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Business Process Simulation

Lecture 1

Laura Genga

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Short intro

Education

- PhD in Engineering Science, curriculum Computer Automation and Management Engineering (2016)

Current Position

- Assistant Professor at TU/e (dal 2019)

Research interests

- Business Process Management, Process mining, Artificial Intelligence

Overview on lecture modules

a) Introduction to simulation
b) Seven steps methodology
c) Step 1: Project definition
d) Step 2: Design the study

Course Objectives

To be able to apply discrete event simulation as a tool for the analysis of performance problems in industrial (service, manufacturing, logistic) systems

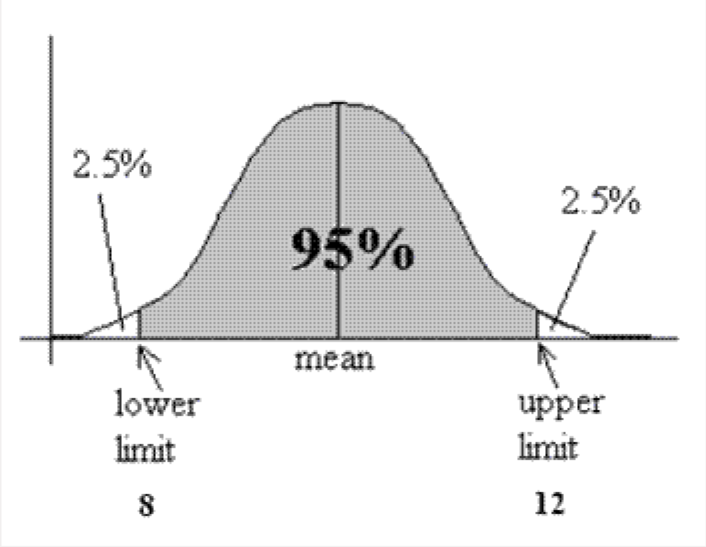
To understand and apply the (presented) simulation methodology

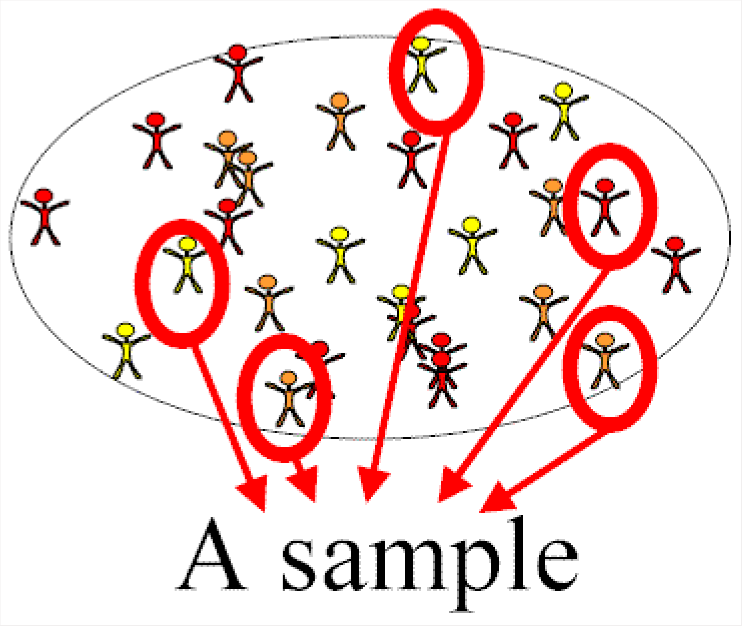
To integrate knowledge on process and data modelling, statistics, stochastic operations research and logic

Prior knowledge

Python programming

Statistics





Additional Material

Banks et al. : Discrete-Event System Simulation
Law and Kelton. Simulation, Modeling and Analysis.

Simulation

Can you provide your definition of *simulation?*

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Simulation

Simulation is the imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviours of a selected physical or abstract system

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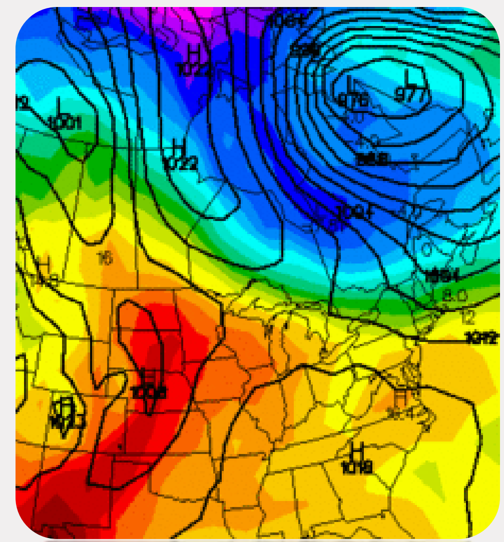


Definitions of simulation

The art and science of creating a representation of a process or system for the purpose of experimentation and evaluation
(Gogg and Mott, 1996)

Computer simulation is the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer
(Pritsker, 1986)

Simulation is the imitation of the operation of a real-world process or system over time
(Banks, Carson, & Nelson, 1996)

Simulation refers to a broad collection of methods and applications to mimic the behavior of real systems, usually on a computer with appropriate software
(Kelton, Sadowski & Sadowski, 1998)

Model development

Creating an abstraction (model) of the real world.
Enabling us to draw conclusions about the real system by studying and analyzing the model.

The physical model

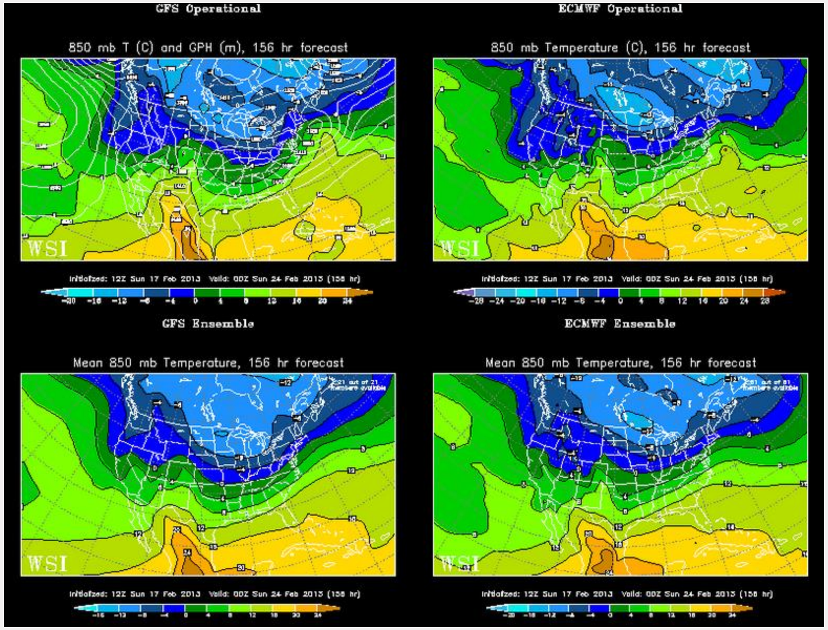
Emergency ‘drills’
Dress rehearsal
Test runs of a new attraction

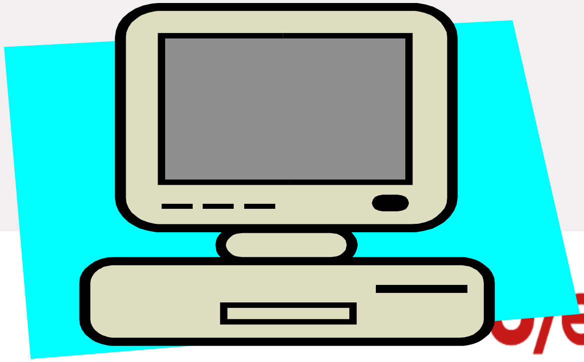
The scaled model

Small scale wind tunnel models
Physical flight simulators to train pilots
Tabletop models of material handling systems
Model trains and railways

The logical (or mathematical) model

mathematical approximations of the system
usually represented in a computer program
easy, cheap, and fast





Why do people use computer-based simulation models?

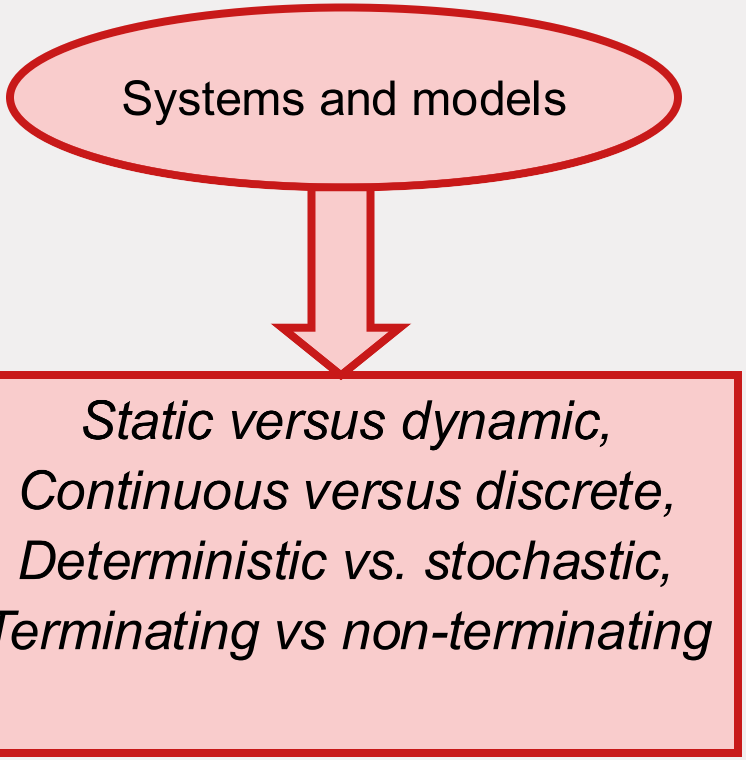
Most systems are stochastic and dynamic

Analytical model not feasible and/or not practical.

