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► **To cite this version:**

Philippe Pesin, Damien Trentesaux, Christian Tahon. TOWARDS A DESIGN METHODOLOGY OF A MULTI-AGENTS STRUCTURE INTEGRATING THE HUMAN OPERATOR FOR THE ACTIVITY CONTROL OF COMPLEX INDUSTRIAL SYSTEMS. 17th European Annual Conference on Human Decision Making and Manual Control (EAM'98), Dec 1998, Valenciennes, France. hal-01876191

**HAL Id: hal-01876191**

**<https://hal.science/hal-01876191>**

Submitted on 18 Sep 2018

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# TOWARDS A DESIGN METHODOLOGY OF A MULTI-AGENTS STRUCTURE INTEGRATING THE HUMAN OPERATOR FOR THE ACTIVITY CONTROL OF COMPLEX INDUSTRIAL SYSTEMS

Philippe PESIN  
Damien TRENTESAUX  
Christian TAHON

*Laboratoire d'Automatique et de Mécanique Industrielles et Humaines (LAMIH)  
Equipe Génie Industriel et Logiciel (EGIL)  
Université de Valenciennes et du Hainaut Cambresis  
Le Mont Houy  
BP 311  
59304 Valenciennes Cedex  
France*

*E-mail: [Philippe.Pesin, Damien.Trentesaux, Christian.Tahon]@univ-valenciennes.fr*

## ABSTRACT

This paper proposes a framework to build a methodology for the design of a multi-agents architecture for the activity control of complex industrial systems. This methodology uses a generic agent model enabling a better integration of the human operator in the decision process. Determination of the parameters of a particular multi-agents architecture is based on systemic approach, allowing exhaustiveness and structuring. Then viability of the methodology is shown on two practical examples.

## KEY WORDS

design framework, multi-agents structure, activity control, complex industrial systems, man-machine cooperation, .

## INTRODUCTION

Today's decision makers have to face up to more and more drastic cost, delay and quality constraints in always more reduced time periods. Activity control function corresponds to the information and decision structure associated to the real-time management of the controlled system [1]. In this context, activity control consists in two main functions: dispatching and reporting. Dispatching solves unsolved problems in forecasted phase, considers constraints and

reacts to perturbations whereas reporting collects all the essential data in order to have the more accurate view as possible of the system. As a consequence, performing a reactive activity control represents one of the most important stakes for decision makers. Studied industrial systems (e.g. transportation networks and manufacturing processes) are characterized by their complexity. So, reaching control system reactivity requires to cope with such a feature. Compatibility of multi-agents architecture [2] [3] [4] and of optimised integration of the human operator [5] [6] with our requirements have been shown. Advantages of distributed intelligence and of multi-agents systems especially for the processing of complex problems are: real-life (complex) problems modelling capability, reduction of problem complexity, performance of the problem solving, easy evolving of the multi-agents system, reliability, coherence with the main computer engineering norms. Nevertheless, given complexity, it is very hard for engineers to design such a structure. So, it is necessary to provide them with a design framework to support a structured building of the multi-agents architecture. In this context, this paper focuses on the design of a methodology supporting the building of a multi-agents architecture for the activity control of complex industrial systems taking into account the human operator.

## ISSUES

### Activity control issues

Activity control issues highly influences corresponding design methodology issues.

### *Complexity*

Studied systems are complex industrial ones, and, as a consequence, are characterized by: large number of components, multiplicity of types of components, highly coupled components, presence of disturbances [6], dynamic environment [7]. But controlled system complexity entails corresponding management system complexity [6]. Activity control function system is a sub-system of the management system. So, controlled system complexity requires to consider activity control system as complex too (if goals are hard to be reached, i.e. in the most common industrial situations). Nevertheless, as mentioned in the introduction, activity control is made of two sub-functions (i.e. an information one and a decision one). As a consequence, two types of complexity have to be managed: data and decision complexity [5].

### *Relevance of the human operator integration*

In a data and decision complexity context, although a computerized system is more able than a human operator to manage huge amounts of data in a reduced amount of time for the most common situations, it is weaker to reason, that is to say to process complex situations and to recognize ill-structured states (and, as a consequence, to manage complexity and to provide reactivity) [5] [6]. It has been shown that the solution to take advantage of the respective skills of the computer and of the human operator is an optimised integration of the human operator in the computerized system. Then computerized system should help the human operator to cope with the two main aspects of complexity.

