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**CENTRALE  
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## Competence Unit Training CU 34 – Process Selection

### Course: AM Cost Evaluation and management based on process oriented approach (Part 1)

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# Outline

## **Introduction: Value chain and Performance**

What is Performance

Key performance indicators

## **Process approach for performance assessment**

Recall of Process oriented approach

Bizagi tool for process simulation and KPI evaluation

Standard AM Processes

## **Particular KPI for AM process: Cost evaluation and monitoring**

Cost centers within AM process

Generic process for cost estimation

Learning AM cost estimation by examples

Other Cost models in literature

## **Case studies**

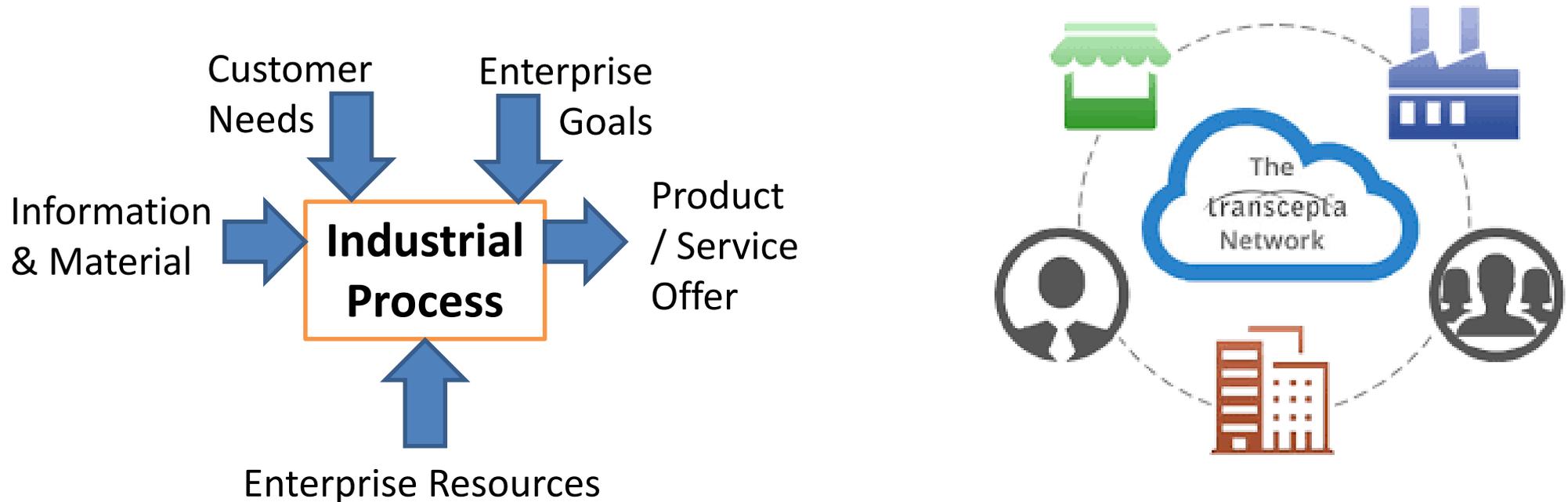
Advanced Case 1

Homework: your particular case study

# Introduction to Value chain and Performance

# Enterprise as a System

Application of the principles of the systemic theory to organization



**Enterprise as a system:** Something (that we can identify) that do something (Process/activity) and have a structure. It evolves in time and in something (environment) for some reasons (Goal).

# Value chain and industrial processes

## How to reach the objective of the enterprise

- **Requirement Engineering**
  - Understand customer needs
  - Transform needs to formal specifications
- **Design**
  - Transform specification to product functions
  - Describe physical solution for each function (Module)
- **Process engineering**
  - Define manufacturing operations for each module
  - Identify necessary material and resources
- **Production planning**
  - Schedule operation and assign resources
  - Built the supplier network
  - Procure raw material
- **Manufacturing**
  - Send production orders
  - Realize operations



Requirement  
Engineering

Design

Process  
Engineering

Production  
Planning

Manufacturing  
& Assembly

Usage

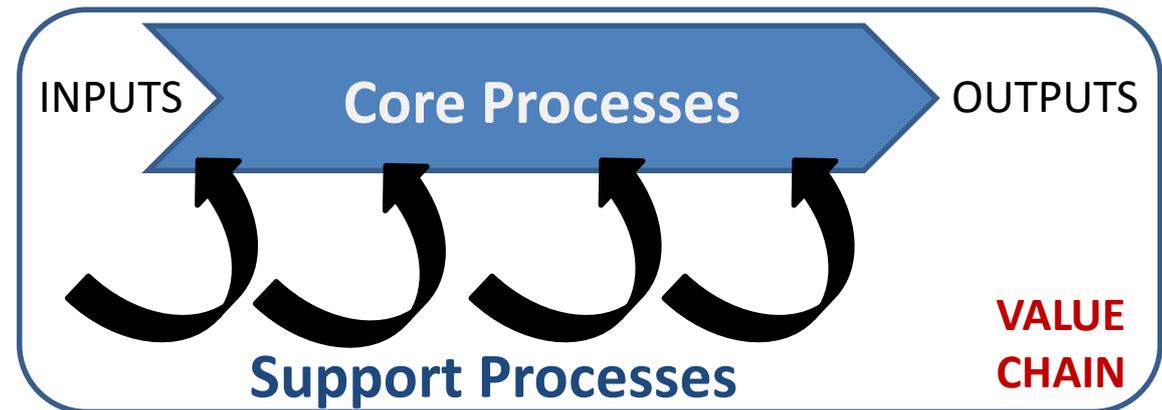
Recycling

# Value chain and industrial processes

## Value Chain definition

A value chain is the full range of activities – including design, production, marketing and distribution – businesses conduct to bring a product or service from conception to delivery.

## Porter's value chain classification



## CORE PROCESSES

### Primary level of core activities

**Core Operations:** the stage at which the raw materials are turned into the final product.

### Second Level of core processes

**Inbound logistics:** receiving, storing and distributing of raw materials used in the production process.

**Outbound logistics:** the distribution of the final product to consumers.

**Marketing and sales:** advertising, promotions, sales-force organization, distribution channels, etc.

**Service** refers to the activities needed to maintain the product's performance.

## SUPPORT PROCESSES help the primary functions

**Procurement** is how the raw materials for the product are obtained.

**Research and development** for technology procurement

**Human resource management** to maintain the employees to help design, build and market the product.

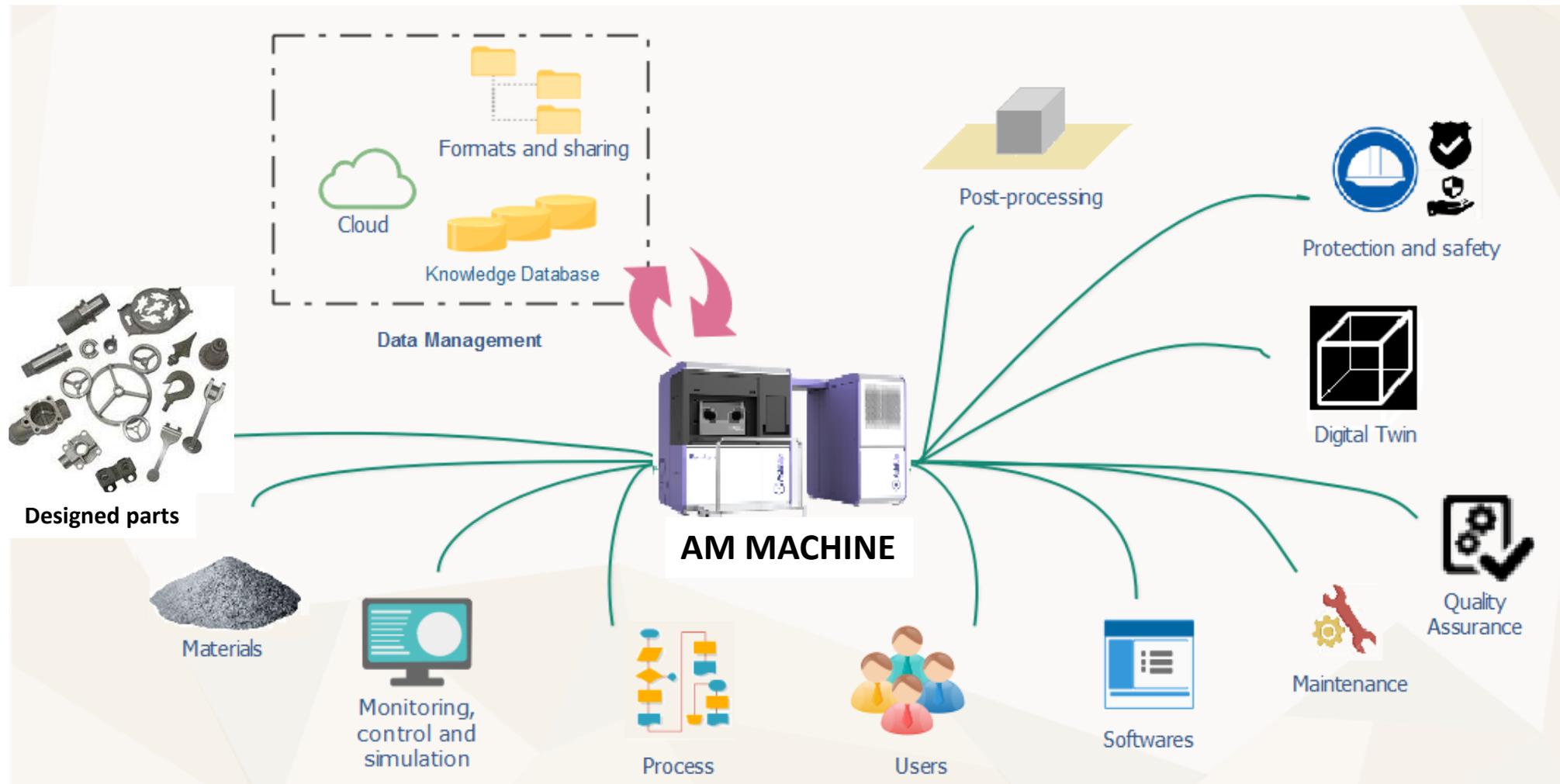
**Firm infrastructure** planning, accounting, finance and quality-control mechanisms. ... ..

# Interactional point of view

**Heterogeneous entities**  
**Lot of interactions**

Internal environment Vs External environment

- Every interaction is done by one or a set of processes



# Operational point of view

## Description of the work: Concept of task and activity

- Definition of Acacia**

Reference: J. O. Hernandez : « Les systèmes de production automatisés : Une approche socio-technique »  
Thèse de Doctorat, Université de Franche Comté 1995.



Performance = Task value – Activity value



# Key Performance

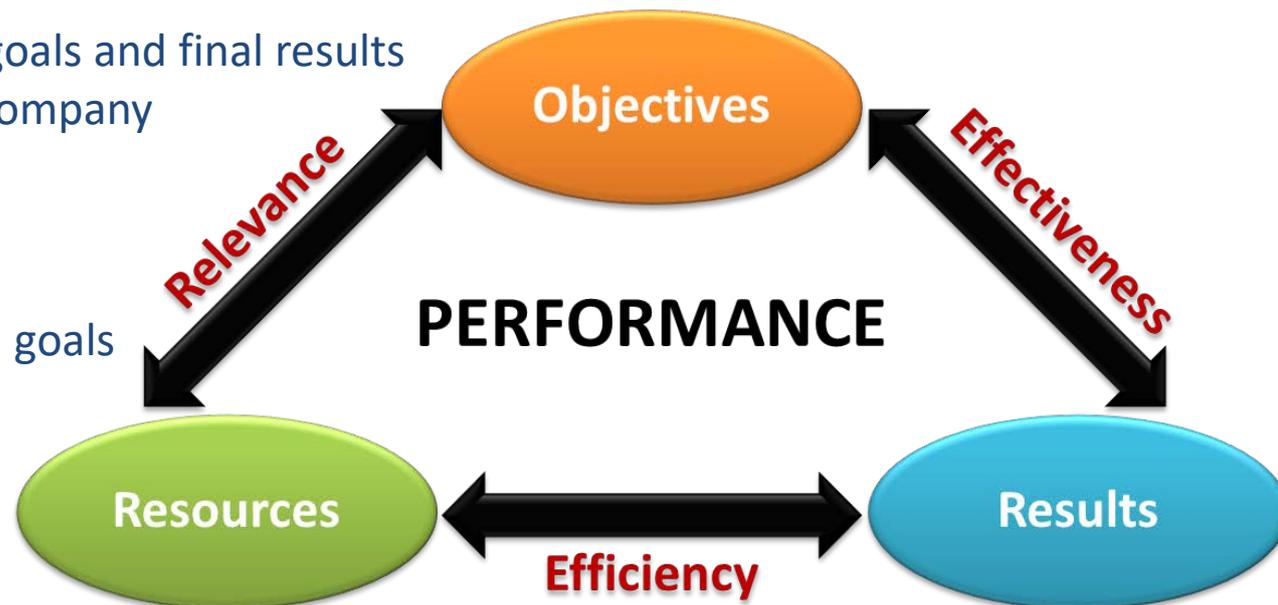
- **Company should provide a product with high performance:**
  - High quality, low cost and short time of delivery
  - But granting maximum of profit for the company

>>> **KPIs ??**

- **Effectiveness**
  - Difference between expected goals and final results
  - Inform on the capacity of the company to reach the goals

- **Relevance**
  - Comparison between expected goals and engaged resources
  - Inform on the capacity of the company to forecast and plan

- **Efficiency**
  - Difference between resources and final results
  - Inform on the capacity of the company to optimize its resources



# Enterprise Performance Indicators

- **Economic**
  - Cost,
  - Profitability,
  - ...
- **Quality**
  - Product features,
  - Client satisfaction,
  - ...
- **Time**
  - Cycle time of process,
  - Delay on delivery,
  - ...
- **Sustainability**
  - Carbone footprint,
  - ...
- **Social**
  - Recruitment capacities
  - ...



Product Oriented Indicators

Process Oriented Indicators

Organization Oriented Indicators

Environment Oriented Indicators

# Recall of Process Oriented Approach

# Operational point of view

- **Definitions of task and activities**

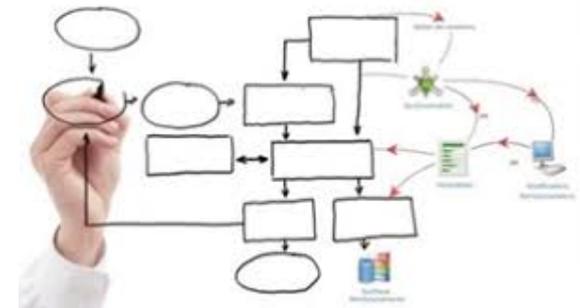
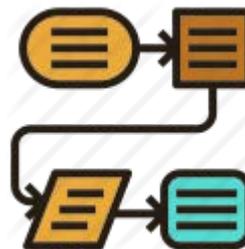
- Activity is a set of tasks carried out in order to create a deliverable (project management), while Task should be thought of as a subset of an activity.
- The word task refers to 'work' or 'a piece of work to be done or undertaken'. The word activity refers to 'happening'. (ex, There are many activities going on in the club).
- Task is an activity that needs to be accomplished within a defined period of time or by a deadline to work towards work-related goals.

- **Concept of Process**

- Group of tasks/activities that are (semi-) organized in a consistent way, exchange inputs and outputs and contribute to the same generic goal. It calls to various resources to achieve a set of transformations on some objects from the same type.

- **Concept of Role**

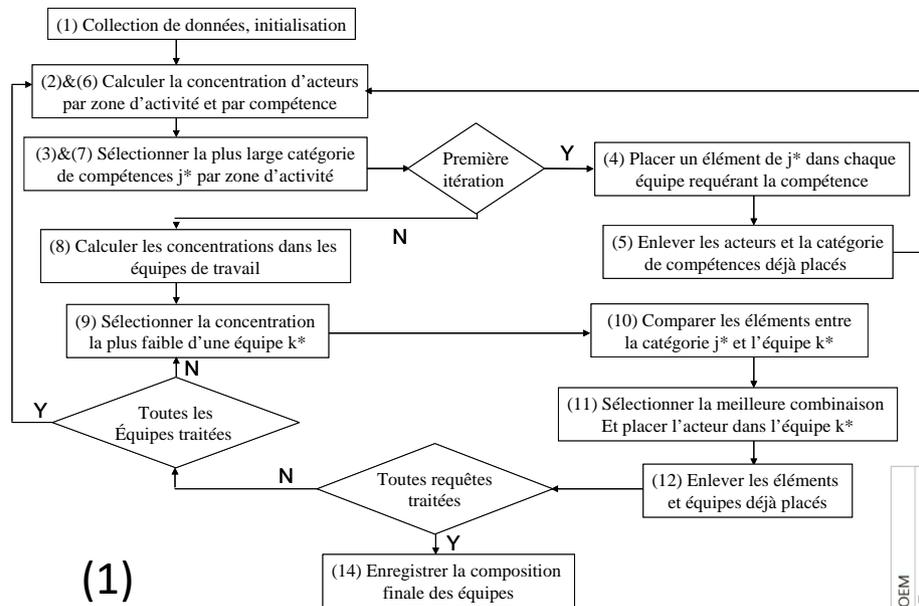
- How one resource contribute to an activity?
- Define set of missions and authorities
- In information systems : set of access rights to data (administrator, viewer, modifier, etc.)