Trial by implementation can be too costly, or too time consuming, or even too dangerous.

Timescale may be too long to get accurate real measurements.

Different kinds of systems



Static versus dynamic

A static model

- Not dependent on time
  - A dice

A dynamic model

- Time dependent
  - Service and manufacturing related systems
  - A few examples of dynamic variables:
    - production schedules,
    - equipments utilizations,
    - customer arrival rates and processing times

Discrete-event versus Continuous

Discrete-event simulation

- the state variables change instantaneously at separate points in time.
- time is advanced in discrete “jumps” as the simulation advances from event to event
- e.g. orders handled by servers.

Continuous simulation

- the state variables change continuously with respect to time.
- time is advanced in (almost) infinitely small increments
- e.g. mass-spring system (suspension of a car), or models of economic systems

Discrete-event versus Continuous

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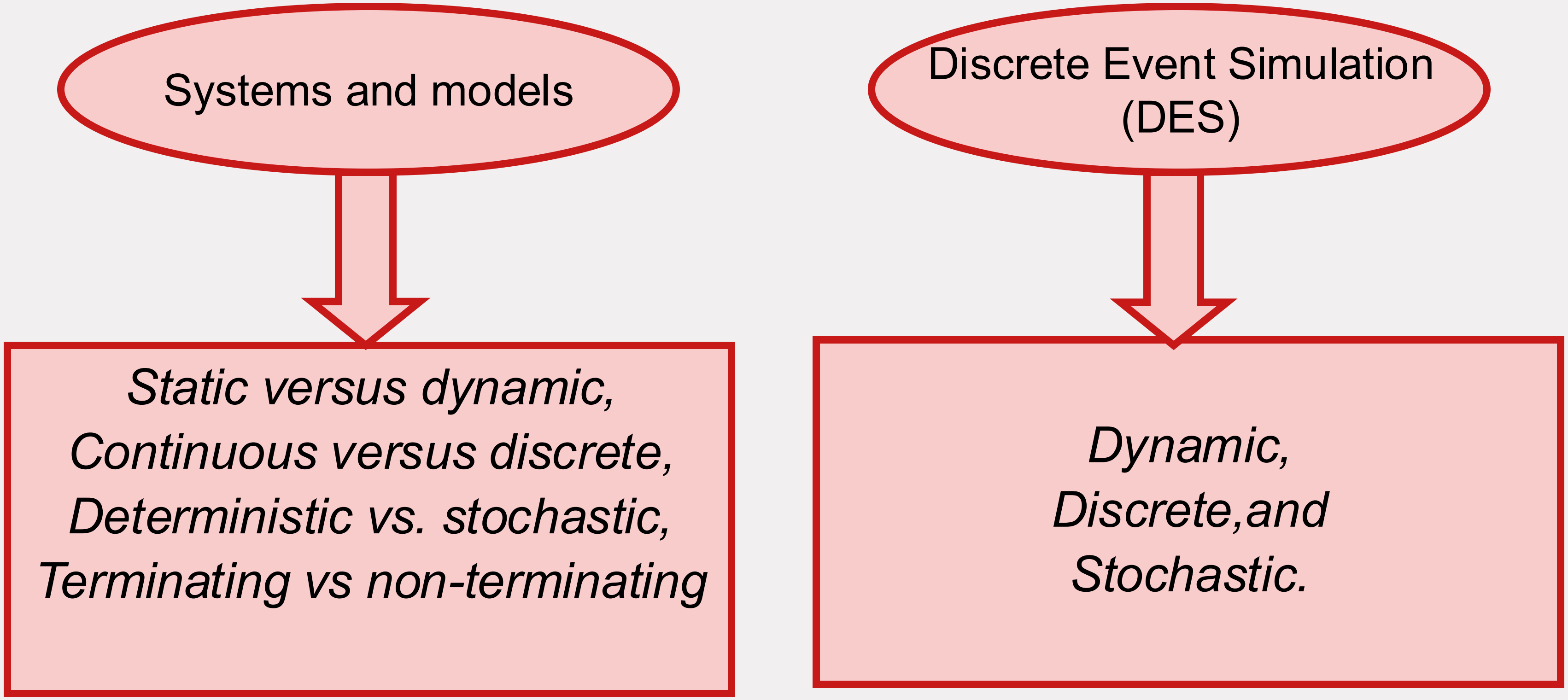
System	Discrete events	Continuous events
The flow of customers through a bank's drive-in teller	X	
The consumption of fuel by a fighter jet during routine flight manoeuvres		X
The spread of cancer through a victim's lymphatic system		X
The assembly of cars at an automobile assembly plant	X	

Stochastic versus deterministic

A stochastic model contains processes controlled by random variables. The word *variables* implies that something is capable of changing. It does not have a specific value, but rather a range of values.
Random signifies that the changes can occur with no particular pattern.
A stochastic process is composed of a sequence of randomly determined values.

A deterministic model does not contain random variables and is not influenced by probability

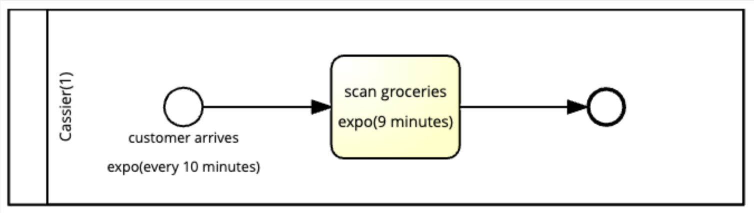
Different kinds of systems



Business process simulation

Discrete Event Simulation techniques

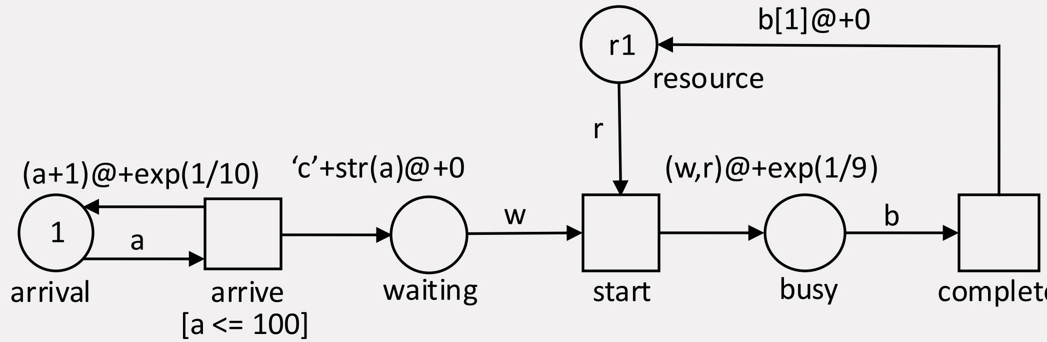
- Sthocastic, dynamic, discretely evolving systems



Processes can wait for 'events'

- time passes
- a resource becomes available
- an event is generated by another process
- or a combination of the above (using and/or).

The logical (or mathematical) model




```python
from simpn.simulator import SimProblem, SimToken

shop = SimProblem()

resources = shop.add_var("resources")
customers = shop.add_var("customers")

def process(customer, resource):
    return [SimToken(resource, delay=0.75)]

shop.add_event([customers, resources], [resources], process)

resources.put("cassier")
customers.put("c1")
customers.put("c2")
customers.put("c3")

from simpn.reporters import SimpleReporter

shop.simulate(10, SimpleReporter())
```

Business Process Simulation

Lecture 1b – Seven steps methodology

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Overview on lecture modules

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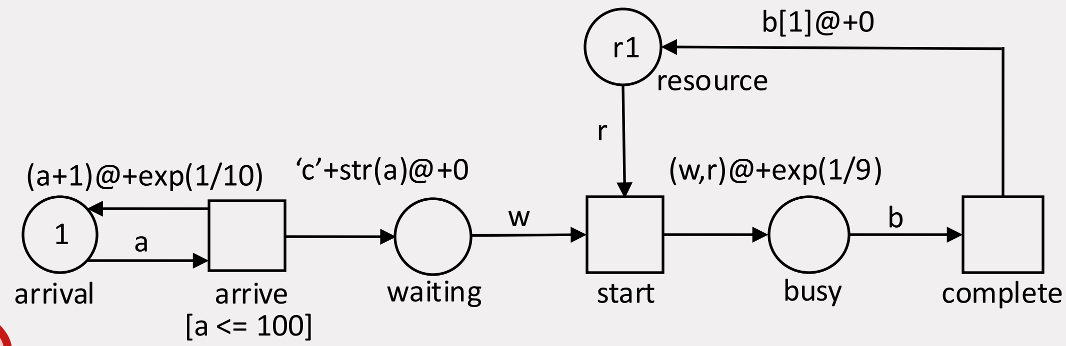
Business Process Simulation



Discrete Event Simulation (DES)

Dynamic, Discrete,and Stochastic.

Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

STEP 5: Validation

STEP 6: Experiments and output analysis

STEP 7: Conclusion

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Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

STEP 5: Validation

- **Context of the project**
- **Problem definition**
- **Objective of the research**

STEP 6: Experiments and output analysis

STEP 7: Conclusion

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Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

- **Determine variables:**
- **(i) Environmental, (ii) Decision, (iii) Output**
- **List assumptions**
- **Is simulation the right approach?**
- **Determine number of simulation models**

STEP 7: Conclusion

Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

- **model process, objects, and logic**
- **independent of simulation tool used**

STEP 5: Validation

STEP 6: Experiments and output analysis

STEP 7: Conclusion

Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

STEP 5: Validation

- **Dependent on simulation tool**
- **Verification: does the model behave as you modeled/expected?**

STEP 6: Experiments and output analysis

STEP 7: Conclusion

Simulation Methodology (7 steps)

- **Parameters for experiments: replication lenght, number of replications, warm-up period, etc.**
- **Output analysis: statistically reliable data, valid conclusions**

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

STEP 5: Validation

STEP 6: Experiments and output analysis

STEP 7: Conclusion

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Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

STEP 5: Validation

STEP 6: Experiments and output analysis

STEP 7: Conclusion

- **Answer research questions**
- **Provide recommendations**

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Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

STEP 4: Executable model and verification

STEP 5: Validation

STEP 6: Experiments and output analysis

STEP 7: Conclusion

Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

STEP 3: Conceptual model

"Thinking phase"

STEP 4: Executable model and verification

STEP 5: Validation

STEP 6: Experiments and output analysis

STEP 7: Conclusion

Execution phase

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Simulation Methodology (7 steps)

STEP 1: Project definition

STEP 2: Design the simulation study

process & data modelling, logic → **STEP 3**: Conceptual model

programming → **STEP 4**: Executable model and verification

queueing theory → **STEP 5: Validation**

STEP 6: Experiments and output analysis

statistics → **STEP 7**: Conclusion

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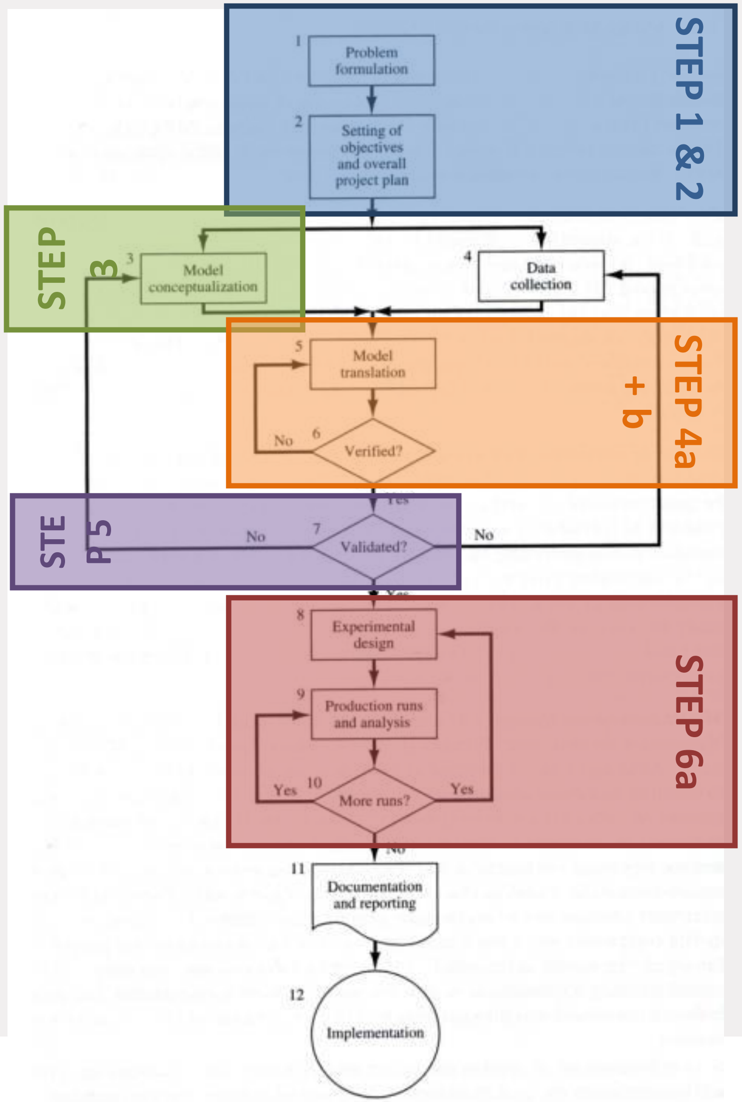
Link with methodology in book



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Business Process Simulation

Step 1: Project definition

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Overview on lecture modules

a) Introduction to simulation
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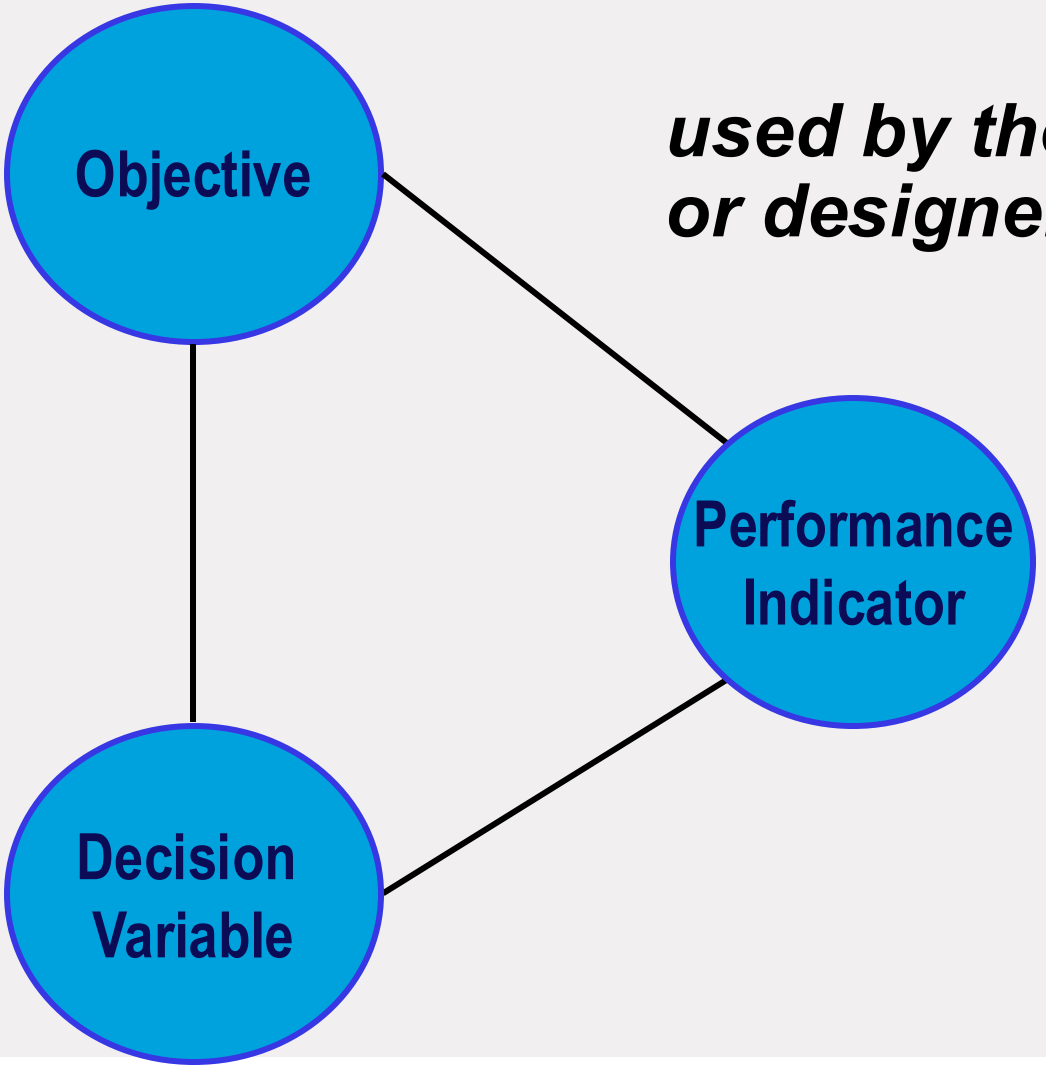
d) Step 2: Design the study

STEP 1: Project definition

1. Problem formulation
2. Phrase research questions
3. Set the scope

4. (Estimate required resources needed to do study)
5. (Perform a cost-benefit analysis)
6. (Create a planning of the proposed project)

