Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-32 (2016) 036–041

Toward a Petri Net Based Model to Control Conflicts of Autonomy between Cyber-Physical&Human-Systems

F. Vanderhaegen*

** University of Valenciennes, LAMIH CNRS UMR 8201*
F-59313 Valenciennes, France (e-mail: frederic.vanderhaegen@univ-valenciennes.fr).

Abstract: A dissonance is a conflict between individual, collective or organizational knowledge. This concept is extended to a conflict of autonomy between components of a human-machine system, such as Cyber-Physical&Human Systems (CPHS). The autonomy of the CPHS is modeled by a triplet representing three sets of knowledge: the Competence, the Availability and the Prescription. The so-called Competence-Availability-Prescription (CAP) model is then proposed to represent the capability of the CPHS to act alone and to control possible emergent behaviours such as conflicts of autonomy in terms of competence, availability and/or prescription. The formalism of the Petri nets is used to model the three CAP model parameters and to control possible conflicts between them. A feasibility study of the application of such CAP model and Petri nets is presented for the car driving domain involving the car driver interacting with Cyber-Physical Systems (CPS) such as an Automated Speed Control System (ASCS).

Keywords: Petri nets, learning, shared control, cognitive systems, CAP model, autonomy conflict, CPHS, emergent behaviors

1. INTRODUCTION

Autonomy is a large concept linked to the capacity of a system to fend alone. Such a system can initially be non-autonomous and becomes semi-autonomous or totally autonomous. On literature, the progress on autonomy is integrated on concepts such as autonomation or autonomisation. The autonomation was developed for manufacturing systems, robotics or lean production (Black, 2002; Saurin et al., 2008; Boakye-Adjei et al., 2014). It focuses on the transfer of human cognition to a machine when detecting and solving problems, and making decisions. The autonomisation (or the empowerment) was developed in social, medical, economical, educational or managerial domains (Métayer, Lanfranchi, 2006; Parron, 2014). It consists in transforming dependent systems into independent ones regarding problem solving or decision making.

Autonomy can then be described by different prerequisites and cognitive characteristics such as (Demazeau, 1995; Carabelea and Boissier, 2006; Zieba et al., 2010, 2011; Schulte et al., 2009):

- An autonomous system has several internal available resources (e.g., physical or cognitive resources) and can choose some of them to achieve a goal.
- An autonomous agent evolves in a given environment but it is not controlled by this environment.
- An autonomous system manages the interactions with other agents and can accept or refuse a mission proposed by another agent.
- An autonomous system has the capacity to select alternatives and more precisely not to respect rules (i.e. to make rule violation).
- An autonomous system can choose an action without interacting with other agents.
- An autonomous system can modify a goal if necessary.
- An autonomous system requires physical and cognitive capacities to apply its knowledge, and predefined prescriptions to authorize or prohibit the achievement of some goals.
- An autonomous system has the capacities to improve its knowledge by learning from known or unknown situations.

As a matter of fact, related to these concepts, an autonomous system can be modelled by three minimum parameters: its Competence, its Availability and its Prescription. The so-called Competence-Availability-Prescription (CAP) model is then proposed to represent the capability of a human-machine system to act alone and to control conflicts of autonomy in terms of competence, availability and/or prescription. The formalism of the Petri nets is used to model the three CAP model parameters and to control possible conflicts between them. Regarding the large number of prerequisites and cognitive characteristics, conflicts of autonomy can exist. They are positive or negative emergent behaviours of CPHS, and are called dissonances. A dissonance is a conflict between individual, collective or organisational knowledge (Vanderhaegen, 2014). This concept is extended to a conflict of autonomy between components of a human-machine system, such as Cyber-Physical&Human Systems (CPHS).

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.12.186

Dissonances are then seen as emergent possible behaviours of CPHS. Techniques for human-machine system analysis such as technical failure analysis or human error analysis exist but are insufficient for being applied to CPHS because all the entire dynamic aspects of the CPS functioning can be not directly perceived by their users, i.e. the emergent behaviours of the CPHS such as dissonances cannot be easily identified (Vanderhaegen, 2010, 2012). This paper proposes an original model based on Petri net for representing the autonomy of CPS interacting with human operators, and for detecting possible dissonances into CPHS. This aims at improving the design of CPHS and the training of their users.

2. THE CAP MODEL FOR THE CPHS AUTONOMY

The CAP model aims at considering three sets of knowledge that represent the main parameters of the autonomy of a system:

- Its Competence (i.e., *C*). It relates to the specific knowledge of the CPHS functioning to use or manage its own skills.
- Its Availability (i.e., *A*). It relates to specific knowledge about the availability control of the CPHS. The autonomy of the CPHS is then linked to the availability of its resources to achieve its goals.
- Its Prescription (i.e., *P*). It relates to specific knowledge about the prescription control of the CPHS. The autonomy of the CPHS is then linked to its authorization to act and achieve its goals.