# Operational point of view

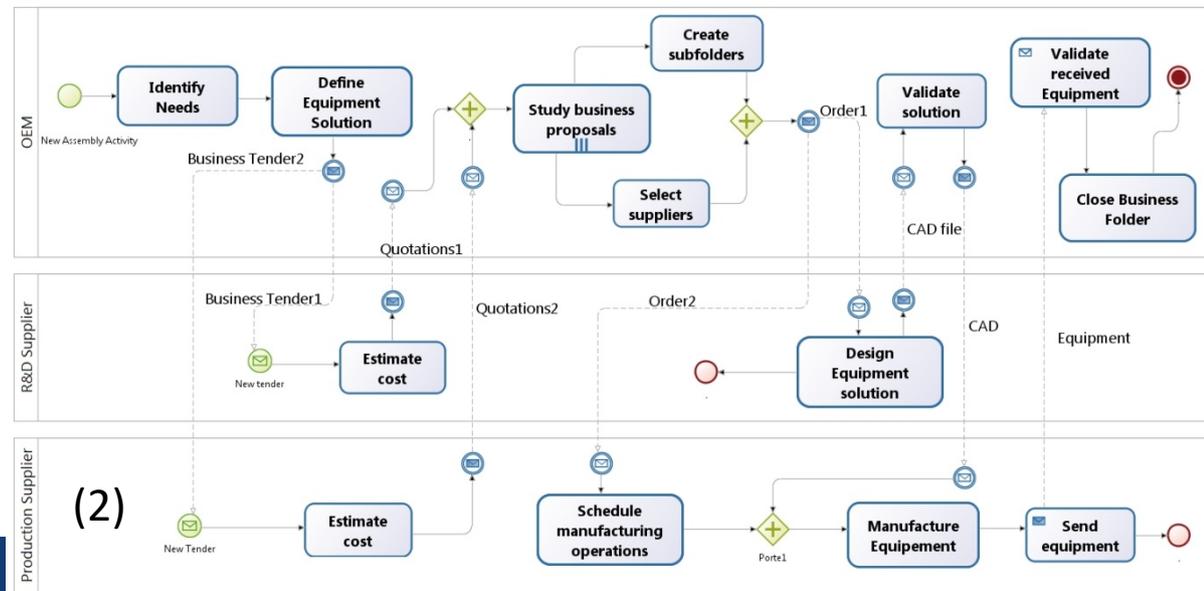
- **Example of processus**

- (1) Workflow with set of actions to do without assignment
- (2) More information about the actors and exchanged flows



(1)

**Need of formal process models**

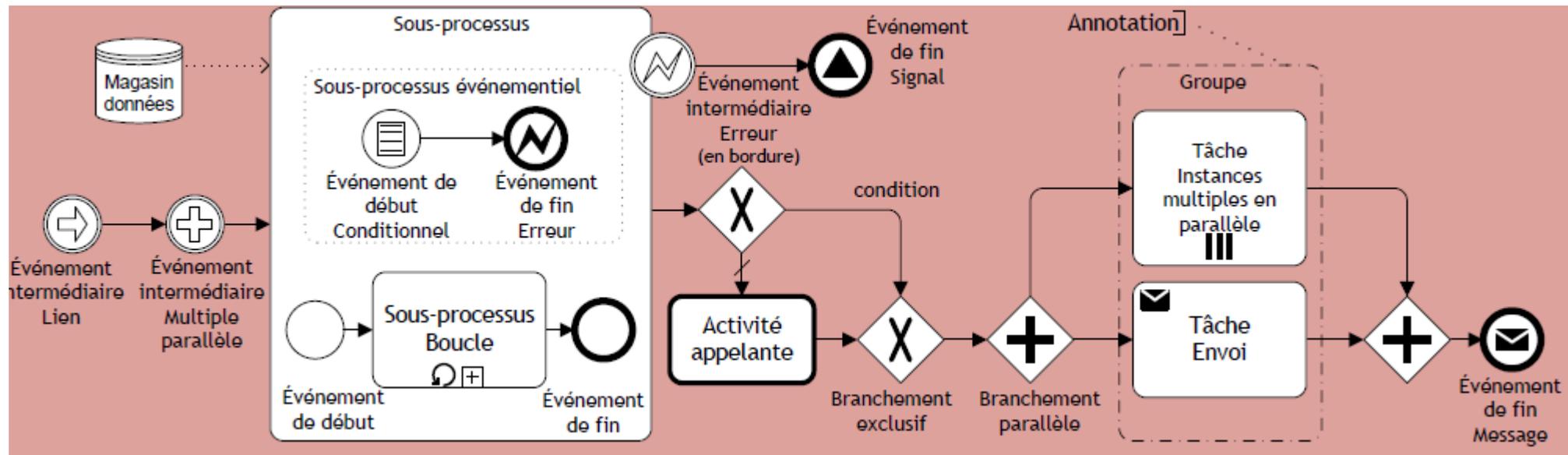


(2)

# Process Modeling : BPMN

## BPMN : Business Process Model Notation

- >> As for UML, BPMN standard is created by OMG (Object Management Group, American Association). As a complementary process modelling language, it is:
- >> **to support Business Process oriented strategies**
- >> to capitalize and unify existing good practices identified in variety of process modelling languages
- >> Standard and rich formalism to cover large wide of operational situations



# BPMN : Basic notations

## The concept of activity

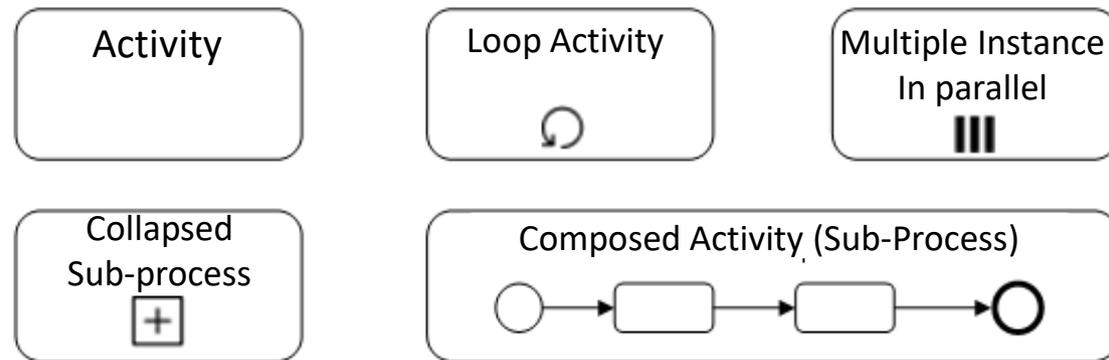
- >> Activity (or task): work unit, a job to be performed
- >> Colored with several notations

## Main types of activities

>> Loop; iterative activity > repeat an activity until one condition

>> Multiple Instances of one activity, started in parallel or in sequence, applied to several objects (similar or not),

>> Collapsed: Main activity is decomposed to sub-activities (Hierarchy relation of processes)



 Sub-Process

 Loop

 Parallel Multiple instances

 Sequential Multiple instances

 AAd Hoc

 Compensation

## Activity Notations

 Sending

 Reception

 User

 Manual

## Types of activities

 Business rule

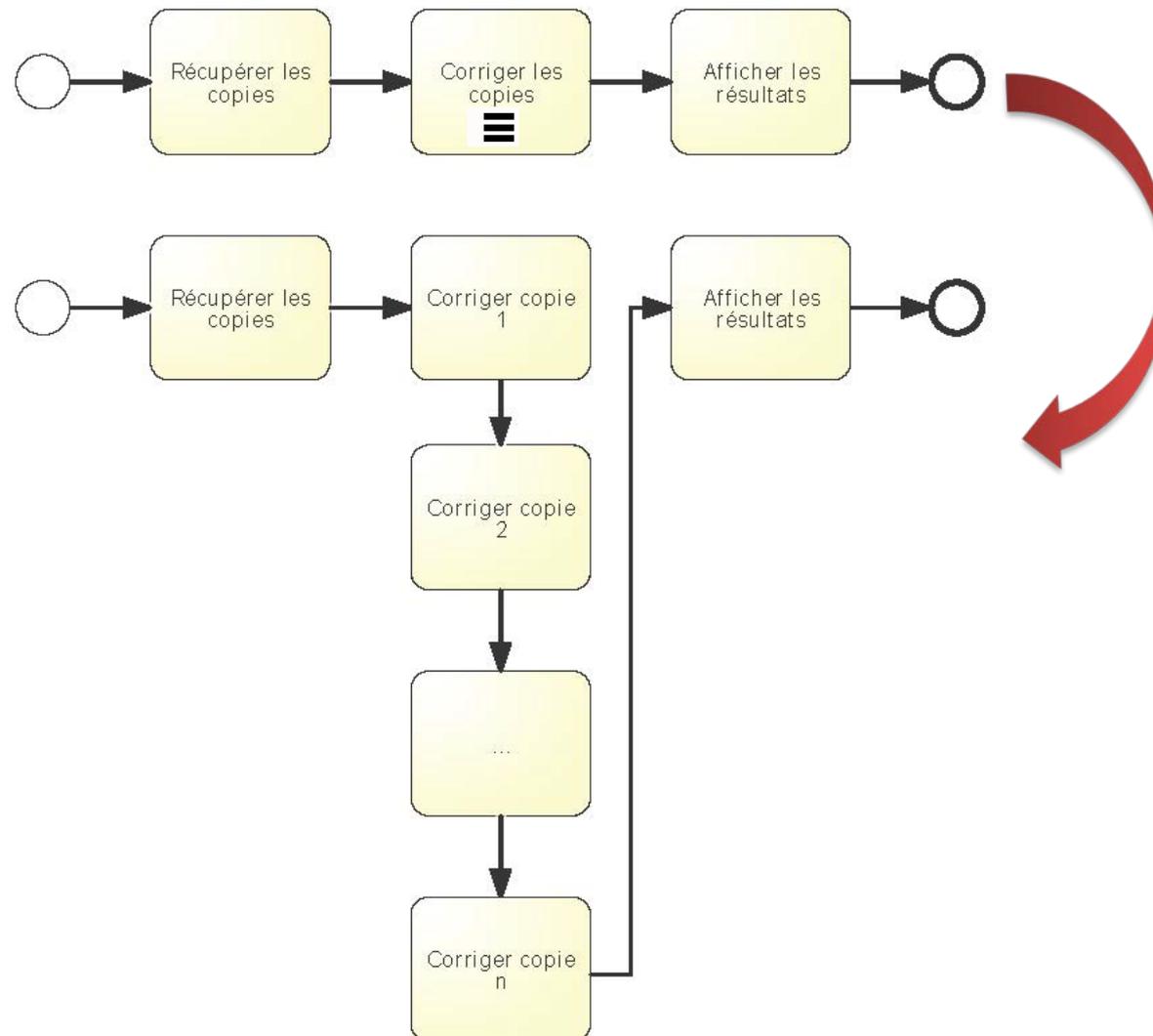
 Service (Automatic)

 Script

# BPMN : Basic notations

## Multiple instance activity (sequential)

>> Correction of students' home works



# BPMN diagram

## 4 types of arrows between activities and events



Untyped relation  
Flow between 2  
Activities from  
The same process  
(Same organization)



Conditional  
Link between  
2 activities



Default  
Link between  
2 activities

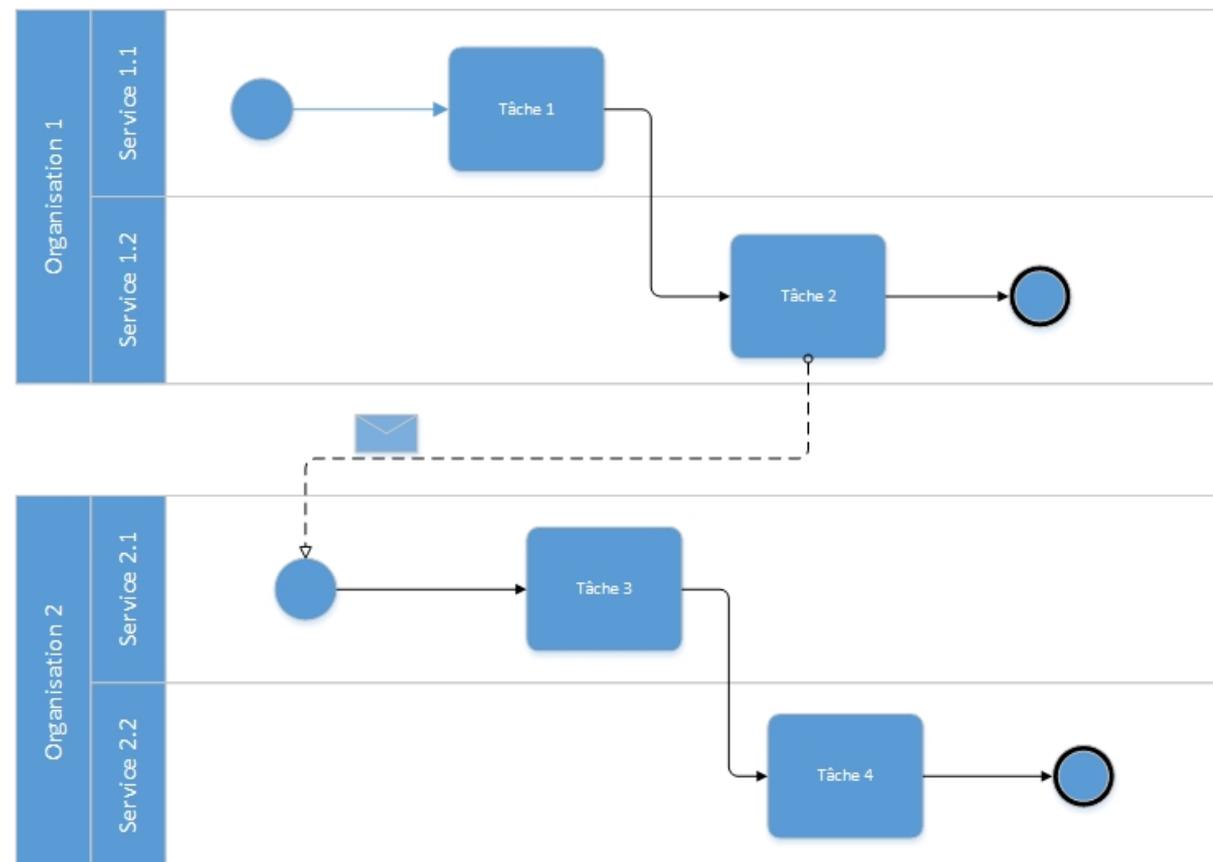


Message between  
2 activities from  
Different processes  
(separate organizations)

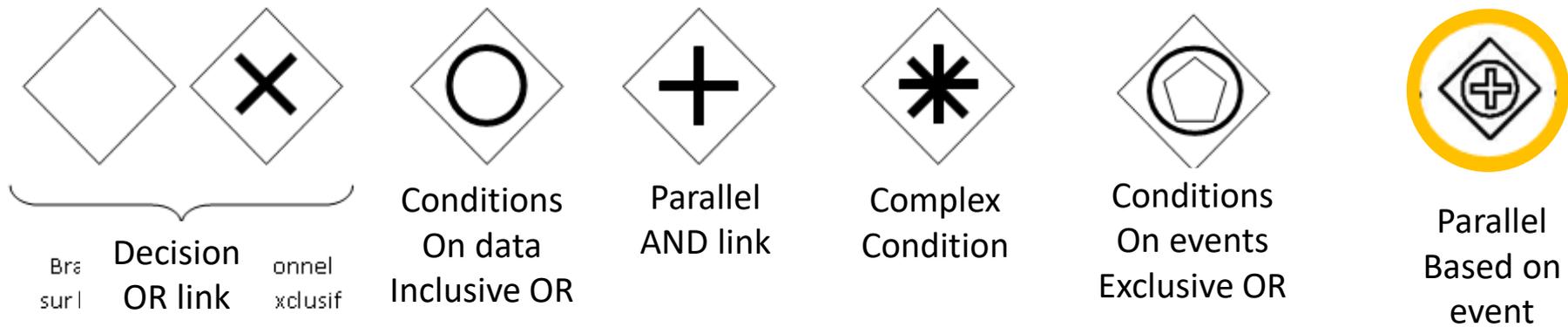
## Swilanes (Pools and Lane)

**Pool** >> represent one organization or system and support one process accross roles or actors,

**Lane** >> represent one actor, role or responsability of activities in the organization or system, regarding the process of interest.