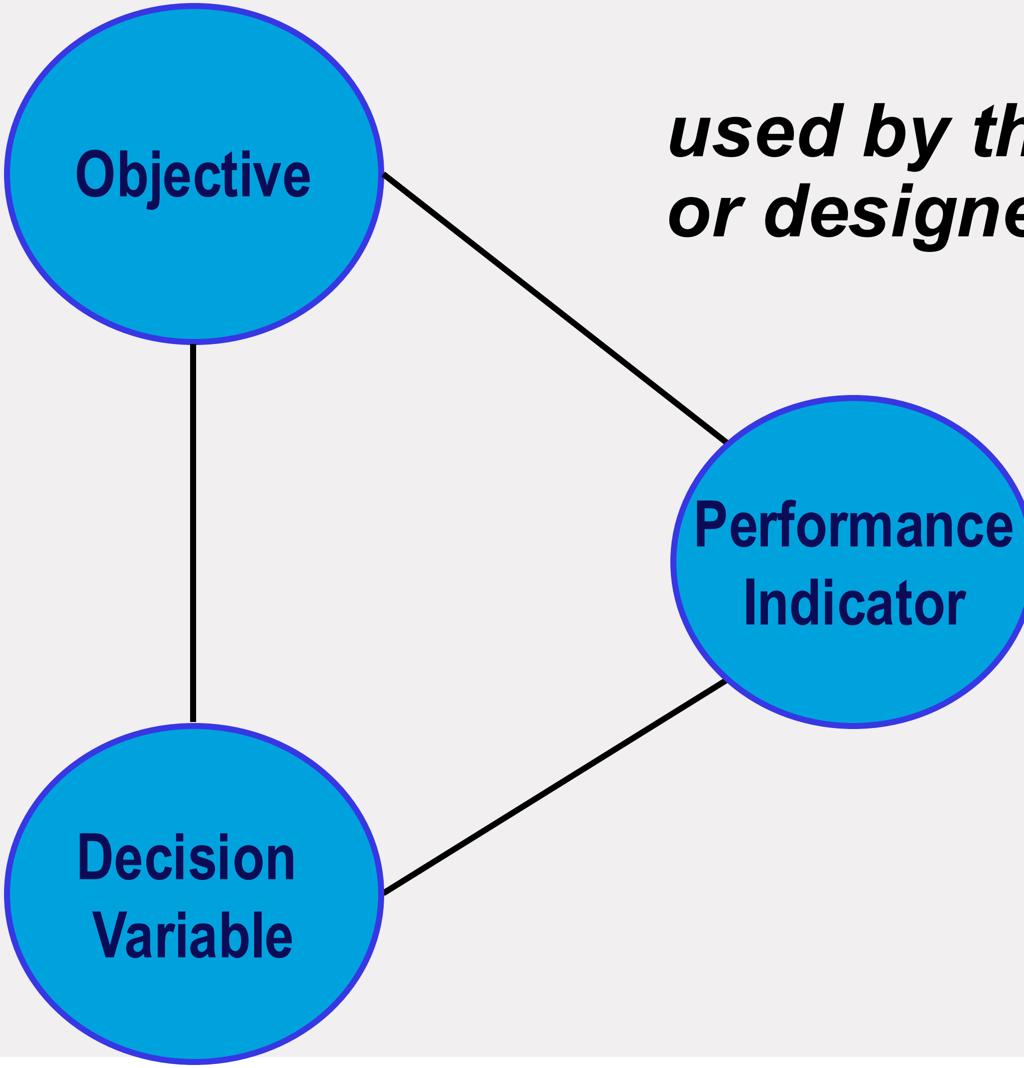
Decision Framework



used by the analyst or designer

Decision Framework

- Optimum X
- Increase X
- …



used by the analyst or designer

Decision Framework

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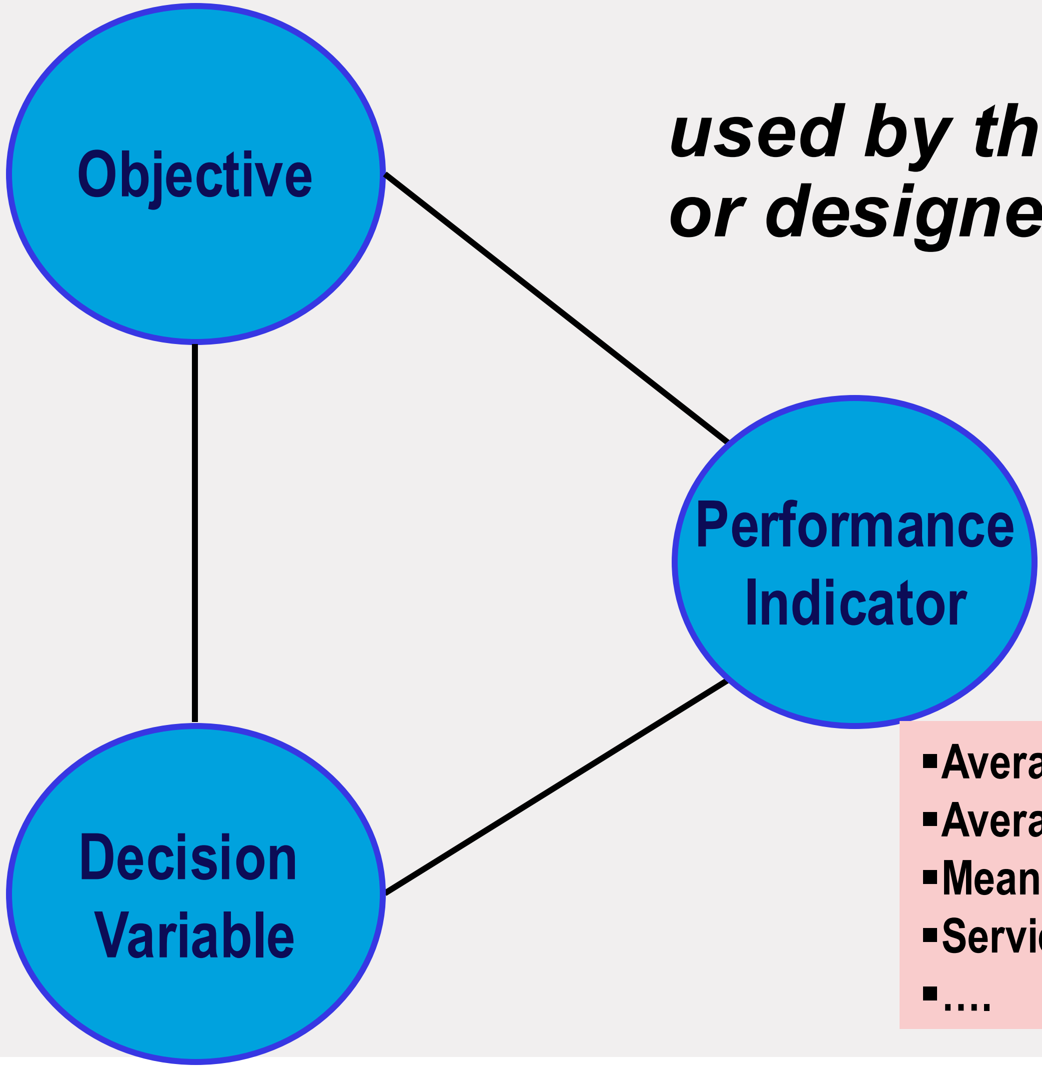
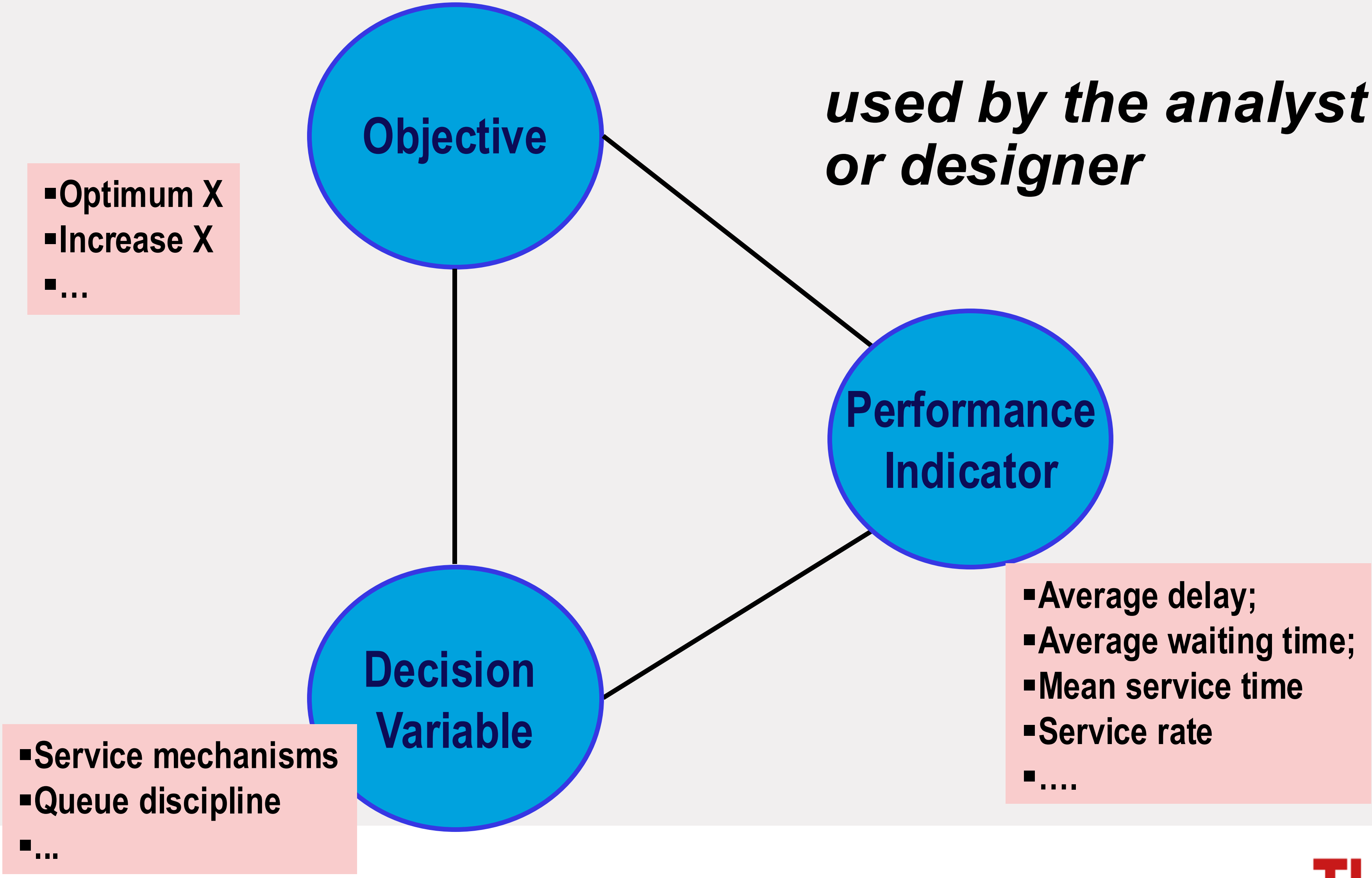


