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The Control Centre: a Basic Concept for Modelling and Simulation of Industrial Control

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ABSTRACT

In the first part of this paper, a review of the main potentials, of some applications and the major limits of simulation are presented. In order to find solution of some limits, we propose in the second part the introduction of the control process into simulation, thanks to the concept of Control Centre (CC). The CC is then described by giving its definition, its components and their organisation in a simplified manner, as well as a typology of the information defining the relations between CCs and the controlled system. These relations correspond to the warning messages circulating between CCs, the base of co-operation and co-ordination relations of the proposed model. Finally, a formalisation of the internal behaviour of the CC is proposed in a detailed way, for its integration in a PPS (Product Processing System)/CC network.

KEYWORDS

Modelling, simulation, control centre, information, manufacturing systems.

INTRODUCTION

Nowadays computer simulation of manufacturing systems is limited to representation, validation, and performance evaluation of complex processes. As we can not react, in a structured and organised way, on the system results during simulation, its role is somewhere "passive". Then, to enhance the capacity of this technique and to make it more "active", the goal of our actual research corresponds to the introduction of some basic concepts concerning the industrial control into the field of simulation. Some existing research works concerning these aspects, are called "reflective simulation" or "external and internal" models of simulation [Kosturiak *et al.* 97].

1. THE SIMULATION

At first, this paper will consider an overview on the state of the art of production simulation,

namely: its potentials, its use in industrial companies, its principal contributions concerning production systems and its limits.

1.1. Potentials of simulation

The potentials of simulation are very large (figure 1). The simulation can help users by contributing in design, in management and in decision making of production systems. Its capacities allow the modelling of all kinds of company flows: the informational flow, the physical flow and the decisional flow. This modelling could be made, on various hierarchical levels (strategic, tactic, operational) [Bakalem *et al.* 95] [Cumenal 97] and abstraction levels (levels depending on the resource states): machine, workshop, production line, factory, busy, idle, breakdown, set-up, etc. Moreover, all the manufacturing system life cycle phases could be covered by simulation: the design, the realisation [Chau *et al.* 94] [Khalfoun *et al.* 95] and the exploitation [Habchi *et al.* 95] of the system.

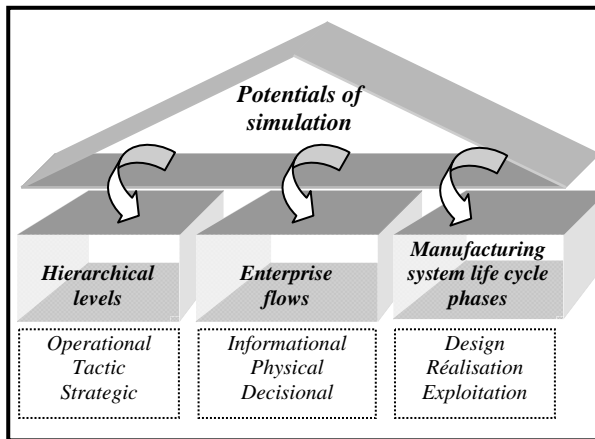


Figure 1. Potentials of simulation.

1.2. Use of simulation

The simulation is widely used in the field of production systems and applications are very numerous. Abundant literature is available on this subject, particularly on the simulation use of manufacturing systems [Gardiner *et al.* 93] [Wagner *et al.* 94] [Bouchez *et al.* 95] [Perona 96] [Claver *et al.* 97], etc. Figure 2 gathers a list of the main contributions of simulation in the field of the production systems [Berchet *et al.* 00].

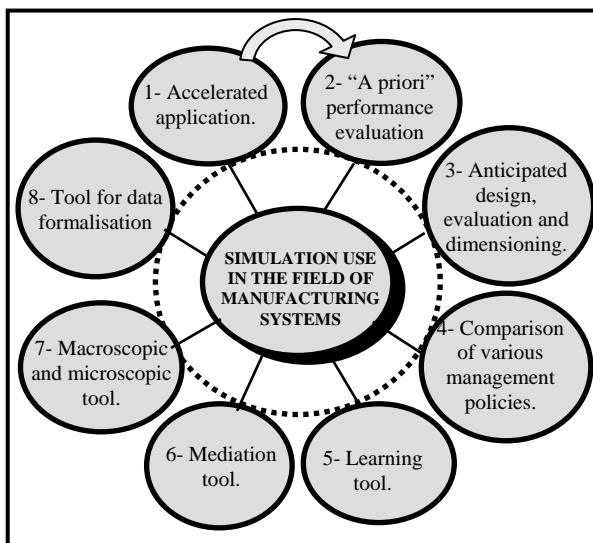


Figure 2- Use of simulation in the field of manufacturing systems.

