Formal Specification of Holonic Multi-Agent Systems: Application to Distributed Maintenance Company

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Abstract. In complex systems, multiple aspects interact and influence each other. A vast number of entities are present in the system. Traditional modeling and simulation techniques fail to capture interactions between loosely coupled aspects of a complex distributed system. The objective of this work is to extend a Holonic methodology by using a formal specification language based on two formalisms: Generalized Stochastic Petri Net (GSPN) and Z language. Such a specification style facilitates the modeling of organizations and the interactions between them with both reactive and functional aspects. We illustrate the suitability of our generic approach by applying it to a Distributed Industrial Maintenance Company.

1 Introduction

In Industrial Maintenance Company (IMC) a vast number of entities interact and the global behaviour of this system is made of several emergent phenomena resulting from these interactions. The characteristics of this system have increased both in size and complexity and are expected to be distributed, open and highly dynamic. Multi-Agent Systems (MAS) are well adapted to handle this type of systems. Indeed, the agent abstraction facilitates the conception and analysis of distributed microscopic models [1].

Using any holonic perspective, the designer can model a system with entities of different granularities. It is then possible to recursively model subcomponents of a complex system until the requested tasks are manageable by atomic easy-to-implement entities. Holonic MultiAgent Systems (HMAS) provides terminology and theory for the realisation of such dynamically organising agents. They transfer modularity and recursion to the agent paradigm. The different organisations which make up an IMC must collaborate in order to find and put in place various strategies

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to maintain different production sites. Several constraints should be integrated in the process of strategy search and decision taking before mobilizing intervention teams. To satisfy some of these constraints, we propose a formal holonic approach for modelling and analysis all the entities that constitutes an IMC.

The objective of this work consists in consolidating an Agent-oriented Software Process for Engineering Complex Systems called ASPECS [2] by using a formal specification and analysis of the various organizations and the interactions between them. This type of analysis, will allow checking certain qualitative properties, as well as a quantitative analysis to measure the indicators of performance.

After a brief presentation of the framework, the maintenance activities in a distributed context are presented. A quick overview of the ASPECS process and modelling approach will be presented in section 3. The analysis and conception phase of the ASPECS process and their associated activities are then described in Section 4, while they are applied to the IMC case study. Section 5 present formal specifications of the various organizations and the interactions between them based in composition of GSPN tool and Z language. Finally, Section 6 summarises the results of the paper and describes some future work directions.

2 Industrial Maintenance Company Distributed Context

In distributed context, the maintenance activities are divided on these two following structures:

- Central Maintenance Team (CMT) which realizes the process of reparation;
- Mobile Maintenance Team (MMT) which carries out inspections, replacement and several other actions on the various production sites.

To ensure the maintenance of several production sites, many teams specialized in various competence fields should be mobilized. Those in charge of handling these resources should overcome complex logistical problems thereby the need to develop aiding methods and tools for decision making to efficiently manage this type of organisations.

3 A Quick Overview of the Used ASPECS Process

Such as it was proposed by Gaud [2] and Cossintino [3], ASPECS is a step-by-step requirement to code software engineering process based on a metamodel, which defines the main concepts for the proposed HMAS analysis, design and development. The target scope for the proposed approach can be found in complex systems and especially hierarchical complex systems. The main vocation of ASPECS is towards the development of societies of holonic (as well as not-holonic) multiagent systems. ASPECS has been built by adopting the Model Driven Architecture (MDA) [4]. In Cossentino and al. [5] they label the three metamodels “domains” thus maintaining the link with the PASSI metamodel. The three definite fields are:

▫ The *Problem Domain*. It provides the organisational description of the problem independently of a specific solution. The concepts introduced in this domain are mainly used during the analysis phase and at the beginning of the design phase.

▫ The *Agency Domain*. It introduces agent-related concepts and provides a description of the holonic, multiagent solution resulting from a refinement of the Problem Domain elements.

▫ The *Solution Domain* is related to the implementation of the solution on a specific platform. This domain is thus dependent on a particular implementation and deployment platform.

Our contribution will relate to the consolidation of the *Problem Domain* and the *Agency Domain*. We propose a formal specification approach for analysis the various organizations and the interactions between them facilitating therefore the *Solution Domain*.

4 Holarchy Design of Distributed IMC

In this section, we use the ASPECS methodology to describe partially the analysis phase, the design of the agent society and propose a holonic structure of the IMC case study. This approach has enabled us to establish the Holonic structure of the IMC (Fig. 1).