# BPMN : Connection between activities

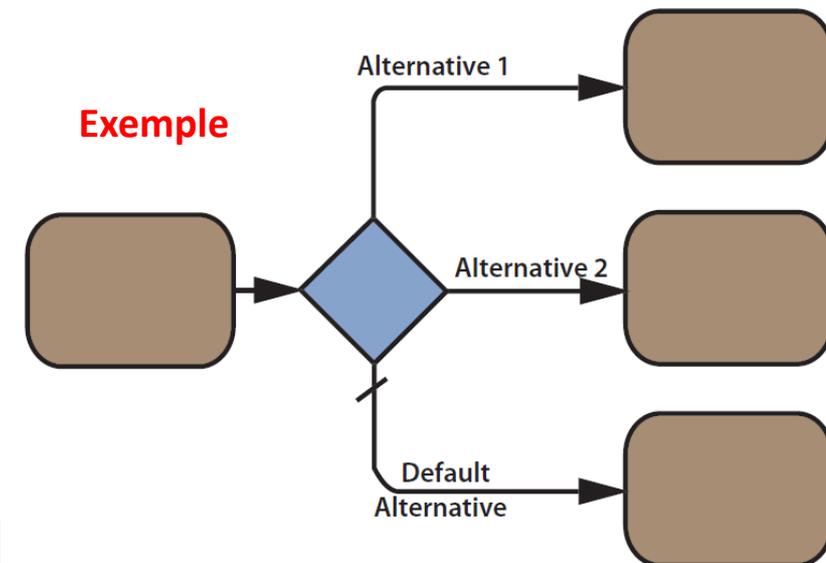
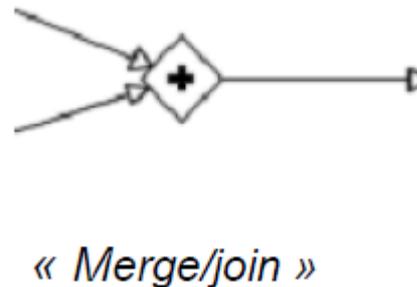
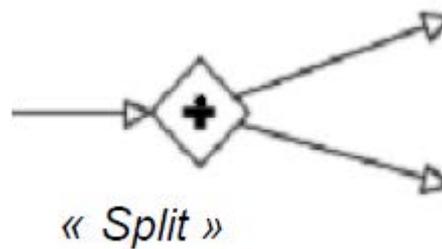


**Inclusive:** all conditions should be completed before creating the instance

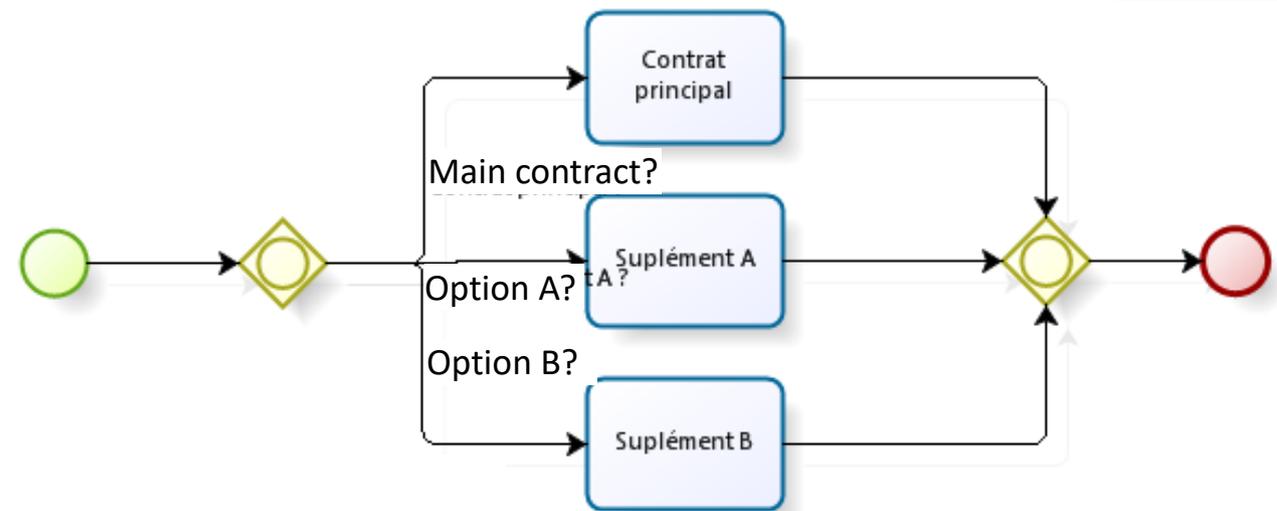
**Exclusive:** each new event create new instance of process

**Parallel:** all input flows are needed to have an output flow

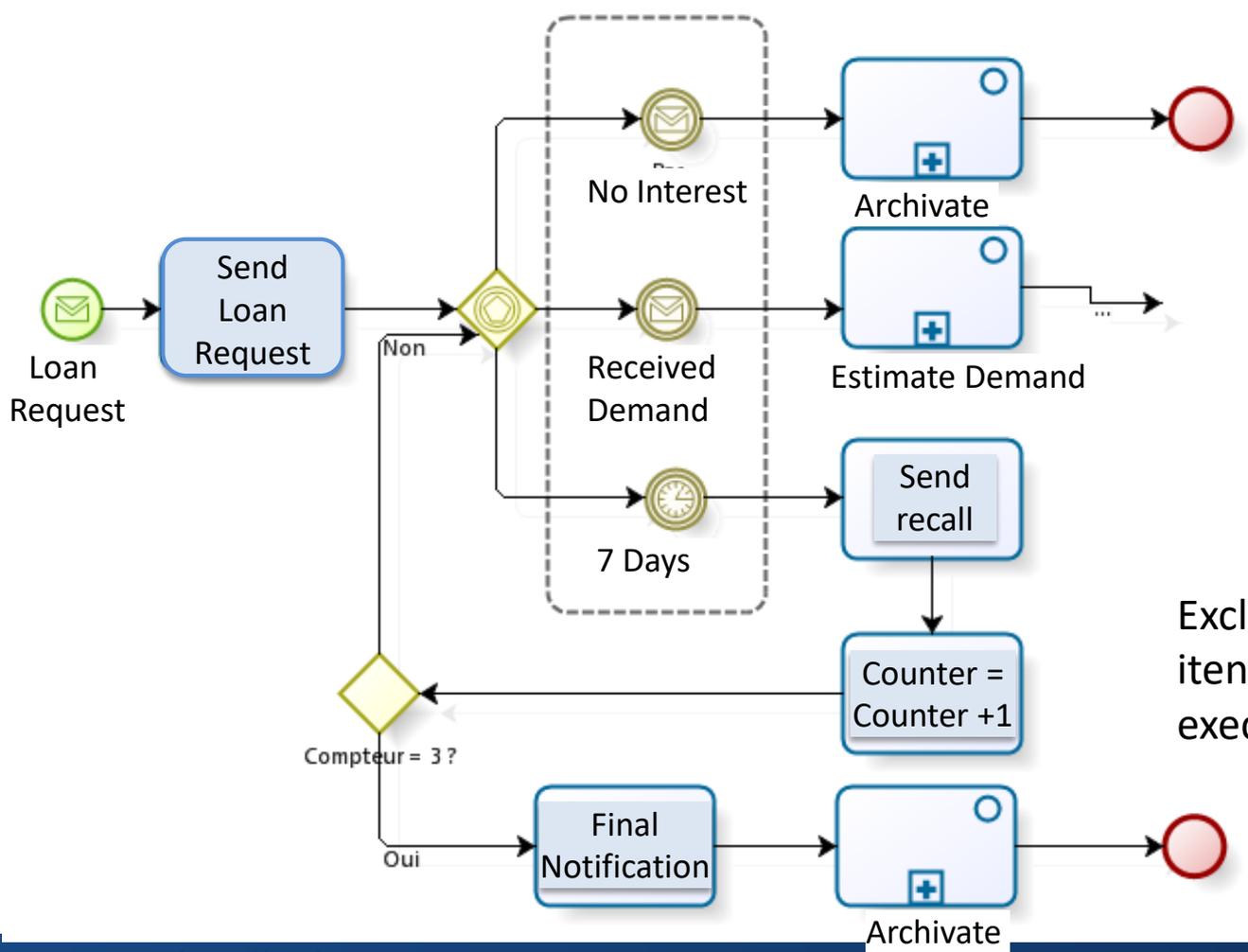
**Parallel based on event:** the apparition of all events create new instance of proces



# BPMN operators



Inclusive Or: according to the choice, one, two or 3 paths (activities and flow) could be executed



Exclusive Or based on event the chosen itenary is those conected to the first executed event

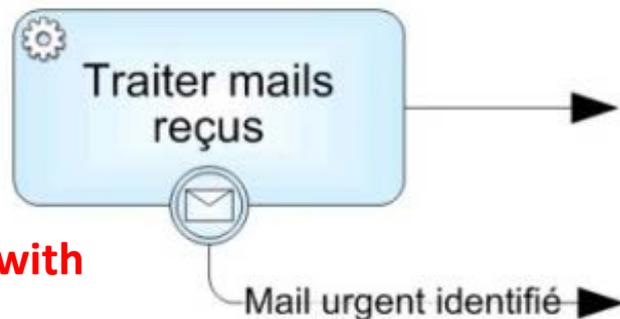
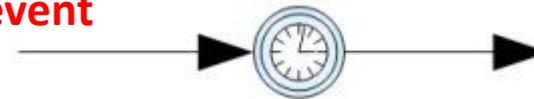
# BPMN Event notations

## What is an EVENTS?

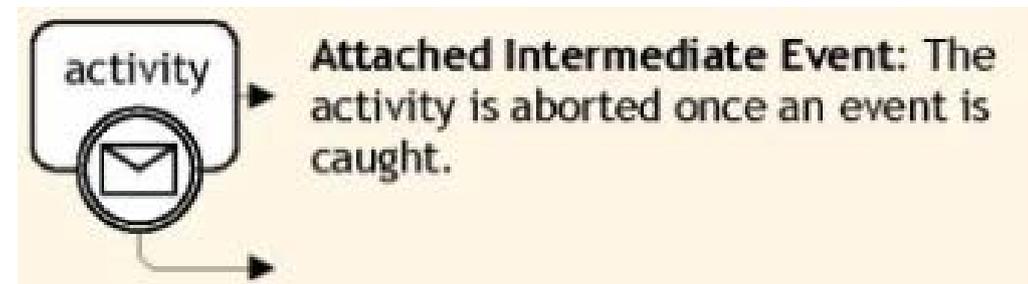
Help to identify particular situation that trigger or stop an activity



## Timing event



Service with event



# Specific event notations

## EVENTS

Help to identify particular situation that trigger or stop an activity

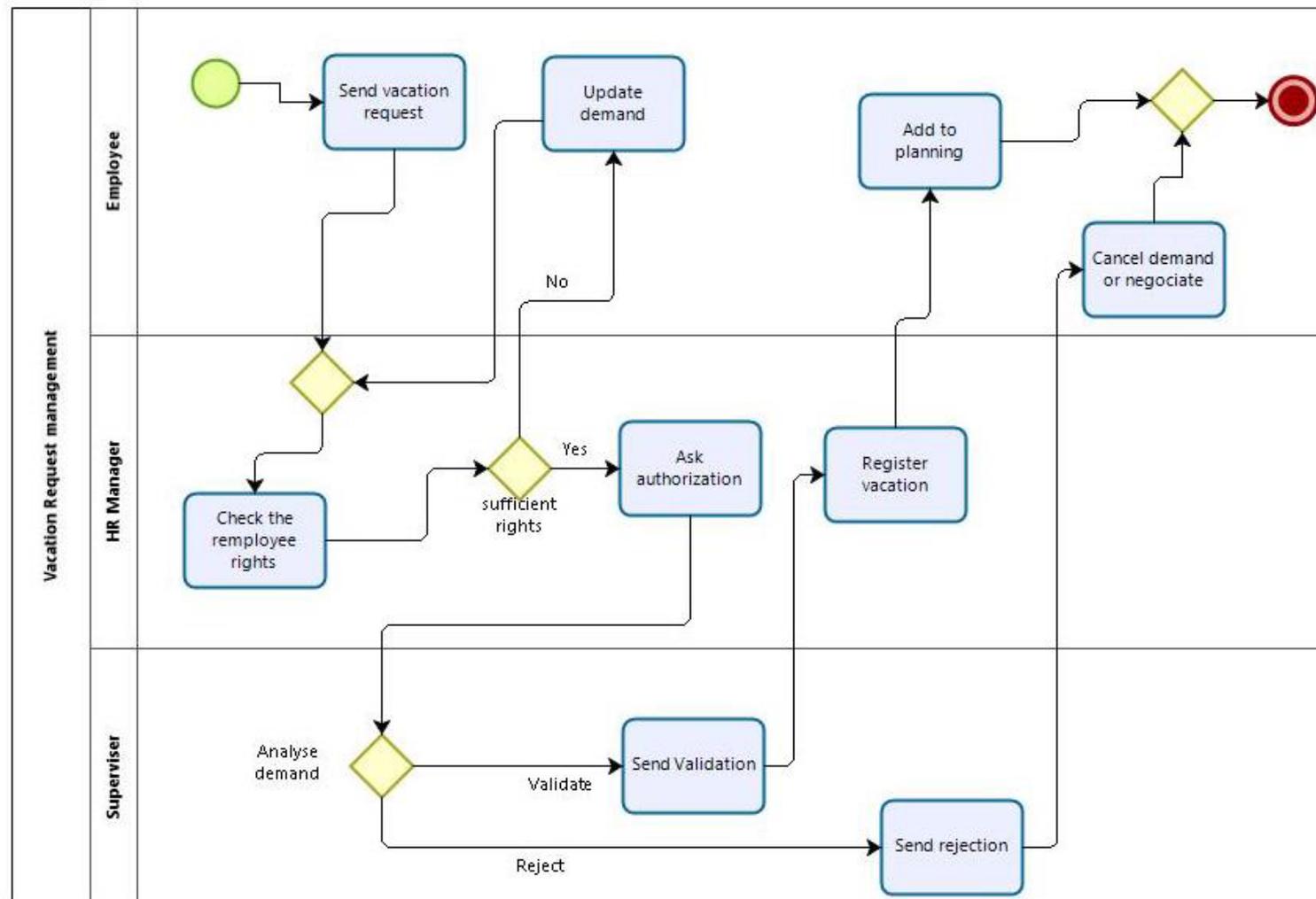
	Start			Intermediate			End	
	Receiving					Sending		
	Up-level process	Event based Sub process with interruption	Event based Sub process without interruption	Reception	Borderline with interruption	Borderline without interruption	Throwing	Closure
<b>Plain:</b> untyped events, when the process start or ends; state change of process								
<b>Message:</b> Receiving and sending								
<b>Cyclic timer events:</b> points in time spans or timeouts								
<b>Climbing:</b> evolving to superior responsibility level								
<b>Conditional events:</b> reacting to changed conditions or integrating business rules								
<b>Link:</b> Off-page connectors, Two corresponding links = sequence (connecting parts of processes)								
<b>Error :</b> Catching / throwing known errors in the planified process								
<b>Annulation: réaction à l'annulation</b> <b>Cancel:</b> reacting to a cancelled transaction or triggering cancellation								
<b>Compensation:</b> handling or triggering a compensation								
<b>Signal:</b> standard notifcations across various processes, 1 signal can be caught multiple times								
<b>Multiple:</b> Catching or throwing one out of a set of events								
<b>Multiple parallel:</b> the reception of all events is done in parallel								
<b>Terminate:</b> triggering termediate termination of a process								

