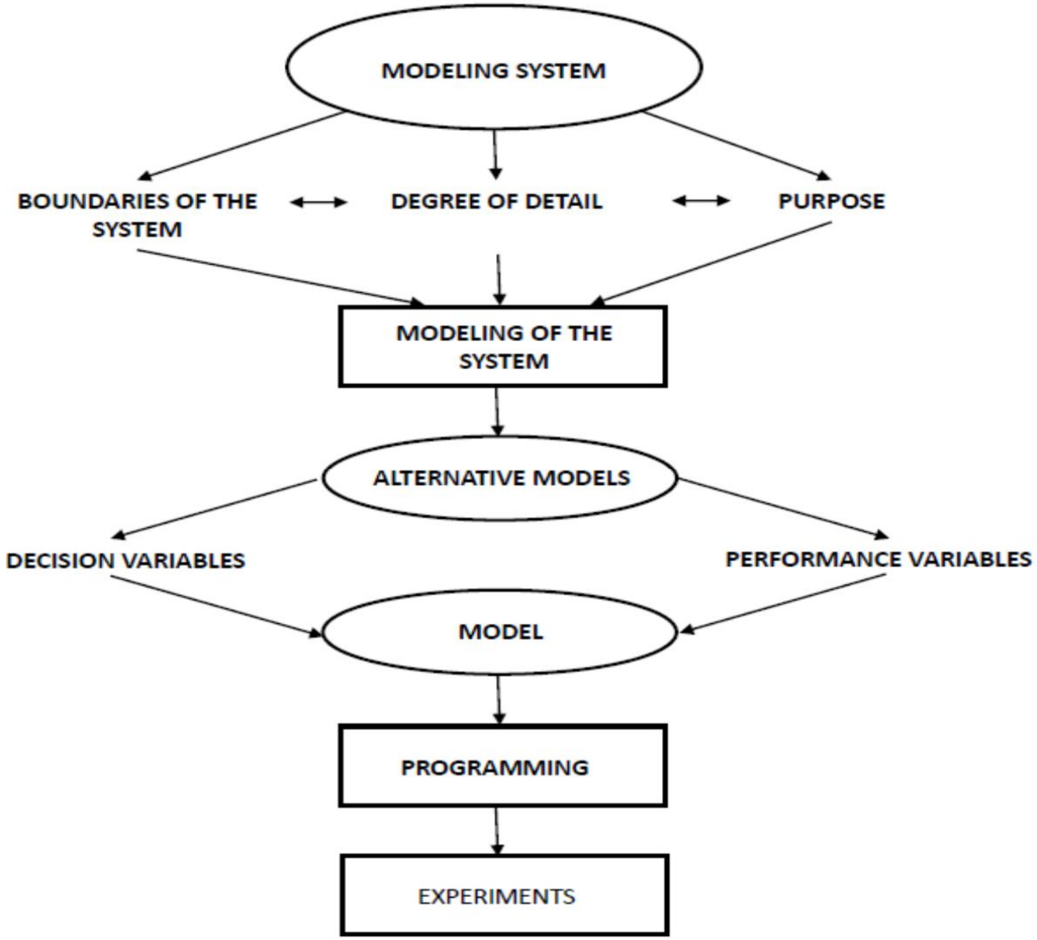
NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Systems and models

The **formulation of the model** will depend on the **degree of formalization**, therefore on the mathematical and logical complications induced (such as the stochastic variable), necessary to obtain an adequate representation of the system during its operation.

It is possible to identify **several equivalent models** having the characteristics observed in the description of the system modeling, however the final choice is also based on the practical possibility of carrying out the simulation.

The **choice** does not depend on the system, but on **the calculation resources** that are used and in particular by the simulation language and the machine available to conduct the same.



NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Systems and models

In case of **models that provide for a continuous change of state over time** and not only in correspondence with certain events, the analysis of continuous flows of material or information is required and individual entities cannot be distinguished (i.e. **economic problems, fluid dynamics, energy diffusion, etc.**).

The **mathematical model** is represented by differential or finite difference equations. These can be resolved analytically, starting from the boundary conditions if the system is not particularly complicated.

On the other hand, when the system is very complex as it happens in most real systems, **numerical analysis** with digital computers is used.

In this situation, numerical calculation methods are used to solve the differential equations, which consist of integrating the equations starting from the initial point and proceeding over time with increments such as to obtain a sufficient degree of precision and detail.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Objects of the simulation model

a) **Entities**

Entities are the components of the system (e.g. machines, materials to be processed, transport devices). In the Simulation syntax these are represented by names.

Entities are generally of two types:

- **permanent**;
- **temporary or transitions**. They are those entities that appear in the model throughout the course of the Simulation experiment. **These are represented by the objects that in the simulated system provide a service (called activity)** for the benefit of the objects that pass through the system, which are called temporary entities or transitions. **Examples of temporary entities are a machine tool, a transport mean, an operator to assembly, etc**.

Their meanings derive from the consideration that during a process transitory (dynamic) entities make use of (static) equipment in crossing the model.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

a) Entities

Permanent variables or **attributes** are defined as the numeric or logical variables that permanently characterize, (i.e. do not change over time), the quantities relating to resources, to the system as a whole or to the entities that circulate in the system (for example, **the capacity of a warehouse, the type of a part to be machined, the cycle time of a machine**, etc.).