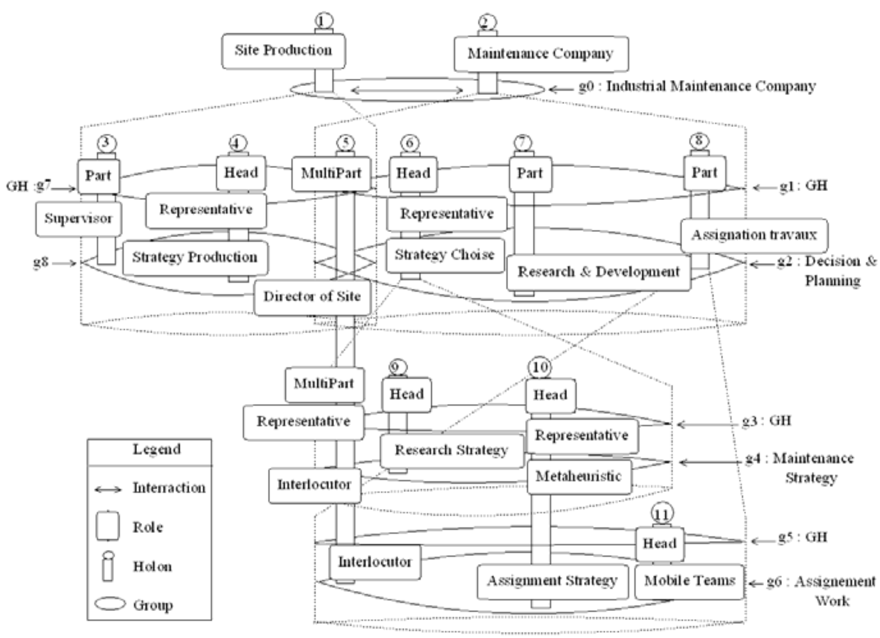


Fig. 1 Holonic Structure of the IMC

Groups (*g1*, *g3*, *g5* and *g7*) are holonic ones (HG). At the 0 level of the holarchy, two super-holons *H1* and *H2* play the role of the "*Site Production*" and "*Maintenance Company*" in *g0* group: *IMC*. Thus, *g0* is an instance of a "*Maintenance Company Organisation*". Each of these two super-holons contains an instance of the IMC organization (group *g8* and *g2*). Inspired by monarchic government type, holon members playing respectively the roles of "*Strategy Production"* and "*Strategy Choice"* (*H4* and *H6*) are automatically named *Head* and *Representative* of the other members. Holon Part *H8* playing the role of "*Assignment Work"* is decomposed and contains an instance of the "*Assignment Work Organization"*. Its government is inspired by the Apanarchy where all the members are implied in the process of decision-making (all holons are *Head*). Holon Head *H6* playing the role of "*Strategy Choice"* is decomposed and contains an instance of the "*Maintenance Strategy Organization"* with the same government as the *H8* holon. The atomic holon *H5* play the role of *Multipart* as it is shared by two couples of super holons (*H1*, *H2*) and (*H6*, *H8*). This holon represents the environnemental part of the application.

5 Formal Specification and Verification of the IMC Organisation

We use our specification formalism ZGSPN introduced in [6] for efficiency modelling and analysis of IMC organisations. This specification formalism combines two formal languages: Z [7] and Generalized Stochastic Petri Nets (GSPN) [8]. Our approach consists in giving a syntactic and semantic integration of both languages. Syntactic integration is done by introducing a Behaviour schema into Z schema. The semantic integration is made by translating both languages towards the same semantic domain. To validate our approach, we have limited our work to the specification of the *Assignment Work Organization* which is a part of the holonic structure of the system studied with two MMT. The choice of the intervening teams depends on the following information: the availability of the MMT, the distance at which the MMT is from the production site and spare parts stock level of MMT. We suppose that our system can be in three different states: Mobile Team(i) Available (MTA(i)), Mobile Team(i) on Production Site (MTPS(i)) and Mobile Team(i) with Critical Level of Stock (MTCLS(i)). For this reason, we use a free [9] or built type to describe the system state:

STATE_SYS ::= MTA(i) | MTPS(i) | MTCLS(i) such as i = (1, 2)

State System and invariants: The system to be specified is described by its state and following average times, estimated by the *Planning organization*, such as: t_{DMMTi} the average time Displacement of Mobile Maintenance Team(i) to reach Production site, associated to transition T(i); $t_{RepMMTi}$ the average time for intervention of Mobile Maintenance Team(i), associated to transition T'(i); t_{SD} the time limit to which Maintenance Team must arrive on a production site; t_{RepCMT} the average time for Repairing the defective parts by Central Maintenance Team, associated to transition T''(i). Other parameters are introduced to supplement the specification such as: Ci the level stock of Mobile Maintenance Team(i)); Cmin(i) the minimum level stock of Mobile Maintenance Team(i) (below this value, MMT(i) must re-enters to the IMC)); *m* and *n* the initial state of stocks. The state system is presented with ***Sys*** schema. In the initial state the MMT are available and the spare parts stock level is at its maximum (*m* and *n*). The initial state is presented with ***InitSys*** schema.