# Short example for understanding

## Process of Vacation Request management

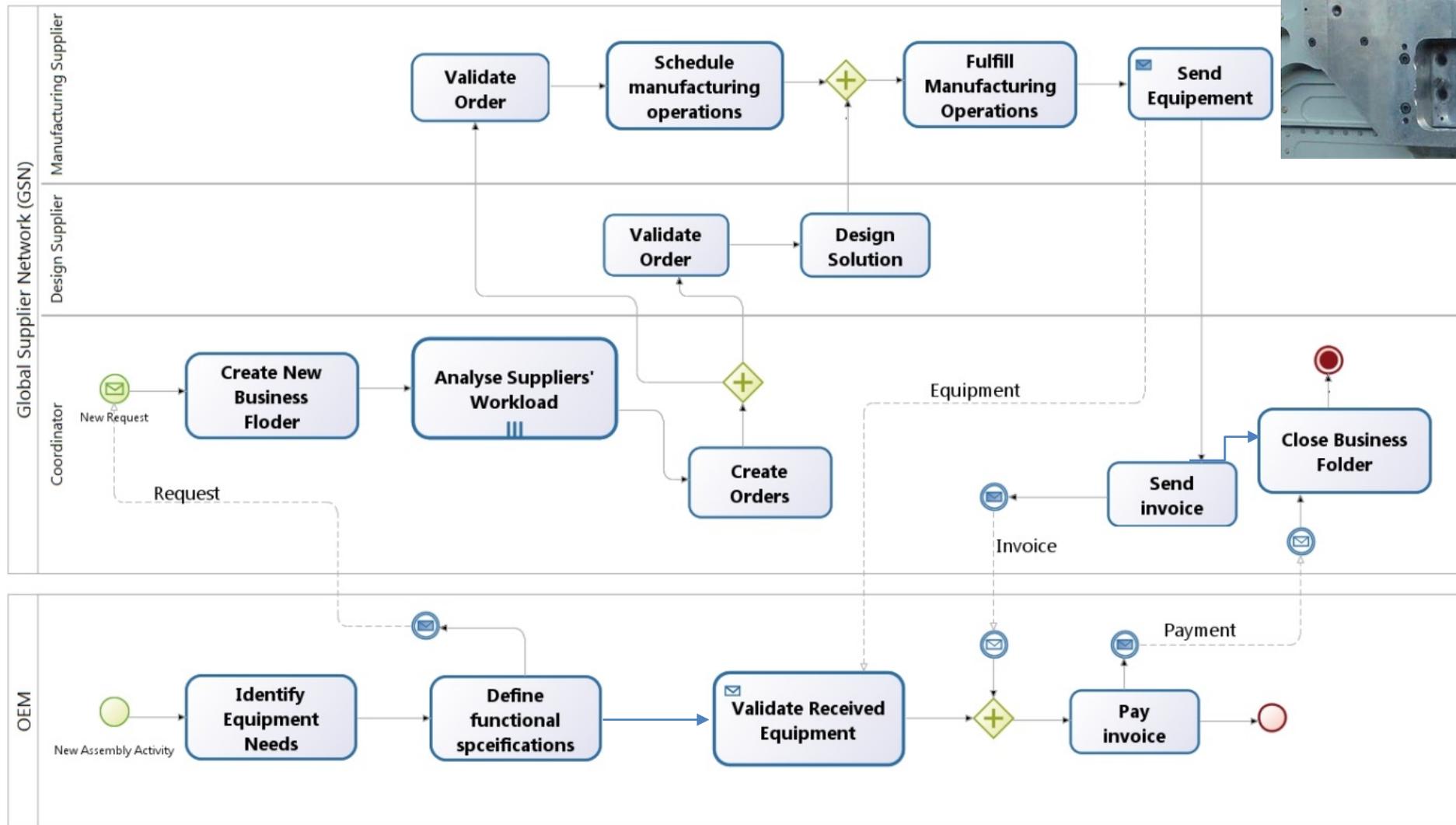
Information: application form; provisional service schedule

Actors: Employee, supervisor and Human Resource manager



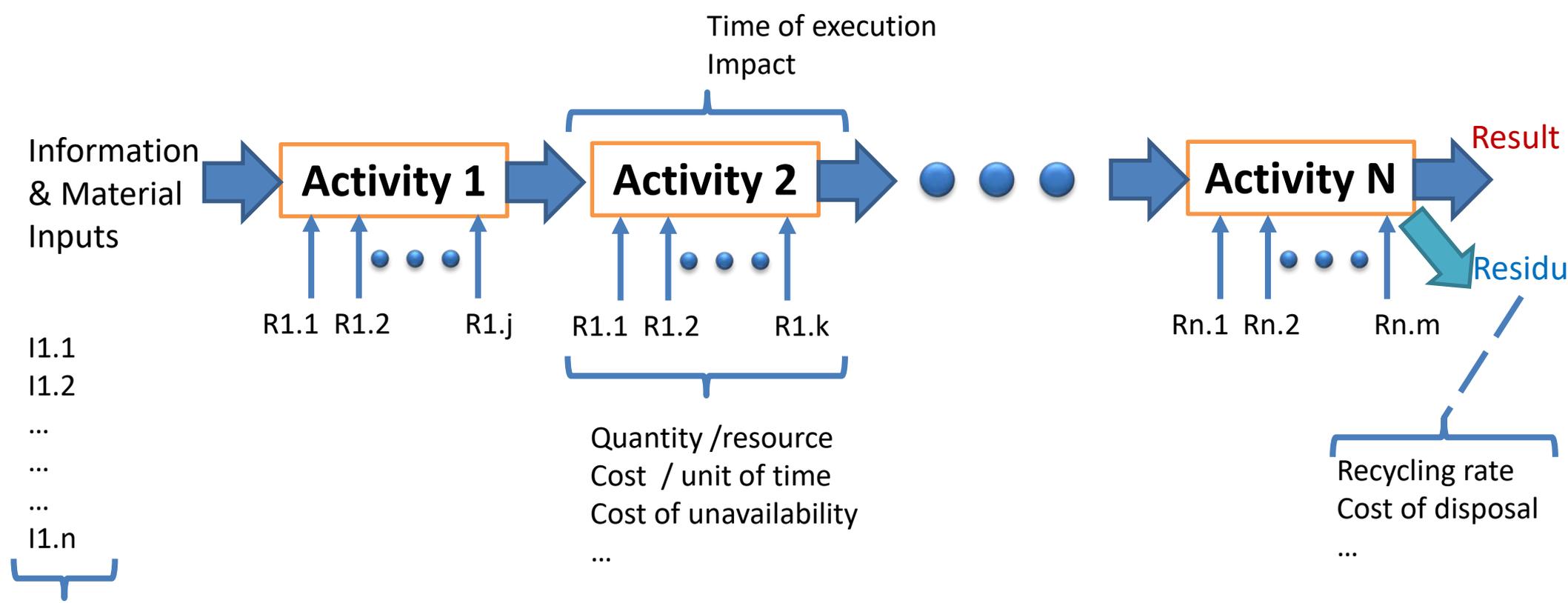
# Second Example for understanding

## Process of fixture tool realization in aeronautic industry



# How to use process approach for costing

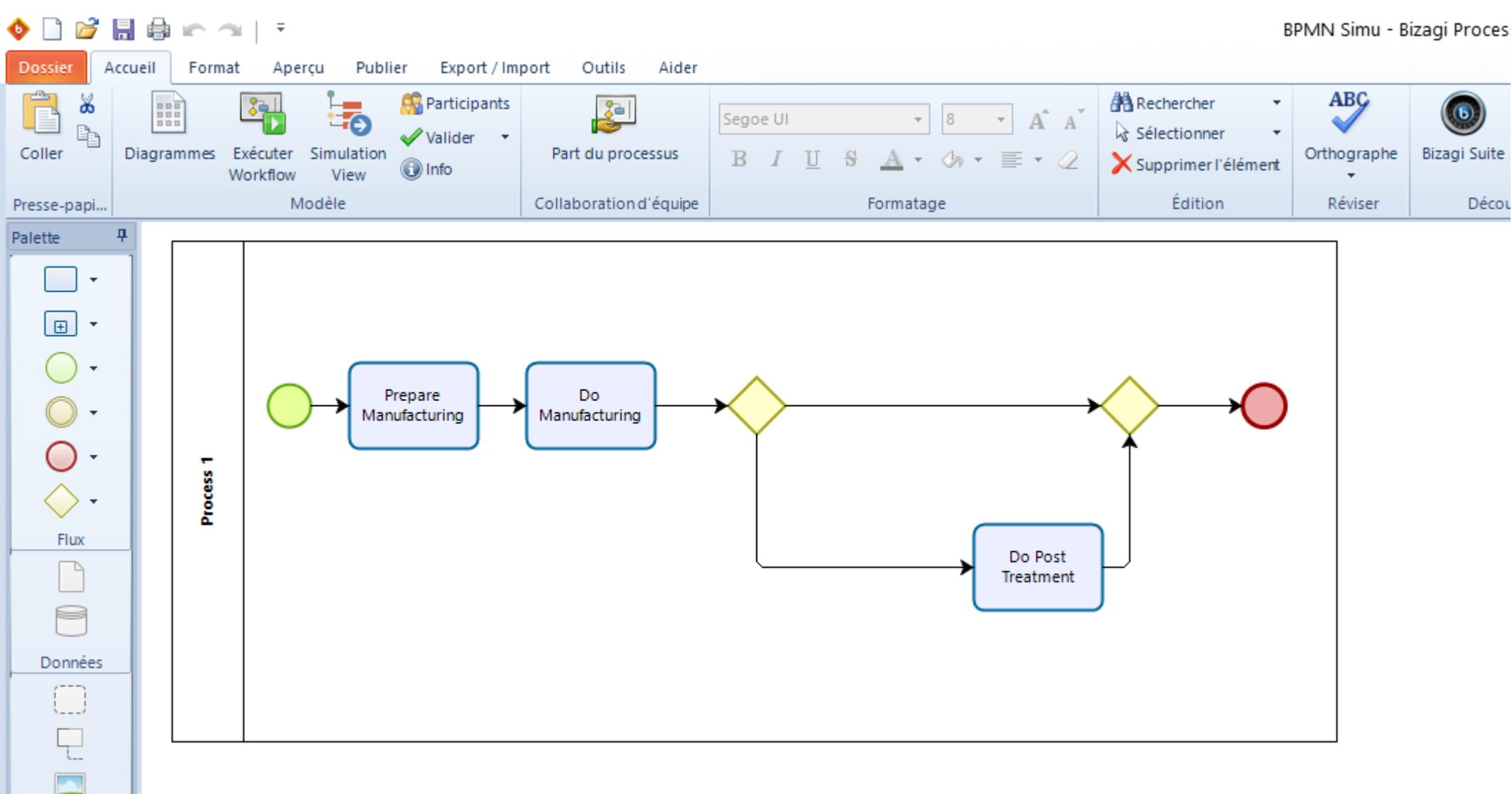
**PRINCIPLE:** Decompose Industrial Process to separate cost centers per activities



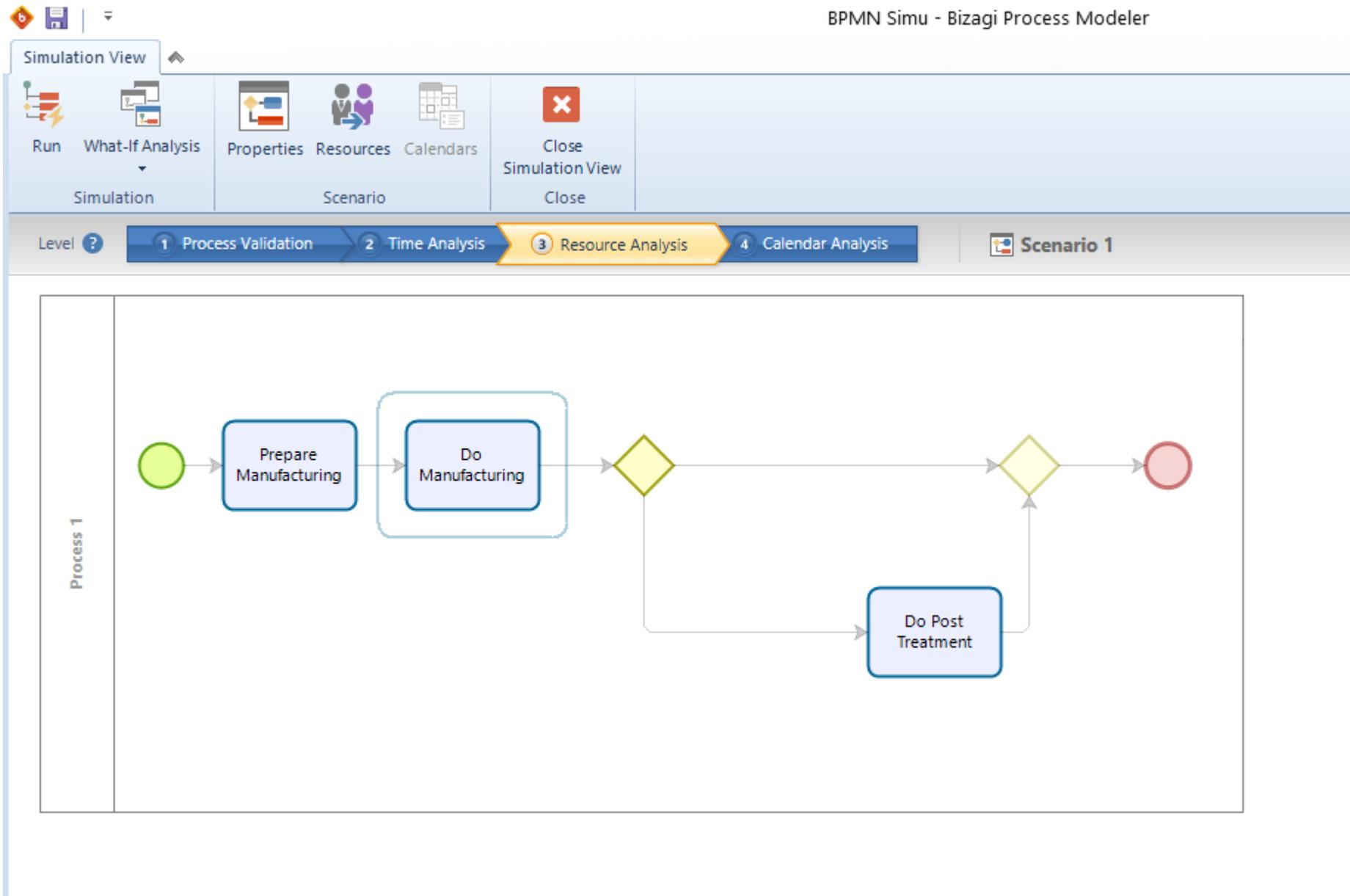
- I1.1
  - I1.2
  - ...
  - ...
  - ...
  - I1.n
- Quantity  
 Cost of Provision  
 Cost of treatment  
 ....  
 ...

**Simplified model:**  
 Cost to obtain result =  
 Cost of inputs + cost of activities + Cost of disposal + ....

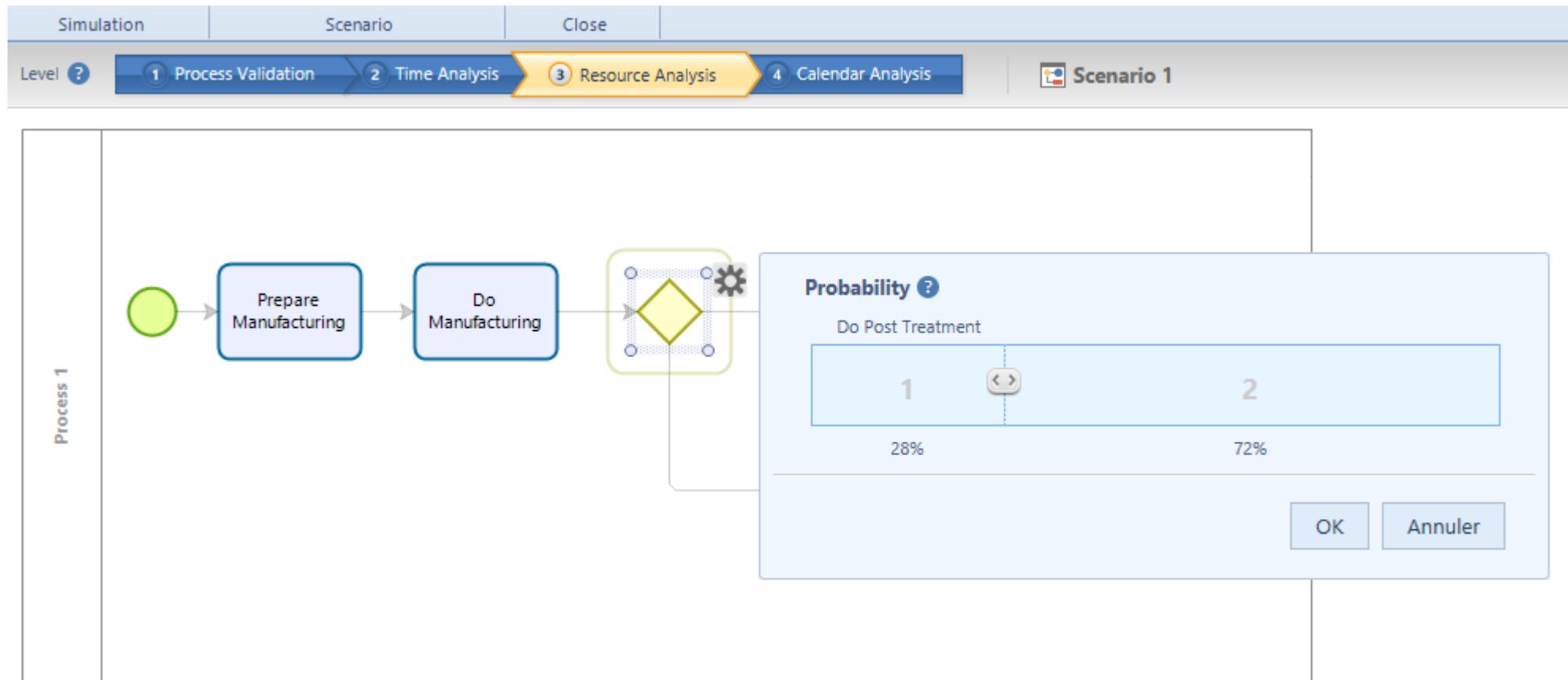
## Example of process simulation with Bizagi : process creation