### **Design methodology issues**

It is very hard for activity control system designers to build a structure coping with the huge amount of constraints induced by the complexity of industrial systems. This is why it is necessary to provide them with a framework helping them to elaborate such a structure, i.e. a design methodology. Building a design methodology requires to cope with two separate but dependant issues: model elaboration issue

and identification issue. Nevertheless, building a multi-agents architecture dedicated to the activity control of complex industrial systems requires to cope with specific problems induced by activity control issue.

### *Model elaboration issues*

Model elaboration requires the definition of a set of basic concepts (constituting a kind of toolbox) enabling the understanding and as a consequence the description of the designed system. Generally speaking, in our context, a “good” model must be:

- (1) able to represent every system of the class of system studied,

- (2) compatible with an identification stage.

Moreover, in our context, generic model must cope with specific constraints:

- (3) compatibility with the agent philosophy [2], i.e. ability to reason and to communicate and to act,

- (4) compatibility with the two aspects of activity control, i.e. reporting and dispatching,

- (5) efficient temporal management: one of the most important stakes in dynamic environments is temporal management [7]. In fact, on the one hand, it is important to be reactive, and on the other hand, to cope with more strategic constraints and goals,

- (6) ability to make easier and to optimize the integration of the human operator in the decision process.

### *Identification issues*

Identification problem is the application of generic concepts described in the model elaboration stage to a particular case study, i.e. a particular system. As a consequence, identification must describe the directions for use of the proposed toolbox. Practically, it means:

- (7) extraction of the relevant features of the particular designed system, i.e. determination of the instantiation parameters of the generic model proposed. In our context, results of identification stage has to be an operational multi-agents

activity control architecture specific to the system to control,

- (8) in an exhaustive way,
- (9) in a structured way enabling an easy and clear link between controlled system features and parameters of the generic model. In fact structuration allows immediate association of extracted data to the corresponding issue.

## **REQUIREMENTS FOR AN EFFICIENT DESIGN METHODOLOGY**

Given the previously introduced issues for the design of the multi-agents architecture, it is possible to define goals associated both at the model and at the identification level.

### **Model requirements**

According to modelling issues, proposed agent model has to be:

- generic: the model must be able to represent the most common multi-agents activity control systems corresponding to industrial applications (issue 1),
- structured: definition of an agent must be performed through a rigorous framework: functional decomposition according to sub-systems, a description of the relationships between sub-systems, a description of the operating mode of singular sub-systems. As a consequence it would be possible to share global identification task into more reduced identification tasks (issue 2).

Moreover, in term of more accurate features, model must:

- integrate agent specific aspects, i.e. knowledge, reasoning, communication and action aspects (issue 3),
- integrate data management functions and decision management functions (issue 4),
- distinguish reaction and anticipation functions. In fact, reaction manage events as soon as they appear whereas anticipation is dedicated to actions appearing before real observation of a phenomenon, corresponding to a more strategic behaviour including the management of goals (issue 5),

- allow integration of the human operator: proposed structure must be designed for allowing an easy integration of the human operator, i.e. support better context analysis for better decision making. In this context, both support to data management and to decision management must be considered (issue 6).

### **Identification stage requirements**

Identification has to define tools supporting instantiation of generic concepts proposed at the model level so as to get an operational multi-agents architecture.

So, identification must help to answer to three main questions (issue 7):

- How many agents constitute the architecture (number and location) ?
- What are the relationships (hierarchical or not) between agents ?
- What are the parameters corresponding to each of the sub-systems constituting the internal structure of each of the agents ?

In this context, identification must be based on a rigorous and systematic method for the extraction of the relevant features of the system to control (issues 8 and 9).

## **PROBLEMS ASSOCIATED TO STATE-OF-ART DESIGN METHODOLOGIES**

The study of existing methodologies (e.g. [3] [8] [9] [10]) for the design of multi-agents activity control systems and the analysis of synthetic studies [11] [12] highlights two main weaknesses regarding the previously introduced requirements:

- integration of the human operator in the generic model (corresponding to requirement 6) and, as a consequence, in the global multi-agents activity control system is never or quite never explicitly taken into account. In most of the cases, generic models of agents assume an auto-organised multi-agents architecture and as a consequence, automatic decisions. So, integration of the human operator in the decision process is not explicitly taken into account.