Temporary variables or **status variables** are defined as the numeric or logical variables that instantly characterize, i.e. changeable over time, the quantities relating to resources, to the system as a whole or to the entities that circulate in the system (**for example the completeness of a warehouse, the position of a part being processed, the total working time carried out by a machine, etc**.);

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

b) Activities

Activities are the actions in which one or more entities are or have been involved; the system changes its state precisely because of these actions, which are called **verbs**. Each **activity is determined when its duration and the conditions that determine its beginning or even existence are known**; it will be easy to predict the end of an activity even when it has an uncertain duration and can be determined by a statistical distribution. As regards the conditions mentioned, **"certain" activities** cannot be confused to **"conditional"** ones. While certain activities take place despite whatever happens at the end of a certain event, the conduct of the conditional activities requires the successful passing of a test.

NUMERICAL SIMULATION

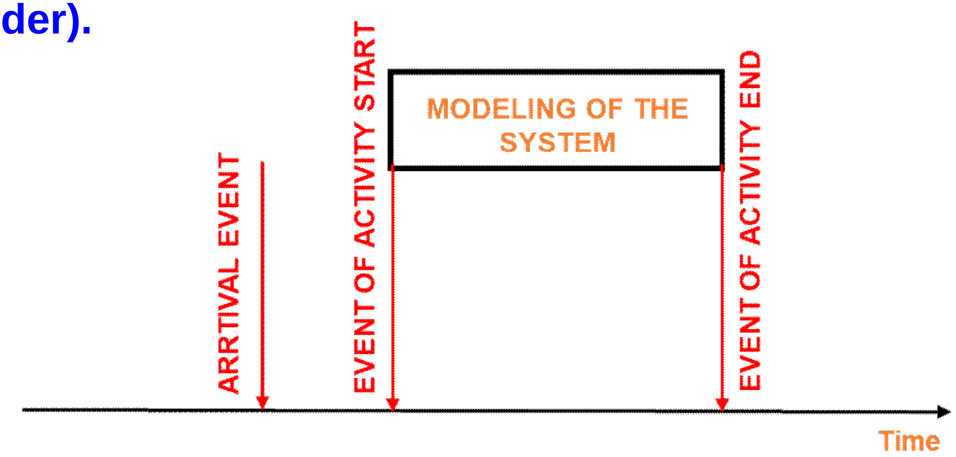
General scheme of the study of a problem based on simulation

Objects of the simulation model

c) Events

Events are the instants of time in which one or more activities begin or end; in these points the model simulates the change of state of the system. Even among events it is possible to distinguish certain ones from conditioned ones. **Conditional events** can be classified into:

- **internal** or **endogenous**, which concern events that depend on conditions inside the model (for example the **end of an operation**);
- **external** or **exogenous**, which are caused by external conditions (for example, **the arrival of a customer order).**



ARRTIVAL EVENT

EVENT OF ACTIVITY START

MODELING OF THE SYSTEM

EVENT OF ACTIVITY END

Time

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

d) queues

The **queues** are passive states of a certain entity and occur while it awaits the conditions for carrying out the operation and the next activity. In a production system there may be **queues of materials waiting for the machines** to free themselves, lots waiting for the machines to be able to evade them or, equivalently, machines queuing for lack of materials;

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

e) Attributes

Attributes are used to identify an entity's permanent characteristics, so they are not subject to change after being set. I.e. **The type and nominal performance of a machine, the number of operations for a given job, the maximum number of pieces in a warehouse and the parameters of the distributions** are some of the attributes that must be defined in the simulation of a production plant. **The attributes** are similar to adjectives and are necessary to distinguish the entity of one type from another. Other times they are indispensable to decide which waiting entities have priority over the others (if you have to choose an entity from a queue). **An attribute can be the time that the temporary entity is in the queue or its position in the storage problems.**

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

f) **series**

The series can order, under a single item, any group of similar and separate entities; therefore lists of entities can be manipulated by updating them at different times or comparing them to obtain useful information.

For example, we can refer to the **series of tools necessary to equipe a machine** and, at the same time, to that of the **tools available in the spare parts warehouse**; the two lists can be updated and compared at the same time to see which entities are not available. The modification of the series is very used and effective;

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

g) states

The state represents the situation of the variables used in the model to describe the functioning of the system in a certain instant; the status variables affecting the entities are continuously updated to allow checking the conditions on which numerous activities are based or to decide between the different possible solutions.

Like attributes, **states** are made up of alphanumeric registers in which numerical or literal values may appear; the latter can indicate, for example, if an entity is in a passive (waiting) state when it is in a queue or in an active state when it is busy in an activity.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

ENTITIES
individual elements of the system that are being simulated and whose behavior is being explicitly tracked. Each entity can be individually identified;

RESOURCES
also individual elements of the system but they are not modelled individually. They are treated as countable items whose behavior is not tracked.