## Example of process simulation with Bizagi



## Example of process simulation with Bizagi: Gate configuration



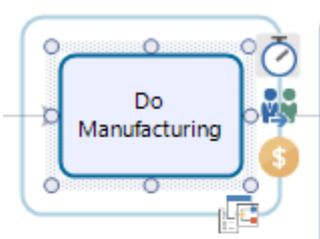
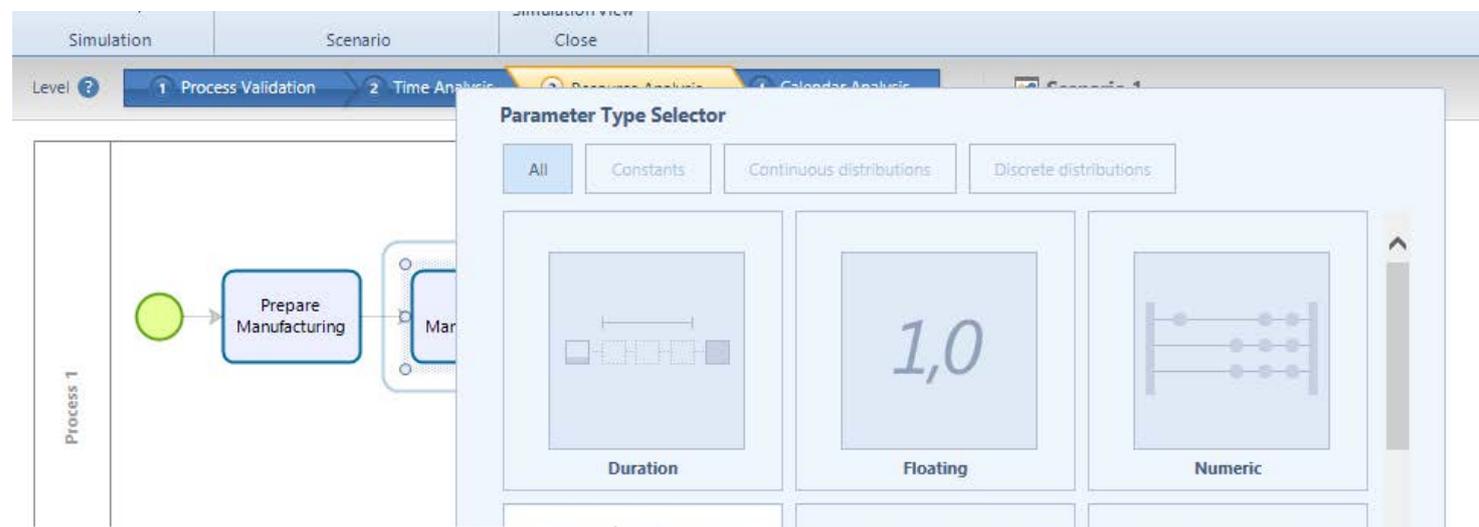
## Example of process simulation with Bizagi: Task configuration

The screenshot displays the Bizagi simulation interface. At the top, there are tabs for 'Simulation', 'Scenario', and 'Close'. Below these, a progress bar shows four steps: 1 Process Validation, 2 Time Analysis, 3 Resource Analysis (highlighted in yellow), and 4 Calendar Analysis. To the right of the progress bar is a 'Scenario 1' icon.

The main workspace shows a process flow for 'Process 1'. A green circle on the left leads to a task box labeled 'Prepare Manufacturing'. This task box is connected to a 'Time' configuration dialog box. The dialog box has two sections: 'Wait time' and 'Processing time'. Each section has four input fields for days, hours, minutes, and seconds, followed by a bar chart icon. The 'Processing time' section is currently set to 0 days, 0 hours, 15 minutes, and 0 seconds. At the bottom of the dialog box are 'OK' and 'Cancel' buttons. An arrow points from the right side of the 'Time' dialog box to a red circle on the right, indicating the next step in the process flow.

# Example of process simulation with Bizagi

## Task Configuration



### Time

Wait time ?

0	0	0	0
days	hrs	mins	secs

Processing time (mins) ?

**Normal Distribution**

Mean:

Standard deviation:

OK Cancel

ribution  
most  
ions in  
symmetrical  
. It is useful  
ations where  
distributed

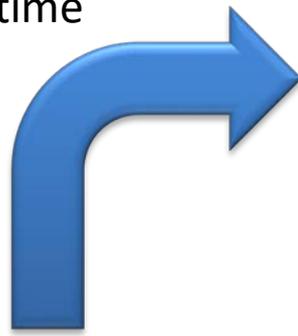
Truncated Normal Distribution

Triangular Distribution

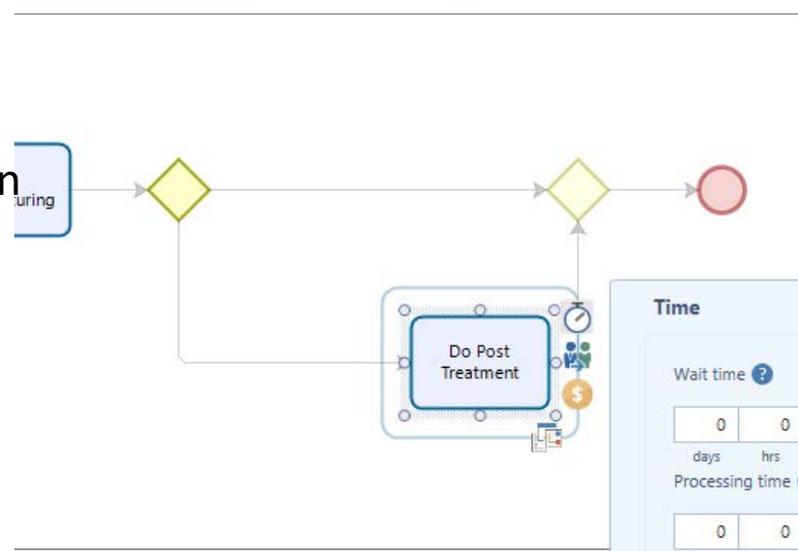
OK Cancel

# Example of process simulation with EPC Task Configuration

Possibility to refine in resource section  
Changing the wait time



3 Resource Analysis 4 Calendar Analysis Scenario 1



**Time**

Wait time ?

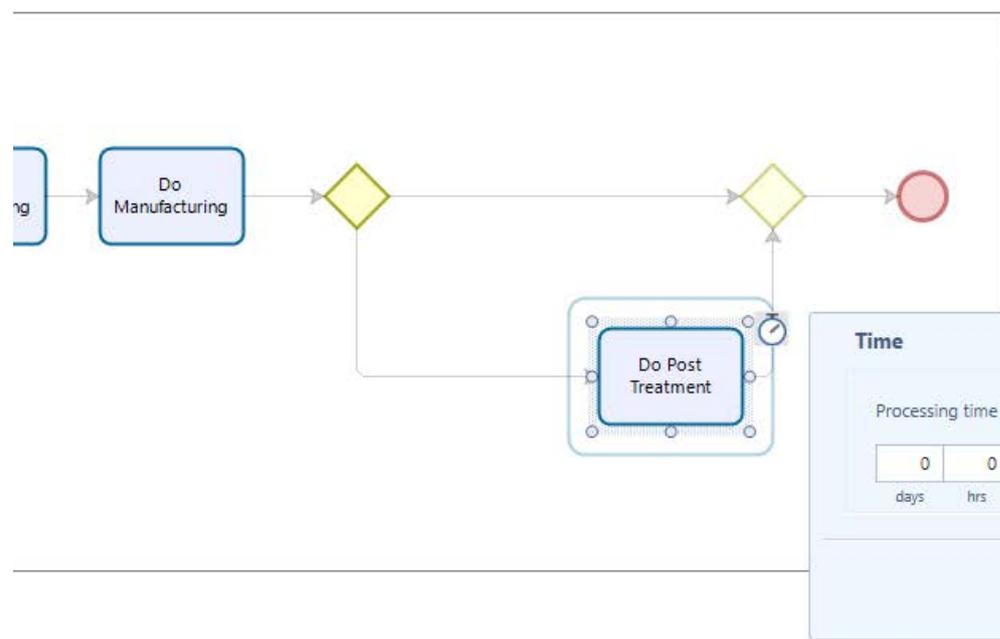
0	0	1	0
days	hrs	mins	secs

Processing time ?

0	0	5	0
days	hrs	mins	secs

OK Cancel

2 Time Analysis 3 Resource Analysis 4 Calendar Analysis Scenario 1



**Time**

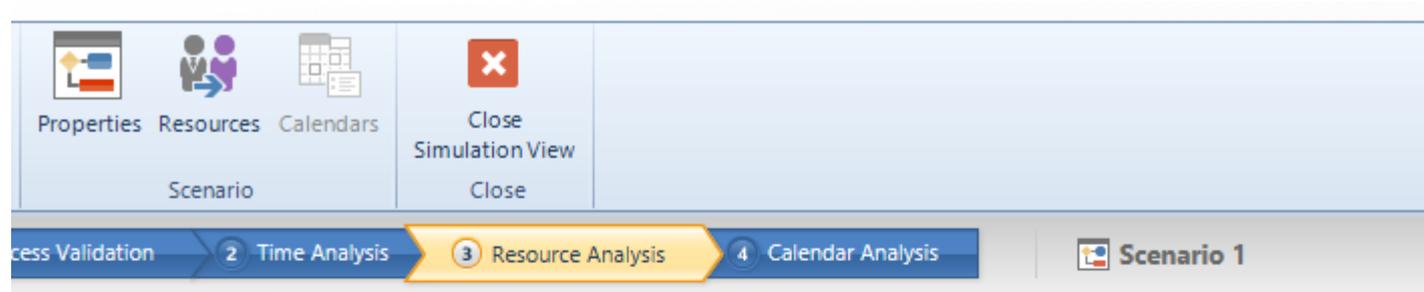
Processing time ?

0	0	5	0
days	hrs	mins	secs

OK Cancel

## Example of process simulation with Bizagi

### Resource configuration



**Resources**

Availability Costs

Resources	Quantities
Machine AM 333	3
Operator	2
Equipment xxz	5

Resources

**Resources**

Availability Costs

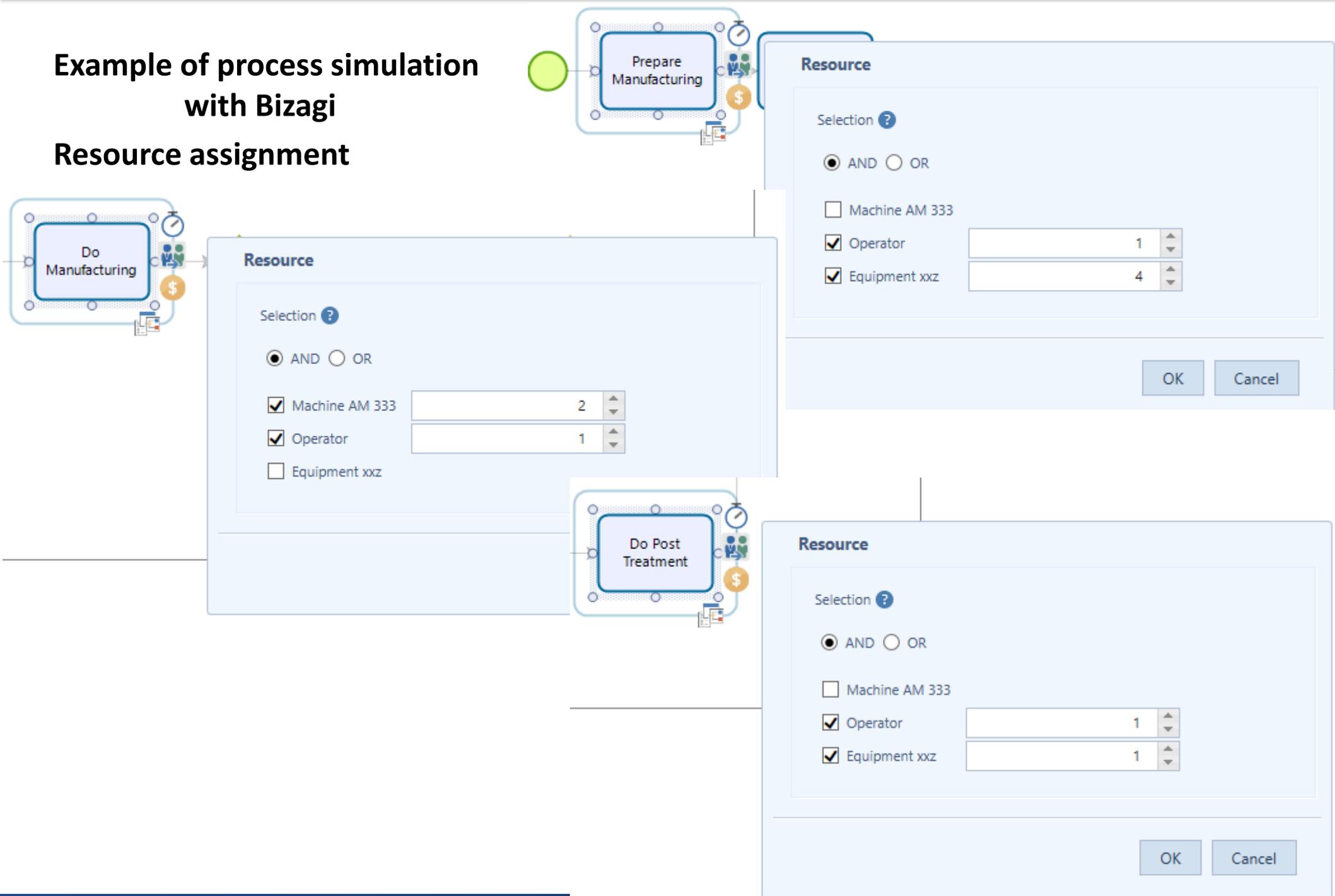
Resources	Fixed cost	Cost per hour
Machine AM 333	0.5	2
Operator	0.3	1.2
Equipment xxz	0	0.3

Resources

Ok

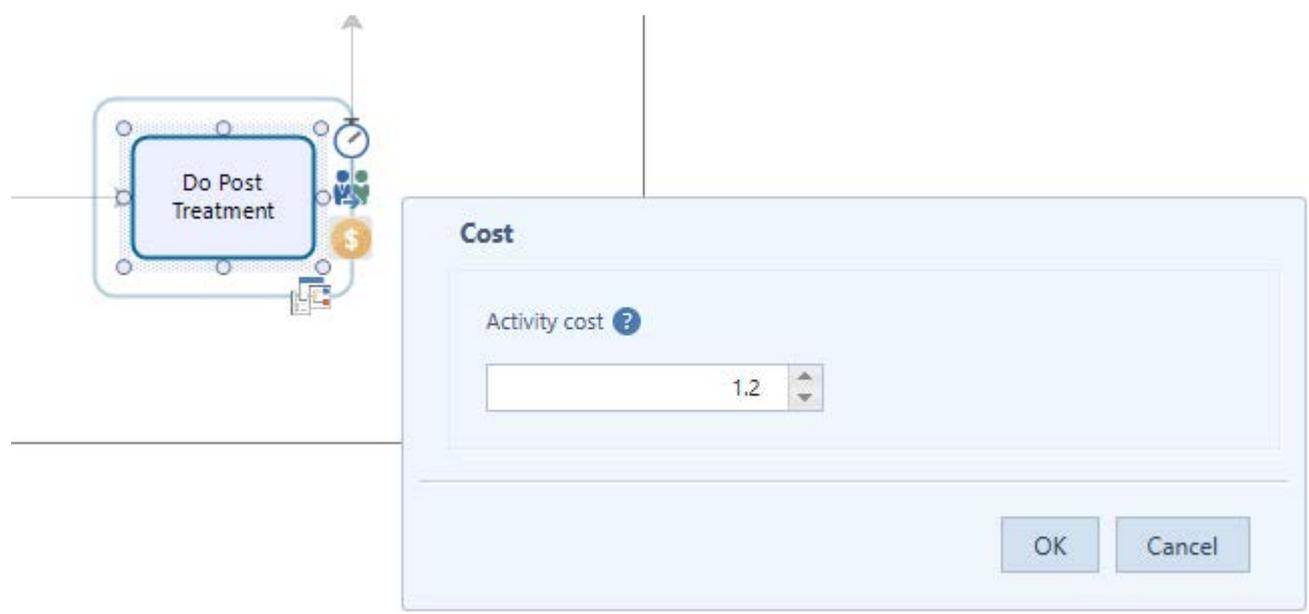
# Example of process simulation with Bizagi