- inefficiency of the identification method (corresponding to requirements 7, 8 and 9) entailed by an insufficient link between the features of the controlled system and the design of the control system. Duality of activity control system and controlled system concepts never explicitly appears. Either the activity control activity is implicit or is considered as a global task to perform. In the first case, the modelling of the system through agents becomes the activity control system itself and it is implicitly assumed that the system organised itself. As a consequence, the controlled system is no more considered after the first modelling stage. In the second case, the activity control task to perform is supposed to be known and an organisation of agents coping with the requirements of this task is searched for. [12] suggests to use a reactive operations list to support the design of the multi-agents system. Nevertheless, this concept is too specific to the manufacturing field and does not cope with a generic model issue. Moreover, goals in term of performance indicators are not clearly taken into account, only “services” to perform are considered, what is not compatible with an activity control issue.

As a consequence, general outlines of a methodology coping with global requirements and most especially with the previously introduced weaknesses are proposed in the following parts.

## **GENERIC MODEL SUPPORTING THE DESIGN METHODOLOGY**

This section proposes a generic model of agent coping with requirements enhanced in the first section. A first model is obtained through a classical systemic study of activity control function. In order to be compatible with our issues, a more accurate description of this model is performed.

### **Systemic design of the activity control process**

#### *Systemic principles*

Systemic can be described as a means to support action in term of understanding and in term of intervention. It provides a methodological and conceptual support, aiming at linking, through the use of modelling and analogy and system concept considering goals [13].

#### *Relevance of the systemic use*

Generally speaking, systemic corresponds to a design issue because it aims at building a more understandable view of a system (a model) based on the system concept and compatible with the reaching of a certain amount of goals. As a consequence, it should make easier the action on the system in order to reach determined goals. So, systemic approach is, on the one hand, compatible with activity control support and, on the other hand, with complexity management. In fact, activity control consists in performing actions in a reactive way, compatible with goals and satisfying constraints.

#### *Model of an activity control agent based on feed-back loop*

Sub-systems and relationships of a basic activity control agent are obtained through the use of concepts introduced at a more macroscopic level (the firm level) [14]. These concepts correspond to a systemic study of feed-back loop (cybernetic). Analysis of a general feed-back loop contributes to genericity whereas systemic analysis contributes to structuring (requirements 1 and 2).

First, two functional levels are proposed to describe the main sub-systems of the generic agent model:

- activity control (formal) sub-system,
- control (formal) and regulation (informal) sub-system.

Second, three temporal levels are used to classify variables. These levels are materialized by different types of variables associated to the system to control:

- goals corresponding to achrony (description of goals and basic functions on which actions are based, i.e. time independent data),
- structure variables corresponding to synchrony (description of operating modes with constant structure variables and a behaviour evaluated by performance variables),
- performance variables (activity variables: quantitative evaluation of the system missions, cost variables: economical evaluation of the system activity, efficiency variables: measurement of the efficiency of the system)

compared to goals) corresponding to diachrony (description of operating modes with evolving structure variables; performance variables being constant).

Considering these two decomposition levels, figures 1 and 2 details this agent model:

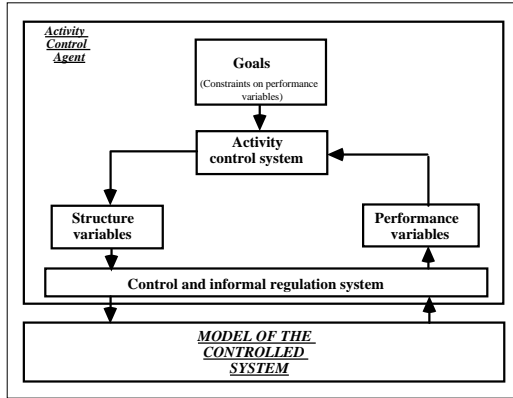


Figure 1: basic activity control agent model

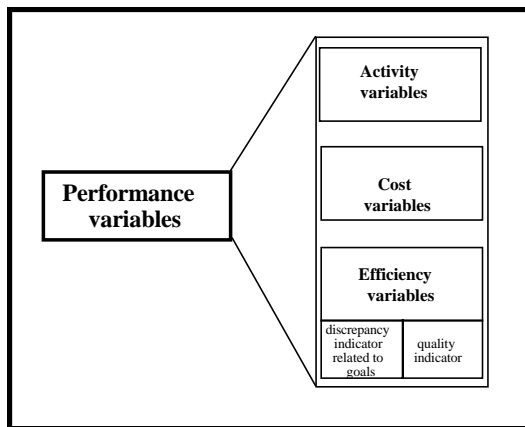


Figure 2: Details of performance variables

It is important to note that the decomposition proposed leads to the distinction of data management and decision management aspects (requirement 4).

Nevertheless this basic model is insufficient. In fact, especially human integration aspects are not taken into account.

### Generic agent model proposed

The generic agent model proposed details previously introduced basic model. It is made of three main sub-systems corresponding to agent specific aspects (requirement 3) and activity control specific aspects (requirement 4):

- activity control system: to perform the activity control task itself (corresponds to activity control of figure 1),

- communication system: to perform the integration in the environment (corresponds to the control of figure 1),

- variables system: to store updated data from which decisions are made (corresponds to variables of figure 1).

Figure 3 summarizes the global structure of the generic model of agent proposed. In order to have a readable diagram, only the most important relationships between sub-systems are mentioned.

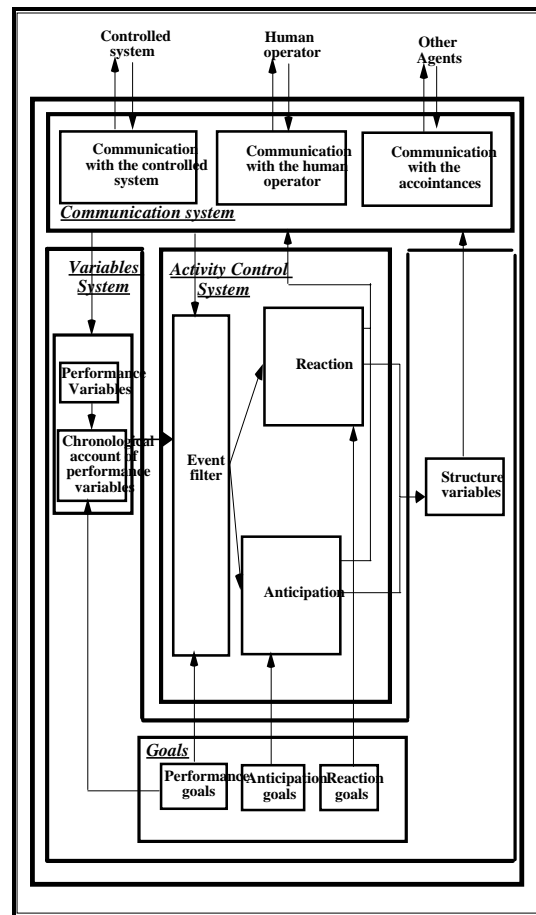


Figure 3: Generic agent model proposed

### Activity control sub-system

The main originality of the proposed activity control sub-system is the integration of an event filter. This concept has been introduced in the

context of the reactive management of complex industrial systems [5]. The goal of this filter is mainly to help the decision centre to focus, as a priority, on the most significant data because it is useless to try to perform an effective activity control if decisions are not focused on the most relevant events occurring in the system. In the case of activity control of complex industrial systems, huge amounts of data are to be simultaneously managed (e.g. [15]). As a consequence, necessity of the integration of the human operator (requirement 6), justifies itself the use of such a concept. Figure 4 summarizes the operating mode of the event filter proposed in [15]:

