# A Norm-Governed Holonic Multi-Agent System Metamodel

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**Abstract.** Modeling and designing systems that require a high level of coordination, control and automation is a very difficult task. The problem is the lack of design processes able to cover all the features these systems present. This paper presents an extension of the ASPECS metamodel for supporting organizational and normative principles and it allows to define models not only from holonic agent viewpoint but also from a normative organization perspective. The extended metamodel was experimented creating a Virtual Enterprise model for the optimization of distributions inside logistic districts. This organizational model is implemented using $\mathcal{J}$-$\mathcal{M}$oise+.

## 1 Introduction

Nowadays, a lot of researchers in the field of artificial intelligence and intelligent systems aim to develop software systems able to act in full autonomy such as a human beings do in reaching their objectives. During their daily activities, human beings pursue multiple goals that sometimes interleave and overlap; in doing that they often communicate and coordinate with other entities of the world they live. We are far from having tools to create systems completely acting as they were in a daily "human routine". Nevertheless, literature proposes way for developing systems trying to reach their goals using the knowledge they have about their environment and adopting the right actions to react to environment changes. The ability of coordinating, controlling and making autonomous the activities of all the different entities involved is a strong requirement for this kind of systems.

This issue can be faced with the use of the Multi Agent System (MAS) design paradigm and above all by considering the, today widely accepted, organizational aspects of MASs. The latter is covered by only a restricted set of agent oriented design processes[4], each of them presents advantages and can be applied for solving several kinds of problems but not all of them cover the whole design process life cycle, from analysis to implementation. Among the others, ASPECS [5] manages abstractions, such as holon, group and goal, for modeling and implementing organizational structures like holarchy and $\mathcal{M}$oise+ [13] deals with the MAS organizational aspects by modeling three different perspectives: the functional, the structural and the normative one. Moreover ASPECS is suitable for solving problems requiring hierarchical decomposability.

The novelty introduced by our work is merging the strength of ASPECS and $\mathcal{M}$oise+ in order to create a complete support for developing MASs structured organizations, as holarchies, which are also ruled by norms. Actually ASPECS does not include the possibility of designing norm-based systems. The need of introducing norms arose from a design requirement, we needed the possibility of modeling constraints in form of institutional rules (Norms) defined outside the agents. Defining external rules (like as social rules, laws, company procedures, etc...) allows to face all the problems related to management, coordination and control of different holons. c The result was an extension of the ASPECS metamodel in order to include all the elements of $\mathcal{M}$oise+ metamodel providing abstractions for managing the normative aspect of an organization. Moreover, we have instantiated this new metamodel in a specific logistics business model which integrates also the virtual enterprise paradigm. This model allows to create an optimized representation of the distribution processes inside a supply chain.

This model along with the definition of some norms allow us to implement the holons as a norm-governed organizations using Jason and $\mathcal{J}$-$\mathcal{M}$oise+ [14].

The rest of the paper is organized as follows: in section 2 an overview on the theoretical background of the work is presented, in section 3 the extended metamodel is shown together with a list of norms we identified for designing holons, in section 4 an overview on the virtual enterprise used for modeling the logistic problem and defined by means of the new metamodel and finally some conclusions in section 5.

## 2 Theoretical Background

An agent is an *autonomous*, *reactive* and *proactive* entity that pursues individual goals interacting with the environment and others agents by means of *social ability* [25]. A multi agent system [8] (MAS) is a software providing a tool to model and reproduce the interaction and social structures observed in real world organizations. It allows to adapt human organizational patterns in agent-based systems that become a virtual counterpart of real organizations.

As it is well known, there are different kinds of organizational schema, such as hierarchies, holarchies, teams, coalitions and so on. Each organizational schema

[4] In this paper we use the term design process instead of methodology, here it is not important to highlight the differences among them hence we consider them as synonyms.

is usually defined by means of roles adopted by an agent, relationships, rules and norms defining the agents behavior and organizational structure.

In this paper we will adopt holarchies as an organizational structure of the agents societies. The concept of Holarchy adopted as an Enterprise model has its origin from the work of Koestler [16]. During his research on self-organization in biological systems, Koestler discovered nested hierarchies of self-replicating structures (*holarchies*). He coined the term *holon* to describe the elements of such systems.