Whether an element should be treated as an entity or as a resource is something that the modeller must decide and depends on the purpose of the simulation. Consider a simple shop. **Clients** will be most likely be **resources since we are not really interested in what each of them do**. **Employees may either be considered as entities or resources**: in the former case we want to track the amount of time each of them are working; in the latter the model would only be able to output an overview of how busy overall the employees are.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Objects of the simulation model

ATTRIBUTES
properties of objects (that are entities and resources). This is often used to control the behavior of the object. In our shop an attribute may be the state of an employee: whether he/she is busy or available. In a more comprehensive simulation, an attribute might be the type of food a customer will buy (for instance, chocolate, vanilla or jam).

STATE
collection of variables necessary to describe the system at any time point. In our shop, in the simplest case the necessary variables are number of customers queuing and number of busy employees. This fully characterizes the system.

LIST
collection of entities or resources ordered in some logical fashion. For instance, the customers waiting in our shop may be ordered in the so-called fist-come, first-served" scheme, that is customers will be served in the order they arrived in the shop.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Operations of the simulation model Objects

EVENT
instant of time where the state of the system changes. In our shop suppose that there are currently two customers being served. An event is when a customer has finished being served: the number of busy employees decreases by one and there is one less customer queuing.

ACTIVITY
A time period of specified length which is known when it begins (although its length may be random). The time an employee takes to serve a customer is an example of an activity: this may be specified in terms of a random distribution.

CLOCK
Variable representing simulated time.

DELAY (QUEUE)
Duration of time of unspecified length, which is not known until it ends. This is not specified by the modeller ahead of time but is determined by the conditions of the system. Very often this is one of the desired output of a simulation. For instance, a delay is the waiting time of a customer in the queue of our shop

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Simulation time concept

In the **simulation technique** it is useful to make a distinction between the different concepts of time:

a) real time

It is the one in which the system evolves, so it is a continuous variable;

b) simulated time

It is the abstraction of real time in the model and is represented by an internal variable also called simulation current time; this is certainly not continuous because it is updated in correspondence with specific critical moments that do not necessarily coincide with an event. In general the advancement methods are:

- **progress by events**: the time is updated precisely at events;
- **advance by intervals**: the situation is updated at intervals, often constant, of a predetermined length.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Simulation time concept

The **simulation time** is defined by the duration of the operation, while the **processing time** is only for the time necessary to change the state of the system, i.e. all the logical and mathematical operations necessary to update the system.

Real time is the sum of all the durations of the activities, while the **processing time** results from the product of the number of state changes (approximately equal to the number of activities) for the time necessary for the processor to manage the logical-mathematical operations required.

The experiment ends when the **simulated time** value reaches the set time.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation Systems and models

First of all, the **state variables** that are of interest in Simulation are established and, subsequently, the way in which the **model** evolves over time starting from the known initial conditions is described.

Assuming that $X_i(t)$ is the i-th quantity at time t and that X(t) represents the whole, the state and evolution of the system takes place by defining an expression that can symbolically be represented by:

$$X(t + dt) = g(X(t), Z(t), W)$$

where:

Z(t) = values of external variables;

W = parameters;

g = function that specifies the functioning of the system.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Countinous model

Developing a **continuous model** means identifying the variables Z(t), determining the function g and making a sufficient number of iterations; if no random variables are introduced, only one iteration will be sufficient for each alternative.

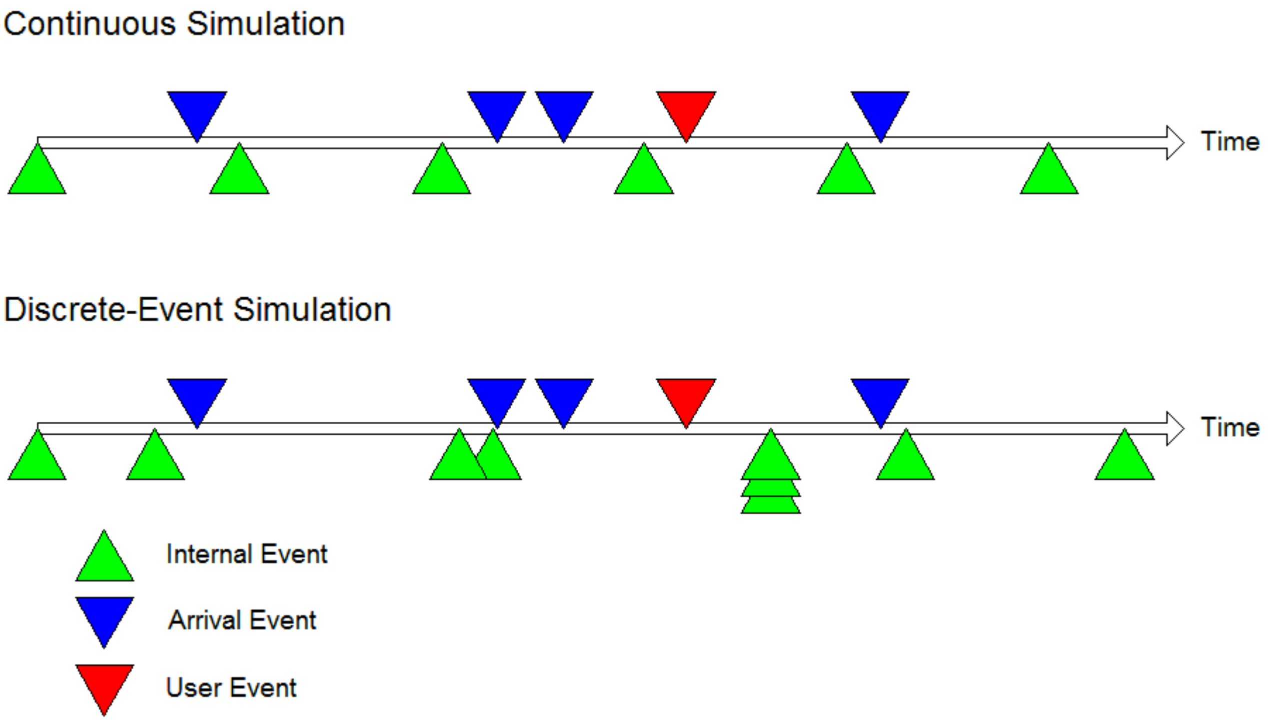
The answer is represented by the series of $X_i(t)$ relating to the values of t taken at intervals dt. The increase or step influences the progress of the assessments: if on the one hand narrower intervals increase the accuracy, on the other there is an increase in the calculation time. each interval.