About this subject, Gregor and J. Kosturiak [Gregor *et al.* 97] establish a state of the art on the use of simulation in this field. They present studies: on the FMS (Flexible Manufacturing Systems), on a comparison between various management models, on some management parameters, on stocks evolution of a production line...

However today, concretely all possibilities of

computer simulation are not used. Then the simulation is limited in its use and its applications.

1.3. Limits of simulation

The main limits of simulation could be explained by the fact that the decision-making and its impact on the production system are not taken into account during simulation because the major existing tools are not adapted for decision and control modelling.

In addition, today simulation tools use complex concepts for the potential user, and this does not support the "democratisation" of this technique. Companies managers often ask simulation specialists to carry out models, then the use of simulation in industrial circle remains specific and limited.

At present time, it's impossible to apply simulation modelling to the production system and to its control system without difficulties. However, in order to have a successful study, the system must be modelled according to all its components (flows): operational, informational and decisional.

Thus, in order to use almost all the capacities of simulation and to make it more "active", our goal is to conceptualise and model the industrial control by the use of a generic object, in order to integrate it in a simulation support tool: the *Control Centre (CC)*.

Other researchers work on these aspects [Castagna *et al.* 99]. Kindler [Kindler 99] writes about "reflective simulation" or about "internal and external" models of simulation.

Even if the modification of a parameter is possible during simulation running, it is not done according to control logic. This logic must imply the introduction of loops of feedback around each resource to be controlled. Currently, because of lack of these feedback loops, the action of controlling requires many experiments to have an optimisation of the results.

Before defining the Control Centre (CC), it is important to know which structure and which type of industrial control we choose.

2. THE CONTROL CENTRE

2.1. Structure and type of industrial control

The selected type and the structure of control are

specified: an "interpreted control" in a "co-ordinated hierarchical structure" [Le Moigne 74] [Trentesaux 96] [Grabot *et al.* 96]. The interpreted control and the co-ordinated hierarchical structure are considered in order to take into account the reality of evolution of the industrial system and of its control process, according to the modification of management methods and the introduction of new concepts. In the contemporary enterprise, individual decision-maker is "responsabilised" and has the capacity of interpretation at each hierarchical level (operational, tactical, and strategic). The decision-making process becomes more interactive, non-linear, complex, etc. due to the exponential increase of decision-makers. So the control is based on a personal interpretation of the actors: each actor has an individual capacity of interpretation [Bitton 90] [ECOSIP 90] [Pellegrin 97] [Kindler 99].

Moreover, the decision-maker must use, manage and control his system in coherence with the other actors, to answer together to the target objectives. Then, in one hand, the decision-making process and the internal organisation of CC must be relevant and in the other hand, the bonds between these various CCs, must be coherent, co-ordinated and organised.

The framework of our research being established, the Control Centre (CC) is then described by giving its definition, its components and its internal behaviour.

2.2. Definition

We define the *Control Centre (CC)* as "an autonomous structure, depending on the enterprise global strategy, having a decisional authority, associated with an entity and having necessary resources to apply actions and to achieve the defined goals within the global framework of the enterprise".

2.3. Components

The components (figure 3) of a CC are the following: *actors*, *referents*, *objectives*, *intrinsic* and *extrinsic information*, *decisional tools* (performance indicators...), *measures* and *performance evaluation*, *decision*, *actions* and *resources* for their implementation.

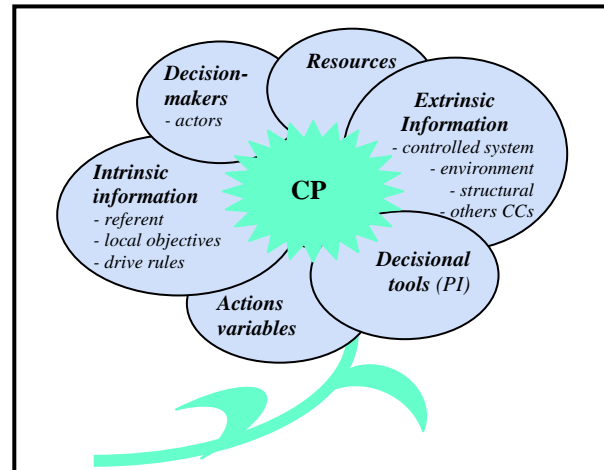


Figure 3- Components of the CC.