A holon is, commonly, defined as a self-similar structure composed of holons as sub-structures. For this reason, it can be seen from different perspectives, either as an autonomous *atomic* entity or as an *organization* of holons. A holon is a whole-part composed of other holons and at the same time, a component of a higher level holon. A holon acts basically as an autonomous entity, although cooperating to form self-organizing hierarchies of subsystems (such as the cell/tissue/organ/system hierarchy in biology) in order to achieve the goals of the holarchy. In addition, holons can simultaneously belong to different super-holons and can be regulated by rules. These rules not only allows to define a system as a holon with an individuality of its own but also to determine its structural configuration, functional patterns and behavioural regulations [23].

Holonic systems, while modeling complex systems, are able to efficiently manage their resources and to adapt themselves to changes of the environments. A useful way to implement holarchies in software system is by means of the Holonic Multi Agent System (HMAS) paradigm.

As it is showed in [9], HMAS paradigm allows to represent a holonic system with individual agents driven by coordination mechanism according to the rules for cooperation of the respective membership to the holon. In HMAS a holon is a set of individual agents organized according to different organizational models (see [9] for more details).

In this paper we use the HMAS and the Virtual Enterprise paradigm to model a holonic framework applied to the cited logistic problem. According to Uliero *et al.* [23] we refer to Virtual Enterprise (VE) as a new organizational form that can be characterized by a collection of geographically apart individuals, groups or entire organizations depending on electronic communications to work collaboratively and to provide a service or to realize a common goal.

Multi agent systems can be developed using several frameworks (JADE[2], JADEX [20],[24], PRACTIONIST [18] etc.) based on different approaches. In this paper we adopt the BDI (Belief-Desire-Intentions) paradigm using Jason for actual agents implementation.

Jason [4] is a Java-based interpreter for an extended version of the AgentSpeak language [21], an abstract agent language founded on the BDI model. A Jason agent is described by means of a set of plans the agent is able to follow in some situations.

$\mathcal{M}$oise+ [13][14] is an organizational model for MAS which specifies the structural, functional and normative aspect of MAS organizations. Each aspect is defined in a specification set. The $\mathcal{M}$oise+ model is based on two key elements:

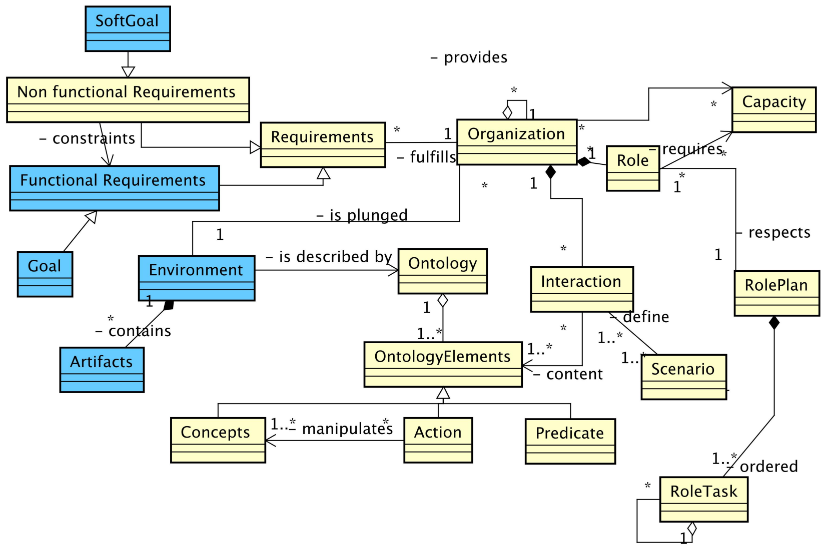


**Fig. 1.** Problem Domain metamodel.

the Organizational Specification (OS) that is the union of structural, functional and normative specifications and the Organizational Entity (OE) that is the instantiation of OS on a set of agents.