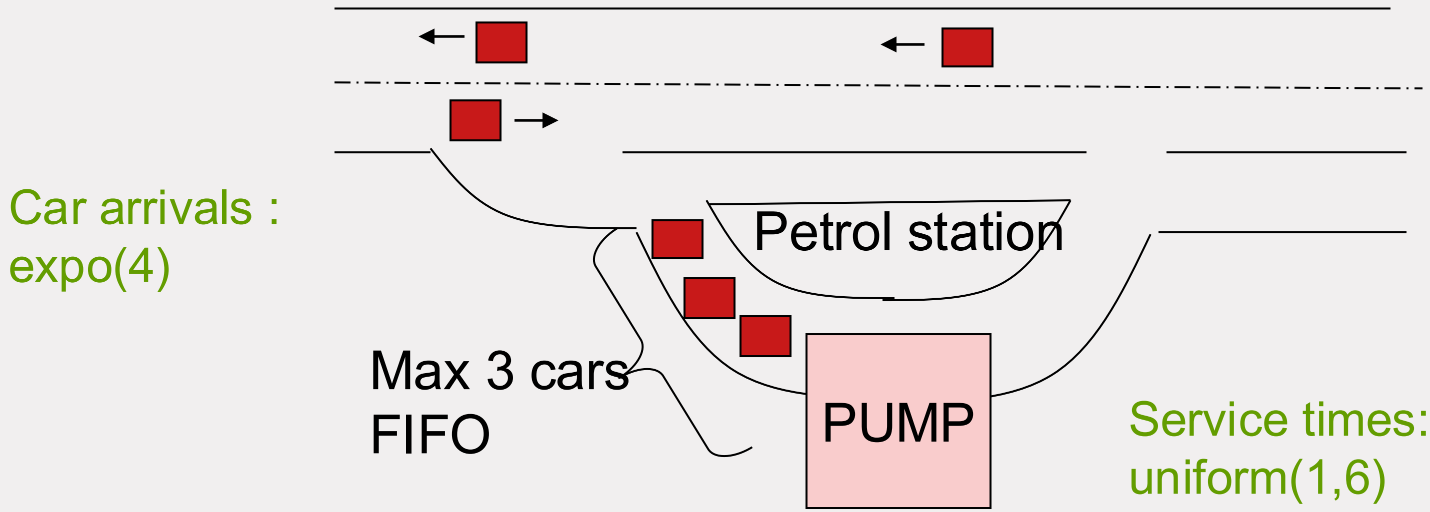
used by the analyst or designer

- Average delay;
- Average waiting time;
- Mean service time
- Service rate
- ....

Decision Framework

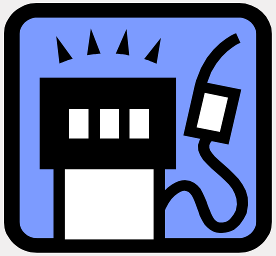


EXAMPLE: The Petrol Station

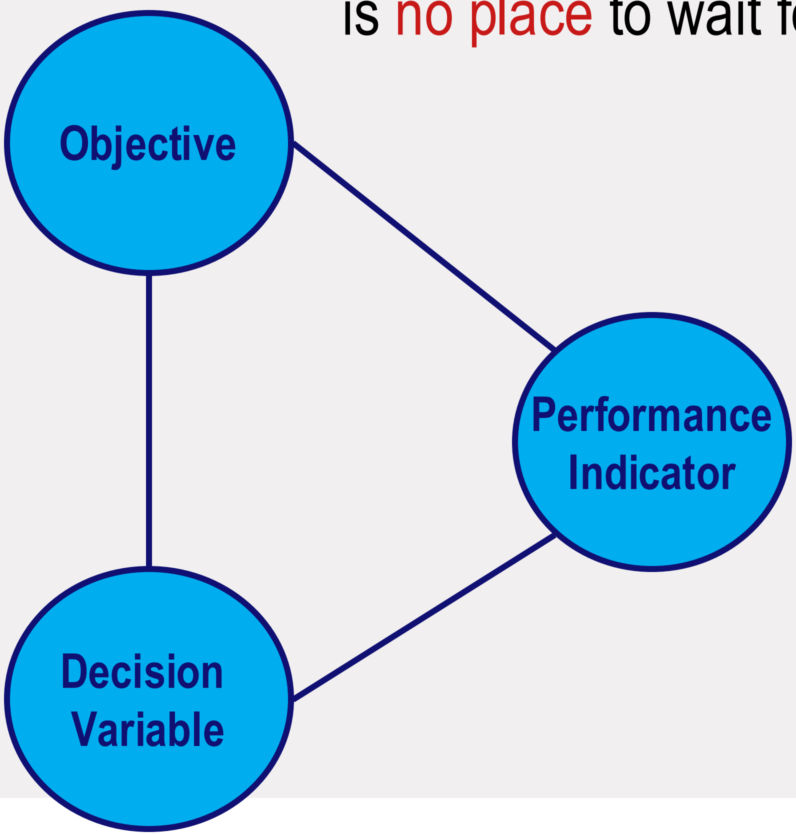


The owner of the petrol station has the feeling that some potential customers are leaving the station because there is no place to wait for service

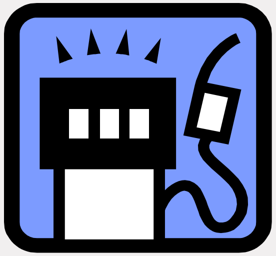
Step 1.1: Decision Frame



…the feeling that some potential customers are leaving the station because there is no place to wait for service

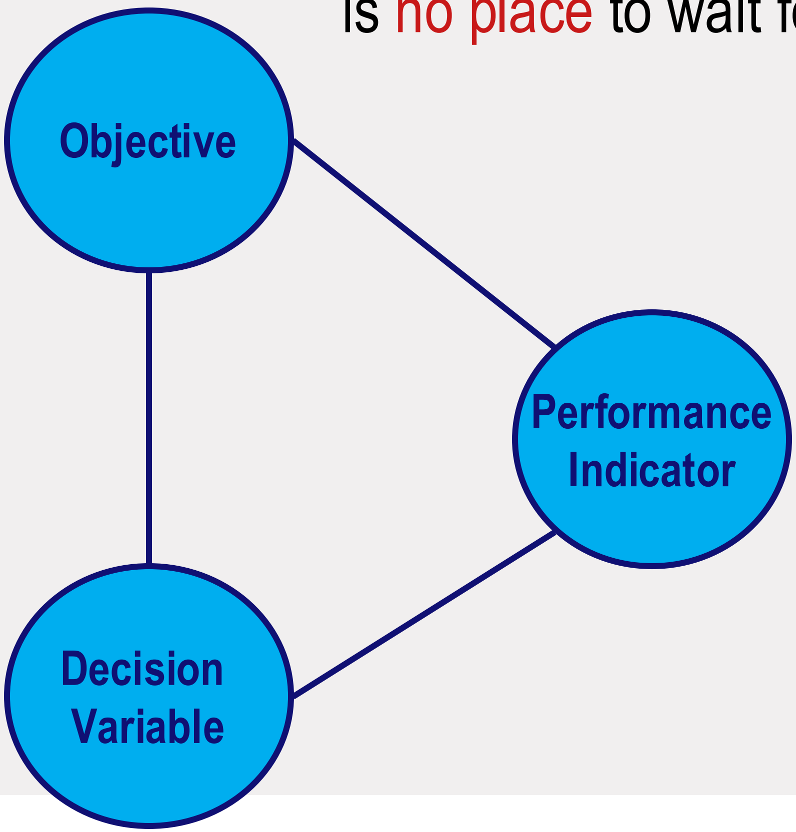


Step 1.1: Decision Frame

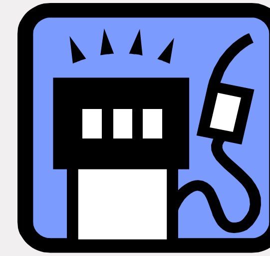


…the feeling that some potential customers are leaving the station because there is no place to wait for service

- Less customers driving on



Step 1.1: Decision Frame



…the feeling that some potential customers are leaving the station because there is no place to wait for service