Then we present the components organisation in a simplified way corresponding to three main phases (figure 4):

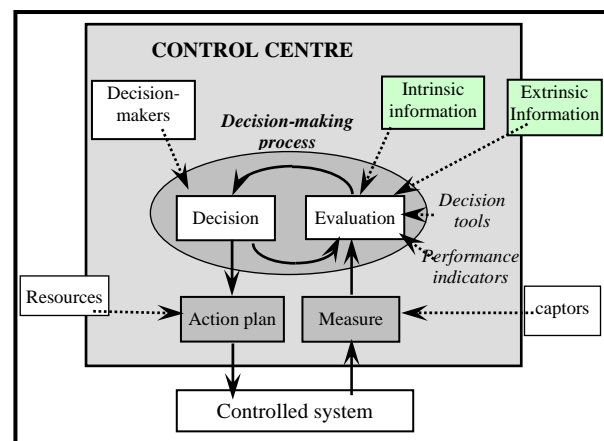


Figure 4- Global internal behaviour of the CC.

- the first phase concerns the gathering of *event* and *periodic measures* from the controlled system,
- the second phase concerns the *decision-making process*,
- the third phase concerns the *application of the decided action plan* on the controlled system.

These three phases are used as a basis for more detailed internal behaviour process of the CC.

2.4. Internal behaviour process of the CC

Finally, to formalise the decisional system, we describe the internal behaviour process of the CC (the precedent simplified global behaviour and the components organisation are presented in a detailed way) (figure 5).