$\mathcal{J}$-$\mathcal{M}$oise+ [13] is an implementation of the $\mathcal{M}$oise+ organizational model, it is based on Jason. It consists of both an OrgBox Api that agents use for accessing the organizational layer and a special agent (called OrgManager) that stores the current state of OE and maintains its consistency during its life-cycle. $\mathcal{J}$-$\mathcal{M}$oise+ basically offers a set of actions allowing to change the state of the organization and produces some events related to organizational changes to which the agent can react.

## 3 A Norm-Governed Holonic MAS Metamodel

In order to have means for developing norm-governed multi agent systems structured by holonic organizations we need a metamodel containing all the abstractions to be treated during the phases/activities of the design process devoted to develop such systems. In this section we illustrate the metamodel we created by adding to the ASPECS metamodel all those concepts from $\mathcal{M}$oise+ metamodel useful for modeling MASs under a normative point of view.

The ASPECS metamodel can be seen in [5], it is divided in three parts, the problem domain, the agency domain and the solution domain; the first contains the elements useful for the description of the problem under an organizational point of view, the second domain provides an agent oriented solution to the previous said problem, finally the third provides the concepts for the implementation in a specific platform. As also stated in [15], ASPECS is one of the most complex and complete organizational approaches because it covers all the organizational aspects considered in other design processes *"(roles, tasks, plans, goals, organizations, resources, agents and, in this case, holonic structures), rich interactions (communication, protocols, messages) and a formal definition of the domain knowledge (ontology)"*.

However ASPECS does not cover some aspects such those related to the tasks to be accomplished by the organization and the rules to observe in order to ensure the profitable achievement of the goals of the organization. For these reasons the $\mathcal{M}$oise+ metamodel was taken into account, it can be deduced from [12]. Here there are three main concepts we are interested in: the role that constraints the agent's behavior; the organizational link that rules the social behavioral part of agents and the group, to which agents belong; the norms which rule the set of roles and mission agents can do. Our work consists in extending, and merging, the ASPECS metamodel with the previous concepts coming from $\mathcal{M}$oise+ in order to emphasize the concepts of *Environment* in which a system is plunged into and *Norms* regulating the organizational aspects. Additionally, we have specialized the concept of norms into three categories: behavioral, structural and adaptive norms.

We paid particular attention to the first two ASPECS metamodeling domains. The new extended metamodels are shown in Figure 1 and 2, where we have differently colored the new concepts to highlight the differences with ASPECS metamodels. In the following we will give a detailed description of these new concepts, refering to ASPECS metamodel for those not mentioned in this paper.

### 3.1 Problem Domain Metamodel

According to ASPECS, an organization can be an aggregate of other sub-organizations. Each organization is composed of Roles which specify the Capacities that should be owned by an agent to play them. Interactions between Roles define Scenarios where each Role contributes to the achievement of organizational objectives (Requirements). Unlike ASPECS, we highlight that an organization is plunged in an environment composed of artifacts that can be either passive elements (e.g. resources) used by agents and normative elements (e.g. social laws) imposed on organizations and their members in order to fulfill their goals. Each element of the environment is described by means of an ontology providing a common vocabulary and a machine-readable knowledge.

A brief description of the domain problem concepts that are most relevant to the proposed work is reported below:

- **Functional Requirements** describe the functions the software has to execute. In some context, often also in agent-oriented systems, they are also known as capabilities [1].
- **Nonfunctional Requirements** are seen as constraints or quality requirements of the solution to be adopted [1].