The determination of the optimal step is made by attempts or with automatic increase control methods; in this way the program changes the step to stay within the maximum error limit allowed for for each interval.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Countinous model

Consider the timing diagram aside. Letôs imagine that we have **two systems** that are each initialized and have some processes taking place. Events associated with these processes are shown on their respective timelines in green. As you can see, in the **continuous simulation the events occur at regular intervals,** while in the **discrete-event simulation the events occur at irregular intervals.** It is also possible for multiple events to occur at exactly the same time in the discrete-event simulation (shown by the stacked events in green).
Events occurring at the same time can be processed in order of arrival or by some sort of priority defined within the system. **All events in continuous simulations are processed at the same time,** though they may be handled in a specified order within the block of processing done on that interval



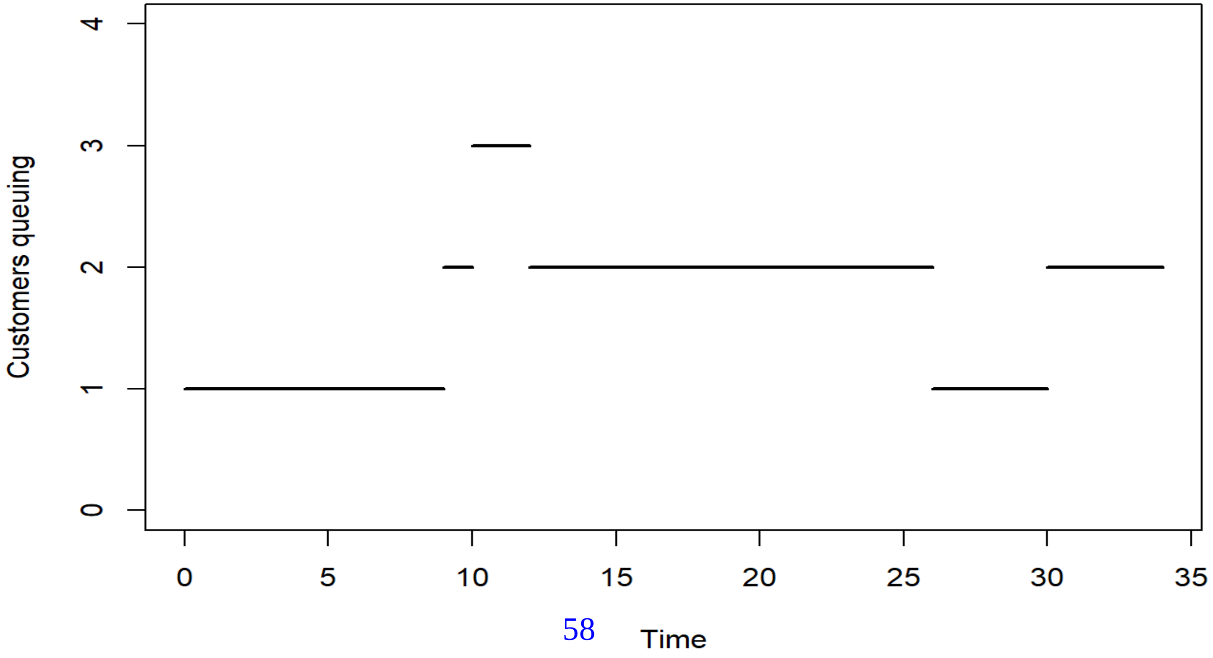
Now let’s consider the arrival of **new entities into each system**, shown in blue. In the discrete-event simulation these events are processed when they occur. In the continuous simulation these events are likely to be buffered and the processing is likely to be done on the next regularly-scheduled event interval. The same is true of user events, shown in red.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Discrete model

This type of **Simulation** assumes that the state variables, which appear in the mathematical model, have certain values only in correspondence to a discrete set of points in time.