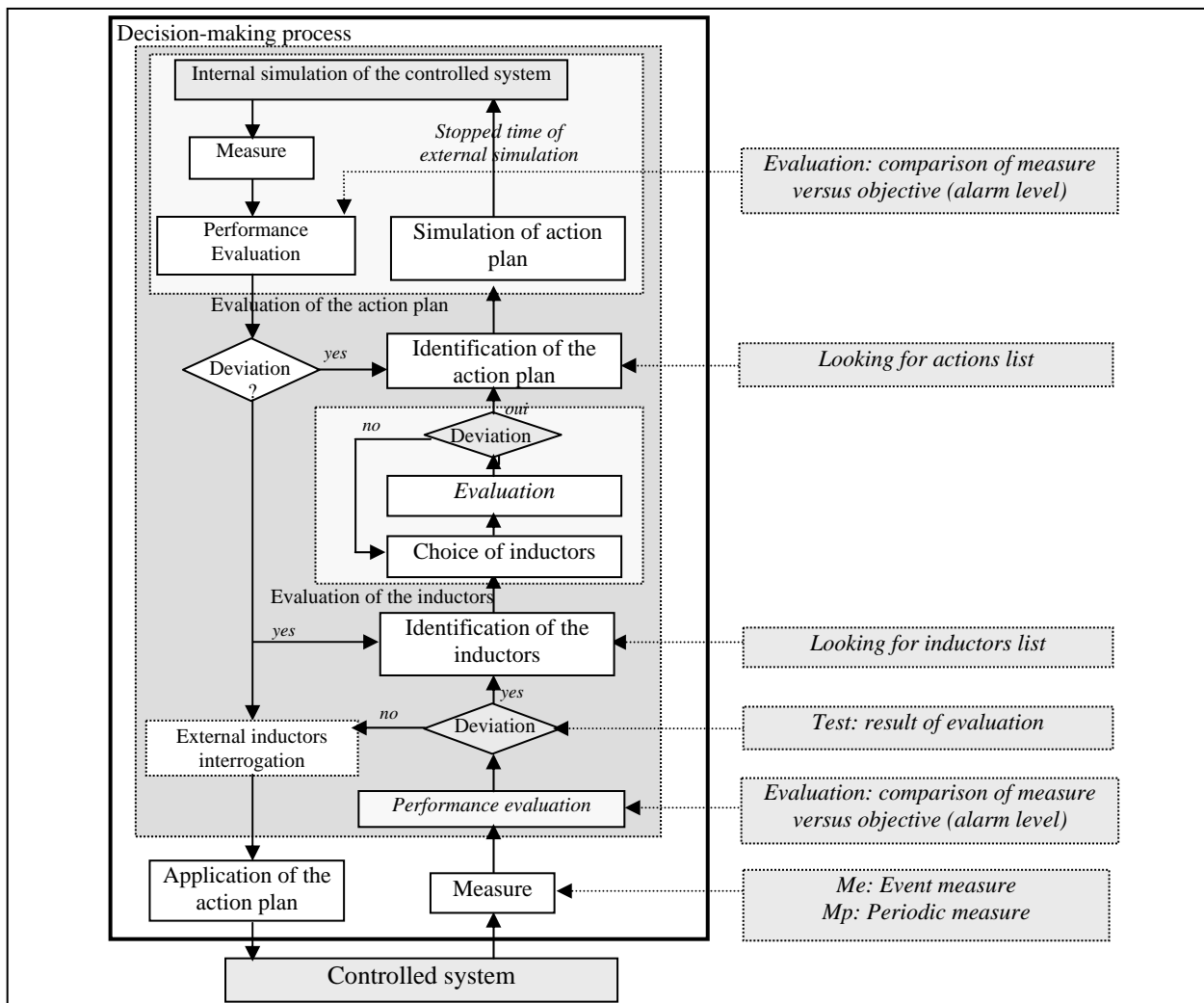


Figure 5 – Detailed internal behaviour of the CC.

Indeed, after having obtained the measure from the controlled system, concerning the PPS state and its flow, by the help of result and process indicators, our objective is to describe the decision-making process of the CC. This process is divided into three steps.

a) Performance evaluation of the controlled system and its physical flow.

This step consists to analyse the measure obtained from the controlled system (PPS), to compare it with the CC local objective, and then to conclude if a deviation exists. During this evaluation the information is taken into account for the co-operation relations between CCs. This formalisation is available in order to integrate the CC in a PPS (Product Processing System)/CC network.

b) Evaluation of the inductors responsible of the deviation.

The second step concerns the identification of the

inductor responsible of the deviation from a list of inductors. The choice of inductor is realised according to a history of the controlled system. Each inductor corresponds to a performance process indicator or a performance result indicator of a lower level of the decision global structure. As each inductor is associated to an objective, the evaluation at this stage consists on the determination of the deviation of each one and its impact on the controlled system.

c) Evaluation of the action plan using “internal simulation”.

The third step of the decision-making process consists of testing the actions determined at the preceding step, by internal simulation using the controlled system (the PPS is simulated at the moment when the measure is gathered). This is a performance evaluation using internal simulation, in order to define the adequate action plan. If the deviation is always reached after simulation of the action plan, other possible actions are tested, until

the deviation is eliminated. If the target level of performance indicator is not reached any more (no deviation), the action plan to be adapted is found and can be applied “really” to the controlled system. This is the last step of the simplified control process.

3. COOPERATION AND COORDINATION BETWEEN CCs

We propose in a no exhaustive manner a typology of information concerning the existing links, between the CCs in the one hand and between the CCs and the controlled system on the other hand [Berchet *et al.* 99]:

- *structural information* (concerning products, resources, customers),
- *decisional information* (objectives emitted by a CC, towards one or several CCs of the same level or of a lower hierarchical level),
- *control information* (state of the controlled system at the operational level),
- *state information* (obtained from the controlled system with an event measure),
- *feedback information* (obtained from the controlled system with a periodic measure),
- *environment information* (concerning CCs at a higher hierarchical level, in the case of strategic decisions).

The goal of this typology is to structure the information used during de CC internal process. The coherence of the whole enterprise system depends on this information, and then, a global hierarchical co-ordinated structure organises CCs between them according to three dimensions (hierarchy, time and space).

This typology is the base support of the co-ordination and co-operation relations. Following this first analysis of information necessary to analyse the relations of exchange between the CCs, we can formalise the co-operation and co-ordination relations between CCs: these information are in fact, warning messages which are circulating between CCs (figure 6).

These messages could be vertical (bottom up or top down), or horizontal. Let us see now which type can be these messages, and which are their points of emission and reception by the CC [Habchi *et al.* 99]. The figure 6 shows these various points of reception and emission which are then detailed in the following part.

3.1. Emission of warning messages by the CC

a) Emission of horizontal messages

① *"my objective is not reached"*

In the case of deviation following the performance evaluation of the controlled system, the CC informs the concerned CCs on its deviation. These CCs could then anticipate action if necessary and a problem appears on their controlled system.