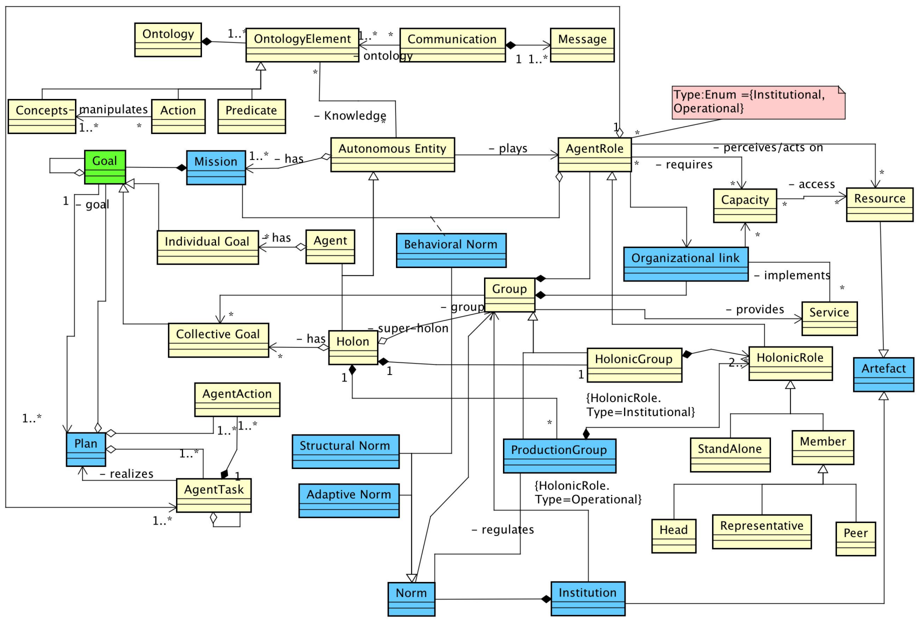


**Fig. 2.** Agency Domain metamodel.

- **Goals** and **Softgoals** are a specialization of functional and nonfunctional requirements respectively. A Goal, representing an actor' strategic interest, can satisfy a system requirement. While Softgoals are generally considered as goals for which it is difficult to decide whether they are satisfied or not. In our model we use softgoals to constrain goals.
- The **Environment** is a first-class abstraction that provides the surrounding conditions for agents to exist and that mediates both the interactions among agents and the access to resources. The passive components of the system, such as resources and objects, that are shared and used, cooperatively or competitively, by agents to support their activities [19] or norms, rules, physical and social laws that act on the environment or govern its living entities are represented by means of **Artifacts**. For this reason, we see the environment as a set of artifacts that form a context in which agents perform their tasks and pursue their goals. A special kind of artifacts that we considered in this paper are the norms, which will be deeply explained in the next section.

### 3.2 Agency Domain Metamodel

Among complex dynamic systems, some of them show common features. For example, many of them are composed of entities operating in parallel (nerve cells into brain, individuals or enterprise in a market economy, etc...), show many levels of organization (proteins and lipids form a cell, cells form tissues, tissues form organisms and so on) and can be characterized by a continuous adaptation of their components through the process of evolution (adaptation involves the recombination of the component elements or the generation of a new one), to name but a few.

Adopting an organizational approach to model these systems is a very useful way to represent their components, structure, and all elements that are necessary to define a solution.

The Agency Domain metamodel shown in Fig.2 describes the organizational solution from the agent-oriented perspective.

As ASPECS does, we consider holons the base elements of the organizational solution, the same holons are recursively composed of other holons, and at the same time, each of them is composed of groups. In our extended model we considered two different kinds of groups: the **Holonic Group** and the **Production Group**. At the first level of abstraction, members of the Holonic Group play *Institutional Roles* to which are assigned the task to regulate the organizational aspect of the system and to enforce the norms. In that, we accepted the position of V. Dignum *et al.* who say [7] that Institutional Roles are roles needed in order to keep the society going. Members of the Production Group play the *Operational Roles* to which is assigned the task to perform activities necessary to pursue the organizational objectives in accordance with the Behavioural norms and their mission. A **Mission** is *a set of constraints that the agent must take into account when it wants to execute parts of this task. It defines an allowed behavior as a consistent set of authorization related to goals to be achieved, plans to follow, actions to execute and resource to use* [11]. A set of missions to which an agent must obey is assigned to each **AgentRole**. A **Plan** is defined as an oriented graph where each node can be a simple agent action or agent task or a set of sub-goals. It represents the way to reach the organizational objective. In this context a goal is seen as an aggregate of plans. The roles inside the different holon are linked by means of Organizational Links. The **Organizational Links** define the way in which the social exchanges between agent roles occur [11].

A general definition of norm is *an authoritative standard or model.* We want to specialize this concept using different kind of norms.