## Resource assignment



# Example of process simulation with Bizagi

## Possibility to refine activity cost

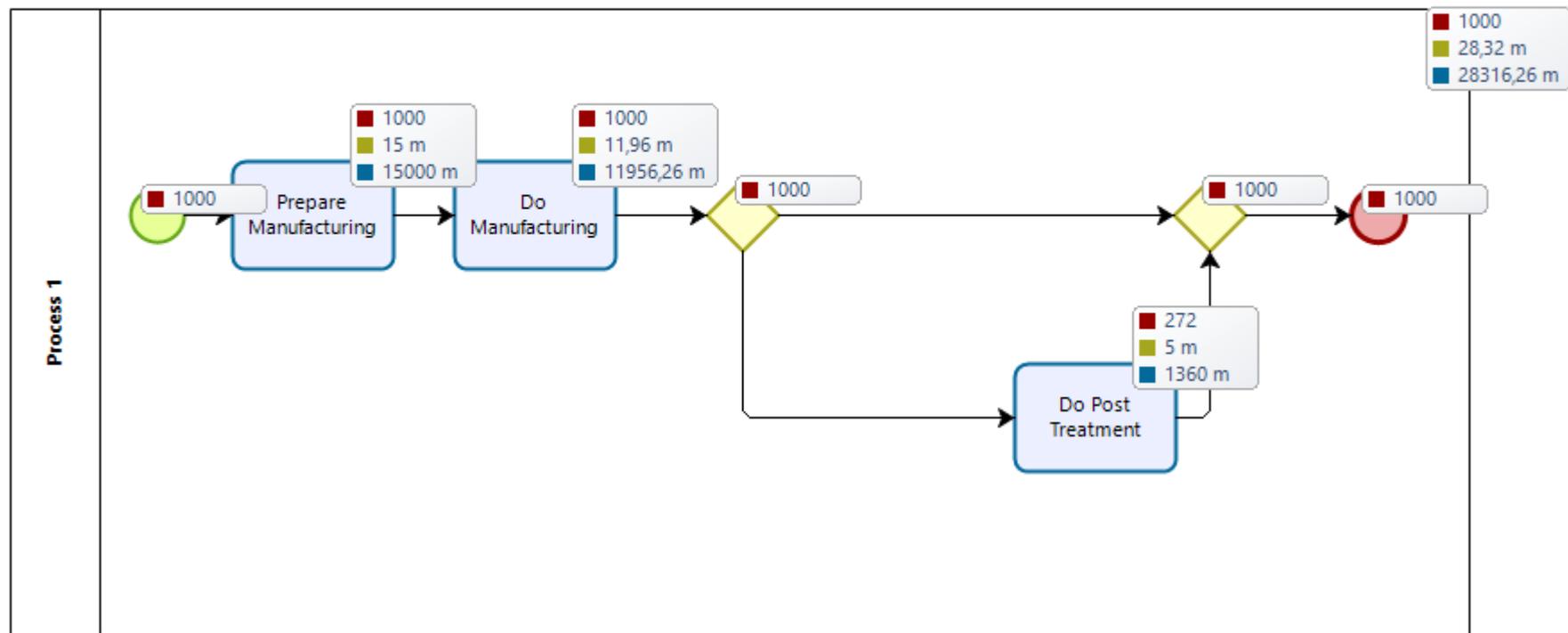


## Example of process simulation with Bizagi

### Time Analysis

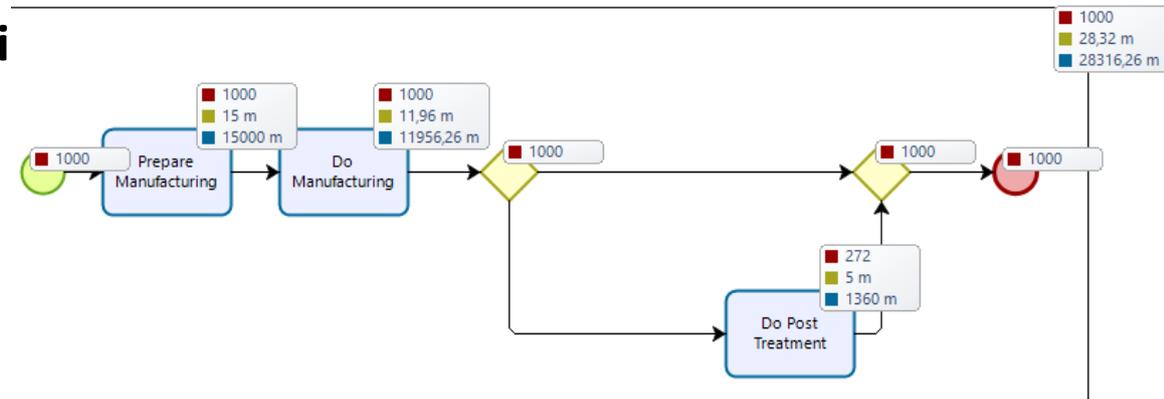
Simulation interface showing controls and real-time display options:

- Simulation:** Start, Stop, Results
- Real Time Display:** Display Off, Completed, Average time, Total time, Position, Analysis
- Close:** Close window, Close



# Example of process simulation with Bizagi

## Time Analysis



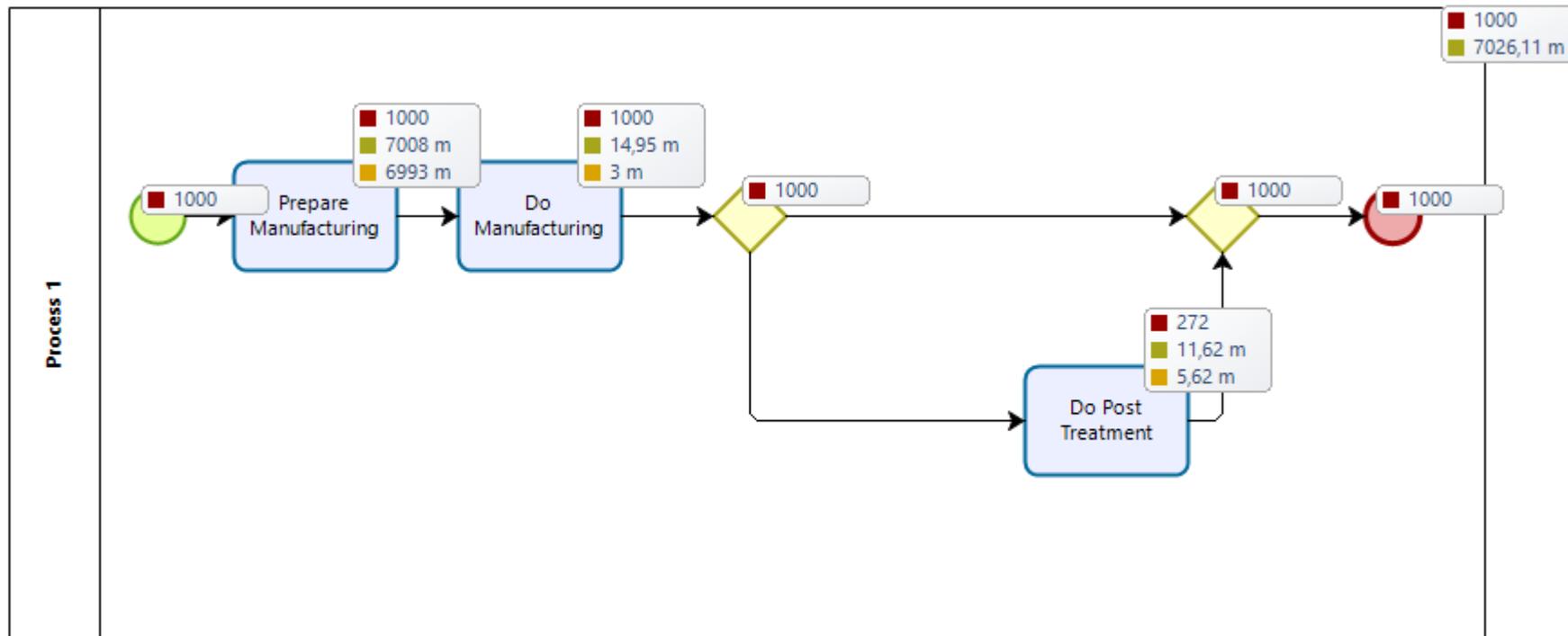
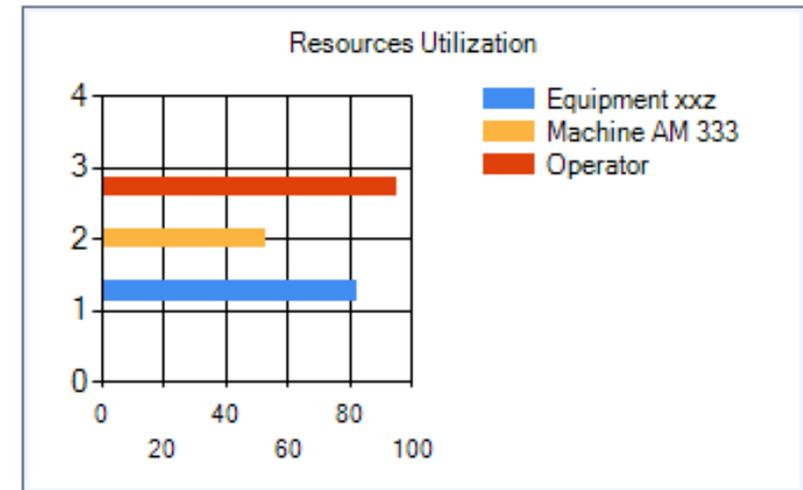
**Scenario information**

Nom	Scenario 1
Time unit	Minutes
Durée	030,00:00:00

Name	Type	Instances completed	Instances started	Min. time	Max. time	Avg. time	Total time
Process 1	Process	1 000	1 000	16m 34s	41m 7s	28m 19s	19d 15h 56m 15s
NoneStart	Start event	1 000					
Prepare Manufacturing	Task	1 000	1 000	15m	15m	15m	10d 10h
Do Manufacturing	Task	1 000	1 000	1m 34s	21m 24s	11m 57s	8d 7h 16m 15s
Do Post Treatment	Task	272	272	5m	5m	5m	22h 40m
ExclusiveGateway	Gateway	1 000	1 000				
ExclusiveGateway	Gateway	1 000	1 000				
NoneEnd	End event	1 000					

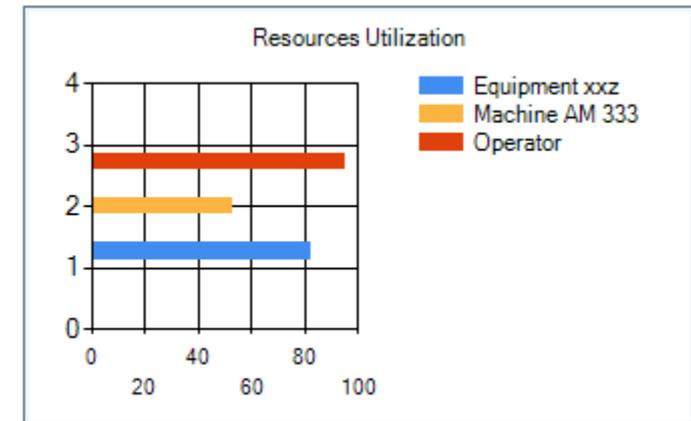
## Example of process simulation with Bizagi

### Resource Exploitation



## Example of process simulation with Bizagi

### Resource Exploitation



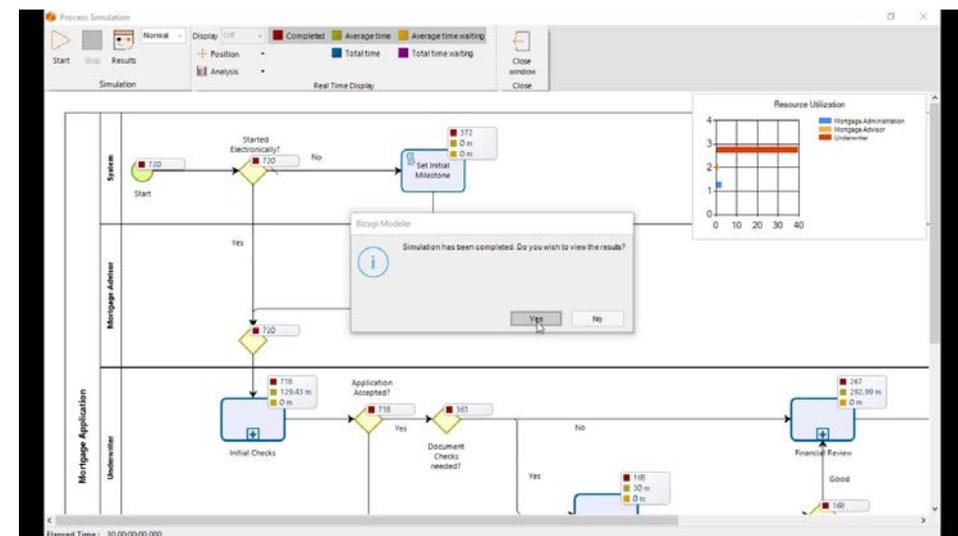
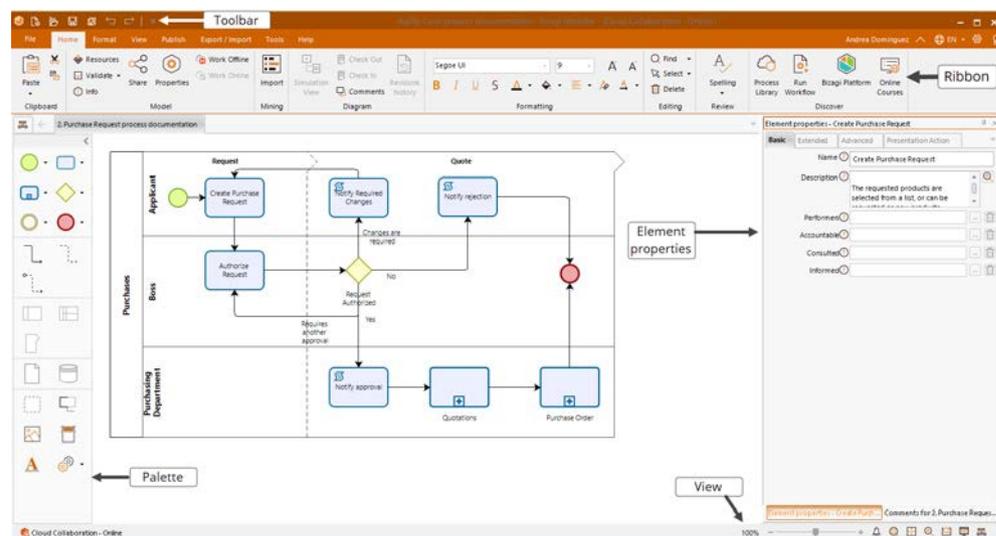
Scenario information				
Nom	Scenario 1			
Time unit	Minutes			
Durée	030,00:00:00			
Resource	Utilization	Total fixed cost	Total unit cost	Total cost
Machine AM 333	53,11 %	500	47 825,04	48 325,04
Operator	95,24 %	681,6	34 305,91	34 987,51
Equipment xxz	82,13 %	0	18 489,6	18 489,6
	Total	1 181,6	100 620,55	101 802,15

# Bizagi Tool for performance assesment within Process oriented approach

[https://www.youtube.com/watch?v=KgO8K6FFJdU&ab\\_channel=Bizagi](https://www.youtube.com/watch?v=KgO8K6FFJdU&ab_channel=Bizagi)