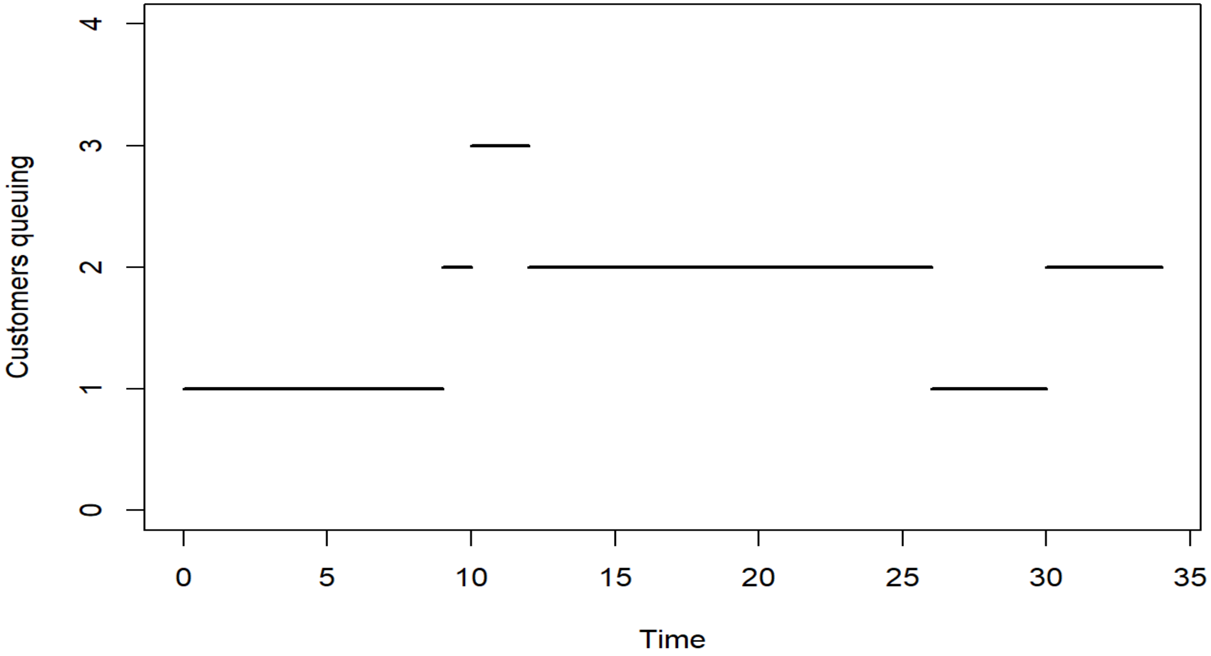
The number of people queuing in front of the cashier unit in a shop is an example of a discrete simulation. The number of customers changes only when a new customer arrives or when a customer has been served.



NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Discrete model



We see that for specific period of times **the system does not change state**, that is the number of customers queuing remains constant. It is therefore **useless to inspect** the system during those times where nothing changes. This suggests the way in which time is usually handled in dynamic discrete simulations, using the so-called ***next-event technique***. The model is only examined and updated when the system is due to change. These changes are usually called ***events***

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation
Mixed model

This type of simulation is obtained from the contextual application of aspects related to **continues and discreet simulation**; this solution arises from the consideration that a real system is described more completely simultaneously by continuous and discrete variables.

The interactions between the two groups of variables can be schematized as:

- a discrete event can cause a discrete change of a continuous variable;
- a discrete event can initiate a process which will then determine the change of a continuous variable;
- a discrete event can take place when the continuous state variable reaches a certain value

Both **temporal** and **state events** are characteristic of this approach; the former include all those whose execution is programmed to take place in certain instants, while the latter group those events that occur when a state variable takes on a certain value.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Simulation time concept

In the **simulation technique** it is useful to make a distinction between the different concepts of time:

real time

It is the one in which the system evolves, so it is a continuous variable

simulated time

It is the **abstraction of real time** in the model and is represented by an internal variable also called **simulation current time**; this is certainly not continuous because it is updated in correspondence with specific critical moments that do not necessarily coincide with an event. In general the advancement methods are:

advance by intervals: the situation is updated at intervals, often constant, of a predetermined length.

progress by events: the time is updated precisely when events happen

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Simulation time concept

The **simulation time** is defined by the duration of the operation, while the **processing time** is only for the time necessary to change the state of the system, i.e. all the logical and mathematical operations necessary to update the system.

Real time is the sum of all the durations of the activities, while the **processing time** results from the product of the number of state changes (approximately equal to the number of activities) for the time necessary for the processor to manage the logical-mathematical operations required.

The experiment ends when the **simulated time** value reaches the set time.