We called **Behavioural Norm** what Boella et.al [3] define "*a principle of right action binding upon the members of a group and serving to guide, control, or regulate proper and acceptable behavior*", similar to the concepts of *Regulative norms* described as *the expected contributions to the social system* [22]. In our model, a Behavioural Norm regulates the way a Role performs a Mission. For the objective of this paper, we consider two types of Behavioural Norms: **Obligations -** an agent is obliged to execute the missions associated to its role; **Permissions -** the agent playing the role can decide to execute the permitted mission or not [11].

In this model we propose two new kinds of norms that consider static and dynamic aspects of an organization separately, named Structural and Adaptive Norms respectively.

The **Structural Norms** define the static structural aspect of the system at the design time, that is the initial composition defined by the designer for the organization to fulfill its objectives.

The **Adaptive Norms** govern the state transition of the organization from a given configuration to a new one according to needs emerging from environmental changes. By means of adaptive norms the agent society spontaneously evolves toward another optimal configuration for the new state of the world.

The last element introduced in the model is the **Institution**. Institutions [6] provide the social and institutional backbone of the agent society and they are the place where social norms are explicitly specified.

In the following subsection we highlight some general structural norms that a holonic organization must comply with. As regard the adaptive norms, in this paper we provide only a preliminary introduction without discussing any theoretical details that will be argued in another specific work.

### 3.3 Structural Norm

Without going into the details of a methodological approach for holonic organization design, when we want to adopt a solution based on organizations, the organizational structure is the first element to be defined. The choice of the appropriate organizational scheme is related, first of all, to the global objective of the system. Its performance depends on the way tasks are distributed among individuals, how their responsibilities (assigned to Roles) are defined and how they could be aggregated in groups. For instance, organizational groups can be created as functional units responsible to execute either a process or some of its phases, depending on the interdependences of groups involved in the work flow execution. In the following, we exemplify an organizational scheme by means of structural norms.

In particular, we distinguish the norms needed for the design of holons from those used for the definition of organizational schemes. The following list shows a sub-set of structural norms that allow us to define holarchy [17]:

- A generic holonic structure must contain at least three levels of representation. The level (n) represents a holon as a *whole* with its unique characteristics, the level (n-1) contains the holons subordinated to the previous one, finally, the level (n+1) holon is a *super-holon* containing the level (n) holon (and others if required).
- A *top holon* is not included in any holon of level(n+1).
- A *bottom holon* does not include holons of level (n-1).
- A *stand-alone* holon is a non-member holon. It can be seen as a top and bottom holon at the same time.
- Holons of the same level cannot be included in each other.
- The number of holons at level (n) cannot be greater than that of the holons at level (n-1).
- Holons at level (n) can be part simultaneously of holons at level(n+1).
- Holons at level (n) that are not decomposable can be brought to a lower level(n-1) by means of virtual holons (see fig.4).

While, in order to define the organizational scheme such as for example a *moderated group* [10] three roles are necessary. The *Head* role identifies the decision maker of the holon. The *Representative* role is the interface of the holon outside the world. Finally, the *Peer* role identifies the default members, generally they perform tasks assigned by the Head.

This organizational scheme will be well-formed when applying the following structural norms:

– A moderated group must contain at least one individual playing the *Representative* role.
– It must contain at least one individual playing the *Head* role.
– It can include from zero to a generic number of *Peer* players.
– Head and Peer are exclusive roles.
– Members belonging to only one super-holon adopt the *Part* status.
– Members of the moderated group can belong to more than one super-holon, adopting the *Multi-Part* status.
– The Part status is adopted by default.
– Part and Multi-Part are exclusive status.

We adopted these norms to define the structural specification for our case study. In the following section we present the virtual enterprise model adopted for the optimization of logistics distributions.

## 4 Virtual Enterprise for Logistics

The work presented in this paper was carried out under the IMPULSO[5] project and it represents the solution we are studying for it. IMPULSO - Integrated Multimodal Platform for Urban and extra urban Logistic System Optimization - aims to develop new technologies and capabilities in order to improve the management and transport of products, based on cooperation models while ensuring highest levels of security. It offers an integrated system for goods management within the logistic districts, for their storage in special metropolitan distribution centers and finally, for distribution within the cities.