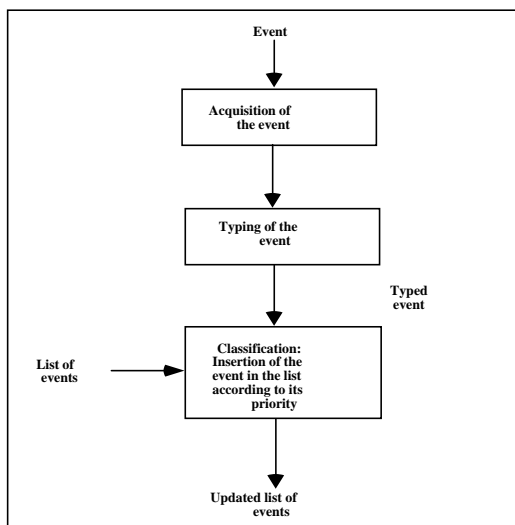


Figure 4: Operating mode of the event filter

The proposed filter is based on an accurate event typology enabling at the same time event characterization and management of heterogeneous types of events (e.g. in our context events related to production or to communication or to activity control activities). It is based on ten characterization axis: compatibility/incompatibility with goals, seriousness, level of emergence, physical location, functional location, occurring time, precedence/simultaneity with situations, amount of time to process the event, programmed/non programmed answer, decision level. Proposed characterization axis allow not only to order events by processing priority but also to dispatch the event towards the most adapted decision level (according to the decision level field) and towards the most adapted “decision maker” (i.e. man, machine or man/machine according to the programmed/non programmed field).

The second originality is due to the clear distinction between “reactive” and “anticipative” activity control (requirement 5). This distinction is justified because these two styles of activity control correspond to two temporal aspects, associated to the management of different types of variables (i.e. continuous variables in the case of anticipation (trends) and discrete variables in the case of reaction (events)). In the case of anticipation, actions are more strategic, i.e. they avoid the occurrence of the problem by acting in a preventive way. The event filter is responsible for dispatching events according to the type of answer they require (i.e. reaction or anticipation). The third originality is the reaction and anticipation mode suggested. According to its characterization, an event is likely to entail: no answer (e.g. in the case of compatibility with goals), automatic processing of events (e.g. in the case of programmed events for which a procedure exists), transmission of the event to the human operator. In this last case, reaction and anticipation consist in providing the best context as possible to solve the problem, for instance by constraining the reasoning of the human operator and by helping him to focus on relevant variables.

### Variables sub-system

- performance variables: as well instantaneous variables as trends are considered. They are used to build a view of the system to control at every moment. Event detection is based on the analysis of these variables compared to goals.
- structure variables: they correspond to action variables.
- goals: Performance goals influence performance variables selection because, according to goals, different types of variables are necessary. Generally speaking, goals are expressed thanks to constraints and drive the reasoning of sub-systems constituting activity control. For instance, performance goals are used to know if an event is compatible or not with goals, allowing to establish processing priorities.

The generic model building is, in the ordinary course of things, performed only once and is used by the identification stage. Nevertheless, it is possible to envisage some corrections on account of experiments. In fact experiments could point out some mistakes or insufficiencies.

## THE DESIGN OF THE MULTI-AGENTS ARCHITECTURE: THE IDENTIFICATION STAGE

Given a generic agent model, proposal of an identification methodology corresponds to the proposal of a multi-agents architecture design methodology. This section tries to propose a framework helping to build the activity control architecture. Methodological and conceptual support provided by systemic are compatible with requirements 8 and 9. As a consequence, it is suggested to use this approach in this phase.

### Systemic contribution

In the context of systemic, F. Le Gallou introduced a very interesting concept: "systemic decomposition" [16]. The goal of this activity is to get coherent and autonomous sub-systems which size and complexity is adapted to action. Nevertheless this "decomposition" must not hide some aspects of reality, i.e. relationships between sub-systems and with the environment (use of relations). At a first level, this concept is compatible, on the one hand, with the determination of significant and coherent activity control areas, in term of location and number and function. At the multi-agents system level, it means the determination of the main decision centres of the activity control structure. On the other hand, if decomposition is performed more deeply, it supports the collection of data required for an efficient activity control (requirement 7). The main issue is: how performing the systemic decomposition process compatible with our goals ?