② *"I determined the causes of my deviation"*

Following a deviation, the CC knows his inductors, then evaluates them to know which one is in deviation. Then the CC informs the other CCs about these inductors. The concerned CCs could then anticipate if necessary a problem on their controlled system.

③ *"I found the action plan restoring my situation"*

By evaluating its action list, the CC found the action plan that restored the situation of “no-deviation”: the behaviour awaited initially. It informs the concerned CCs about this action that will be applied to the controlled system. The CC have to give the parameters of the action, its reaction time (RT) and the result awaited at the end of this RT.

b) Emission of ascending vertical messages

④ *"my objective is not reached or my objective is achieved"*

Following a request for statement, the CC gives to its supervisor CC the result of his performance evaluation: deviation or not.

⑤ *"I tested all possible action plans, but no one restores the situation"*

The CC evaluated all possible actions (corresponding to the inductors having a deviation), but no one of them restores the situation. It informs its supervisor CC about its conclusion. This CC have to analyses the whole of the results of its CCs, perhaps to determine the origin of the problem (it is necessary to re-examine the objectives of the last CC).

⑥ *"My objective is restored"*

The CC found, in its possible action list, that which restored the situation of not-deviation: the behaviour awaited initially. It informs its supervisor CC its objective will be achieved following this action (within its reaction time).

c) Emission of downward vertical messages

⑦ *"I modify some parameters of my controlled system - I modify the objective of my CC"*

Following an action, the CC modifies parameters on its controlled system at the operational level.