The development of the IMPULSO system was the test-bed for evaluating and assessing the newly created metamodel with all its concepts. Indeed through the enactment of the design activities devoted to instantiate each concept we were able to create the model of the system (the Figures from now on are parts of the artefacts composing such model) on the base of the right specification provided by the metamodel. We experienced the completeness of the proposed metamodel, both the domains contain all the useful concepts for representing the problem we were dealing with and for describing the solution in terms of holons, moreover we were able to analyze and establish the behavior of each part of the system through the use of the identified norms.

In the following subsection only three artifacts of the developing process are illustrated, dealing with the concepts of holon, group, role and norm.

[5] Further information available at http://www.vitrociset.it - Section Ricerca&Sviluppo

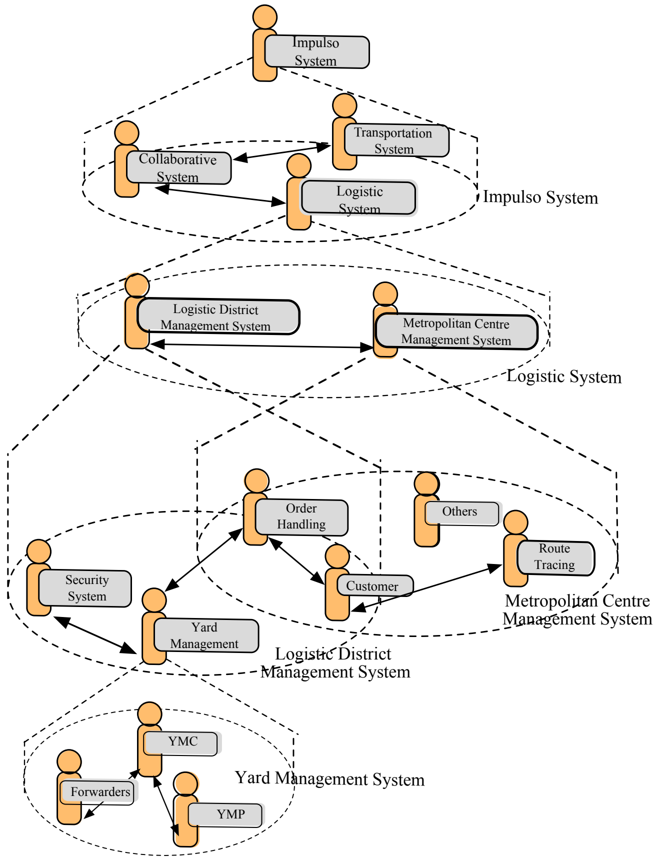


**Fig. 3.** Holonic architecture for logistics

*The Holonic Architecture* As it can be seen in figure 3, we have modeled the entire Impulso System as a Virtual Enterprise that is a holarchy of collaborative systems, where each system is a holon itself. Each of them is composed of other systems that act according to the same organizational scheme but performing different functions at lower levels of resolution.

Top-level holons provide different kinds of services useful for logistic distribution and they form an unique adaptive and collaborative framework.

We consider the Impulso System as a top holon. It is composed by three holonic sub-systems: Transportation, Collaborative and Logistic system. The transportation system provides services for logistics management of transports, making it precise and efficient, reducing the need of human intervention and allowing information gathering. The collaborative system integrates some services that allow the realization of the logistic network of Impulso, such as services for global goods traceability. Finally, the logistic system is considered the core of the entire framework. It provides a predictive system for managing orders, a