### Implementation of systemic decomposition

In order to perform an exhaustive and significant decomposition, a framework based on six significant axis is proposed. This framework is adapted from [16] to the activity control issues. Le Gallou, in order to be as exhaustive as possible, describes basic principles to perform an exhaustive decomposition (scanning, looping, checking, recursivity) and suggests a decomposition order. One of the problems is to chose the decomposition order because sub-systems are different according to the decomposition order chosen (e.g. it is possible to chose a more physical decomposition or a more

functional decomposition), leading to different activity control strategies. Our goal being activity control each step of the decomposition process analyses controlled system and deduces corresponding control system parameters. The decomposition is first based on an external view of the system to control and evolves gradually towards an internal view. So, according to the level of granularity expected, the second section of the framework should be used to detail the contents of the decision centres (e.g. functional decomposition is able to provide the different functions constituting the decision centre and temporal decomposition is able to contribute to the description of the different types of variables of the problem).

The different steps of a possible decomposition framework are described in tables 1 and 2:

<b>Spatial decomposition</b>	<b>structural decomposition</b>	<b>decomposition according to nature</b>
<b>Sights</b>	<b>Morphology</b>	<b>Flows and domains</b>
Determination of interesting areas of study.	Quasi autonomous decision centres (agents) corresponding to typical elements of the controlled system.	Data and decision flows between agents corresponding to physical and resources flows at the controlled system level.
	<b>Hierarchy</b>	
	Organization levels between agents.	

Table 1: First decomposition axis proposed

<b>Functional decomposition</b>	<b>Organical decomposition</b>	<b>Temporal decomposition</b>
<b>Permanent functions</b>	<b>Technological aspect of resources</b>	<b>Achrony</b>
Functions to perform at the agent level knowing functions to perform at the controlled system level.	Nature of resources required to perform agent functions (Man or Machine or Man/Machine).	Goals.
<b>Operations</b>	<b>Location of resources</b>	<b>Synchrony</b>



Detail of set of operations to perform functions.	Description of the location of previously introduced resources	Structure variables.
		<b>Diachrony</b>
		performance variables

Table 2: Other decomposition axis proposed

## Global design framework suggested

It is suggested to apply systemic to determine general features of the architecture backbone. In fact, decomposition according to six axis provides an interesting check-list. In order to be efficient, decomposition has to consider generic model of agent proposed. Nevertheless, systemic seems to be too general to determine more accurately the contents of the different sub-systems, i.e. the accurate behaviour of agents (see for example [2] for a description of the limitations of systemic approach). This is why, it is obvious that systemic has to be completed by knowledge acquisition phases to describe more particularly:

- the contents of the event filter: [5] and [15] suggest the building of a database containing different events that are likely to appear in the system with their generic features,
- the contents of the reaction and anticipation sub-systems: it consists in associating to each event of the database corresponding actions to perform, i.e. reaction or anticipation.

## APPLICATION

Simplified application of our proposal is shown on two short examples in order to show its possible application in a first stage of the design framework. The systemic decomposition is performed according to the previously introduced axis.

### Transportation domain

First, a tramway made of several services is considered. Figure 5 shows a particular service made of single tracks and stations:

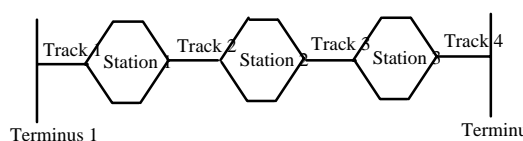


Figure 5: Example of a particular service made of single tracks in a tramway network

Some aspects of the systemic design:

- Spatial decomposition (Sights): services.
- Structural decomposition (determination of the number of agents):
  - \* Morphology: one agent associated to:
    - each of the stations,
    - each of the terminus,
    - each of the tracks,
    - each of the services.
  - \* Hierarchy (determination of the relationships between agents):
    - level 1: terminus and stations and tracks,
    - level 2: line.
- Decomposition according to nature (flows):
  - \* intra-level (<-> means data and information flows):
    - terminus agent<->track agent,
    - terminus agent<->station agent,
    - station agent<->station agent,
    - track agent<->station agent.
  - \* inter-levels:
    - line agent<->station, terminus, track agent,
    - station, terminus, track agent<->physical system,
    - monitoring operator<->line agent, station, terminus, track agents.
- Functional decomposition (From this decomposition level, determination of the internal parameters): the functional decomposition corresponds to the generic agent structure.
- Organical decomposition (technological aspect of resources and location: in every cases it the man correspond to the global monitoring function):
  - stations agents: machine or man/machine,
  - terminus agents: machine or man/machine,
  - tracks agents: machine or man/machine,
  - service agents: machine or man/machine.
- Temporal decomposition (for a station)
  - \* Structure variables:
    - reference waiting time of a tramway,
    - reference time-table.
  - \* Performance variables:
    - comparison of arrival time of a tramway with forecasted arrival time,
    - frequency,
    - mean waiting time.
  - \* Goals:
    - $\min \leq \text{frequency} \leq \max$ ,
    - $\min \leq \text{mean waiting time} \leq \max$ ,
    - $\min \leq (\text{forecasted arrival time} - \text{arrival time}) \leq \max$ .