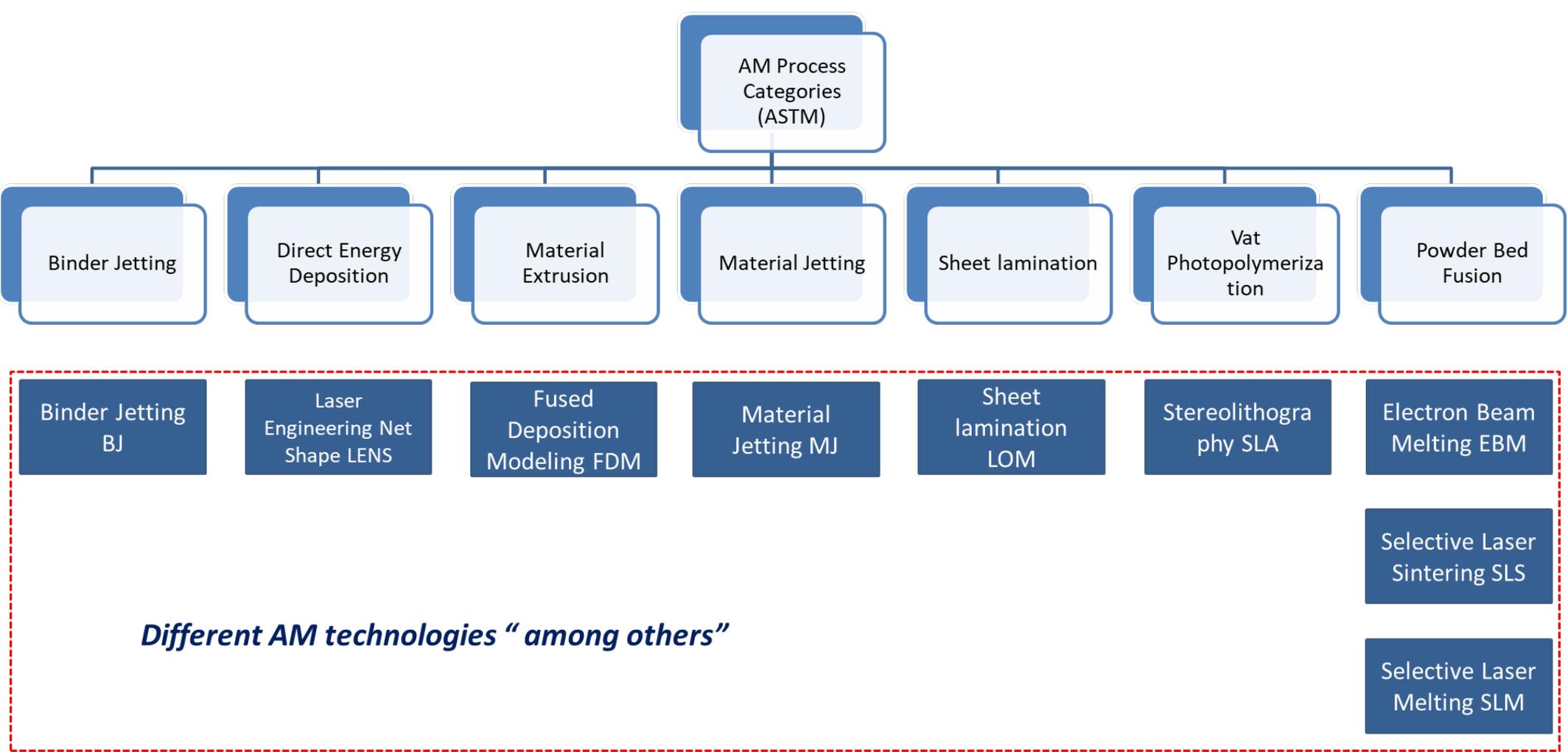
[https://www.youtube.com/watch?v=eJAHrU\\_GvOk&ab\\_channel=Bizagi](https://www.youtube.com/watch?v=eJAHrU_GvOk&ab_channel=Bizagi)

[https://www.youtube.com/watch?v=CeiEjGOT8HE&ab\\_channel=Bizagi](https://www.youtube.com/watch?v=CeiEjGOT8HE&ab_channel=Bizagi)



## Standard AM Processes

# Main AM Technologies (ISO/ASTM 52900 Standard)



# Main AM Technologies

## >> Every technology can be represented by a process

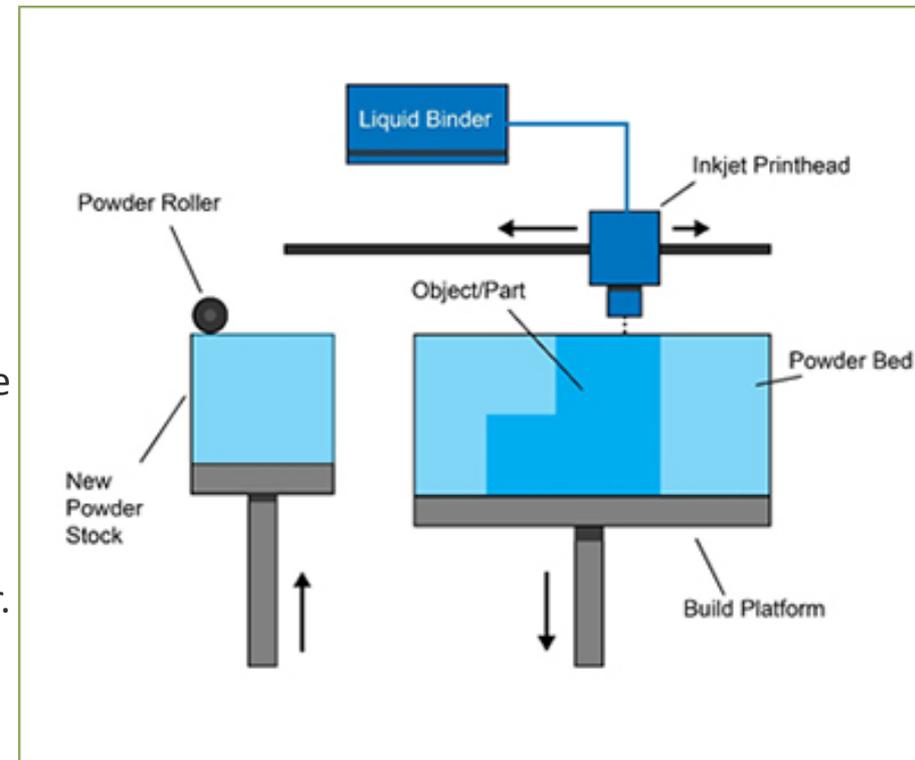
### Material jetting,

Additive manufacturing process in which droplets of build material are selectively deposited.

Ex: PP (Polymer jetting)

#### Steps:

1. Powder material is spread over the build platform using a roller.
2. The print head deposits the binder adhesive on top of the powder where required.
3. The build platform is lowered by the model's layer thickness.
4. Another layer of powder is spread over the previous layer. The object is formed where the powder is bound to the liquid.
5. Unbound powder remains in position surrounding the object.
6. The process is repeated until the entire object has been made.



# Main AM Technologies

>> Every technology can be represented by a process

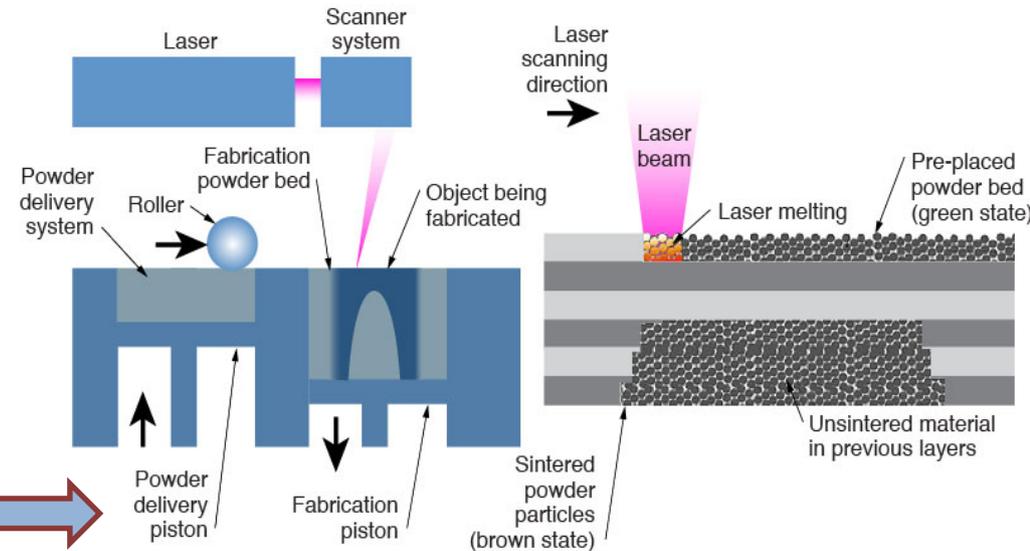
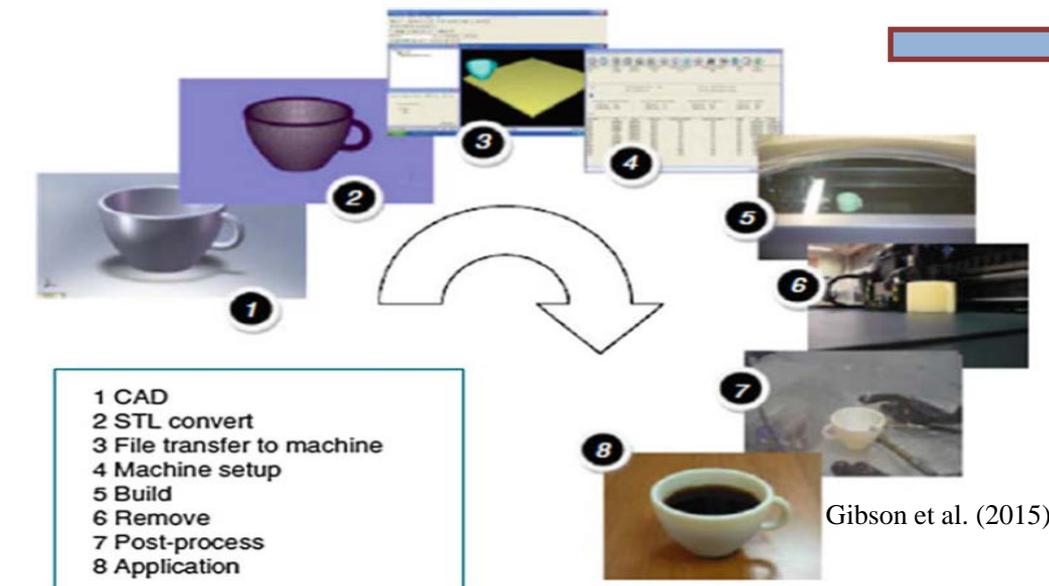
## Powder bed fusion

Thermal energy selectively fuses regions of a powder bed.

Ex: SLS, SLM, DMLS, SMLM, EBM (Electron Beam)

ASTM (2012)

### PBF Process



- A thin layer of powder is spread
- Energy source melts or sinters the powder
- The platform goes down
- The powder is spread for another layer
- The process repeated

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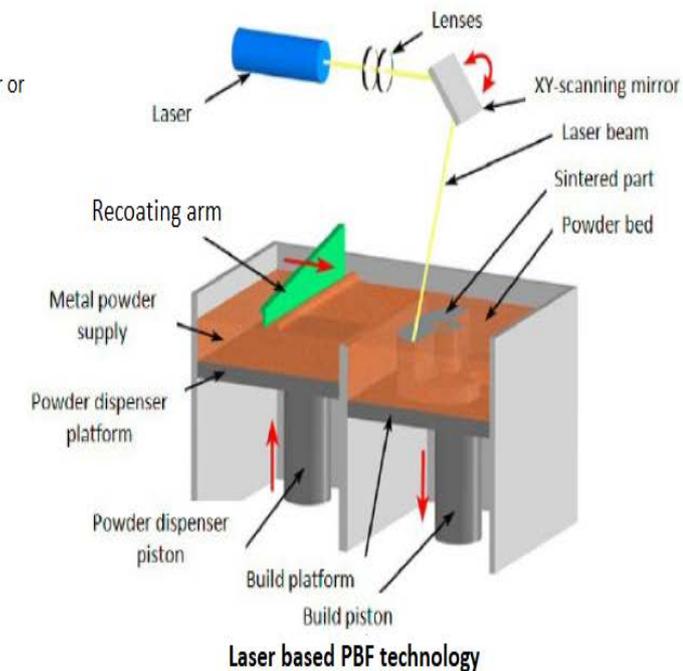
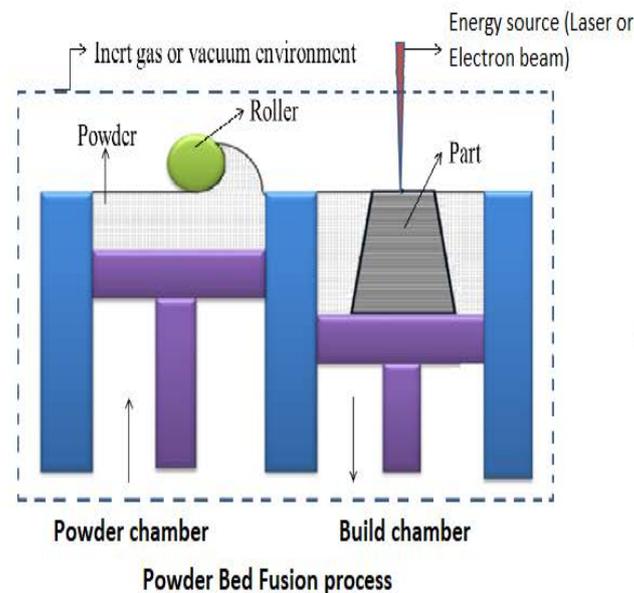
### Powder bed fusion

AM process in which thermal energy selectively fuses regions of a powder bed.

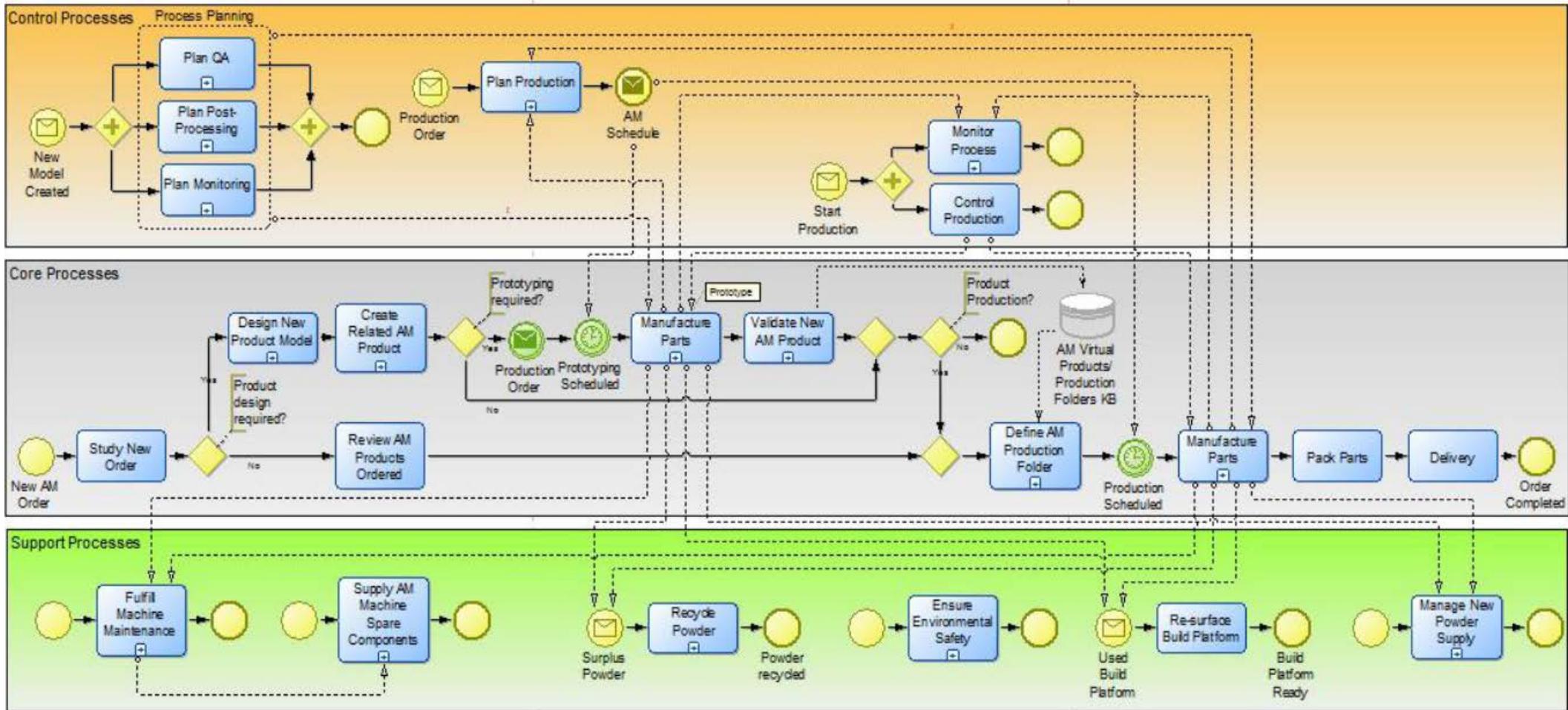
Ex: SLS, SLM, DMLS, SMLM, EBM

### Steps:

1. A layer, typically 0.1mm thick of material is spread over the build platform.
2. A laser fuses the first layer or first cross section of the model.
3. A new layer of powder is spread across the previous layer using a roller.
4. Further layers or cross sections are fused and added.
5. The process repeats until the entire model is created. Loose, unfused powder is removed during post processing.