The CAP model parameters can be static or evolve dynamically. If there are static, a lack of autonomy of the CPHS can be recovered by sharing the control process with other CPHS. If there are dynamic, the shared control and the learning processes are useful for reinforcing the knowledge, the availability or the prescription of a CPHS. Figure 1 is an example of the application of the shared control of the autonomy between CPHS regarding the initial or new allocation of goals to be achieved.

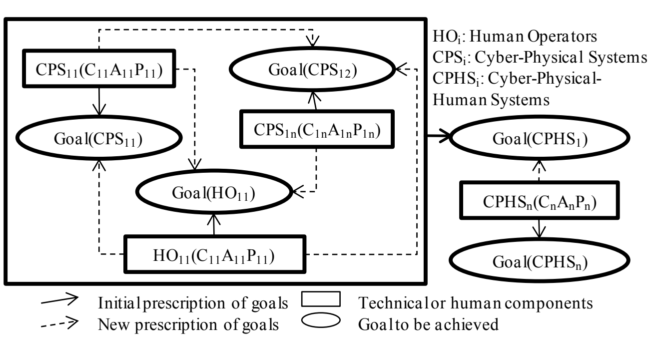

Fig. 1. Example of shared autonomy between CPHS.

Such architecture of autonomy can be organized between several CPHS in different organizational structures (Vanderhaegen, 1999a). Cooperative learning, co-learning, self-learning or auto-learning are other means to increase the autonomy of CPHS (Vanderhaegen, 2012). Figure 2 is an example of learning interactions between CPHS. Several strategies based on cumulative or merged knowledge can then be used for reinforcing the technical or the specific knowledge of the CAP model (Vanderhaegen, et al., 2011; Polet et al., 2012; Ouedraogo et al., 2013)

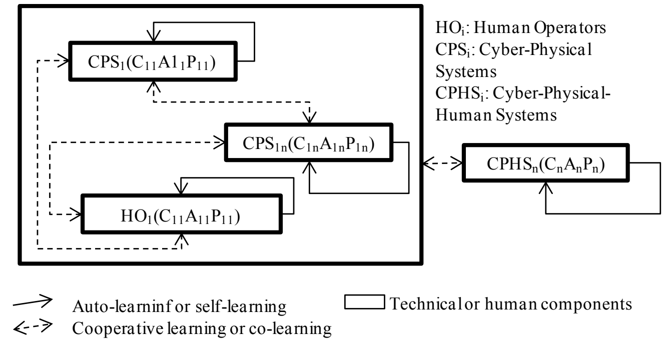

Fig. 2. Example of a learning process between CPHS.

3. THE CAP MODEL WITH PETRI NETS

The technical and specific knowledge of the CAP model is implemented from the well-known Petri Net formalism in system engineering (Girault, Valk, 2003). A Petri Net noted *PN* is an oriented graph. Its formalism is adapted in order present it as a quadruplet *(P, T, L, D)* where:

- *P* is the set of places noted P_i that are connected to transitions. Each place has a label that represents a goal such as an intention or a task to be achieved.
- *T* is the set of transitions noted T_j that are connected to input and output places. Each transition has a label that represents a condition for achieving an intention or a task.
- *L* is the set of possible links between places and transitions of *PN*, noted $L_{ijk}=(P_i, T_j, P_k)$.
- *D* is the set of the decision-makers of the CPHS, noted $D(L_{ijk})$, associated to the achievement of a given link.

The *PN* formalism was chosen, instead the formalism of the ordinary state machine for instance, because it can take into account parallel activities related to a same component or between different components of a CPHS or of different CPHS. Therefore, a transition can be linked to several input places and output places, and the links are the translation of all the possible serial and parallel sequences of behaviors.

As example, Figure 3 implements rules or loops related to technical competences by applying the proposed *PN* formalism. While the variable *Condition* is true, then the task *A* is applied by the $CPHS_1$. In the contrary case, i.e. the variable *Condition* is false, it is the task *B*. The presence of a token of the place entitled "Initial activated place" means that this place is activated. The corresponding links between places and transitions are listed on the table of Figure 3.The specific knowledge for the availability and the prescription parameters can apply particular standard frames. Figure 4 gives some examples of *PNs* associated to the availability of a component of CPHS, and based on maximum value on a criterion such attention, vigilance or workload. For instance, workload assessment approaches were used for identifying overloaded situations in the air traffic control domain (Vanderhaegen, 1999b, 1999c).