NUMERICAL SIMULATION

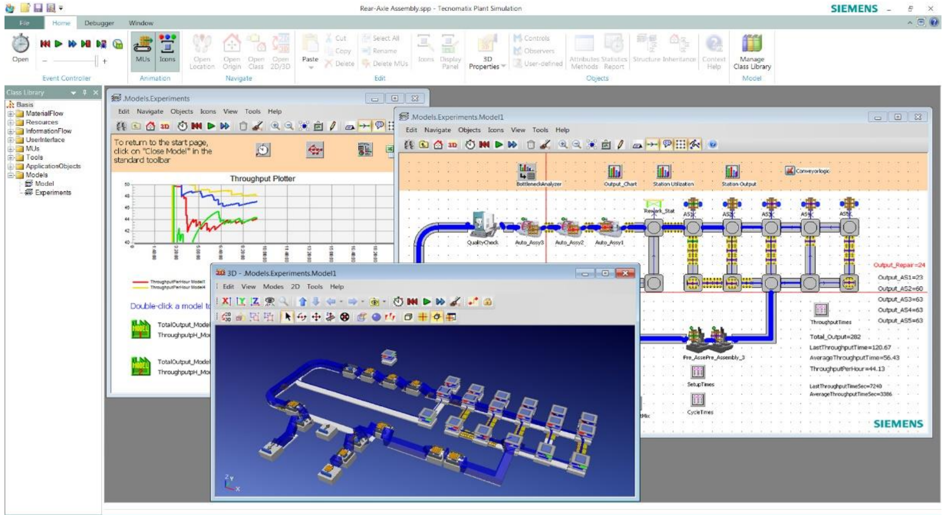
General scheme of the study of a problem based on simulation

Synchronous simulation or for constant intervals

The **progress of time** is managed by an appropriate internal variable (called **clock** or **simulated time**), generally initialized to zero or to the predetermined time of the start of simulation. With this method, time advances in constant increments (hours, minutes, seconds).

Together with the clock, a suitable **list** is also created which stores, from time to time, **the future events and the respective activation times to allow the identification of the event following a change of state**: between two consecutive updates, a procedure is carried out check to identify which events will take place in that time interval.

If multiple events have been identified, then the Simulation manager will carry out all these events and update the system only at the end of the time interval.



NUMERICAL SIMULATION

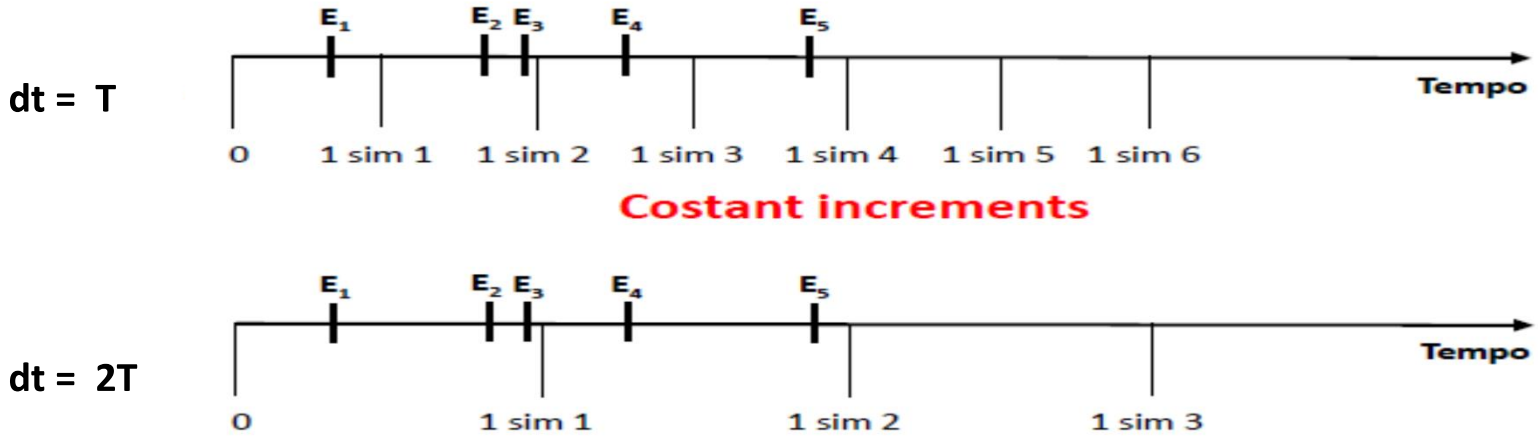
General scheme of the study of a problem based on simulation

Synchronous simulation or for constant intervals

Although there is an extreme **simplicity of implementation of the programs** that are based on these assumptions, there are also several drawbacks that affect the proper functioning of the experimentation.

The first notable inconvenient lies in the fact that the **events distinguished over time, but very close to each other, so much so as to fall in the same interval, are then concomitant**; the program must necessarily be equipped with a procedure that determines the precedence between these events.

Influence of the minimum increase in time on the degree of detail of the synchronous simulation