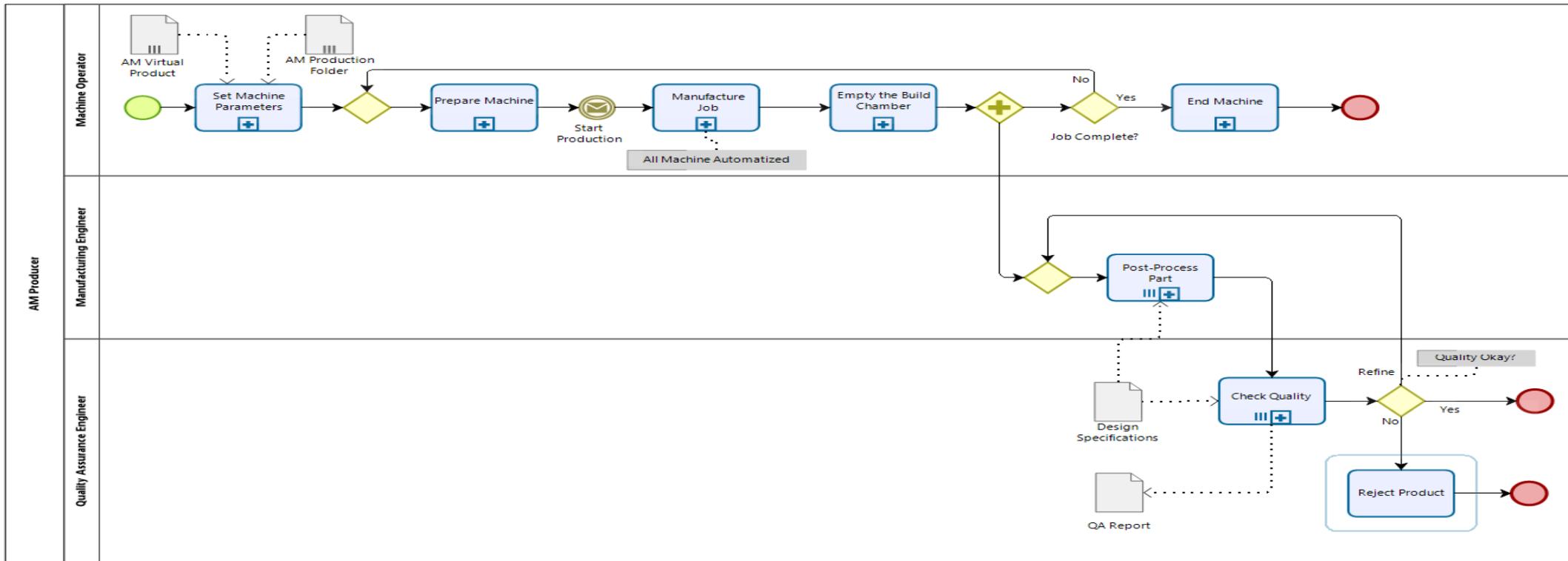


# Main AM processes according to value chain model



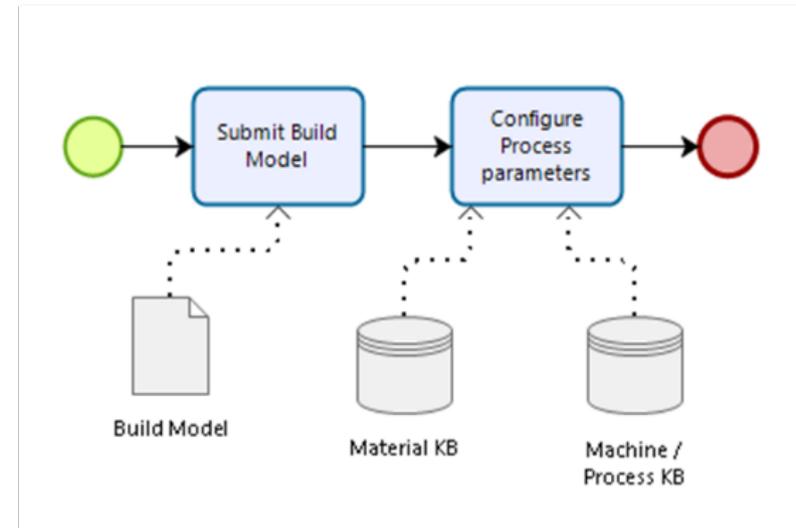
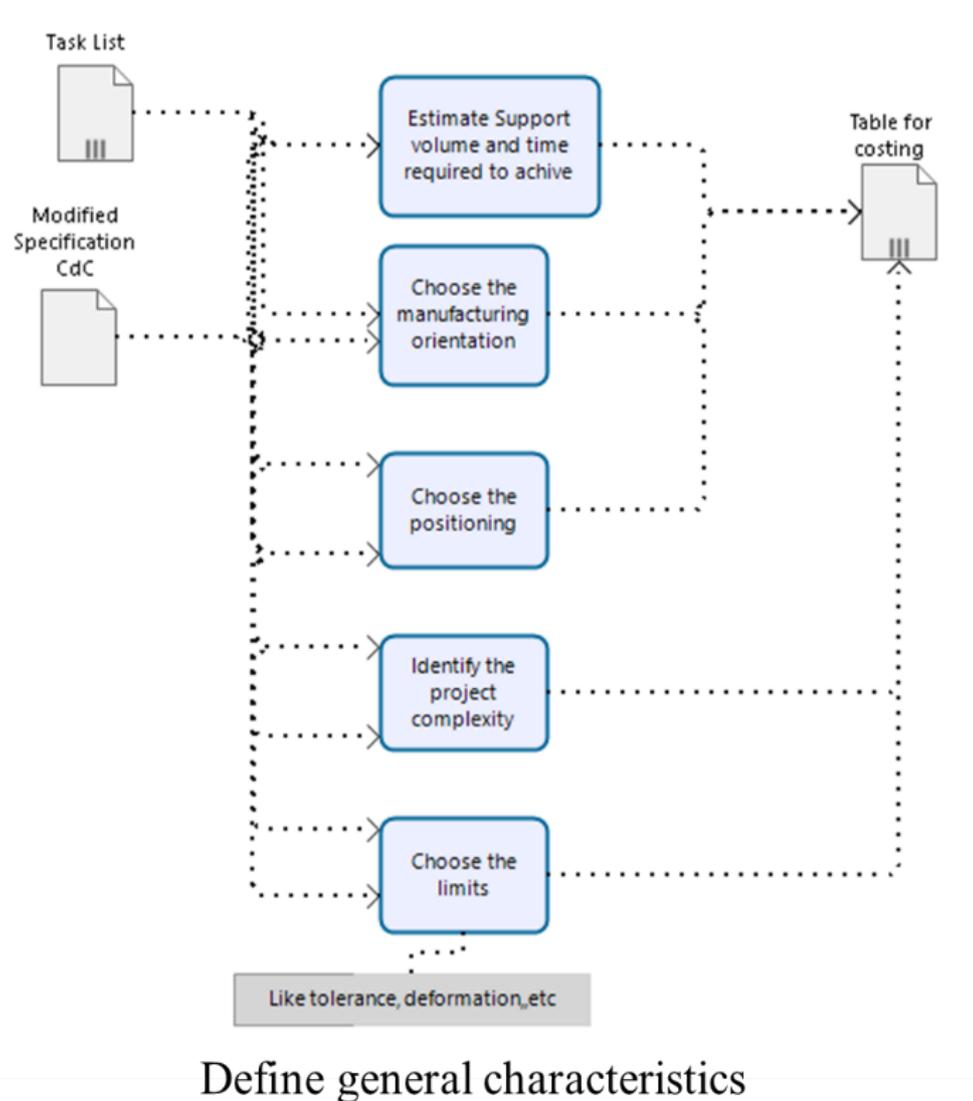
# Main AM processes according to value chain model

## Generic Process



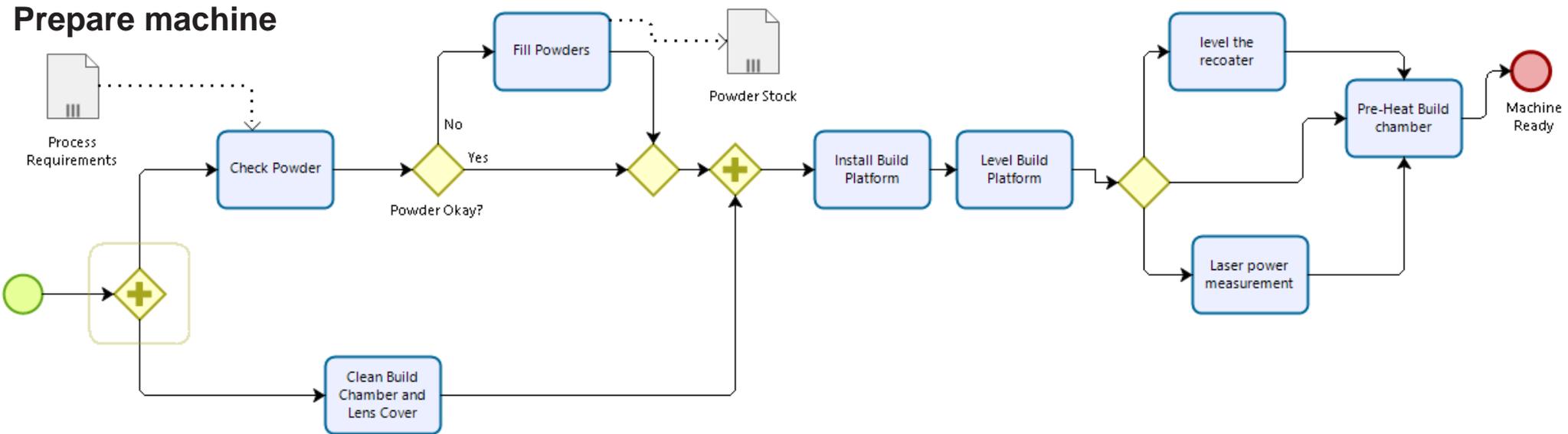
# Main AM processes according to value chain model

Define general characteristics and set machine parameters

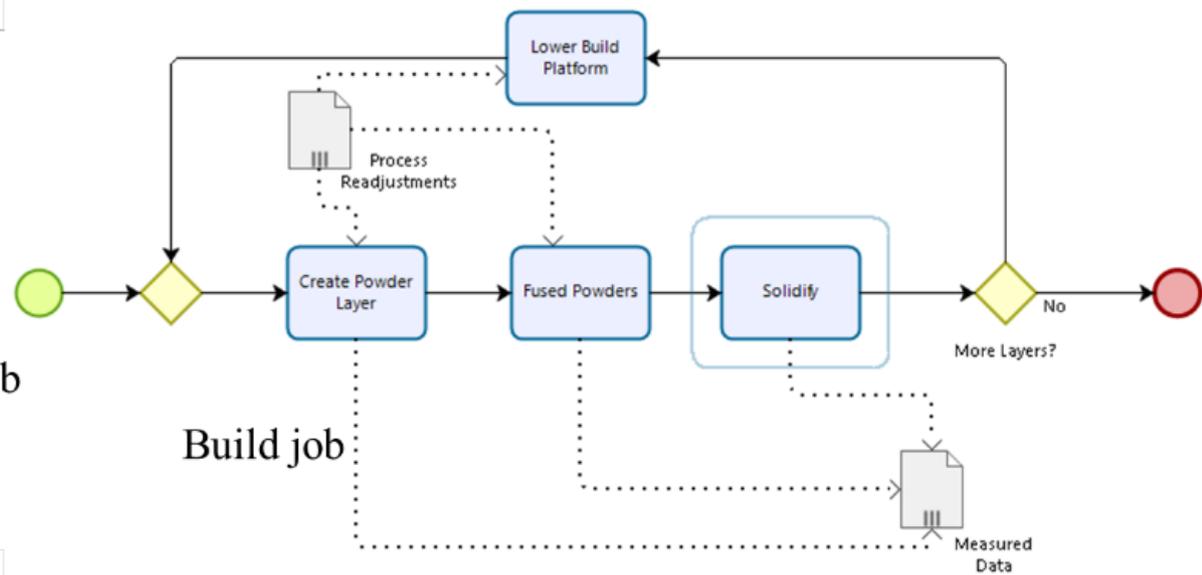
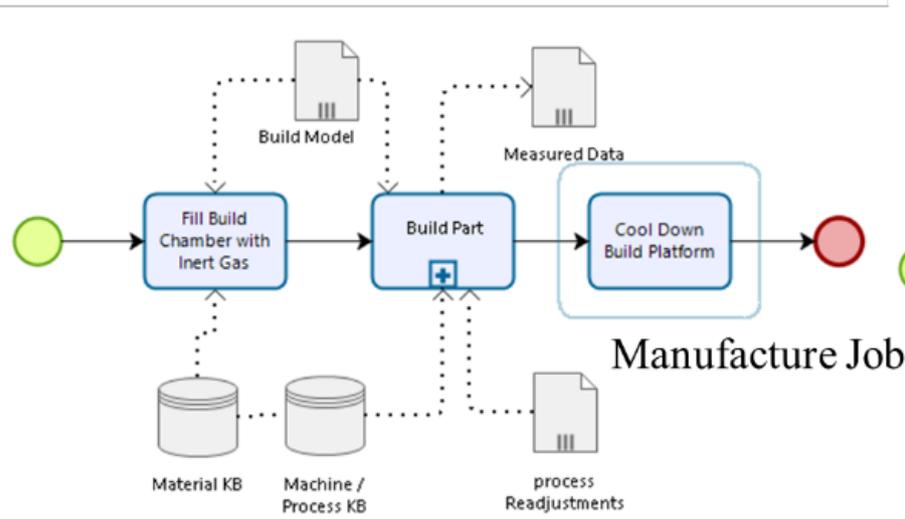


Set machine parameters activity

# Main AM processes according to value chain model

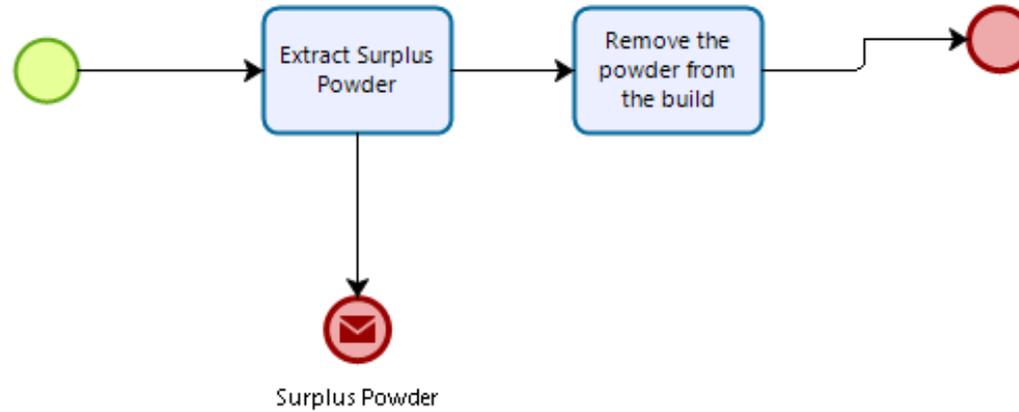


### Manufacture Job and Build Job

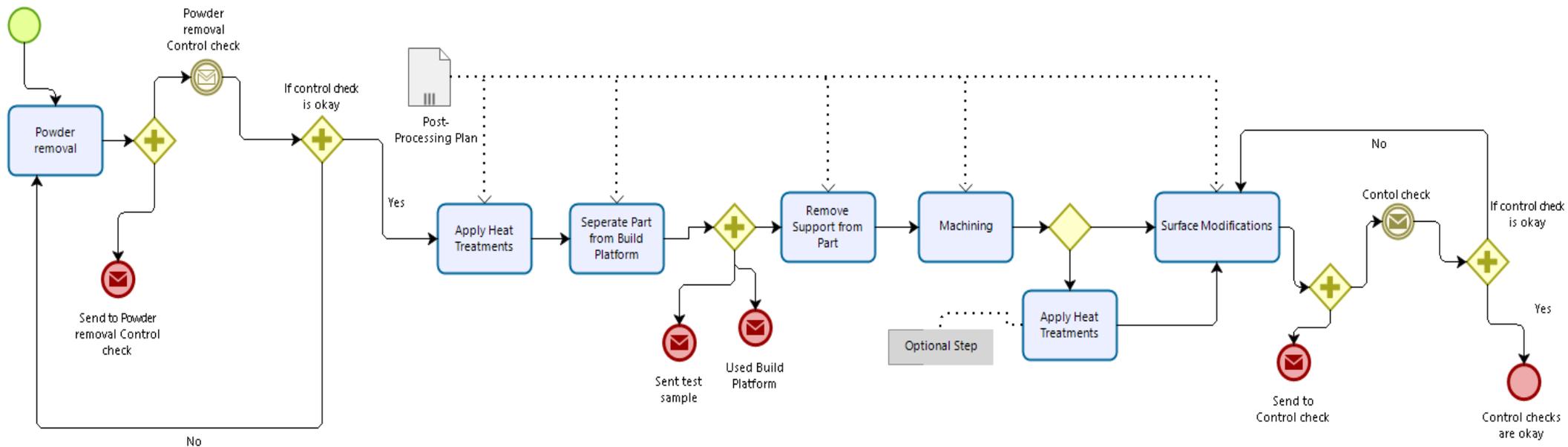


# Main AM processes according to value chain model

## Machine output treatment



## Post Process treatment





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NANTES**



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## Competence Unit Training CU 34 – Process Selection

**Course: AM Cost Evaluation and management based on  
process oriented approach (Part 1)**

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