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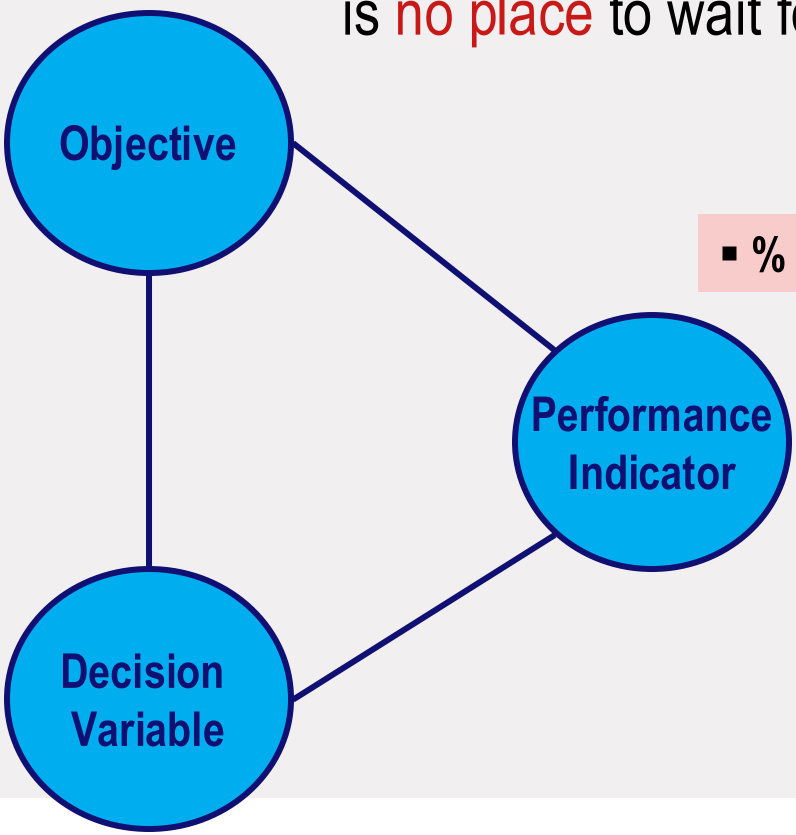
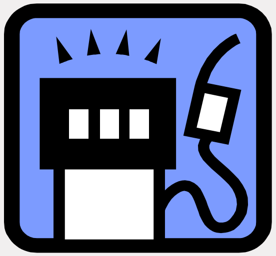


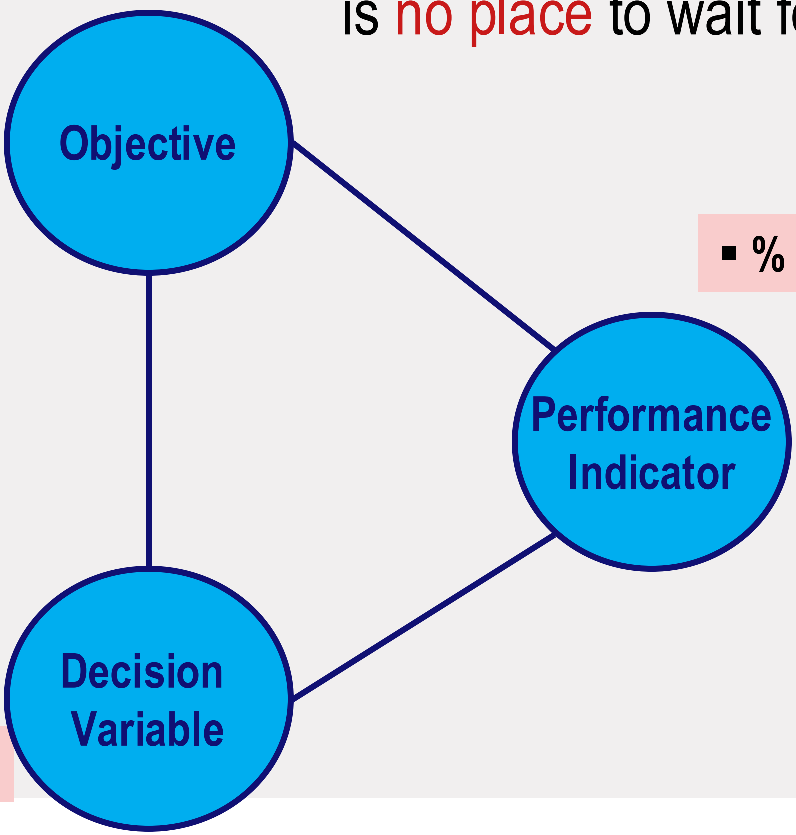
- % of customers driving on

Step 1.1: Decision Frame



…the feeling that some potential customers are leaving the station because there is no place to wait for service

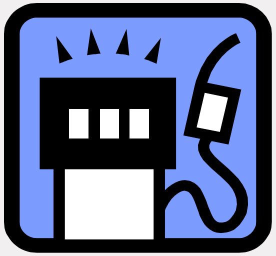
- Less customers driving on



- % of customers driving on

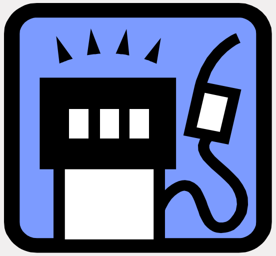
- size of queue area

Step 1.2: Research Questions



What is the percentage of customers that drive on without being served?
What is the effect of increasing the capacity of the queue area on the percentage of cars leaving without being served?

Step 1.3 Scope



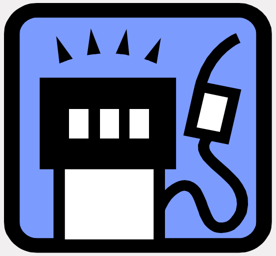
Included in the model:

- The pump with service start and service end events.
- The queue area with arrival, departure events
- The cars with the events matching the queue area and petrol events.
- The decision of the car to drive on when it finds the queue area full.

Excluded from the model:

- The time for paying
- The volume of gas tanked
- The type of car
- The shop
- etc.

Alternative decision frame 1



Suppose:

- Customers get angry and unsatisfied when they have to wait too long; waiting time should not increase more than 10%

Decision Frame:

- **Objective**: optimize the number of places in the queue area such that a minimum % of customers drive on, but the average waiting time in the queue does not increase more than 10%
- **Decision variables**: capacity of the queue area
- **Performance measures**:
  - % of customers driving on
  - Average waiting time of customers in the queue

Manager’s perspective on decision

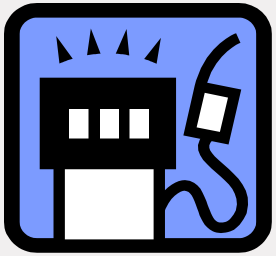
Company looses money when customer leaves

- Each customer that leaves costs ?

Does an investment in more queueing places pay off?

- How much does the additional queueing place cost?
- When should this be earned back? After one year?

Alternative decision frame 2



Suppose:

- One extra queueing place costs 750 euros
- Each customer leaving ‘costs’ 100 euros
- Manager wants return on investment after 1000 customers

Decision Frame:

- **Objective**: earn more money by serving more customers (decrease the number of customers leaving because of full queue by extending the queue area)
- **Decision variables**: capacity of the queue area
- **Performance measures**: money lost by customers driving on because of a full queue:
  - number of customers lost * 100 euro’s +
  - number of additional queueing places * 750 euro’s

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Exercise: the harbour case

A harbour can host two types of ships; Small and Big ships, which arrive with an interarrival time exponentially distributed with a mean of 5,5 hours and 6.7 hours respectively. There are two docks (dock1 and dock2) where ships can be unloaded.

Small ships (big ships) are unloaded at dock1 (dock2) with a service time uniformly distributed between 3 and 7 (2 and 8).

If dock1 is empty and there are Big ships waiting at dock2 then a Big ship can go to dock1 and is served with 1,5*Uniform(2,8). If dock2 is empty and there are Small ships waiting at dock1 then a Small ship can go to dock2 and is served with 2*Uniform(3,7).
For both docks the queue discipline is SPT (Shortest processing time first).

The management team of the harbour would like to improve the mean expected throughput time. Possible options are closing dock1 to Big ships and dock2 to small Ships, or to change the queueing discipline.

<u>Formulate a decision frame for this problem, together with its research questions and scope</u>

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Proposed solution

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Problem formulation. Waiting by ships is expensive for their owner-operators. For this reasons harbours could explore options to reduce waiting time.