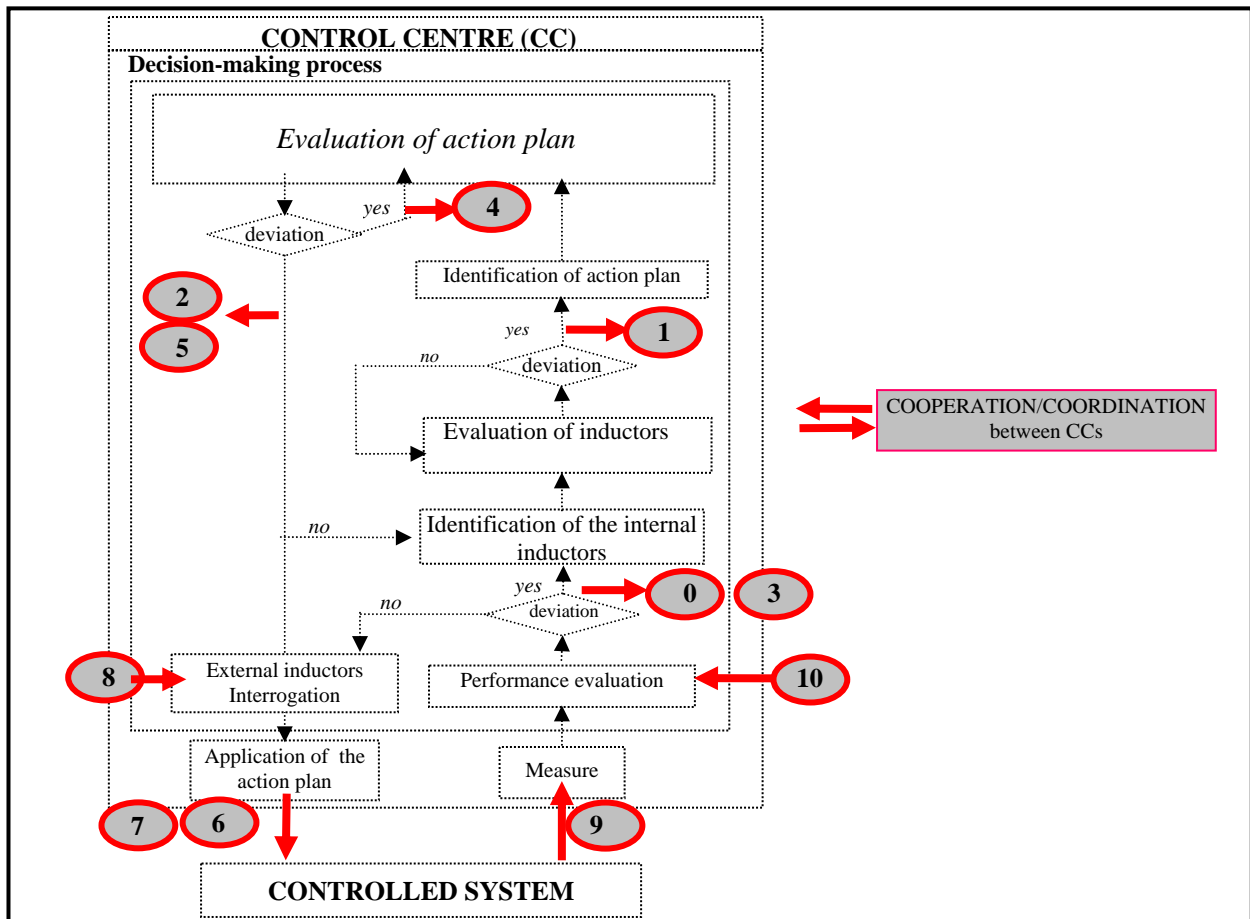


Figure 6- Emission and reception points of warning message of the CC.

If it is about a CC of higher hierarchical level, it will modify the objective of the controlled CC.

⑦ "What is your current situation?"

The supervisor CC can require a report of the situation of a CC, which will become for it, a measure to be evaluated and compared to its own objectives.

3.2. Reception of warning messages by the CC

a) Reception of horizontal messages

⑧ "Are there any messages of my near CCs?"

Following warning messages from the nearest CCs as:

"my objective is not achieved",

"I determined the causes of my deviation",

"I found the action restoring my situation".

If these messages could have an influence on the behaviour of the controlled system of the concerned CC, the CC can decide to apply a preventive action to its system.

b) Reception of ascending vertical messages

⑨ "Are there any messages of my lower CCs?"

Following the warning messages of the lower CCs as:

"my objective is not achieved or is achieved",

"I tested all the possible actions plan, but none restores the situation",

"my objective is restored".

The supervisor CC evaluates its performance according to this new information (state, and feedback information) and to its own objective.

c) Reception of downward vertical messages

⑩ "Are there any messages of my supervisor CC?"

The CC must take into account these messages coming from of its supervisor:

"I modify the objective of my CC":

In this case, the CC has to update its objective to do the next evaluations according to this new data.

"What is your current situation?":

In this case, the CC has to evaluate the performance of its controlled system and give an account of its state of deviation or not-deviation.

Some authors [Camalot *et al.* 97] formalise interactions between computer agents using the principle of communication by messages sending. This approach that will be used in our model to formalise the interactions between CCs, makes it possible to give to each message sending the statute of an act of language answering an objective and a context given from which a logic of the conversations is built. Thus, the agents' exchange messages answering using the same format.

These messages contain the information described below:

- *Action*; (desired action selected by CC among the list of pre-established possible actions),
- *Sender*; (source of message corresponding to the CC which sends the message),
- *Receiver*; (target CC corresponding to the CC for which the message is intended),
- *Message identifier*; (the identifier or name given to the message),
- *Date of emission*; (date at which the message was transmitted),
- *Limit date*; (date at which the message does not take place any more to be or is not valid),
- *Matter*; (contents of the message, the parameter of the system to be controlled for example),
- *Objective*; (event that processing is at the origin of the interactions).

CONCLUSION

The research presented in this article will complete precedent works of our research team on the physical flow modelling and simulation of manufacturing systems using the PPS concept (Product Processing System). Indeed, the behaviour of the PPS was being already formalised in precedent work. This generic concept called PPS has the same structural and behavioural characteristics as a resource (machine, stock, operator, etc.). It carries out mainly the three basic functions: "*reception*", "*transformation*" and "*supplying*". In addition, it is able to model the different resource states: idle, busy, blocked, broken down, etc.

We propose the modelling of the informational and physical system using the PPS concept in one hand, and the modelling of decisional system using the CC concept in the other hand.

Then, our actual research work lies the CC to the PPS, formalises the CC behaviour and the links between CCs and PPSs. This formalisation allows us to introduce *reactive control* into simulation at the operational level of manufacturing systems, and then:

- to make simulation more "*active*",
- to react in a structured way on the system in the case of deviations with respect to its expected behaviour during the simulation,
- to widen and benefit more from the potentials of simulation.

Lastly, the different objects which form the "PPS/CC network" (PPSs, CCs, entities, generator of orders, etc.) are modelled using Unified Modelling Language (UML).

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