## Production domain

Second, a job shop scheduling system is considered. Each manufacturing order is made of operations. Each of the operations can be performed on one or more machines.

Some aspects of the systemic design:

- Spatial decomposition (Sights): shop.
- Structural decomposition:
  - \* Morphology: one agent associated to:
    - each of the machines,
    - the monitoring function.
  - \* Hierarchy:
    - level 1: machines,
    - level 2: monitoring.
- Decomposition according to nature (flows):
  - \* Intra-level:
    - machine agent <-> machine agent (communication messages in order to find the next machine to perform the next operation of the manufacturing order).
  - \* Inter-levels:
    - monitoring agent <-> machine agent (reporting informations from the machine agent and orders from supervision agent in order to cope with goals).
- Functional decomposition: the functional decomposition corresponds to the generic agent structure.
- Organical decomposition (technological aspect of resources and location):
  - machine agent: machine or man/machine,
  - monitoring agent: machine or man/machine.
- Temporal decomposition (in the case of the monitoring agent)
  - \* Structure variables:
    - reference planning,
    - priority between machines.
  - \* Performance variables:
    - occupation rate of machines,
    - comparison forecastings/reality.
  - \* Goals:
    - $\min \leq \text{difference forecasted/real} \leq \max$ ,
    - $\min \leq \text{occupation rate} \leq \max$ .

## Correspondence with identification requirements

This decomposition effectively allows to answer to the three questions:

- Structural decomposition provides the number and the nature of agents,

- Decomposition according to nature provides the relationships between agents,

- Temporal decomposition provides internal parameters corresponding to the elements of the variables sub-system of the agent, i.e. structure variable, performance variables and goals.

## Discussion

These two short application examples shows that proposed methodology provides an interesting framework to get the general features of the multi-agents architecture, i.e. number of agents, location of agents, main relationships and main internal parameters. Moreover it allows to build the controlled system considering the system to control avoiding lack of coherence.

Nevertheless weaknesses of systemic appear. First, although systemic provides an interesting check-list to get a general control architecture, "decomposition" is open to discussion. In fact, on the one hand, no method is given to chose a "good" decomposition order compatible with goals, and, on the other hand, no method is given to get the better decomposition. As a consequence, it would be useful to complete the design framework by a simulation phase evaluating the impact of different decisions on the quality of activity control (number of decision centres, level of intelligence, number of relationships,...). Second, systemic does not provide enough information to describe the accurate behaviour of agents, justifying the use of a knowledge acquisition phase, as previously introduced.

## CONCLUSION

This paper has proposed a framework to design a multi-agents structure for the activity control of complex industrial systems.

This framework is based on a generic model of agent integrating an event filter. This filter especially aims at integrating the decision maker in the decision process by helping him to focus on the most relevant events and, as a consequence, to perform the best decisions. Distribution of intelligence in the context of the multi-agents architecture coupled with integration of the human operator will contribute to reactivity.

Then, given this model, elements to design the global architecture are suggested. In this context,

systemic approach provides interesting tools to build an activity control architecture coherent with the system to control and with goals. Nevertheless the abstraction level of systemic is too high to describe accurately the behaviour of agents, requiring complementary knowledge acquisition phases. Moreover, "decomposition" is too intuitive, not enabling to prove compatibility of the proposed architecture with our goals.

As a consequence future works should focus on the refinement of the design method including more formal tools to make choices. A validation platform is being developed. First results showed the huge amount of events to manage and the pertinence of the event filter concept integration.

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