NUMERICAL SIMULATION

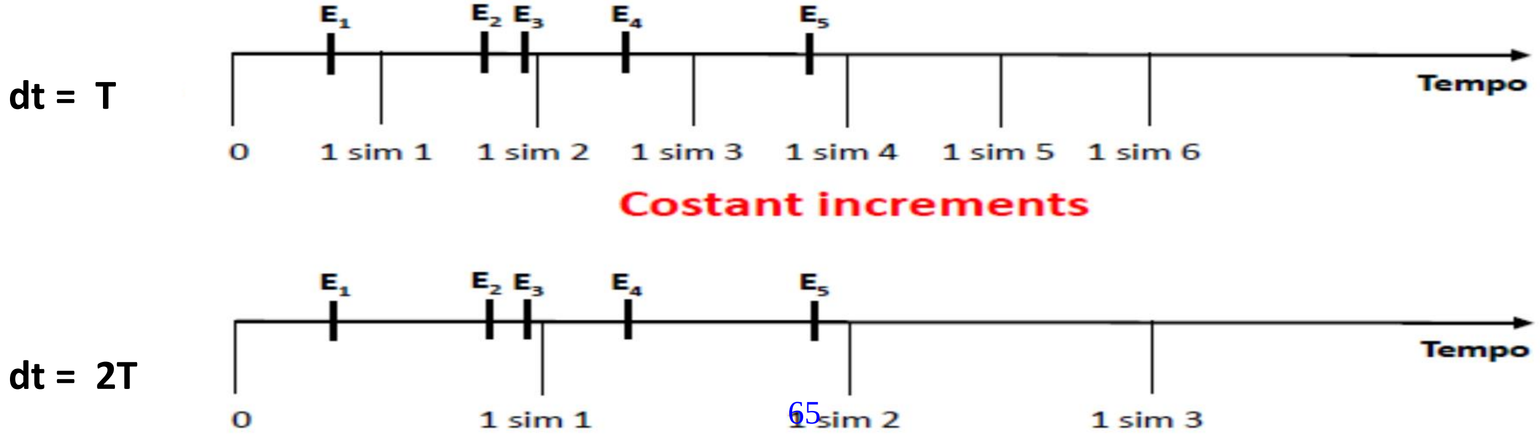
General scheme of the study of a problem based on simulation

Synchronous simulation or for constant intervals

A second problem is represented by the **shift in the time axis of the events** and although this is generally very limited it can cause significant errors in the development of the model.

Finally, since updates occur at multiple intervals, even when the model foresees a waiting state (faults or queues), **the program continues to carry out checks and updates, working ineffectively until the system's waiting state ends**; this implies an unuseful consumption of the calculation time at the expense of the speed of program execution.

The size of the intervals plays an important role: decreasing them, it limits the error of the translation of the events and improves the degree of detail of the Discreet Simulation so as to make it tend to the continuous one, on the other hand increases the machine time so as to be sometimes prohibitive.



NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Asynchronous simulation or for events

This method differs from the previous one only in the concept of **advancing time**, while the **list of future events** is used in the same way as synchronous simulation; in this case the **clock** advances irregularly of what is necessary for the development of the closest event on the list, which is updated at the same time.

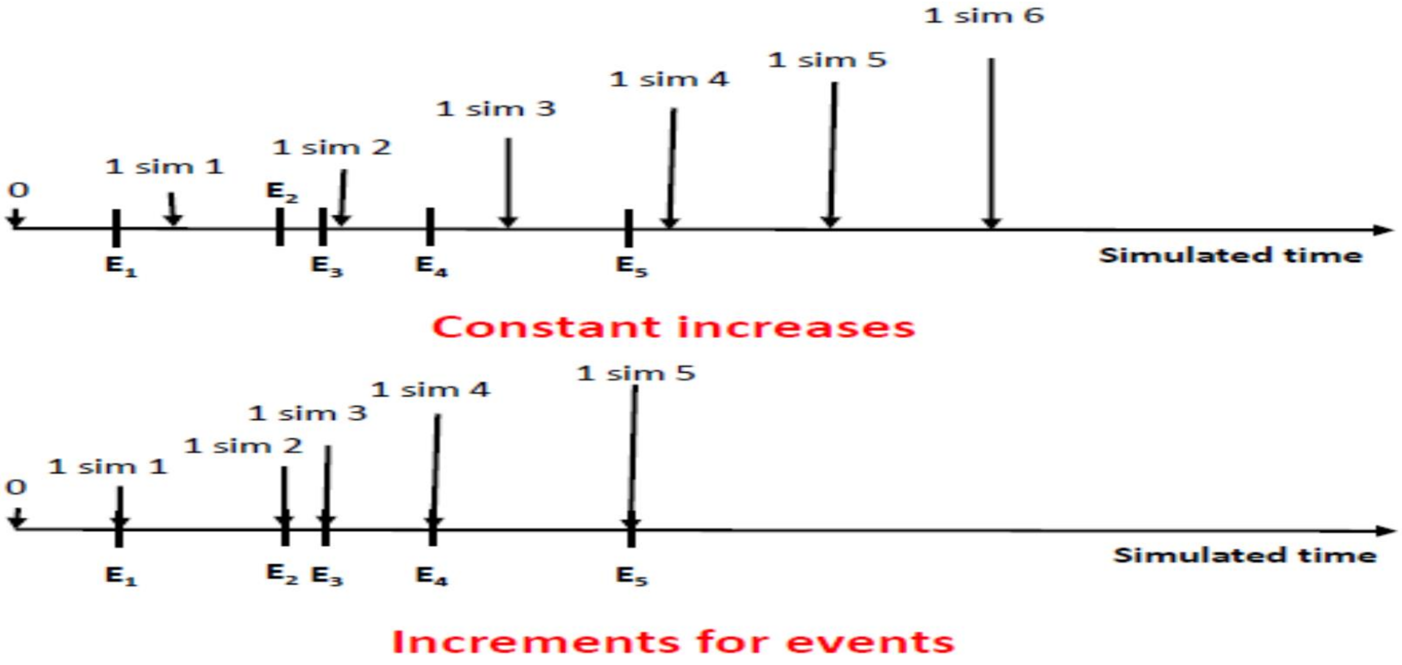
The first advantage is linked to the **saving of the calculation time** because during the waiting states, in which everything remains unchanged, the computer does not work. Machine time will only be consumed in correspondence with the first event that changes the state after inactivity.

NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

Asynchronous simulation or for events

The diagram in the figure shows the points where the computer works with the two methods and the consumption of machine time.



Comparison of time progress for intervals and for discrete events. The vectors module qualitatively represents the progressive consumption of the computing time of the computer

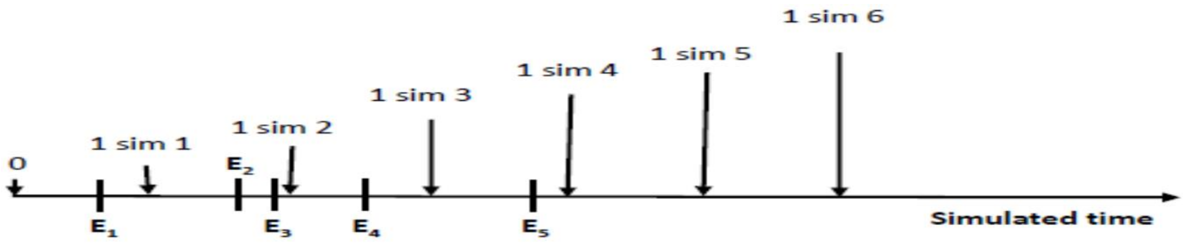
NUMERICAL SIMULATION

General scheme of the study of a problem based on simulation

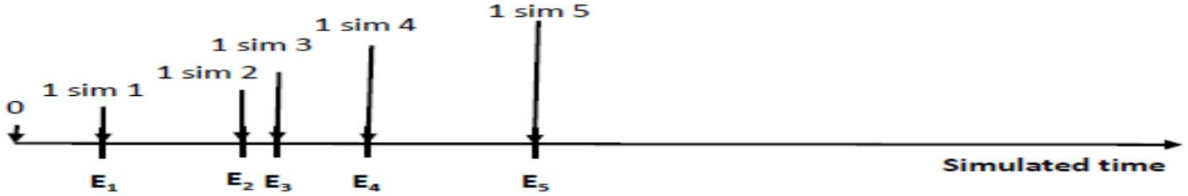
Asynchronous simulation or for events

From the diagram in the figure a second advantage of this approach can be deduced compared to that for constant intervals: two events in general are never concomitant (unless they have the same instant of occurrence), as sometimes happens for the constant step method; moreover, the simulation time in the first case is described in the succession of the times t_i which generate the events E_i, while in the second case it is independent of the instants in which the events occur. In this case, the registration of the events during the experiment can also be noted.

From what has been observed, it is quite obvious that **simulations with advancement of time for events are preferable**.



Constant increases



Increments for events

NUMERICAL SIMULATION

Three approaches for simulation

The advancement of the simulated time occurs by updating the clock for each new event. However, when you find yourself coding the program, you need to decide how to use the logical-mathematical relationships contained in the model to choose future events in an appropriate way to advance simulation over time.

In general, the **approaches** followed to organize the executive procedure of the program are based on three differently oriented philosophies:

Activities-oriented programs

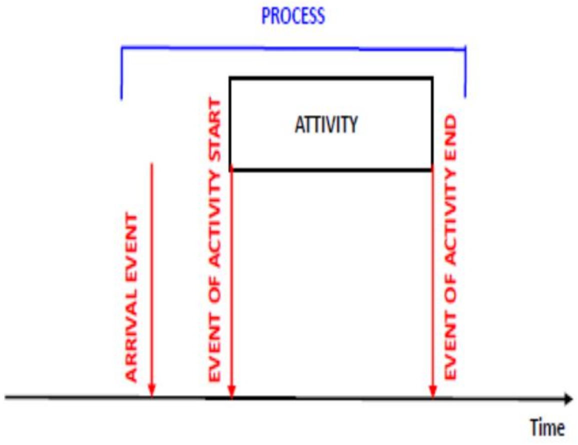
Process-oriented programs

Event-oriented programs

NUMERICAL SIMULATION

Three approaches for simulation

Activities-oriented programs means using **procedures that describe the development of individual activities**, determining their duration and end, in which the system is updated; an executive procedure manages them and determines their start.



Event-oriented programs use **procedures to describe the conditions necessary for an event**, foreseen in the model, to take place together with the relative change of state. The **classic approach** to **discrete simulation** is the **event-oriented one**. The routine are written to describe the discrete events of a system's operations.The operations that can be performed by a CNC machine on a piece are:

- **arrival of a piece to work;**
- **entry into the waiting queue upstream of the machine;**
- **execution of the operation;**
- **out of the machine**.

Process-oriented programs means that the code is developed mainly to generate single **procedures to describe the process to which all entities are subjected over time**; similar procedures are generated for each class in which the entities are divided. **The process approach simplifies the creation of complex models since it allows you to describe the behavior of an entity**