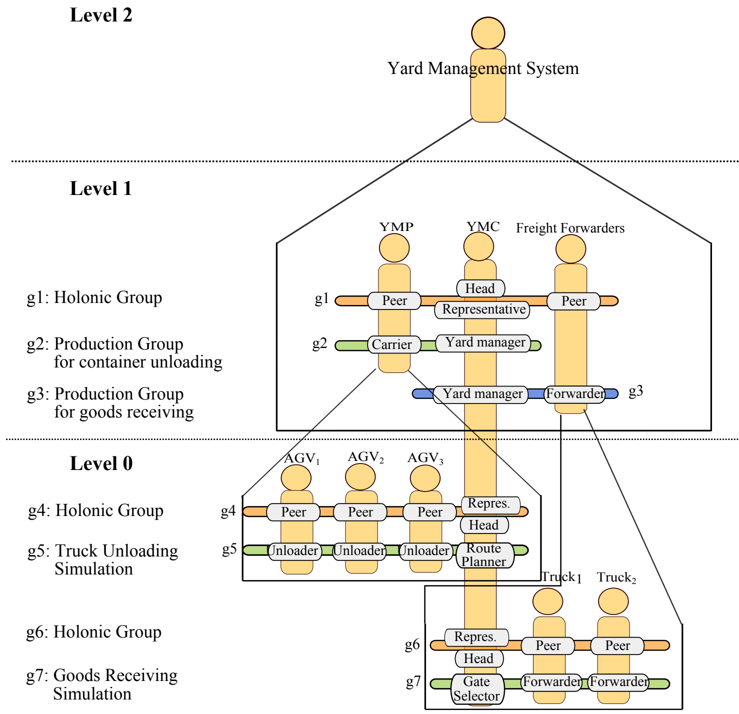


**Fig. 4.** Roles/Groups of the Yard Management System.

real time tracking system that gives the positions and conditions of vehicles and goods, a route tracing system that models and provides the conditions for urban and interurban traffic, calculating the best routes for the journey of the goods and many others.

In this paper, we paid particular attention to the Yard Management system. This system deals with goods traffic inside logistic districts. It manages the automatic container loading and unloading by means of the use of AGVs (Autonomous Guided Vehicles) which move independently but are coordinated in accordance to predetermined patterns by a remote control center.

As shown in figure 3, the Yard Management system is composed by the YMC (Yard Management Central), some Forwarders and the YMP (Yard Management Peripheral). These holons interact to fulfill the goal of their organization, the Yard Management system, although they themselves are autonomous entities with personal objectives. The holonic enterprise framework, which connects enterprise entities, allows information exchange through communication channels and resources management.

In the following subsection, we will focus on the model of the holonic organization for the Yard Management System, on its groups, roles and norms.

*Groups, Roles and Norms* In this section we define the entire composition of the holonic organization of the Yard Management System. Initially we define its structural and functional aspects, then we will discuss its normative features. The figure 4 shows the organizational scheme of the Yard Management holon.

According to the metamodel shown in fig.2, there are two aspects that overlap in a holon. The first is the *holonic aspect* that is directly related to the holonic character of the entity, i.e. a holon (super-holon) is composed of other holon members. The fig.4 shows that a super-holon is an entity on its own although composed by members. So, the holonic aspect refers how members organize and manage their representative super-holon (i.e. how they form the Holonic group). We adopted the *moderated group* configuration as an organizational structure for the holonic group of each super-holon according with the structural norms defined in the section 3.2.

The second aspect of the holon is related to the problem the members are trying to solve (we will call that the production aspect in order to maintain a uniform nomenclature). The production aspect refers how members of the holon are organized to pursue their goals according to the global objective of their super-holon.

This holonic representation by means of holonic and production groups allows to clearly distinguish the different features and functionalities to be attributed to each member.

For simplicity and clarity, we will describe only the lowest level of abstraction of the Yard Management System architecture (see Figure 4). At this final (finer grained) level of decomposition, the holons are represented by groups of agents which play institutional and operational roles at the same time. In the following, we focus on operational roles and production groups, since the institutional roles of the holonic groups have been already described in the section 3.2. For the simulated scenario, we have defined two production groups (*Truck Unloading Simulation* and *Goods Receiving Simulation*) of two high-level holons.

The *Truck Unloading Simulation* is a group formed by the *Unloader* and *Route Planner* roles. The Route Planner can be played by YMC agents, which have the capacity to perform the related task. While the Unloader is played by AGV agents which emulate the behaviour of real automated guided vehicles.