Proposed solution (continue)

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Business Process Simulation

Lecture 1d - Step 2: Design the study

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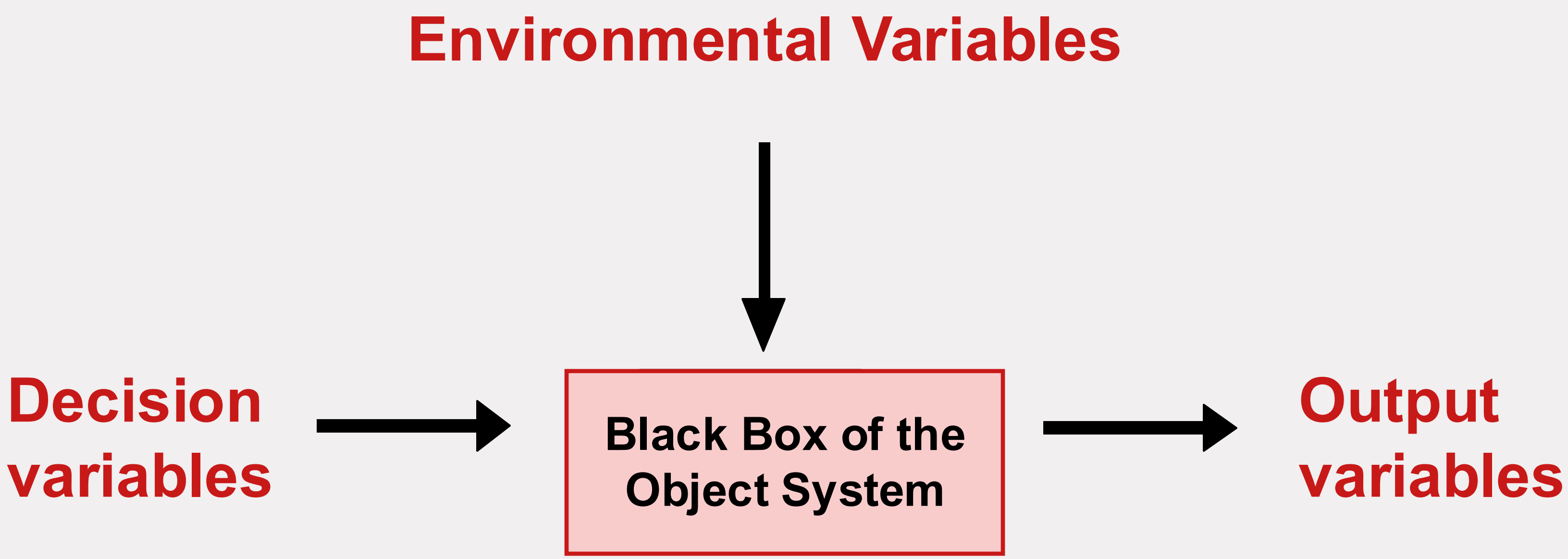
STEP 2: Design the Study

1. Create black box representation.
2. List assumptions
3. Determine if a simulation model is actually needed
4. Estimate the number of models required.
5. Make a detailed planning

6. (Select the tool: done, it is SimPN)
7. (Collect data: it is given; identify the relevant data)

Step 2.1: black box representation



In 't Veld (1CK10):
A black box representation is a representation of a system or sub system of which the internal components and relationships are not (yet) known to the analyst.

Decision Variables

Other names:

- decision variables (ISO 15704)
- control variables (Bertrand/Fransoo)
- design/control variables (Kulkarni)
- ‘stuurvariabelen’ (Griep/Flapper):
- ‘beslissingsvariabelen’ (Griep/Flapper)
- design parameters (Cochrane)

Used to consciously influence the system

Examples:

- Queue discipline: FIFO or SPT?
- Resource allocation strategies

Output Variables

Other names:

- performance variables (Bertrand, Fransoo)
- performance indicators (ISO 15704)
- key performance indicators

Used to measure the performance of the system

Examples:

- Mean waiting time
- Service time of a car

Law & Kelton Chapter 9: Output Analysis

Environmental Variables

Other names:

- Input variables
- ‘omgevingsvariabelen’ (Griep/Flapper):

Influence the system (are givens)

Examples:

- Car interarrival time
- Service time of a car

Law & Kelton Chapter 6: Input Analysis

Black Box Representation

Environmental Variables

e.g.:
- Interarrival time of clients
- Service time
- ….

Decision variables → **Black Box of the Object System** → **Output variables**

Decision variables

e.g.:
- Service mechanism
- Queue discipline
- …..

Black Box of the Object System

Output variables

e.g.:
- Mean waiting time
- % not served
- ….

Step 2.2: Assumptions and Givens

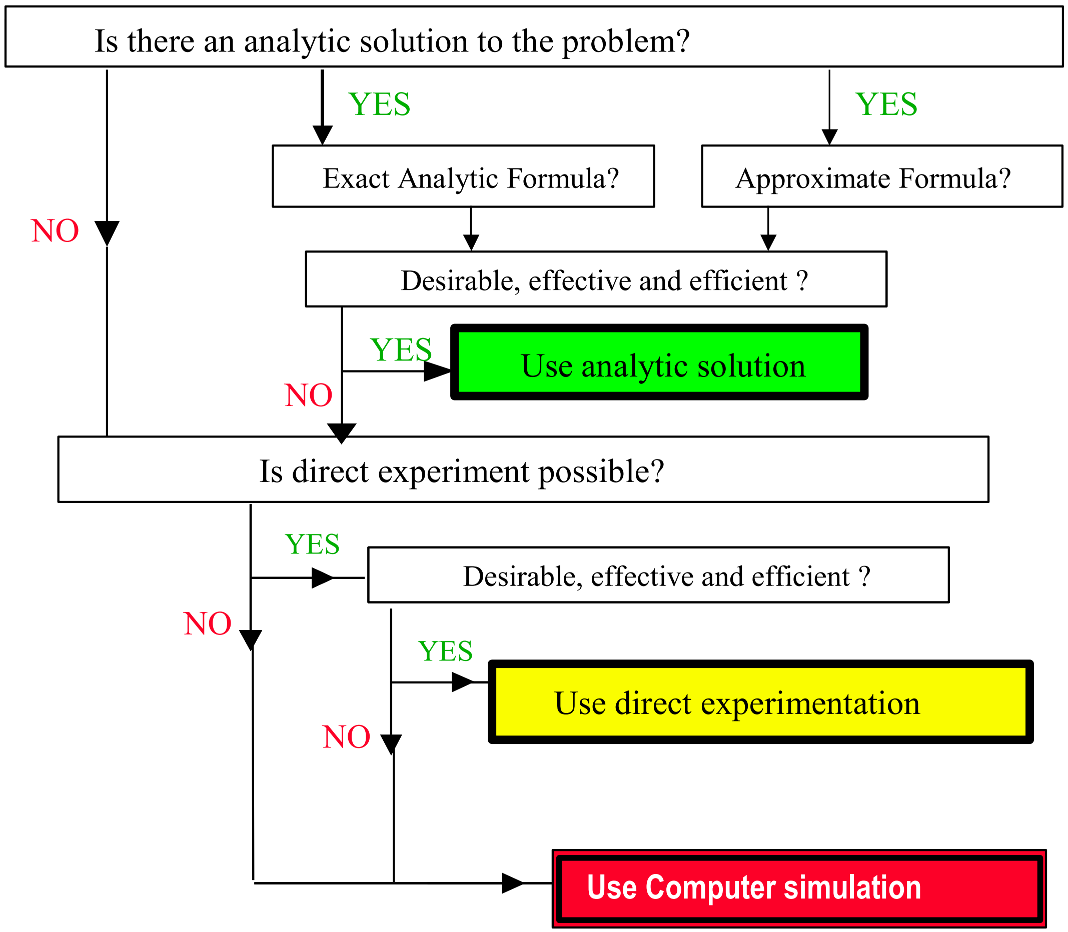
A formal list must be maintained and approved by the stakeholders (possibly validated)

Assumptions determine:

- The scope of the work
- Micro-level decisions in models depend on them

TIP:
Keep a list of all assumptions you make throughout the steps of your project !

Step 2.3: Is simulation suitable?

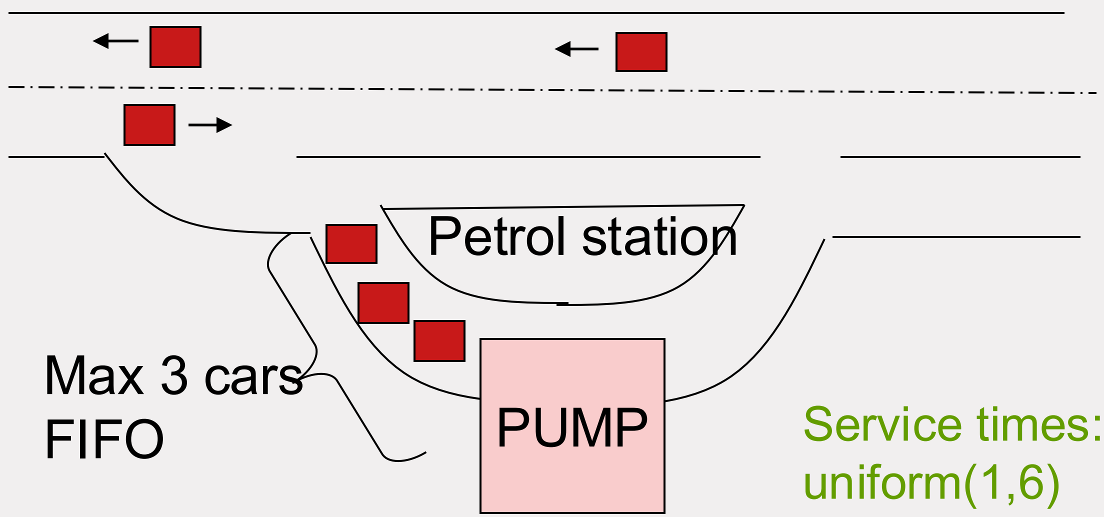


Step 2.4 Number of models

Different variants / designs?
Different parameter settings?
Simulation / validation?