Sys

S: STATE_SYS
$t_{DMMT1}, t_{DMMT1}, t_{RepMMT1}, t_{RepMMT2}, t_{RepCMT}, t_{SD} : \mathbb{Z}+$
C1, C2, Cmin1, Cmin2 : $\mathbb{N}$

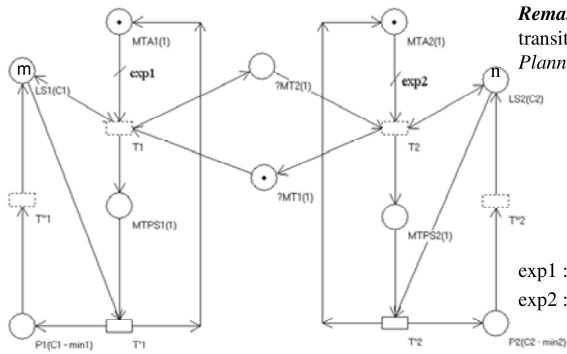
$t_{RepMMT1} < t_{RepCMT}$
$t_{RepMMT2} < t_{RepCMT}$
$Cmin1 < C1 \leq m$
$Cmin2 < C2 \leq n$

InitSys

Sys

S = MTA
C1 = m
C2 = n

InterventionsMobilesTeams



Remark: Transitions in dotted lines are transitions who interact with *Decision & Planning organisation*

exp1 : if M(LS1)>Cmin1 then 1 else ∞
exp2 : if M(LS2)>Cmin2 then 1 else ∞

ΔSys

$M(MTA1) = 1 \wedge M(LS1) > Cmin1 \wedge t_{DMMT1} \leqslant t_{SD} \Rightarrow S' = MTA1 \wedge (\lambda_1 = 1/ t_{DMMT1})$
$M(MTPS1) = 1 \Rightarrow S' = MTPS1 \wedge (\lambda'_1 = 1/ t_{RepMMT1})$
$M(MTA1)=1 \wedge M(LS1) > Cmin1 \wedge t_{DMMT1} > t_{SD} \Rightarrow S' = MTA1 \wedge (\lambda_1, \lambda'_1, \lambda''_1) = 0$
$M(MTA2) = 1 \wedge M(LS2) > Cmin2 \wedge t_{DMMT2} \leqslant t_{SD} \Rightarrow S' = MTA2 \wedge (\lambda_2 = 1/ t_{DMMT2})$
$M(MTPS2) = 1 \Rightarrow S' = MTPS2 \wedge (\lambda'_2 = 1/ t_{RepMMT2})$
$M(MTA2)=1 \wedge M(LS2) > Cmin2 \wedge t_{DMMT2} > t_{SD} \Rightarrow S' = MTA2 \wedge (\lambda_2, \lambda'_2, \lambda''_2) = 0$

*Operations and interrogations: "**Interventions Mobiles Teams**"* is a behavioural schema since it allows the description of the reactive aspect of the system which is no more than its status change in response to demand requested production site. The predicates part allows also modifying the observation *S* to make it compatible with the system status at a given time. Each place represents a system state. For example, when *MTA1* place (respectively *MTA2*) contains token, and that *LS1* place contains tokens strictly higher than a critical level *Cmin1* (respectively *Cmin2* for *SL2*) and that the average time so that *MMT1* arrives at the destination site production remains lower than equal to one pre-estimated limiting time T_{SD}, consequently the marking of *MTA1* place remains unchanged (respectively for *MTA2*) and a rate $\lambda_1=1/\ t_{DMMT1}$ will be associated to *T1* transition from the GSPN (respectively $\lambda_2=1/\ t_{DMMT2}$ for *T2*). Finally, *exp1* and *exp2* expressions translate the fact that if the level of the inventories of *MMTi* teams with reached critical level, it will not have the possibility of intervening on any site of production (probably it will turn over to IMC).

6 Conclusion

In this article we showed that HMAS is well adapted to analyse and design an IMC holarchy. The meta-model utilized can be exploited in the implantation stage with the advantage of having formally validated its structure and its behaviour by using composition formalisms Approach. Our future works will focus on a finer analysis of this system type and on a formal modelling of the various scenarios associated with the analysis stage. The notion of multi-views should be integrated. Indeed, the search for and the choice of strategy depends on the point of view of the person or the team required to take decisions according not only the constraints linked to the system but also to their environments. At the same time, it will be interesting to use HMAS to propose a multi-view holarchy introduced in [10] and consequently integrate it in the different existing meta-models.

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