The *Goods Receiving Simulation* group is formed by the *Forwarder* and *Gate Selector* roles. The Forwarder is a role adopted by agents emulating the behaviour of the trucks.

The Route Planner player in the Truck Unloading Simulation group adopts the role of Gate Selector in the Goods Receiving Simulation group, at the same time. This is allowed by the structural norm concerning the multi-part status.

The functional specification defines a set of plans and missions the agents can commit into a Social Scheme. It describes how an organization can achieve its global goals. The figure 5 gives an overview of the Social Scheme of the organization shown as a goal decomposition tree. The root goal of the Yard Management System is sorting out goods toward metropolitan centres. To do that, the members of two production groups can play the permitted roles according to the

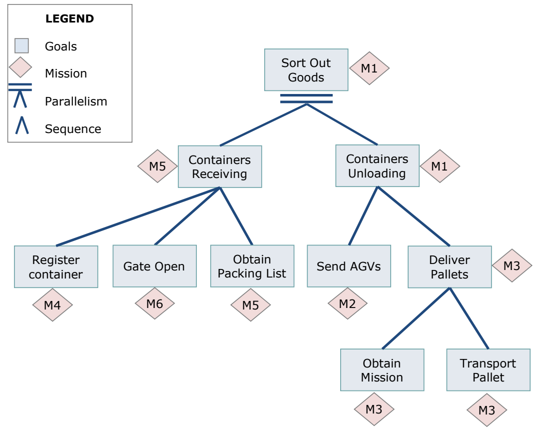


**Fig. 5.** The functional specification of the production groups represented by a goal and mission decomposition tree.

structural norms and commit to some missions according to behavioural norms described below. Groups perform their activities independently. Holonic groups are responsible for managing their respective production groups and their coordination. For everything else, the figure 5 is self explanatory.

Finally, we defined the behavioural norms and we introduced some adaptive norms concerning our case study.

We show the behavioural norms according to following template:

$$norm < id >: type = [Obligation \mid Permission]$$
$$role =< RoleName > mission =< MissionName >$$

These norms impose agents to commit to certain missions when they choose to play a role. Some of them are reported below:

```
norm 1: type=Obligation role=unloader
        mission=AgvMission
norm 2: type=Permission role=forwarder
        mission=ForwarderMission
norm 3: type=Permission role=representative
        mission=ManagementMission
norm4:  type=Permission role=representative
        mission=RecruitmentMission
  ...
```

The Adaptive norms instead allow us to regulate the dynamic evolution of the system. In our case study, we have defined a set of norms that allow the adaptation of the holon to perceived environmental changes. In particular, two examples are:

– If the workload grows beyond some limit (for instance a new trucks arrives to be unloaded), the Representative holon creates a new Truck Unloading Simulation groups.

– If the workload decreases (for instance unloading operations of a truck are over), the Truck Unloading Simulation groups are removed proportionally.
– If all role-players leave Representative or Head roles an election or a choice has to be made for new players.

If the second norm is applied, the number of Truck Unloading Simulation groups can not become less than one, because it violates a structural norm of this production group.

## 5 Conclusions

In order to solve problems and engineering systems related to fields in which a high level of coordination, control and automation is needed we propose an extension of the ASPECS metamodel obtained by introducing some new concepts such as Norms. Norms are used to regulate holons' behavior, these norms separately deal with the behavioral aspect of the holonic members from the organizational one. From the agents viewpoint, behavioral norms impose constraints to their actions in order to maintain a social order. Conversely, from an organizational perspective it is useful to separate the static aspect from the dynamic one, in this paper this is done by respectively introducing Structural and Adaptive Norms. The formers define the static structural aspect of the system at design time and provide the initial composition required to the organization to fulfill its objective. The latters govern the state transition of the organization from a given configuration to a new configuration to fit the environmental changes.

In addition, a Virtual Enterprise model based on holonic organizational principles for the optimization of distribution in logistic districts was proposed as an application of the described metamodel.

The proposed metamodel fully supports, and we experimented that by developing the IMPULSO system, a methodological approach for holonic multi-agent system design in which the holons are ruled by means of norms. In the future we will improve the design process based on the new metamodel that is obviously an extension of ASPECS.

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