EXAMPLE: The Petrol Station

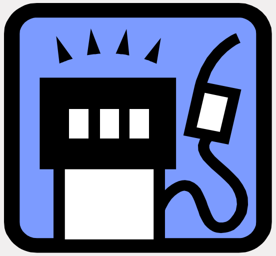
Car arrivals : expo(4)



Service times: uniform(1,6)

The owner of the petrol station has the feeling that some potential clients are leaving the station because there is no place to wait for service

Step 2.1: Black Box



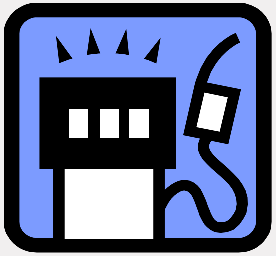
Environmental Variables
- interarrival time of cars
- service time of cars

Decision variables → PETROL STATION → **Output variables**

- Size of the queue area

Output variables:
- percentage not served
- (mean waiting time)
- (number not served)

Step 2.2: Assumptions and givens

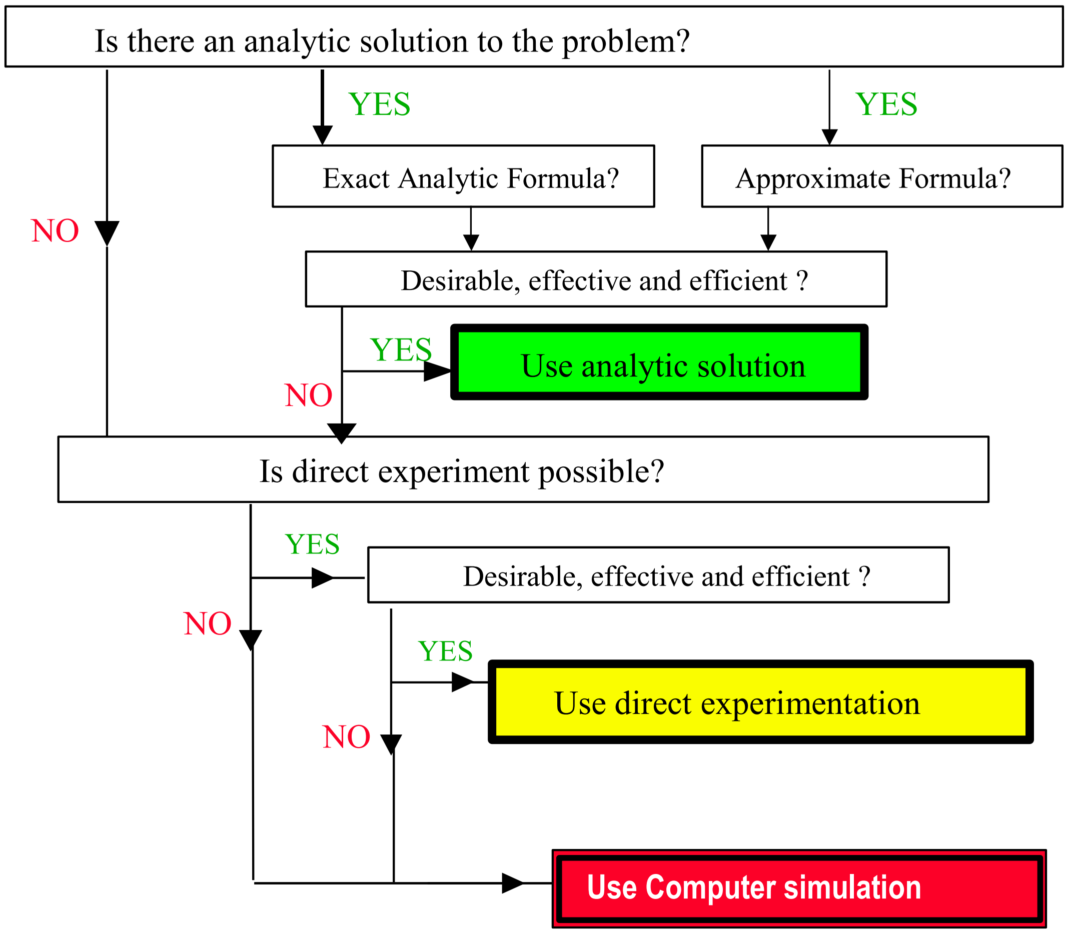


G1. the interarrival time of cars is expo(4)
G2. the service time of cars is uniform(1,6)
G3. queue capacity is 3 cars (plus 1 car in service)
G4. queueing discipline is FIFO

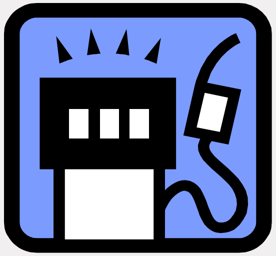
A1. the business operates 24 hours per day; 7 days per week
A2. no defects of the pumps occur
A3. time of payment can be incorporated into processing time

List of assumptions must be maintained as the study (and the modelling) proceeds

Step 2.3: Is simulation suitable?



Step 2.3: Simulation suitable?



Characteristics of the system:

- Single class system
- No admission control
- One queue (FIFO) with limited capacity (3+1 = 4)
- One server
- A/B/M/K/N notation? $\Rightarrow$ M/G/1/4 system

Are there analytical methods available for M/G/1/4?

- No!

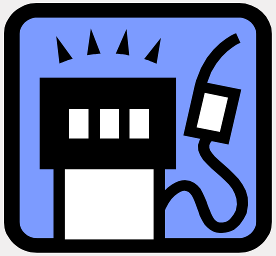
Can we make any approximation?

- Yes: M/M/1/4 system, but not precise enough!

Is direct experimentation possible?

- No!

Step 2.4: Number of models



For the problem owner:

1. current situation (queue length = 3)
2. situation with longer queue
   a) Queue length = 4
   b) Queue length = 5
   c) Queue length = 6
   d) … ?

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Exercise: the harbour case

A harbour can host two types of ships; Small and Big ships, which arrive with an interarrival time exponentially distributed with a mean of 5,5 hours and 6.7 hours respectively. There are two docks (dock1 and dock2) where ships can be unloaded.

Small ships (big ships) are unloaded at dock1 (dock2) with a service time uniformly distributed between 3 and 7 (2 and 8).

If dock1 is empty and there are Big ships waiting at dock2 then a Big ship can go to dock1 and is served with 1,5*Uniform(2,8). If dock2 is empty and there are Small ships waiting at dock1 then a Small ship can go to dock2 and is served with 2*Uniform(3,7).
For both docks the queue discipline is SPT (Shortest processing time first).

The management team of the harbour would like to improve the mean expected throughput time. Possible options are closing dock1 to Big ships and dock2 to small Ships, or to change the queueing discipline.

Draw a black box representation for this problem. Is simulation needed? Why?

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Proposed solution

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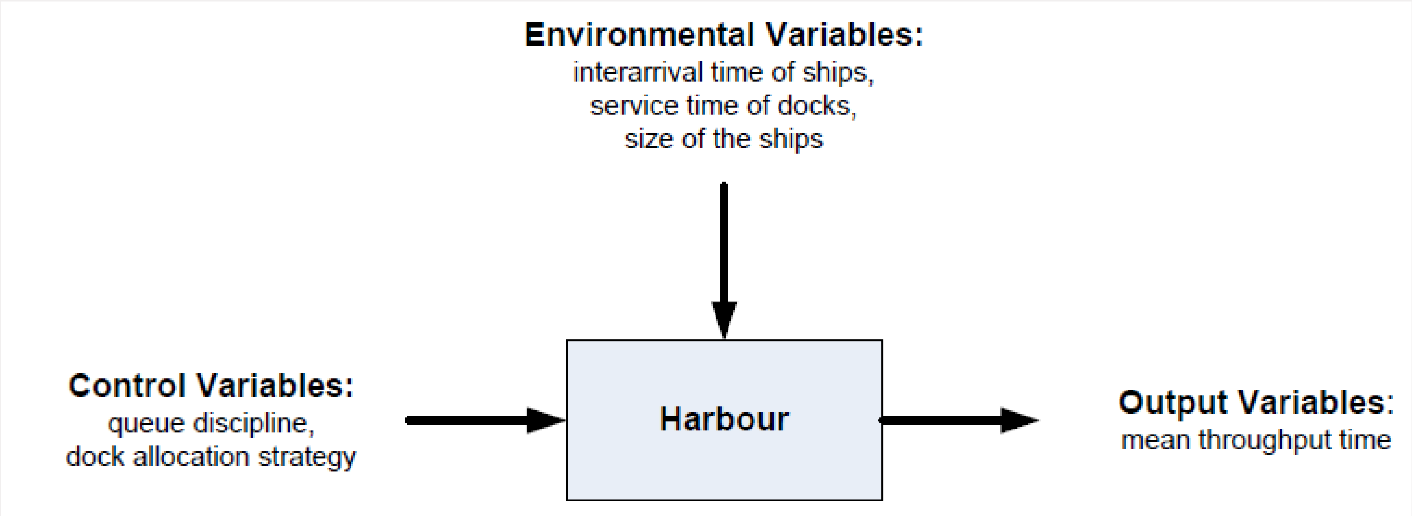

Is simulation needed?
Yes. No analytical models available, direct experimentation not possible

Summary of today's lecture

Introduction
Simulation methodology (7 steps)

STEP 1: Problem Definition

1.1 Problem Statement

1.2 Objectives

1.3 Research questions

1.4 Scope and level of detail

STEP 2: Design of the study

2.1 Black box representation

2.2 Assumptions and givens

2.3 Simulation suitable

2.4 Number of models

TU/e